Instituto Superior de Engenharia do Porto

DEPARTAMENTO DE ENGENHARIA MECÂNICA

TERMINAL DEFECT ANALYSIS AND CLASSIFICATION METHODOLOGY FOR AUTOMOTIVE INDUSTRY

António Ricardo Almeida Teixeira

2013

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Dissertação apresentada ao Instituto Superior de Engenharia do Porto para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Mecânica, realizada sob a orientação do Doutor Francisco José Gomes da Silva, Professor Adjunto do Departamento de Engenharia Mecânica do ISEP.

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"There is in nowadays an important Company Global
effort for Quality improvement on going, therefore,
I have immediately volunteered myself to help on
this greater target achievement by taking this subject
under my responsibility as soon I knew about it."

Antonio Teixeira, 2013

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Keywords

Analysis, Brittle, Broken, Classification, Complaint, Copper, Cracks, Crimping, DMAICR, Design, Ductile, Failure, Fatigue, Fracture, Hardness, Inspection, Ishikawa, Mechanism, Metallographic, Pareto, Quality, Specification, Root-cause, Strain, Terminal, Tensile, Testing, Yield.

Abstract

The impact of end customer quality complaints with direct relationship with automotive components has presented negative trend at European level for the entire automotive industry.

Thus, this research proposal is to concentrate efforts on the most important items of Pareto chart and understand the failure type and the mechanism involved, link and impact of the project and parameters on the process, ending it with the development of one of the company's most desired tool, that hosted this project – European methodology of terminals defects classification, and listing real opportunities for improvement based on measurement and analysis of actual data. Through the development of terminals defects classification methodology, which is considered a valuable asset to the company, all the other companies of the YAZAKI's group will be able to characterize terminals as brittle or ductile, in order to put in motion, more efficiently, all the other different existing internal procedures for the safeguarding of the components, improving manufacturing efficiency.

Based on a brief observation, nothing can be said in absolute sense, concerning the failure causes. Base materials, project, handling during manufacture and storage, as well as the cold work performed by plastic deformation, all play an important role. However, it was expected that this failure has been due to a combination of factors, in detriment of the existence of a single cause. In order to acquire greater knowledge about this problem, unexplored by the company up to the date of commencement of this study, was conducted a thorough review of existing literature on the subject, real production sites were visited and, of course, the actual parts were tested in lab environment.

To answer to many of the major issues raised throughout the investigation, were used extensively some theoretical concepts focused on the literature review, with a view to realizing the relationship existing between the different parameters concerned. Should here be stated that finding technical studies on copper and its alloys is really hard, not being given all the desirable information.

This investigation has been performed as a YAZAKI Europe Limited Company project and as a Master Thesis for Instituto Superior de Engenharia do Porto, conducted during 9 months between 2012/2013.

Resumo

O impacto das reclamações de qualidade do cliente final com relação directa com os componentes de automóvel tem apresentado tendência negativa a nível europeu para toda a indústria automóvel.

Assim, a proposta desta investigação é concentrar-se nos itens mais importantes do gráfico de Pareto e entender o tipo de falha e o mecanismo envolvido, ligação e impacto do projecto e parâmetros do processo, terminando-o com o desenvolvimento de uma das ferramentas mais desejadas pela empresa que albergou este projecto – metodologia europeia de classificação de defeitos em terminais, e listando reais oportunidades de melhoria com base em medições e análise de dados reais. Através do desenvolvimento da metodologia de classificação de defeitos em terminais, que é considerado uma mais-valia preciosa para a empresa, todas as empresas dedicadas à produção no grupo YAZAKI passarão a ser capazes de caracterizar terminais, entre o frágil ou dúctil, a fim de colocar em movimento, de forma mais eficiente, todos os outros diferentes procedimentos internos já existentes, para a salvaguarda do componente e melhoria da eficiência de fabricação.

Apenas com uma primeira observação, nada poderá ser dito em sentido absoluto, relativo às causas de falha. Materiais de base, projecto, manipulação durante a fabricação e armazenamento, assim como o trabalho a frio realizado por deformação plástica, todos desempenham um papel importante. No entanto, já era esperado que a falha se desse devido a uma dada conjugação de factores, em detrimento da existência de uma única causa. Com vista a adquirir um maior conhecimento sobre esta problemática, inexplorada pela empresa até à data de início deste trabalho, foi realizada uma profunda revisão da literatura existente sobre a matéria, foram visitados locais de produção real e, claro, as peças reais foram testadas em ambiente de laboratório. Para responder a muitas das principais questões levantadas durante toda a investigação, foram usados exaustivamente os conceitos teóricos focados na Revisão Bibliográfica, com vista a perceber a inter-relação existente entre os diferentes parâmetros em causa. Deverá aqui ser referido que encontrar estudos técnicos sobre o cobre e suas ligas é realmente difícil, não sendo fornecidas todas as informações requeridas.

As conclusões foram traçadas e, mesmo que algumas delas possam ser consideradas como pouco relevantes ou não tenham um impacto directo neste estudo, deverão ser considerados em casos de investigação futura como oportunidades de melhoria.

Esta investigação foi realizada como um projecto para a YAZAKI EUROPE LIMITED e ainda como uma dissertação no âmbito do Mestrado em Engenharia Mecânica – Opção de Materiais e Tecnologias de Fabrico, no Instituto Superior de Engenharia do Porto.

Abbreviations and Symbols

A50	Elongation
Al	Aluminum
Ag	Silver
ASTM	American Society for Testing and Materials
BOM	Bill Of Material
BT	Bend Test
Cu	Copper
CFM	Crimping Load Monitory
DT	Destructive Test
DMAIC+R	Define, Measure, Analyze, Improve, Control + Replicate
ε	True Strain
e	Conventional Strain
Fe	Iron
h	Instantaneous Height
HV	Hardness Vickers
IMDS	Material Supplier Information Submission
K	Strength Coefficient
Kt	Stress Concentration Factor
Kts	Shear Stress
KME	Cooper Alloys Supplier Company
ME	Metallographic Examination
MO	Metallographic Observation
n	Strain Hardening Exponent
Ni	Nickel
NDT	Non Destructive Test
P	Phosphorus
Pb	Plumb
P/N	Part Number
PT	Dye Penetrant Testing
Qty	Quantity
Rm	Tensile Strength
$Rp_{0,2}$	Yield Strength
RT	Radiographic Testing

STD	Standard
SiC	Silicon Carbide
Sn	Tin
Si	Silicon
σ	True Stress
τ	Tension
T	Temperature
TD	Terminal Defects
TT	Tensile Test
UTS	Ultimate Tensile Strength
V	Velocity
VI	Visual Inspection
VHN	Vickers Hardness Number
W/H	Wiring Harness
Y	Yield Strength
YS	Yield Strength
YZK	YAZAKI Europe Limited
Zn	Zinc

Glossary of Terms [1]

A

Accuracy

The agreement degree of a measured value with the true or correct value for the quantity measured.

Annealing

The generic term denotes a material thermal treatment. It consists of heating and holding at a suitable temperature followed by cooling at a suitable/moderate rate. It is used primarily to soften metallic materials, but also to simultaneously produce desired changes in other properties in microstructure. The purpose of such changes may be, but is not confined to: facilitation of cold work and improvement of mechanical or electrical properties. When applied only for stress relief, the process is properly called stress relieving or stress relief annealing.

In nonferrous alloys, such Copper ones, annealing cycles are designed to: remove part or all of the effects of cold working (recrystallization may or may not be involved), cause substantially complete coalescence of precipitates from solid solution in relatively coarse form, both, depending on composition and material condition.

Abrasion

Roughening or scratching of a surface due to particles and/or bodies.

Abrasive Wear

It means the removal or material displacement from a surface when hard particles slide or roll across the surface under pressure. The particles may be loose or may be part of another surface in contact with the surface being worn.

Anvil

It is a metal block that supports the frame structure and holds the stationary die of a forging hammer.

Anisotropy

This characteristic defines different values of mechanical properties in different directions with respect to a fixed reference system in the material.

Automatic Press

Press with built-in electrical in which the work is fed mechanically through the press in synchronism with the press action.

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[1] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993
[2] M.R. Notis (vol. Chairman), "Alloy Phase Diagrams Metals Handbook Vol.3", by ASM International, Lehigh (USA), 1992
[3] D.L. Olson (vol. Chairman), "Heat Treating Metals Handbook Vol.4", by ASM International, Colorado (USA), 1991

B

Bend Angle

It is an angle through which a bending operation is performed.

Bending

It is straining of a flat sheet by moving it around a straight axis, laying it in the neutral plane. Metal flow takes place within the plastic range of the metal, so that the bent part retains a permanent set after removal of the applied stress. The cross section of the bend inward from the neutral plane is in compression, the rest of the bend is in tension.

Brittle Fracture

Define the separation of a solid into two or more parts, accompanied by little or no macroscopic plastic deformation. Typically, brittle fracture occurs by rapid crack propagation with less expenditure of energy than for ductile fracture.

C

Cold Working

Term used to define the plastic deformation of metal under conditions of temperature and strain rate that induce strain hardening. Usually, but not necessarily, conducted at room temperature. Also referred as, cold forming or cold forging.

Compressive Strength

It is defined as resistance of a material to breaking under compression. Defined as well the maximum compressive stress a material is capable of developing.

Compressive Stress

A stress that causes an elastic body to deform (shorten) in the direction of the applied load.

Creep

It is time-dependent strain that occurs under stress application. The creep strain occurring at a diminishing rate is called primary or transient creep, occurring at a minimum and almost constant rate, secondary or steady-rate creep, that occurring at an accelerating rate.

Crimping

The forming of small electrical components extension wings in order to set down and lock wire filaments by creating an arc around them and consequently reducing by compression the assembly terminal and wire filaments initial sections.

Crystalline Defects

The deviations from a perfect three-dimensional atomic packing that are responsible for much of the structure-sensitive properties of the materials. Crystal defects can be point defects (dislocations) or surface defects (vacancies), line defects (dislocations), or surface defects.

Crystalline Fracture

It is a pattern of brightly reflecting crystal facets on the fracture surface of a polycrystalline metal, resulting from cleavage fracture of many individual crystals.

Cycle

In fatigue failure, it is the definition of one complete sequence of values of applied load that is repeated periodically. The symbol *N* represents the number of cycles.

D

Discontinuous Yielding

It is the non-uniform plastic flow of a metal exhibiting a yield point in which plastic deformation is inhomogeneously distributed along its length. Under some circumstances, it may occur in metals not exhibiting a distinct yield point, either at the onset of or during plastic flow.

Ductile Fracture

Fracture characterized by tearing of metal accompanied by appreciable gross plastic deformation and expenditure of considerable energy.

Ductility

It means the ability of a material to deform plastically without fracturing, measured by elongation or reduction of area in a tensile test.

E

Embrittlement

It is the severe loss of ductility, toughness or both, in a mechanical component. Many forms of embrittlement can lead to brittle fracture. Metals and alloys can be embrittled by environmental conditions (environmentally assisted embrittlement). The forms of environmental embrittlement include acid embrittlement, caustic embrittlement, corrosion embrittlement, creep-rupture embrittlement, hydrogen embrittlement, liquid metal embrittlement, neutron embrittlement; solder embrittlement, solid metal embrittlement, and stress-corrosion embrittlement.

Elastic Limit

The maximum stress a material can sustain without any permanent strain (deformation) remaining upon complete release of the stress.

Elastic Deformation

A change in dimensions that is directly proportional to and in phase with an increase or decrease in applied load, deformation which is recoverable when the applied load is removed.

Elasticity

It is the property of a material by which the strain caused by stress disappears upon removal of the stress. A perfectly elastic body completely recovers its original shape and dimensions after the release of stress. In reality, such conditions do not exist, there are always some residual stress remaining in the material.

Elongation

A term used in mechanical testing to describe the amount of extension of a test piece when stressed by tensile stress.

Engineering Strain (*e*)

A term sometimes used for average linear strain or conventional strain in order to differentiate it from true strain. In tensile testing it is calculated by dividing the change in the gage length by the original gage length.

Engineering Stress (*s*)

A term sometimes used for conventional stress in order to differentiate it from true stress. In tensile testing, it is calculated by dividing the breaking load applied to the specimen by the original cross sectional area of the specimen.

F

Forming

The plastic deformation of a billet or a blanked sheet between tools (dies) to obtain the final configuration. Metal forming processes are typically classified as bulk forming and sheet forming.

Fracture Surface

The irregular surface produced when a piece of metal is broken.

G

Guide (or Linear Guide)

Usually 2 or 4 conductor parts in a press structure that guides the up-and-down motion of the ram in a true vertical direction.

Grain Size

For metals, a measure of the areas or volumes of grains in a polycrystalline material, usually expressed as an average when the individual sizes are fairly uniform.

Granular Fracture

A kind of irregular surface produced when metal is broken that is characterized by a rough, grain like appearance, rather than a smooth or fibrous one.

I

Inclusions

It is particles of foreign material in a base metallic matrix. The particles are usually compounds, such as oxides, sulfides, or silicates, but may be any substance ore chemical element foreign to and essentially insoluble in the matrix.

Intergranular Fracture

It is brittle fracture of a metal in which the fracture is between the grains, or crystals that forms the metal. It is also called intercrystalline fracture.

Intermediate Annealing

Annealing wrought metal at one or more stages during manufacture and before final thermal treatment.

L

Lubricant

A material applied to dies, molds, plungers, or a work piece that promotes the metal flow, reduces friction and wear, and aids in the release of the finished part.

M

Mechanical Working

The subjecting of material to pressure exerted by rolls and presses in order to change the shape or physical properties of the material.

Metallography

The science dealing with the constitution and structure of metals and alloys as revealed to the unaided eye or by using such tools as low-power magnification, optical microscopy, electron microscopy, and diffraction or x-ray techniques.

Micro-Hardness

The hardness of a material is determined by forcing an indenter such as a Vickers indenter into the surface of a material under very light load. Usually, the indentations are so small that they must be measured with a microscope.

Modulus of Elasticity (*E)*

It is the measure of rigidity or stiffness of a metal (ratio of stress) below the proportional limit, to the corresponding strain. In terms of the stress-strain diagram, the modulus of elasticity is the slope of the stress-strain curve in the range of linear proportionality of stress to strain. Also known as *Young's modulus*. For materials that do not conform to Hooke's law throughout the elastic range, the slope of either the tangent to the stress-strain curve at the origin or at low stress, the secant drawn from the origin to any specified point on the stress-strain curve, or the chord connecting any two specific points on the stress-strain curve is usually taken to be the modulus of elasticity. In these cases, the modulus is referred to as the tangent modulus, secant modulus, or chord modulus, respectively.

Necking

It is the reduction of the cross-sectional area of metal in a localized area by uniaxial tension or by stretching.

O

Oxidation

A reaction in which there is an increase in valence resulting from a loss of electrons. The corrosion reaction corrodes metal, which forms an oxide.

P

Plastic Deformation

The permanent (inelastic) distortion of metals under applied stresses that strain the material beyond its elastic limit. The ability of metals to flow in a plastic manner without fracture is the fundamental basis for all metal-forming processes.

Plastic Flow

It is the phenomenon that takes place when metals or other substances are stretched or compressed permanently without rupture.

Plasticity

It is the ability of a metal to undergo permanent deformation without rupture.

Polished Surface

It is a surface that reflects a large proportion of the incident light in a specular manner.

Polishing

A mechanical, chemical, or electrolytic process or combination thereof used to prepare a smooth, reflective surface suitable for microstructural examination that is free of artifacts or damage introduced during prior sectioning or grinding.

Precipitation

It is a separation of a new phase from solid or liquid solution, usually with changing conditions of temperature, pressure, or both.

Precipitation Hardening

Hardening caused by the precipitation of a constituent from a supersaturated solid solution.

Press

A machine tool with a stationary bed and a slide or ram that has reciprocating motion at right angles to the bed surface, the slide is guided in the frame of the machine.

Press capacity

The rated load a press is designed to exert at a predetermined distance above the bottom of the stroke of the slide.

Press forming

Any sheet metal forming operation performed with tooling by means of a mechanical press.

R

Recrystallization Annealing

It is an annealing cold-worked metal to produce a new grain structure without phase change.

Residual Stress

Remaining stresses within a body as result of heterogeneous plastic deformation cooling/relaxation.

S

Scanning Electron Microscopy (SEM)

An analytical technique in which an image is formed on a cathode-ray tube whose raster is synchronized with the raster of a point beam of electrons scanned over an area of the sample surface. The brightness of the image at any point is proportional to the scattering by or secondary emission from the point on the sample being struck by the electron beam.

Scratch

A groove produced in a surface by an abrasive point.

Shear

The kind of load that causes or tends to cause two contiguous parts of the same body to slide relatively to each other in a direction parallel to their plane of contact.

Shear Strength

The maximum shear stress a material can sustain. Shear strength is calculated from the maximum load during a shear.

Shear Stress

It is a stress that exists when parallel planes in metal crystals slide across each other. The stress component tangential to the plane on which the loads act.

Sheet

It is any material or piece of uniform thickness and of considerable length and width as compared to its thickness. With regard to metal, such pieces less than 6.5 mm thick are called sheets, and those 6.5 mm thick and over are called plates.

Sheet Forming

It is the plastic deformation of a piece of sheet metal by tensile loads into a three-dimensional shape, often without significant changes in sheet thickness or surface characteristics.

Strain

It is the unit of change in the size or shape of a body due to load, in reference to its original size or shape.

Strain Aging

The changes in ductility, hardness, yield point, and tensile strength that occur when a metal or alloy that has been cold worked are stored for some time.

Strain Hardening

It is an increase in hardness and strength caused by plastic deformation at temperatures below the recrystallization range.

Strain-Hardening Exponent (*n*)

The value n in the relationship $\sigma = K \cdot \varepsilon^n$, where σ is the true stress; ε is the true strain; and K, which is called the strength coefficient, is equal to the true stress at a true strain of 1.0. The strain-hardening exponent, also called *n*-value, is equal to the slope of the true stress/true strain curve up to maximum load, when plotted on log-log coordinates. The *n*-value relates to the ability of a sheet material to be stretched in metalworking operations.

Stress

The intensity of the internally distributed loads or components of loads that resist a change in the volume or shape of a material that is or has been subjected to external loads. Stress is expressed in load per unit area. Stress can be normal (tension or compression) or shear.

Stress-Strain Diagram

Graph in which, corresponding values of stress and strain from a tension, compression, or torsion test are plotted against each other. Values of stress are usually plotted vertically (ordinates or *y*-axis) and values of strain horizontally (abscissas or *x*-axis). Also known as deformation curve and stress-strain curve.

Stress-Concentration Factor (*Kt*)

A multiplying factor for applied stress that allows for the presence of a structural discontinuity such as a notch or hole; *Kt* equals the ratio of the greatest stress in the region of the discontinuity to the nominal stress for the entire section. It’s also known as theoretical stress-concentration factor.

Stress-Strain Diagram

It's a graph in which corresponding values of stress and strain are plotted against each other. Values of stress are usually plotted vertically (ordinates or *y*-axis) and values of strain horizontally (abscissas or *x*-axis).

Also known as deformation curve and stress-strain curve.

T

Transgranular Fracture

Fracture through or across the crystals or grains of a metal. It's also called transcrystalline fracture or intracrystalline fracture.

Tensile Strength

In tensile testing, it's the ratio of maximum load to original cross-sectional area.

Tensile Stress

It is a stress that causes two parts of an elastic body, on either side of a typical stress plane, to pull apart.

Tension

It is the load or load that produces elongation.

Thermo-Mechanical Working

A general term covering a variety of processes combining controlled thermal and deformation treatments to obtain synergistic effects, such as improvement in strength without loss of toughness.

Total Elongation

The total amount of permanent extension of a test piece broken in a tensile test usually expressed as a percentage over a fixed gage length.

True Strain

It is the ratio of the change in dimension, resulting from a given load increment, to the magnitude of the dimension immediately prior to applying the load increment.

True Stress

The value obtained by dividing the load applied to a member at a given instant by the cross-sectional area over which it acts.

U

Ultimate Strength

The maximum stress (tensile, compressive, or shear) a material can sustain without fracture; determined by dividing maximum load by the original cross-sectional area of the specimen.

Uniform Elongation

Elongation at maximum load and which immediately precedes the onset of necking in a tensile test.

Uniform Strain

Strain occurring prior to the beginning of its localization (necking). Strain to maximum load in the tensile test.

W

Wire

A thin, flexible, continuous length of metal, usually of theoretically constant circular cross section and usually produced by drawing through a die.

Wear

It is the damage of a solid surface, generally involving progressive loss of material, due to relative motion between that surface and a contacting surface or substance.

Y

Yield

It is an evidence of plastic deformation in structural materials. It is also known as plastic flow or creep.

Yield point

It's the first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only certain metals--those which exhibit a localized, heterogeneous kind of transition from elastic to plastic deformation--produce a yield point. If there is a decrease in stress after yielding, a distinction can be made between upper and lower yield points. The load at which a sudden drop in the flow curve occurs is called the upper yield point.

Yield strength

Stress at which, a material exhibits a specified proportionality deviation from a stress and strain. A theoretical offset of 0.2% is used for many metals.

Yield stress

It is the stress level of highly ductile materials, such as structural steels, at which large strains take place without further increase in stress.

Young's modulus

A term used synonymously with modulus of elasticity. It is the ratio of tensile or compressive stresses to the resulting strain.

X

X-Radiation

It is electromagnetic radiation of the same nature as visible light, but having a wavelength approximately 11000 that of visible light. It is commonly referred to as x-rays.

X-ray Fluorescence

X-ray fluorescence is a spectroscopic method that is commonly used for solids in which secondary X-ray emission is generated by excitation of a sample with X-rays. The X-rays eject inner-shell electrons. Outer-shell electrons take their place and emit photons in the process. The wavelength of the photons depends on the energy difference between the outer-shell and inner-shell electron orbitals. The amount of X-ray fluorescence is very sample dependent and quantitative analysis requires calibration with standards that are similar to the sample matrix.

X-ray Spectrometry

It is a measurement of wavelengths of x-rays by observing their diffraction by crystals of known lattice spacing.

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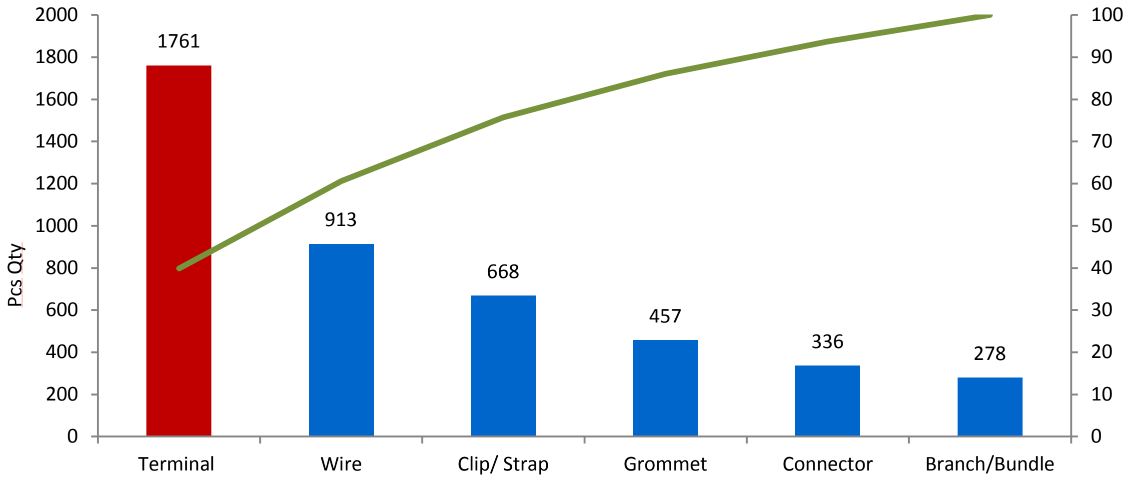
1. Introduction

1.1. Scope

During the year of 2013, at YAZAKI Europe Limited, one of the greatest European wiring harness suppliers for automotive industry, it was decided to understand the weight of the most important and common components in wiring harness products, in 0 km Customers Quality Complaints, at European level, considering the period of time between July 2011 and June 2012. After a complete compilation on internal data from different Customers projects, the component *terminal* came up as the top of Pareto, against others such as wires, clips and connectors.



Graphic 1 | 0 Km Quality Customer Complaints for Wiring Harness products between July 2011 and June 2012

As can be checked on the Pareto graphic presented above, terminal related defects have a very important and negative impact at the final Customers. Represent almost 2 times more than wires related defects, 2nd placed.

The urgent necessity to start a deeper investigation to understand why terminals have such big influence on this very important supplier performance indicator (nr. of quality complaints), internal and most important to customers eyes was raised.

As all unexplored themes, a complete internal database information analyzes was performed, very useful information was outcome as Pareto and Histogram graphics, such as: Customers more impacted, Internal production plant affected, production dates and complaints dates top 5 months, and others, for internal company eyes only, meaning, will not be presented here.

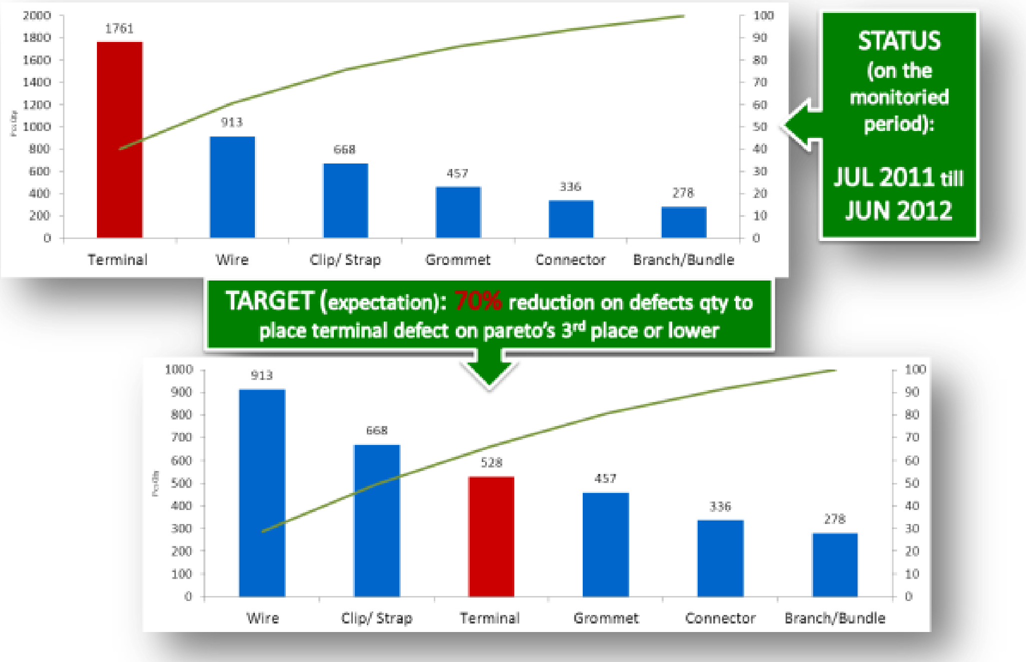
In a different perspective, other information was detailed as well, complaints root-cause and outflow, pictures, products technical information was collected and, at the end, all information that could be accessed. Is noteworthy that not everything was easy to get, and some other was quickly understood that was rather impossible to, even after several contacts with different interlocutors, internal and external.

Finally, a unique database was assembled. The present investigation could be initiated driven by problem solving methodology, the DMAIC+R (Define, Measure, Analyze, Improve, Control + Replicate) process (Six Sigma methodology).

1.2. Objectives

Company internally as for academically main objectives are the definition of real complaints root-causes determination based in real measurements, and analysis of work methodologies and practical tests results (simulation and validation of defect-related complaints).

Most important Company expectation is the definition of a methodology for terminals mechanical behavior. This classification is intended for production plants usage manly in early production preparation stage (inspection reception area). As well, but in this case considered as a long term expectation, is intended that a procedure can be established and introduced to European Company plants in order to allow implementation and/or recommendation of good practices in production shop floor in order to reduce in 70% the contacted number of 0 Km Quality Customer Complaints.



Graphic 2 | Quality Customer Complaints reduction Target expectation

1.3. DMAIC+R Methodology[2]

DMAIC+R methodology objective is to drive costly variation from manufacturing and business processes. There are six steps, *Define*, *Measure*, *Analyze*, *Improve*, *Control* and Replicate. DMAIC+R delivers sustained defect-free performance, provides a structure for improving metrics such as customer satisfaction, warranty, liability costs, in-house waste, and countless other possibilities.

Simple stated, DMAIC+R allows:

- Assists problem solving teams by providing a template to assure that data driven decisions are made in the problem solving process by ensuring robustness of the resolution;
- Individual summary of each DMAIC+R step that is simplified and standardized.
- The six-step is a format that is flexible enough to be used by all business units;
- Simplified and consistent communication to management in a concise way;
- Quality Leadership behavior is improved by encouraging management and problem solving teams asking the right questions.

Intensify Communication

- The six-step is a story about the logical thinking process
- Grasps the situation with facts/data
- Reviews are simple and consistent

Improves Working Process

- Standardizes the problem solving process and language
- Cadence set at meetings and operations reviews

Quality Leadership Initiative

- Technical employees engaged at reviews
- Improves Quality Toolsets utilization

Quality Toolsets

- DMAIC+R is the foundation
- Containment measures included

Answering the "Key Questions" will help guide teams through their problem solving report-out to management. To encourage an organization to communicate in a common robust problem solving language, each organization must disseminate is own "Key Questions" Cards.

[2] Internal Company documentation

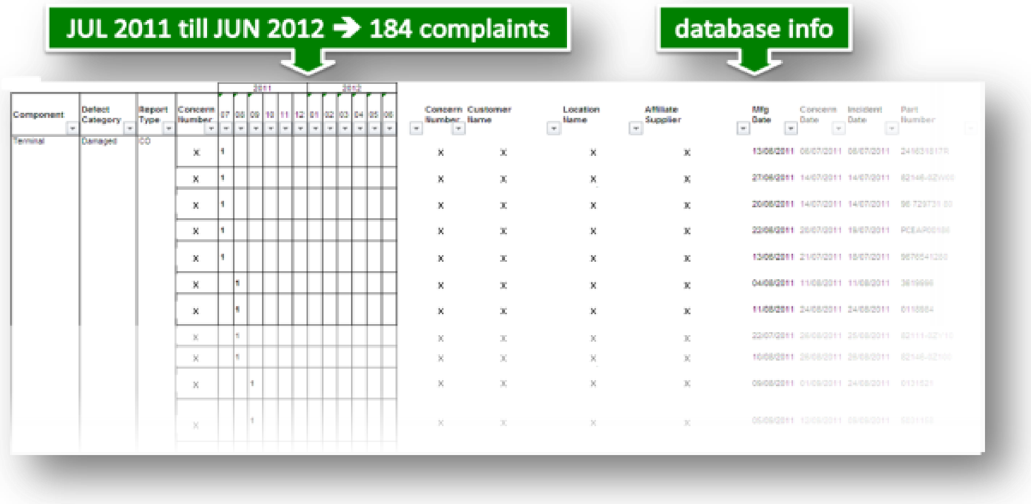
"Key Questions" card example:

Table 1 | DMAIC+R methodology "Key Questions" card example

	Corrective and Preventive Actions
Define	Who is my Customer? What matters? What's the scope? What Defect am I trying to reduce? By how much (Realistic/Appropriate Goal)? What's the current Cost of defects (Poor Quality)?
Measure	What's my Process? How does it function? Which outcome affect most? Which Inputs seem to affects Outcomes most? Is my ability to Measure/Defect "Good enough? How's my process doing today? How good could my (current) process be written everything is running "smoothly"? What's the best that my process was "Designed" to do?
Analyze	Which Inputs actually (for sure) affect most? By how much? Do combinations of variables affect outcomes? If I observe results (outcomes) from the same process, different locations, and results appear to be different… are they really? How many observed do I need to draw conclusions? What is the level of confidence do I have regarding my conclusions?
Improve	Once I know "for sure" which inputs most affect my outcomes, how do I "set" (properly implement) them? How many trails do I need to run to find and confirm the optimal setting / produce of these key points?
Control	Once I've reduced the defects, how does the functional team ensure we keep them there? How does the functional them keep it going routinely? What do we need to set up to keep it going routinely? What do we need to set to keep it going when things change… people, technology and customers…
Replicate	Who else at the company can benefit from the project findings? What can be done to update the cooperate knowledge? After six months Is the improvements sustained?

1.4. Structure & Strategy

Firstly, during the period of July 2011 till June 2012 were recorded 184 Quality Customer Complaints at European level, terminals defects related only.

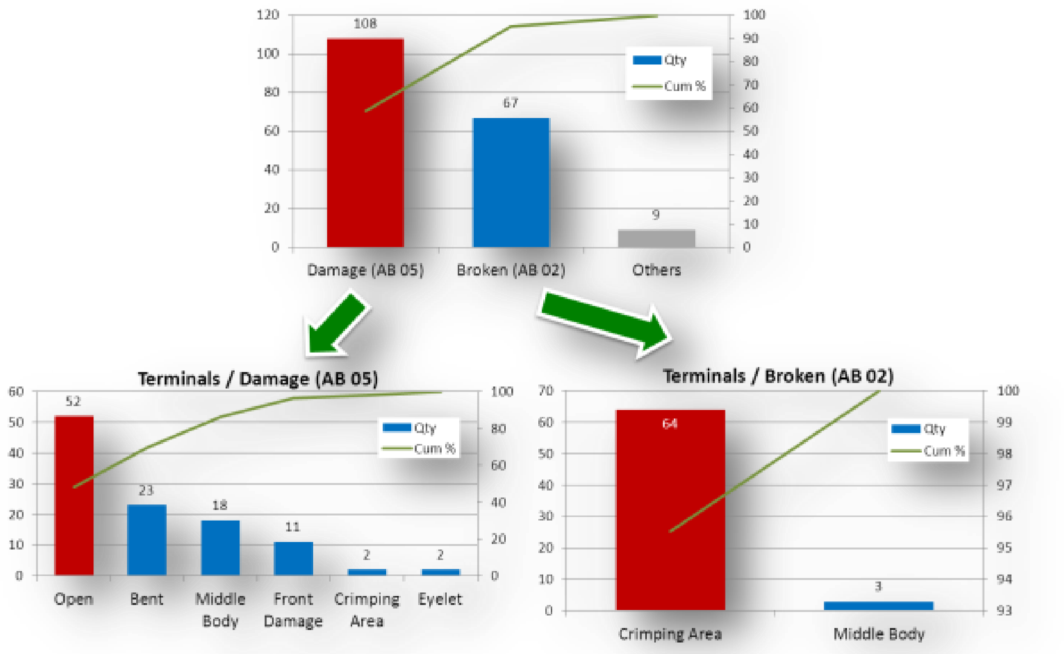


Picture 1 | Total Quality Customer Complaints database information

Secondly, and as previously mentioned, complaints root-cause and outflow, pictures, products technical information was collected exhaustibly.

Picture 2 | Total Quality Customer Complaints Root-causes and Outflows database information

Root-cause and Defects kinds Pareto's graphics were realized for a better and quicker results interpretation as well to identify which defect kinds and root-cause have more impact.



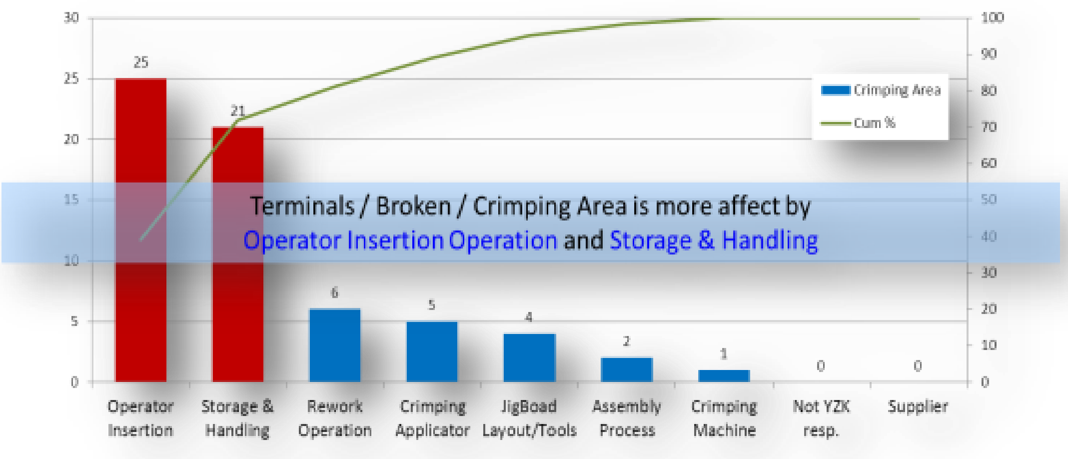
Graphic 3 | Root-cause and Defects types Pareto's graphics

In summary, two main kinds of terminal defects are defined at this stage, *Damage* (AB05 – internal company defect code) and *Broken* (AB02 – internal company defect code).

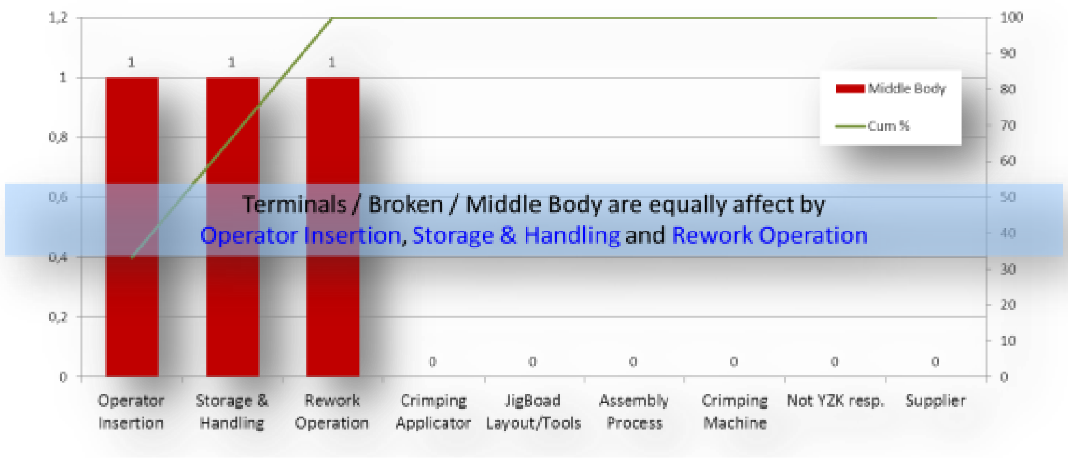
Others were considered not relevant mainly justified by its occurrence frequency and typology.

Going deeper in each kind, starting by *Damage* kind, Open is clearly the top of root-cause Pareto, among six. In the other hand, on broken kind, Crimping Area is the top of Pareto, among two identified root-causes.

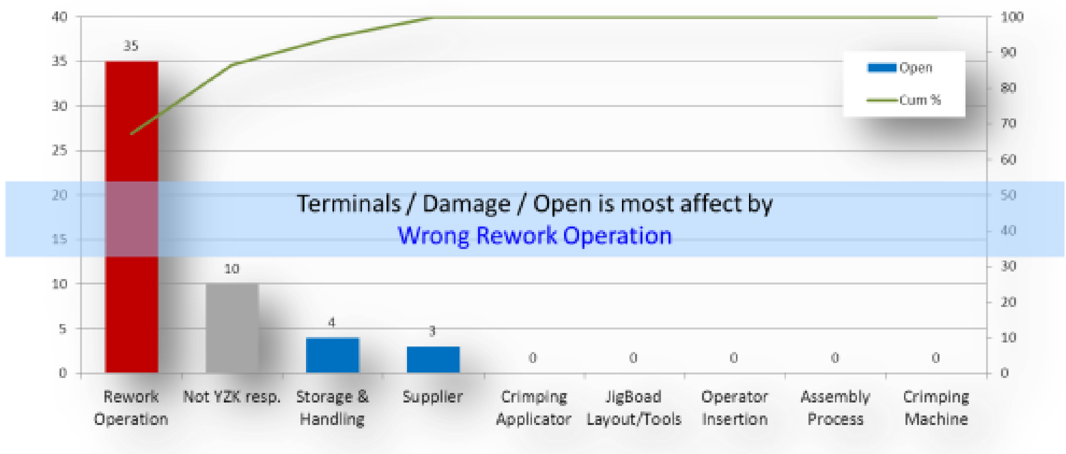
Next step, undoubtedly and using the '5 why' analysis method principle, it was realize what was behind of the identify root-causes, all were divided and Pareto's risen, as follows.



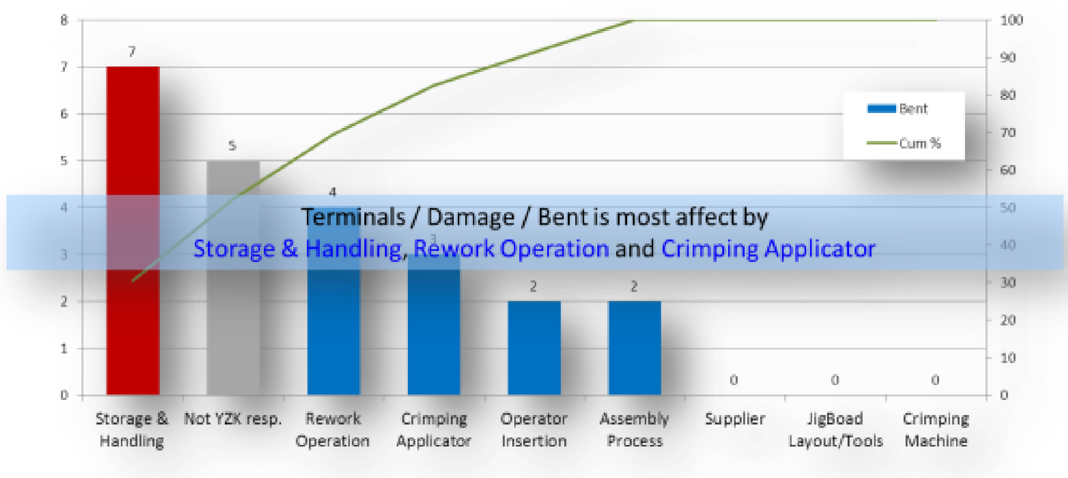
Graphic 4 | Terminals / Broken / Crimping Area root-cause Pareto graphic



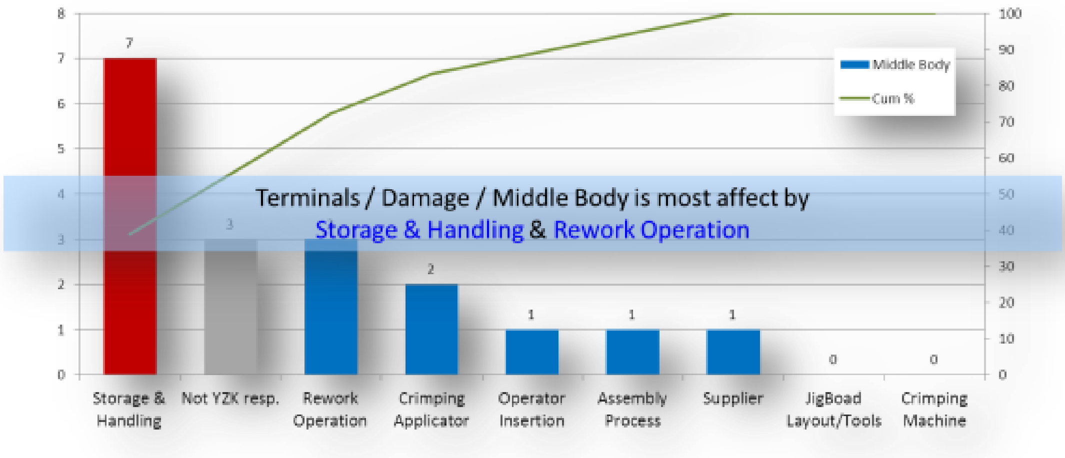
Graphic 7 | Terminals / Broken / Middle Body root-cause Pareto graphic



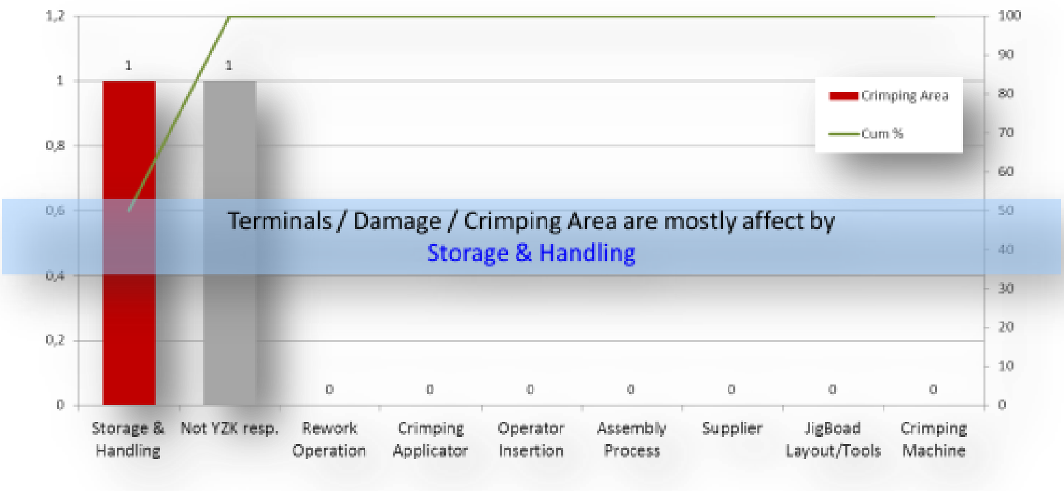
Graphic 7 | Terminals / Broken / Open root-cause Pareto graphic



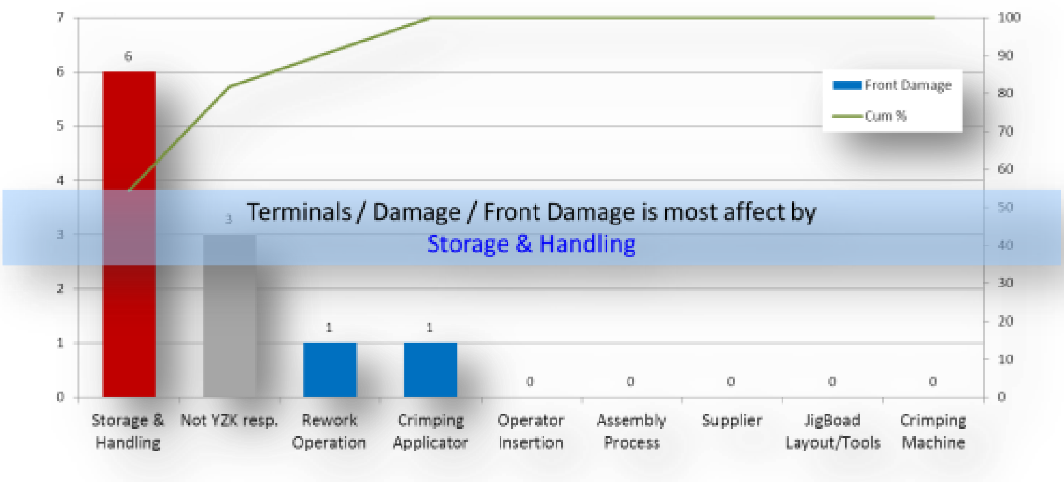
Graphic 7 | Terminals / Damage / Bent root-cause Pareto graphic



Graphic 10 | Terminals / Damage / Middle Body root-cause Pareto graphic



Graphic 10 | Terminals / Damage / Crimping Area root-cause Pareto graphic



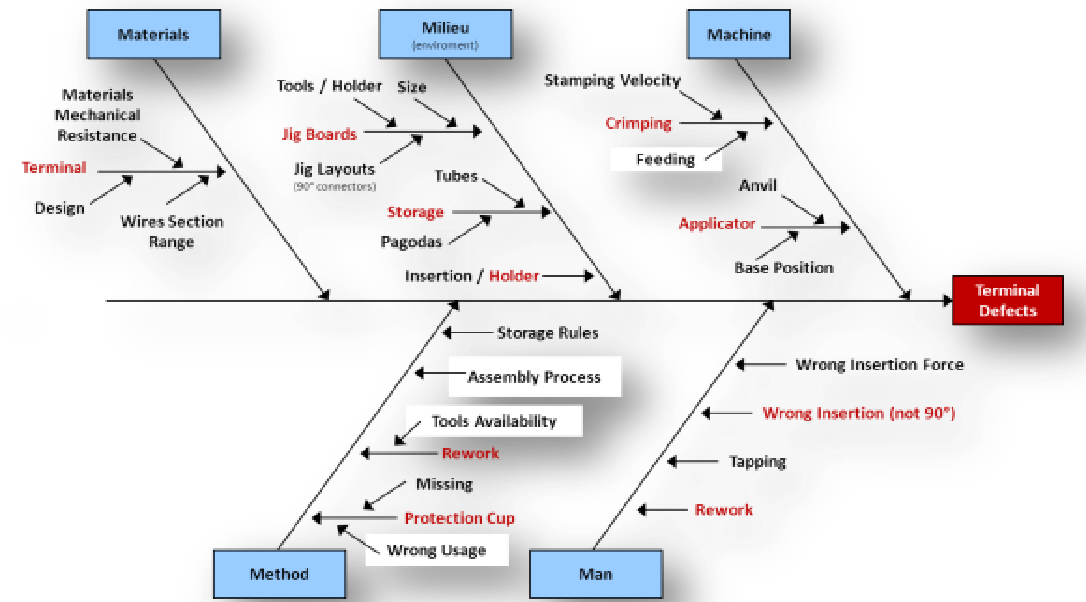
Graphic 10 | Terminals / Damage / Front Damage root-cause Pareto graphic

As a visual resume, the following table was created with pictures of real cases for each defect kind and kind, in direct correspondence with its root-cause. For information, N/A means, not applicable or no pictures available.

Picture 3 | Pictures of real cases for each defect type versus root-cause

As a Company expected investigation outcome, a visual structure was designed in an Ishikawa diagram form, where are identified all the investigation strategic areas of interest.

The following steps were mainly focus on Materials, Machine and Method areas.



Picture 4 | Terminal defect root-causes Ishikawa diagram

2. Bibliography Revision

2.1. Automotive Industry components production

2.1.1. Automotive Industry particularly characteristics[3]

Top quality demand is total customer satisfaction - worldwide

Building long-term relationships with customers based on trust and a dedicated work environment – top service focused on customers must be the main goal. Long-lasting consulting relationships within an international customer base – a result of consistently developing solutions that are both practical and economical.

Expertise at hand

A supplier for automotive systems must support customers with consultation services tailor-made for every individual product requirement.

With global support close to customer, expert assistance must be given on such wide-ranging aspects as in order to reach to leadership:

- All automotive segments from small passenger cars to heavy duty trucks
- Best-in-class design processes and tools
- Design and manufacturing disciplines for outstanding quality and reliability
- Business models from "build to print" to "system integrator"
- Industrialization support
- Complexity management and optimization
- End-customer specific products (KSK)

Providing the Tools for Tomorrow – Today – Worldwide

A supplier has to act in step with today’s world and society’s requirements. Through careful research of market demands and trends, developing business specifically with customer needs in mind. Offer the latest technologies and development tools, whilst maintaining supplier emphasis on interaction with the valued customers. Introduce local development and testing centers, providing up to date solutions exactly where and how they are needed.

[3] [4] www.yazaki-europe.com
[5] www.yazaki.com

Continuous improvement

Product feasibility and competent manufacturing are of paramount importance to the value chain, as mistakes mean loss of valuable time and increased costs. Unique industrialization process results in the elimination of product feasibility problems both in value chain and in OEM assembly.

Having close links between development, design and manufacturing must become a basic philosophy. By this treatment it is guarantee the best value-add for all customers.

Also part of continuous improvement is “Go to the source - Listen to the customer”.

Customer total project and lifecycle management

Project management system must provide a sound basis for comprehensive lifecycle management, including:

- Common design targets definition in the concept phase;
- On-site service during the development process;
- Flexible and quick supply of proto kind parts;
- Industrialization planning within our customers’ targets;
- Full product history documentation available at any time;
- Managing all environmental aspects;
- Continuous improvement activities during the product lifetime;
- Spare part management and supply.

Environmental lifecycle

As environmental performance is becoming ever more important, new vehicle programs have several important targets for environmental product design, like improving the re-use, recyclability and recoverability, reducing substances of concern and increasing fuel efficiency.

In order to ensure these goals meet the environmental life cycle, it is necessary to consider environmental performance at an early stage of the design process:

- Environmental expectations are considered as part of the total product design;
- Environmental design is more effectively integrated in the early stages of the product design.

Product tracking

Employment of sophisticated product tracking system which allows tracing back to the faulty component batch and reporting all components affected.

Bridging the gap

The supply of components must be secured for all customers for a long-term basis over the entire lifecycle. Detailed requirements are necessary for the long-term supply of components with regard to the terminated production and/or delivery (end of life).

Supplying information by customer need

Suppliers must inform customers of changes and end of life of sub-components, materials and tools. Investigate alternative solutions together, supplier and customers, in order not to jeopardize deliveries.

2.1.2. Automotive Industry required Quality[4]

Quality is what a supplier must stand for

Competent and motivated suppliers achieve this by using advanced tools, excellent materials and capable processes.

Maintained Quality System ensures consistent and effective operation of processes affecting the quality for product and services. It includes processes that relate applicable standards and provides policy and guidance.

Total quality excellence-guiding principles

To continually improve products and services in accordance with the customer needs and in order to supplier prosper in automotive business.

Quality comes first

To achieve customer satisfaction, the quality of products and services is number one priority.

Customer focus

Supplier work must be done with all customers in mind, providing better products and services than next competitor.

[4] [4] www.yazaki-europe.com
[5] www.yazaki.com

Quality is everyone's job

Each individual can influence some parts of the manufacturing process of a product or service provided, therefore, affecting the quality of its output and ultimately the customer's satisfaction. Continuous Training is required.

Prevention

Quality excellence can best be achieved by preventing problems rather than by detecting and correcting them after they occur.

Continuous improvement is essential to success

Supplier must strive for excellence in everything he does, in its products, in their safety and value, in its services, human relations, its competitiveness and its profitability.

Internal customer / supplier relation

Each employee is a customer for work performed by other employees or suppliers, with a right to expect good work from others and an obligation to contribute work of high quality to those who, in turn, are his or her customer.

Customer and suppliers must be consider partners

The company must maintain mutually beneficial relationships with customers, suppliers and associates.

Employee involvement must be a way of life

Everyone must treat each other with trust and respect.

Quality requirements

Ultimate target is to have zero incidents. Zero disruptions provide products with zero defective, flawless delivery performance and on time responsiveness to issues.

Quality System Requirements

The supplier manufacturing location is required to be registered under a recognized automotive industry standard. Since January 2004, only ISO TS 16949 is accepted.

All automotive suppliers should use AIAG (Automotive Industry Action Group) procedures for per example process such as FMEA's.

Performance Requirements

- Monitoring the process and product quality performance and demonstrate continuous improvement. Effective tracking methods which drive continuous improvement;
- Full responsibility for production including financial aspects for all non-conforming materials/products and their effects;
- Ensuring 100% on time delivery as per customer schedule requirements;
- Performance in production is constantly followed: ppm level and demerits, cost reduction, delivery.

Product requirements

- All evidences are required of compliance to the customer specifications and governing requirements for "restricted, toxic and hazardous substances";
- Monitor and control all product features, key characteristics (safety and regulation);
- Process must be in statistical control and capability indices must be calculated initially and then on an on-going basis.

2.2. Automotive Industry Wiring Harness[5]

In recent years, automotive vehicles have undergone many technological changes in a short period of time. Vehicles are now more comfortable, safer, more fuel efficient but also highly complex. This drives the Electrical Distribution Systems suppliers to continuously undergo innovative processes in concept, quality and technological requirements. Long-term experience has been used for wiring harnesses engineering with minimal production deviations, maximum integrity and the ability to keep extreme tolerances over long distances.

YAZAKI’s timeline of success dates back to 1929 when YAZAKI began selling wiring harnesses for automobiles. After important changes in governmental regulations in 1935, Japanese companies were allowed to start domestic automotive production – with positive effects for YAZAKI: In 1939 the business could be expanded and in 1941, YAZAKI Electric Wire Industrial Co. Ltd. was established with about 70 employees.

[5] [4] www.yazaki-europe.com
[5] www.yazaki.com

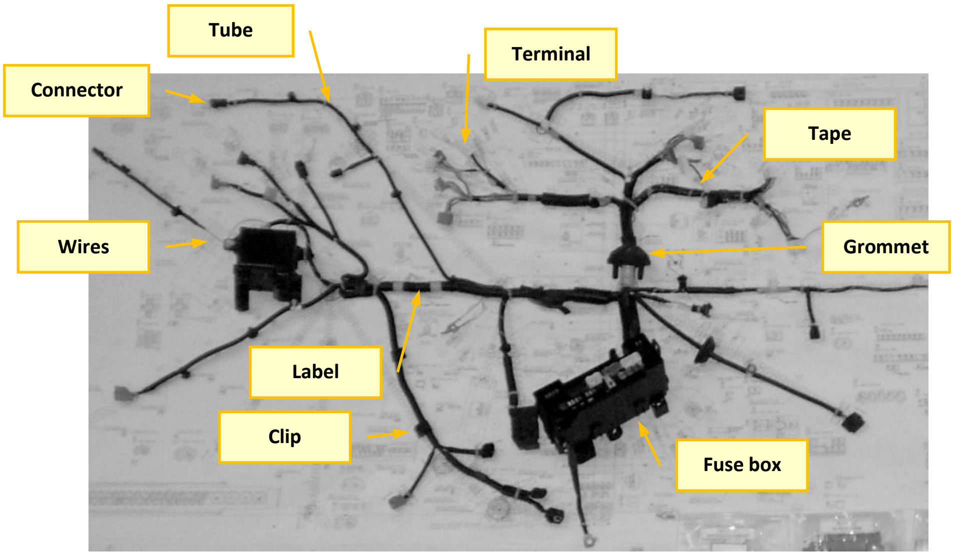
At this time, automotive engineering was a promising branch of industry and so in 1949, YAZAKI made an important strategic decision: to focus on the production of automotive wiring harnesses. This was a groundbreaking decision, which resulted in today's global leadership.

Picture 5 | YAZAKI manufacturing plant in 1949

The competencies that YAZAKI developed in the automotive business were used to establish various kinds of equipment for the city gas industry, amongst others, also the world's first solar-powered absorption cooling system, designed and built, in 1974. Since then the company products that support the supply and utilization of various energy sources, such as electricity transmission cables, gas security systems, air-conditioning equipment and the aforementioned absorption chillers. As a result, YAZAKI began to cater for a safe and environmentally friendly society. These products are now integrated under the environment & energy equipment operations, the second biggest sector in the YAZAKI Group, emphasizing its continued commitment to an environmentally friendly future.

2.2.1. Automotive Industry Wiring Harness characterization

A wiring harness can be described as an assembly of several electrical conducting wires (Copper alloy base is the most common) and their fixing components. Some of those components support the product on the vehicle structures, others do electrical connection function and others have the ability to shape its rooting path. The principal function of a wiring harness is to coordinate and control all electric system distribution on the vehicle.



Picture 6 | Wiring Harness main components

Cutting and Pre-Assembly area

It's the production location where all wires are cut and crimped. Fully Automatic and Semi-Automatic press machines are used. All the semi-products that are derivate are now assembled in others and/or other components are added, such as connectors.

Picture 7 | Actual wiring harness manufacturing plant- Cutting area

Assembly Area

This is the production area were final product takes its final format and shape. Most of the operations performed are hand-made. Qualified man-work is one of the most added values at this stage. There are several assembly equipment systems available, from wooden fixed tables to automatized assembly lines.

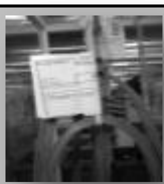
Picture 8 | Actual wiring harness manufacturing plant – Assembly area

2.2.2. Wiring Harness production process planning

A Bill Of Material (BOM) list is one very first and important outcome from Customer new project consultation (example) that needs to be analyzed in detail by every answering expert Supplier.

For wiring harness a BOM list is in general cases formed by several components such.

Table 2 | Example of a Wiring Harness BOM List

PART Name	CUSTOMER Reference	SUPPLIER Reference	PHOTOS	SPECIFICATION Reference DWG Reference	W/H PRODUCER Reference	W/H PRODUCER Name	COLOUR or SIZE
Wire	A3Z 1.0 BA	T4062A		8200337674	180 F34060	A3Z 1.0 W	Red
Connector	964232628	211PL022 S4049		211FT0366	7282-0658	x	Yellow
Terminal	13522325	13522325		13522326	7116-5082	x	(0.35~0.5)
Tube	TwistTube 2420	TwistTube 2420		TwistTube	450 213	TT2420 D5	Black
Tape	Z00022542	294		X	430 F8 19	ST294 19 B	Black
Clip	961683388	30013738		30013738	7047-3938	x	Black
Grommet	965172318	A0016600		9651723180	7235-9896	x	Black
Protector	455457000	45545570		212793000	7173-1667	x	Black

2.2.3. Wiring harness production dedicated equipment

A Production Flows are raised, equipment necessities are judged according the BOM list and, of course, customer technical product specifications. Among other requirements, complete production steps are assembled. For wiring harness a Production Flow in general cases is consider several equipment, as we can see in the next table.

Table 3 | Example of a Wiring Harness Production Flow

PROCESS	EQUIPMENT	PHOTO
Automatic Cutting and Crimping	Press Machine	
Semi-automatic Crimping	Press Machine	
Sub-Assembly	Gabarit	
Assembly	Fixe Tables and Automatized Lines	
Connectors, Tube, Grommets and Tape application	Manually	..
Clips application	Clips Gun	

2.2.4. Demanded and Guarantied Quality process

A process Control Plan is a Quality tool that must exist in any automotive production step.
On this document Production as long Quality and Process Engineering departments need to work as a TEAM to initially identify product key characteristics, then identify in which production step a specific control needs to be implemented in order to which demanded internal, customer or legal specification. Control Frequency, sampling size and method are then established taking into consideration production efficiency. Assembly and Quality Operators are trained and documents are respected. Wiring harness business a Control Plan in general considers the following items:

Table 4 | Example of a Wiring Harness Process Control Plan

PROCESS	**CHARACTERISTIC**		**SPECIFICATION**	**EVALUATION**	**SAMPLE**
Name	**Product**	**Process**	**Tolerance**	**Measurement**	**Size/Freq.**
Receiving Inspection	**Wires** kind, size, color, appearance **Components** dimension, appearance, color, reference	Inspect Wires Measure Wires Inspect component, Identify status of inspection	sample board, wire specification, inspection standard, FAST - CHECK	Visual	Sampling
Sub-Assembly	**Connector** reference, color, appearance **Wire** kind, size, color, appearance **Terminal** Reference, position	Terminal insertion into the connector cavity, push-click-pull pull test	According work, Instruction, Internal drawing	Visual push-click-pull pull	100%
Assembly	**Wire** kind, size, color, length, appearance, position **Connector** Reference, position, appearance	wire layout position, terminal push out	must be conform with wire layout drawing, assembly drawing	Visual push-click-pull pull	100%
Taping	tape kind, color, appearance, quality	Taping wires	must be according to drawing	Visual	100%
Clips Assembly	reference, attachment place, direction, condition attachment, condition of clips on connectors	Clip attachment	must be according to drawing	Clip gun Assembly drawing	100%
Electrical Inspection	Electrical continuity Existence of clip Condition of the terminal insertion Waterproof test	Electrical continuity check 	Terminal not pushed Out, no cross circuit, secondary lock should be closed, No missing secondary, lock, no air pass for sealed connectors	Electrical continuity check	100%
Final Inspection	**Wiring Harness** Appearance, measure dimension, kind of taping, orientation of branches **Components** appearance, position, orientation, fixed	Branches orientation Taping : kind, appearance Parts : position, orientation, fixing, appearance, check	Master sample and Customer Drawing	Visual, meter.	100%

2.3. Automotive Industry wiring harness component: Terminal

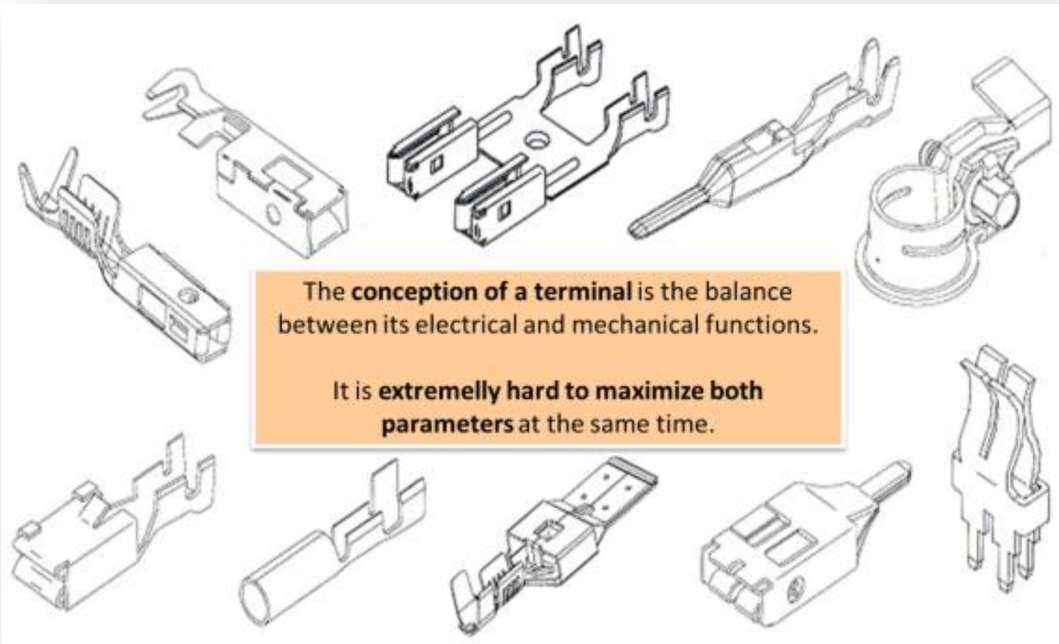
"What's a Terminal?"

This question can be answered in two ways: functionally and structurally.

First, the functional definition will follow.

Terminal Function

A Terminal provides a separable connection between two elements of an electronic system without unacceptable signal distortion or power loss. There are two important parts to this definition, the "separable connection" and the "unacceptable" performance. Both depend on the connector application and its electrical and environmental requirements. The separable connection is the reason for using a connector in the first place, to provide easy repair, upgrading, maintenance or inter-connectability. Requirements on the separable Interface include mating load limitations and meeting a specified number of mating cycles. "Unacceptable" performance includes a large range of characteristics.[6]

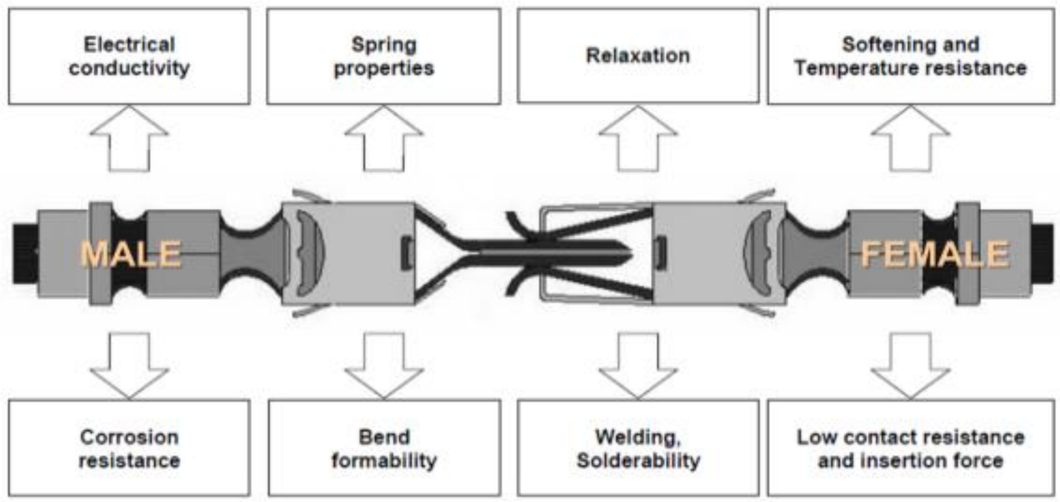


Picture 9 | Different kinds of terminals

[6][6] Robert S. Mroczkowski, "Connector Design/Materials and Connector Reliability", by AMP Incorporated, Harrisburg (USA), 1993

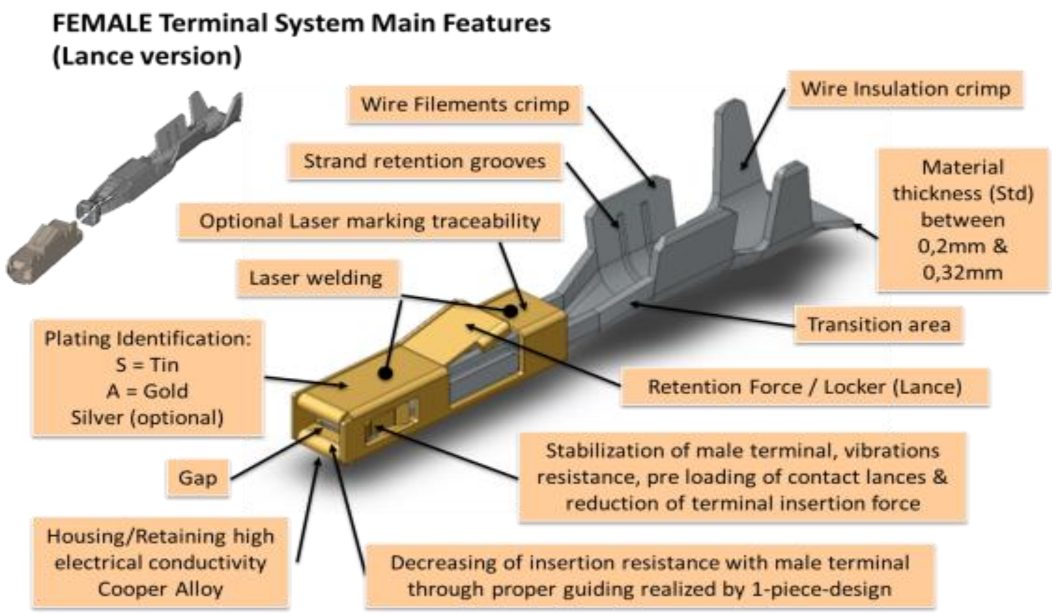
2.3.1. Terminals Geometry

As a common sense when there is a connection between two metallic components that can be mated and unmated, there are two genders of terminals, FEMALE and MALE. For each gender of terminals that are specific general requirements, minimums in different fields, (material characteristics, functionality and design) in order to fulfill their main role.[7]



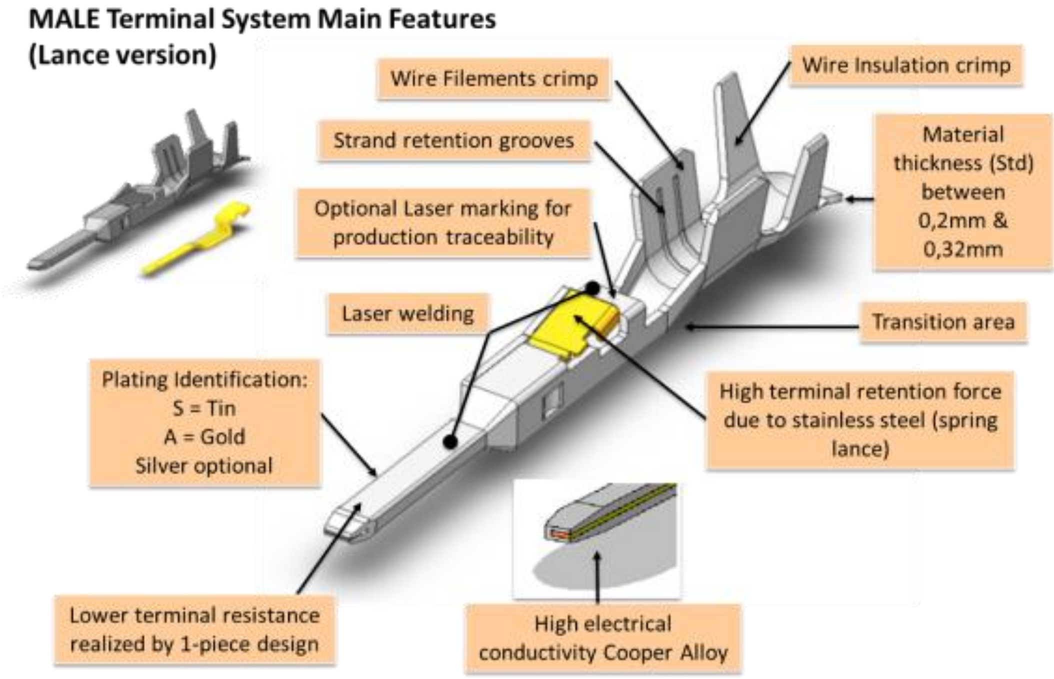
Picture 10 | Terminals main functions and characteristics

In the next two pictures, each gender is fully described for understanding of their composition.



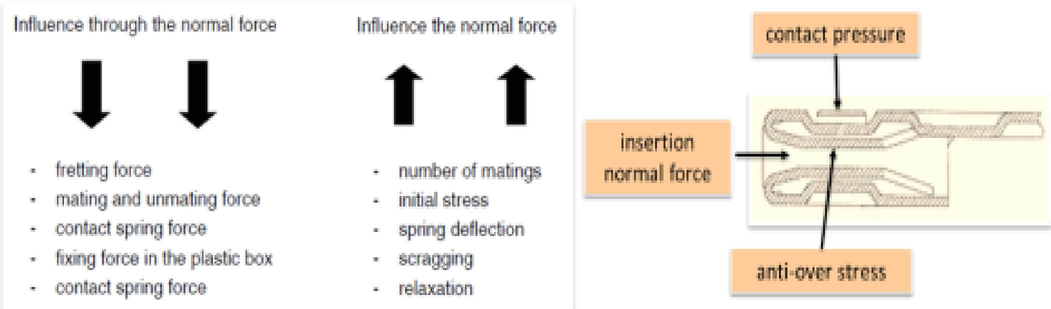
Picture 11 | Female Terminal system main features

[7][7] Udo Adler, Josef Mommertz and Dr. Holder Warnecke, "Technical Manual Strips of copper and copper alloys plain and tinned", by KME AG & Co, Germany, 2010



Picture 12 | Male terminal system main feature

There is an important characteristic that cannot be forgotten: Contact pressure (Normal load). By design, the contact pressure assures its mechanical and electrical functions. Ability to withstand repeated deformations by repeated flexion and traversed insertions. When a connection is repeatedly inserted the contact point/s are flexed. This could lead to a plastic deformation at every cycle and overstress the contact performance by reduction of the contact pressure.[8]



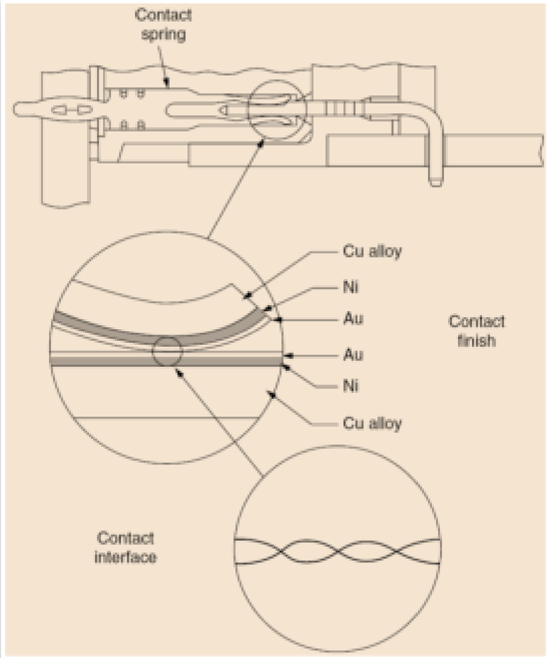
Picture 13 | Terminal contact characteristics and Female Terminal system main features

[8][6] Robert S. Mroczkowski, "Connector Design/Materials and Connector Reliability", by AMP Incorporated, Harrisburg (USA), 1993

Every terminal includes:

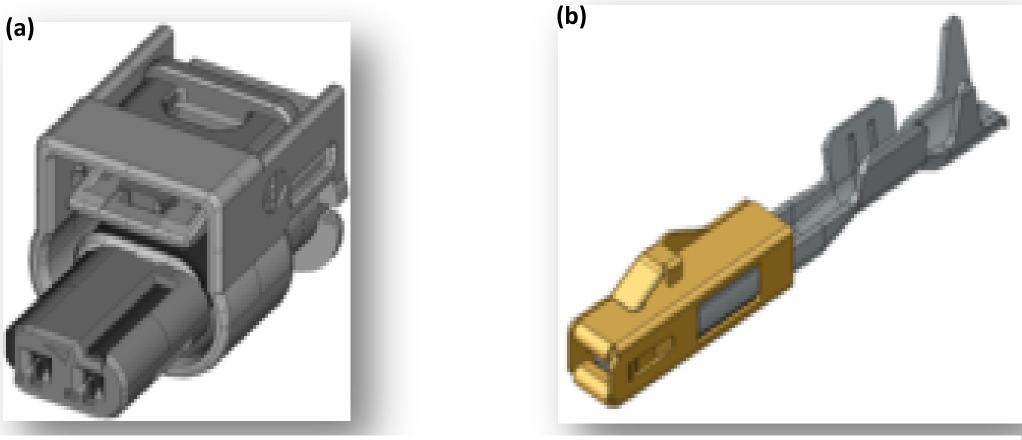
- Two permanent interfaces, the connections to the sub-units which are to be connected;
- The contact springs in each half of the terminal;
- The separable interface;
- The terminal housing which maintains the location of the contacts and isolates them from one another electrically.

The insets in the figure 14 depict the contact finish and the structure of the separable interface on a microscopic level.[9]



Picture 14 | Terminal contact interface features

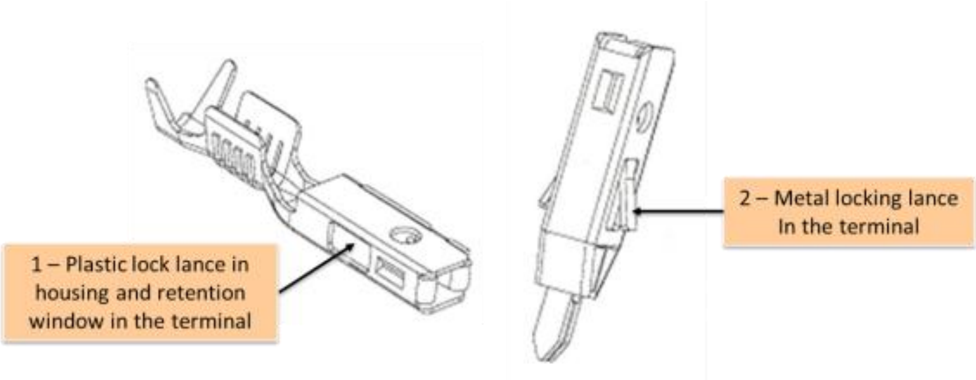
Above all else, the terminal is a key to a good connection system, its characteristics are vital to system function and design. The Connector is the plastic box that locks, holds and isolates the terminals and assures the electrical connection of one or more terminals at the same time.



Picture 15 | (a) Example of connector; (b) example of female terminal

[9] [6] Robert S. Mroczkowski, "Connector Design/Materials and Connector Reliability", by AMP Incorporated, Harrisburg (USA), 1993

There are two possibilities, with or without lances. Both concepts have advantages and disadvantages. The trend is to avoid terminal locking lances to prevent problems at wiring harnesses manufacturers, but metal locks are more suitable for the conception of non-sealed connections.



Picture 16 | Terminal lances typology

Common Defects

Material

- Wrong Physical Characteristics (Hardness, Tensile Strength, etc.)
- Different Material than specified

Plating

- Without surface coating
- Discontinuity on coating
- Incorrect thickness
- Stains

Stamping

- Cracks
- Deformed
- Scratches
- Crushed

2.3.2. Terminals common materials usage

Copper is an element and a mineral called native Copper.

- Found in Chile, Indonesia and USA.
- Copper is an industrial metal and widely used in unalloyed and alloyed conditions.
  (Second ranked from steel and aluminum)
- Used mostly in building constructions and as electronic products.

Picture 17 | as extracted copper

Picture 18 | Copper wire conductors

Copper have excellent electrical and thermal conductivities, exhibit good strength and formability, have outstanding resistance to corrosion and fatigue, and presents usually a nonmagnetic behavior.

Can be readily soldered and brazed, and many can be welded by various gas, arc and resistance methods.

Pure Copper is used extensively for electrical wire and cable, electrical contacts and various other parts that are required to pass electrical current because of their outstanding ability to withstand corrosion.[10]

[10] [8] "Copper Is… brochure", by Copper Development Association, Ltd, New York (USA), 2011

Application of Copper in automotive

Copper usually is working behind the scenes in automotive applications. Increasing the use of electronic parts in cars raise the amount of Copper used per vehicle.

Picture 19 | Copper applications

Extraction of Copper from ores

Copper ores are usually associated with sulphur and can be extracted from chalcocite Cu_2S, chalcopyrite $CuFeS_2$ and cuprite Cu_2O.[11]

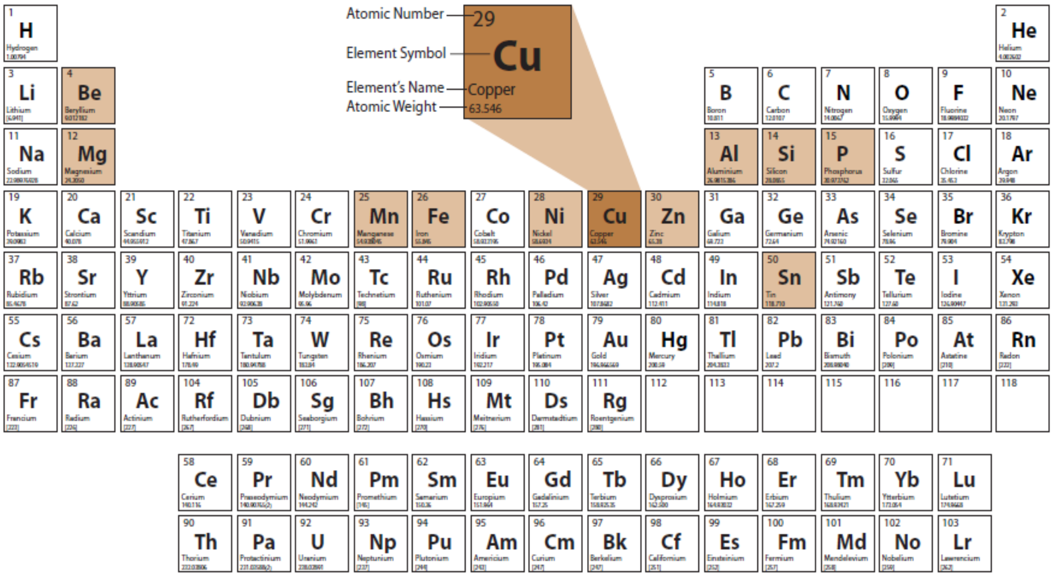
Chalcocite (Cu_2S, copper sulphide) | Chalcopyrite (CuFeS2, copper iron sulphide) | Cuprite (Cu2O, copper oxide)

Picture 20 | Different copper ores presentation, as extracted

- **Copper** exhibits a face-centered *cubic crystal structure*.
- **Noble metal** has inherent properties similar to those of silver and gold.
- **High solubility** for other elements such as nickel, zinc, tin and aluminum.
- **Density** is 8.89 g/cm^3 (0.321 lb/in^2), and its **Melting Point** is 1083 °C (1981 °F).

Note: All of these properties are significantly modified when Copper is alloyed.[12]

[11] [9] "Copper and its alloys - Chapter4 ", by Suranaree University of Technology, Tapany Udomphol (Thailand), 2007
[12] [8] "Copper Is… brochure", by Copper Development Association, Ltd, New York (USA), 2011



Picture 21 | Copper on the periodic table of elements, [8]

Classification of Copper and Copper alloys

Copper and Copper alloys are designated according to the Copper Development Association (CDA).

Wrought alloys

C100-C799

Cast alloys

C800-C999

Wrought alloys	
C1xx	Coppers[1] and high-copper alloys[2]
C2xx	Copper-zinc alloys (brasses)
C3xx	Copper-zinc-lead alloys (leaded brasses)
C4xx	Copper-zinc-tin alloys (tin brasses)
C5xx	Copper-tin alloys (phosphor bronzes)
C6xx	Copper-aluminum alloys (aluminum bronzes), copper-silicon alloys (silicon bronzes) and miscellaneous copper-zinc alloys
C7xx	Copper-nickel and copper-nickel-zinc alloys (nickel silvers)
Cast alloys	
C8xx	Cast coppers, cast high-copper alloys, the cast brasses of various types, cast manganese-bronze alloys, and cast copper-zinc-silicon alloys
C9xx	Cast copper-tin alloys, copper-tin-lead alloys, copper-tin-nickel alloys, copper-aluminum-iron alloys, and copper-nickel-iron and copper-nickel-zinc alloys

[1] "Coppers" have a minimum copper content of 99.3 percent or higher.

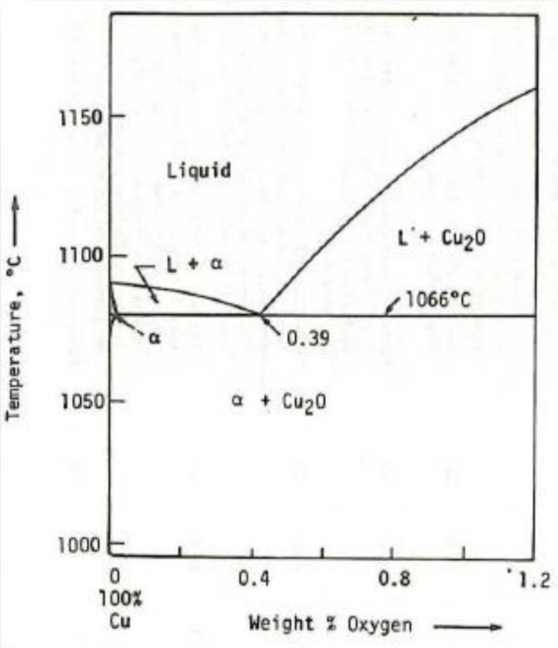
[2] High-copper alloys have less than 99.3% Cu, but more than 96 percent, and do not fit into the other copper alloy groups.

Picture 22 | Copper alloys classification

The wrought Coppers

Unalloyed Copper usually presents the following properties[13]:

- Good electrical and thermal conductivities;
- High corrosion resistance;
- Easily fabricated;
- Reasonable tensile strength;
- Controllable annealing properties;
- Good soldering and joining properties.



Picture 23 | Copper-oxygen phase diagram, [2]

Wrought Coppers are classified according to oxygen and impurity contents. Can be roughly divided into:

- Electrolytic tough pitch;
- Oxygen – free;
- Phosphorus deoxidized.

Copper is well-known to be a soft, malleable metal. Copper alloys offer a wide variety and combination of mechanical properties that reflect a degree of adaptability not available in other alloy systems. Grain refinement, are selected to maximize strength, ductility and conductivity. The highest strength and stress relaxation resistance characteristics are offered by the precipitation strengthened alloys. Copper alloys are strengthened by cold work or by solid solution additions that enhance strain hardening. In the annealed condition, the yield and tensile strength vary inversely with grain size. The addition of alloying elements to Copper increases tensile strength, yield strength and the rate of work hardening. For example, in brasses, the tensile strength and yield strength both increase as the zinc content increases.

Picture 24 | Some different copper colors

[13] [9] "Copper and its alloys - Chapter4 ", by Suranaree University of Technology, Tapany Udomphol (Thailand), 2007

Copper Nickel

Alloys containing from 2% to 30% of nickel, are highly corrosion-resistant and thermally stable. The addition of iron and/or manganese can improve their strength and corrosion resistance.

Copper Zinc

Exhibit good strength and ductility and are easily cold worked, properties which improve with increased zinc content 35%.

Copper Tin

Contain up to 8% tin. All alloys contain a small amount of phosphorus (0.02 .. 0.4%).

When cold worked, the alloys are hard and springy, but tin has a marked effect on conductivity.

One exception is an alloy containing 1.0 .. 1.5% tin, which is used for trolley wire, having high strength and wear resistance.

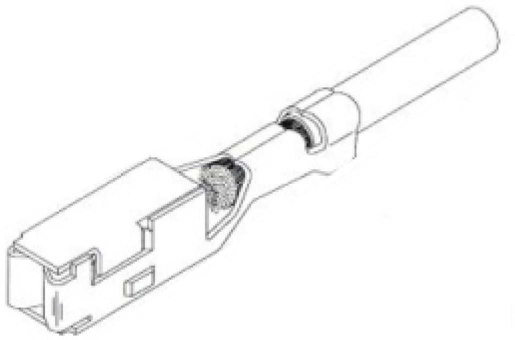
Copper Nickel Tin and Copper Nickel Silicon

Both alloys provide unique combinations of properties due to their intrinsic precipitation hardening capability. Good formability, electrical conductivity makes them appropriate for use in electrical and electronic connectors and hardware.

2.3.3. Terminals Crimping Method, Equipment and Evaluation

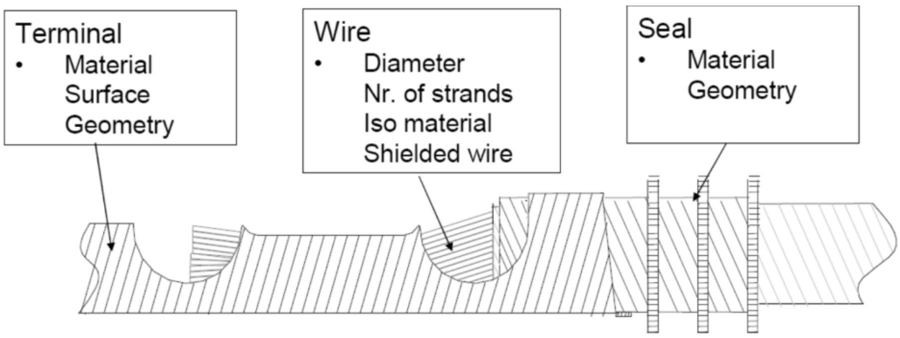
What is CRIMPING?

CRIMPING is the controlled deformation of a terminal and wire into a solid connection. Controlled deformation is the pre-requisite for the reliable achievement and reproduction of mechanical and electrical parameters in the crimped connection.



Picture 25 | Crimped Female Terminal

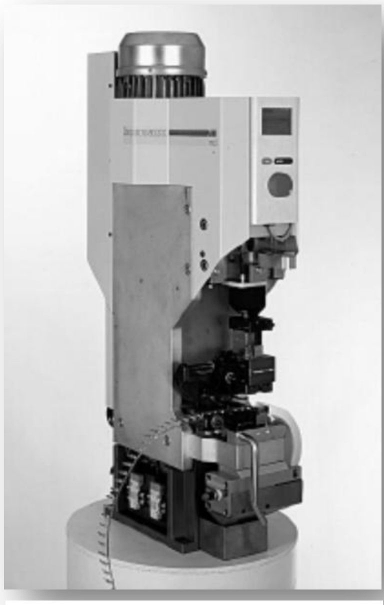
Next picture description of kinds of crimping connections and crimping zones:



Picture 26 | Schematic diagram of a crimped terminal

Crimping Process Equipment / Tools – Press kinds:

- Automatic / Manual;
- Mechanical / Hydraulic;
- Single / Double station ;
- Wire feeding system;
- Stripping blades;
- Seal insertion device.



Picture 27 | Crimping press

Note:

Automatic machine is available to do cutting and crimping of wires between 0.25 .. 6.0 mm² sections.

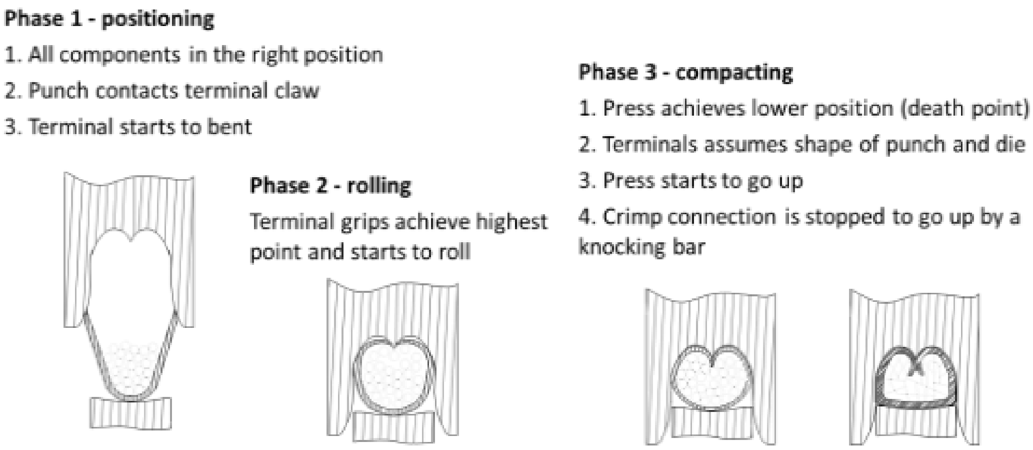
On the picture aside can be found a typical crimping applicator tool. Hereunder it can be finding the main characteristics description:

- The feeding system can be mechanical and or pneumatic;
- Its crimping height is adjustable depending on the kind of terminal;
- Terminal pitch is controlled;
- Step and or Screw adjustment capability;
- Is equipped with a knocking bar;
- Allows spare parts fixation.

Picture 28 | Crimping Applicator

Crimping Process Description

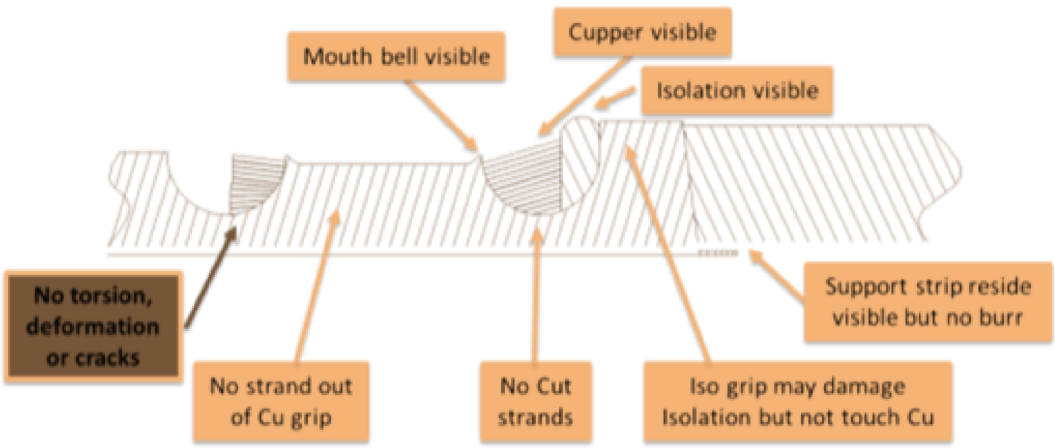
It is a process that creates the mechanical connection between an electrical conductor terminal and one or more electrical conductor wire filaments. A very specific tool – applicator - is involved on the process. Next, the main phases of the process are presented:



Picture 29 | Crimping process graphical description

Evaluation of Crimping Connections – Visual aspect – in a MACRO perspective

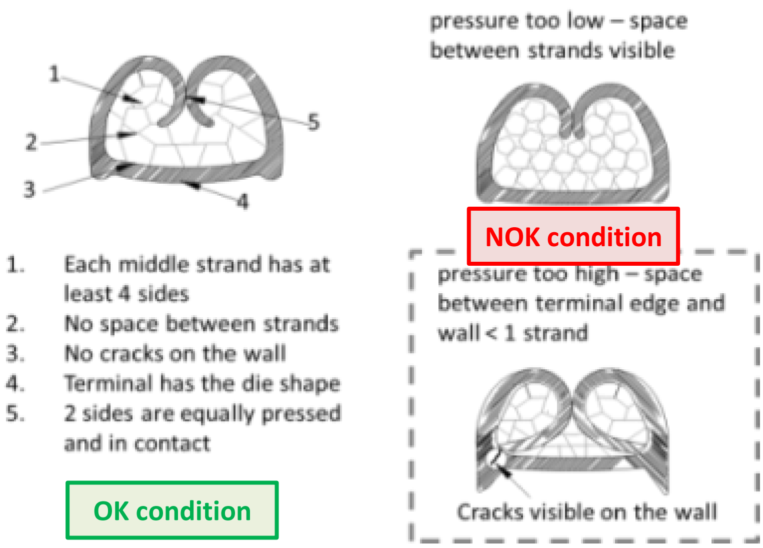
In order to consider that a crimping is conform (OK) imply that it will be compared and verified against the specification. Just after the cold work forming process, crimping, follows the correspondent automatic evaluation (CFM machine). Additionally, some other external characteristics (MACRO perspective) are evaluated visually by trained operators. Next picture resumes all important checking points for visual inspection:



Picture 30 | Checking points on crimped terminals – MACRO

Evaluation of Crimping Connections – Cross Section (Micro cut) – in a MICRO perspective

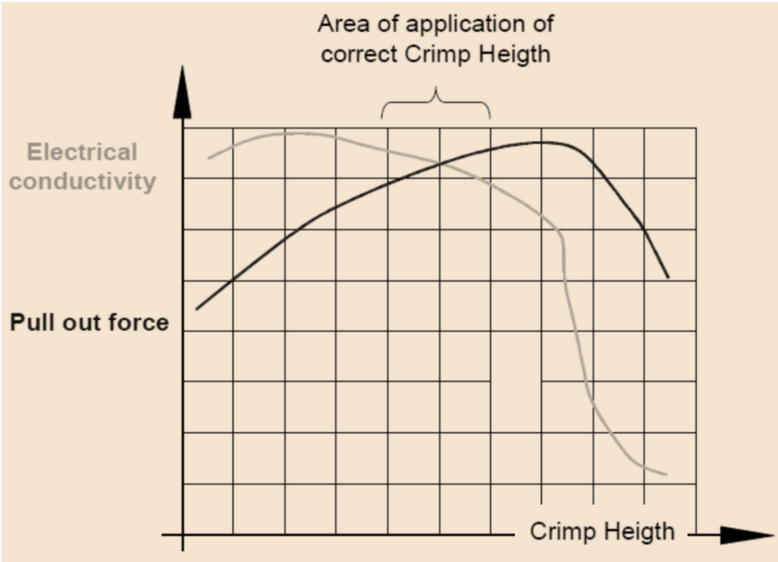
MICRO checking is a very important procedure of crimping evaluation process. It requires initial sampling preparation, which means, a certain number of crimp terminals are micro cut, respecting a very well defined method, in a determinate number of cycles of the crimping process. The resulting cross section (micro cut) is evaluated in laboratory condition mainly in several bellow listed items:



Picture 31 | Checking points on crimped terminals – MICRO

Evaluation of Crimping Connections

Influence of crimping Height to Mechanical and Electrical properties is represented on the following graphic.



Picture 32 | Typical results for the crimping process evaluation

2.4. Crimping Process Capability Control

To ensure the crimping process capability control there are two main methods:

- Automatic.
- Manual, where the skill and operator training takes higher importance.

Automatic process

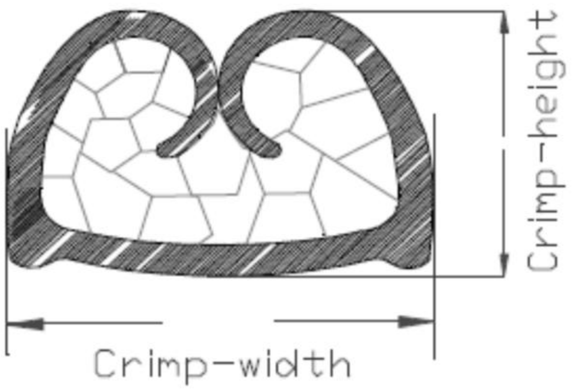
Mainly depending on the product configuration, the operation of crimping can be divided by fully automatic and semi-automatic machines. Fully automatic machines are used when the wire-harness producer is fully responsible to cut and crimp both ends of the wire. Semi-automatic machines are responsible only to crimp on of the wire ends once the other end has already one component assembled by the sub-supplier. Common for both machines kinds is the CFM (Crimping Force Monitory) gauge, which evaluates the terminal crimping capability. Many customers request its permenent presence, one for each crimping press machine, meaning, all crimpings are 100% controlled. This kind of control equipment has a vital importance for the process, allows to “filter” the good products from the not good ones by the crimping load monitoring (press machine forming load).

Manual Process

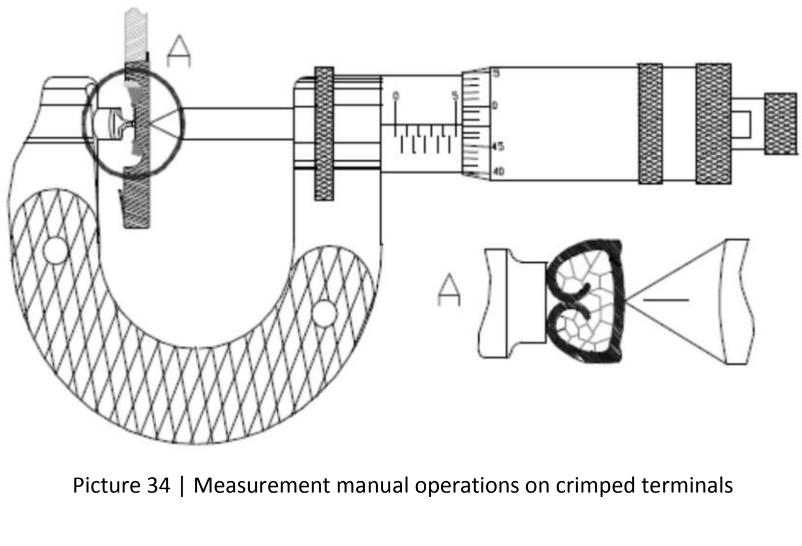
At all production start up, at team shift or terminal reference changement, a well defined number of crimped terminals are measured as well by a manual operation with a calibatred gauge, a micrometer. Same measures (terminal crimping area height and whith) are taken and recorded, if all measures are considered Conform (OK) against specification, then the production have an OK to start.

As a final note, crimping conformity analysis process is finalized by a phisical tensile load test. Resulting value is verified against the combination (terminal + wire) specification.

Example, ~60 N for a 0,35 mm² wire section.



Picture 33 | Terminal main dimensions after crimping process



Picture 34 | Measurement manual operations on crimped terminals

3. Development

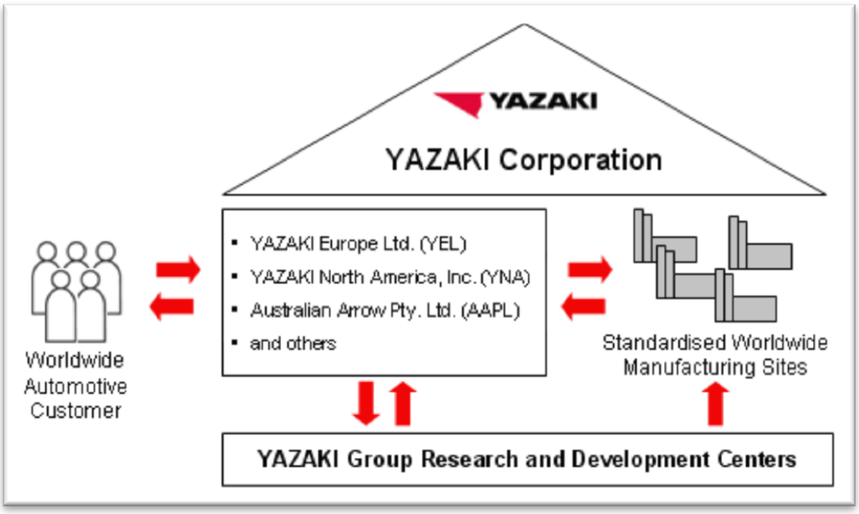
3.1. Practical rehearsals targets

- Define and evaluate the relationship / influence of several steps of actual production process and plant environment risks on terminals defects;
- Product base materials and geometry relationship / influence on terminals defects;
- Introduction of several new theoretical & practical perspectives for 0 Km complaints real cases analysis and evaluation;
- Recommendations on material characteristics definition, process parameters adjustment, in a material/terminal geometry basis;
- Creation of a terminals classification matrix based in real data / location measurements.

3.2. Characterization of the company where this thesis was developed[14]

YAZAKI Cooperation

The Company integrates a worldwide business system and incorporates research and development, production, sales, and local management.



Picture 35 | YAZAKI's worldwide organization

[14] [4] www.yazaki-europe.com
[5] www.yazaki.com

As a truly global company deeply rooted in Japanese cultural traditions and values, YAZAKI strives to be a reliable partner to its customers as well as a promoter of environmental sustainability throughout the World.

YAZAKI is especially proud to be the world's largest producer of wiring harnesses and at the same time offering environmental systems, with emphasis on energy-related equipment.

YAZAKI Worldwide

- Privately owned;
- Top market share in global wiring harnesses;
- 154 affiliate companies across 38 countries in 421 locations;
- An established workload in excess of 200,000 employees.

YAZAKI Europe Limited

- European operations first established in the UK in 1980;
- R&D center first established in Cologne, Germany in 1989;
- R&D centers in four countries with more than 400 employees;
- Facilities in 19 countries with more than 23,000 employees;
- 15 manufacturing plants with more than 21,000 employees.

YAZAKI is a supplier of a broad range of products that support automotive electronics, with a focus on wire, wiring harnesses, instrumentation and electronics sub-assemblies. YAZAKI hold a leading position in the worldwide wiring harness market. Furthermore, YAZAKI’s product line includes fiber optics, display and clock modules, power centers, electronics, combination switches, connectors, terminals and high voltage cables and components. About 90% of YAZAKI business derives from this sector.

Customer focus first

Customer satisfaction is the foundation for good business results. Yazaki puts customers first and is committed to deliver superior value and services to all our customers – worldwide. The customer-centric attitude is supporting the corporate goal. Research, development and customer service centers are closely located to our customers, allowing us to respond quickly and flexibly to all their requirements as global local partner.

Old traditions still valid today

YAZAKI Europe executive management follows leadership traditions set down by the YAZAKI family and adeptly balances these traditions while respecting regional cultures and simultaneously realizing its high standards.

Defining successful principles

YAZAKI is committed to five principles that make a substantial contribution to the overall success of its global business:

- Increase company efficiency and provide value through continuous effort and implementation of new concepts;
- Uphold legal regulations, respect regional cultures, and contribute to economic and social development;
- Contribute to a prosperous future society through environment and security focused business;
- Conduct business openly and fairly, with the goal of co-existence and prosperity;
- Care for employees by creating a corporate culture that prioritizes individuality and team-work while empowering people's dreams.

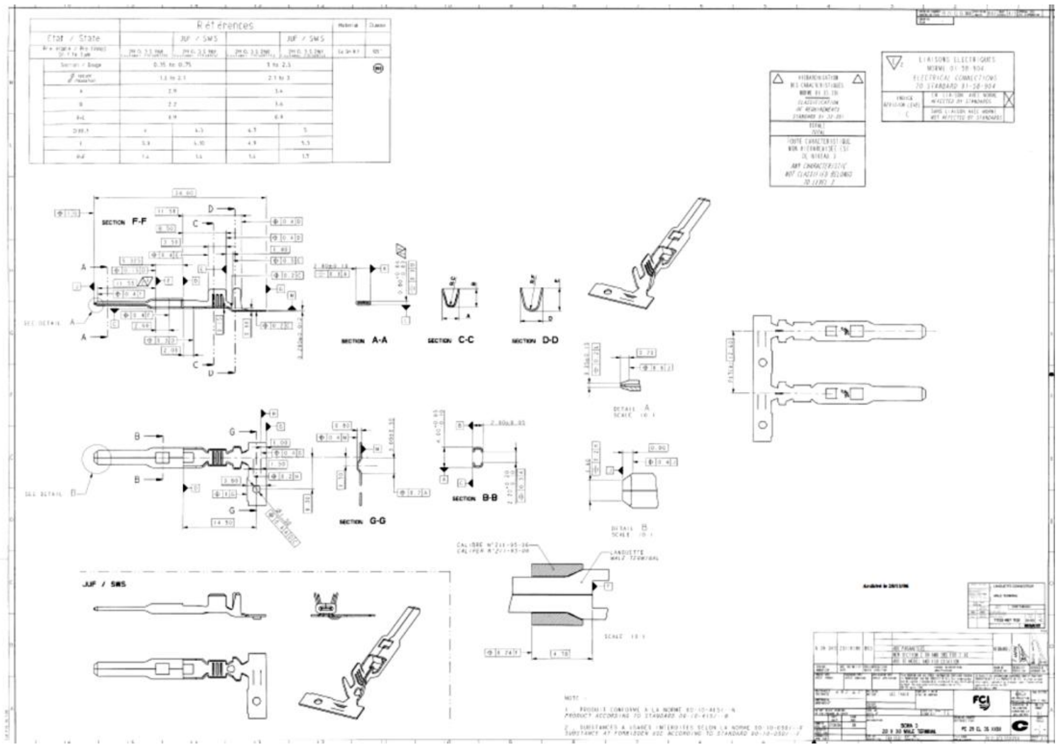
3.3. Problem Characterization

Following DMAIC+R methodology, the following step is Define and Measure.

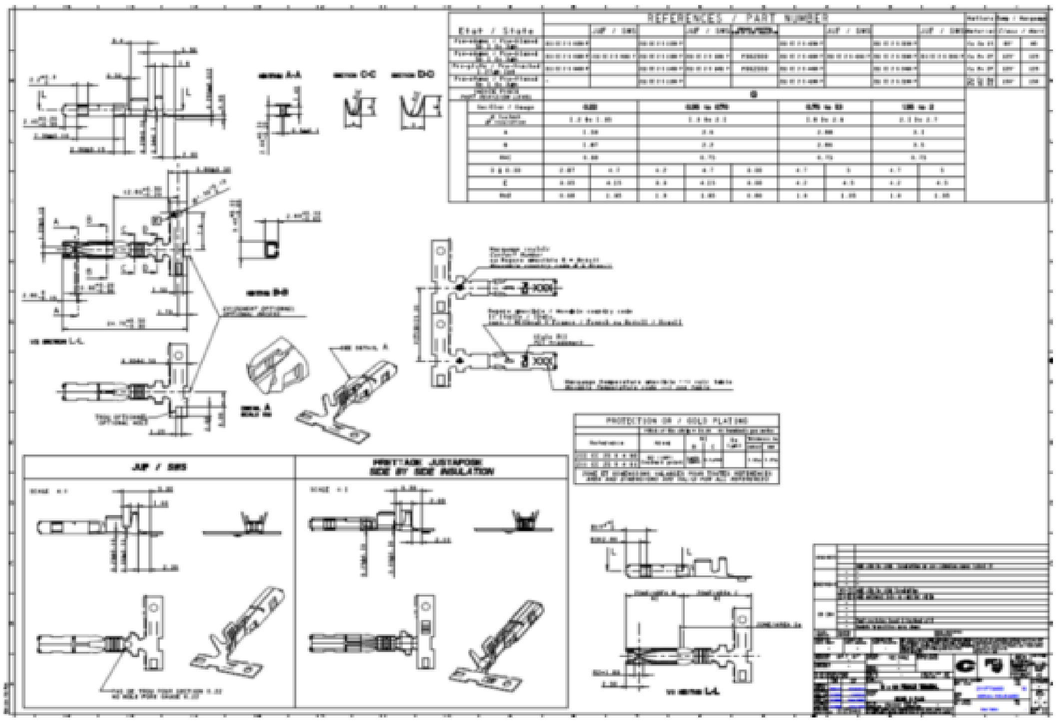
Table 5 | DMAIC+R methodology Define and Measure steps definition

Define	**Customer:** YAZAKI Europe Limited **CTQ (Critical To Quality):** Terminals Defects **Scope:** • Analyzing 184 complaints (Customer Official (CO) and Resident Engineer (RE)); • Monitoring period from JUL'11 till JUN'12; • Analyzing internal Company databases; • Internal Company plants storage, manufacturing and handling methods analysis; • Approach to External Entities (Terminals and Crimping Machines producers); • Approach to Internal Company entities (Crimping Centre, Laboratory and R&R offices). **Defect to reduce:** Damage and Broken Terminals. **Goal:** Reduce the number of defects by 70% (expectation).
Measure	**Process:** Suppliers; Processes and Technical information; Plants Crimping (Validation and Production) and Handling (Storage and Assembly). **Outcomes:** Terminals Classification Matrix, European Procedure for Storage and Handling Method for Crimped Circuits on the Shop Floor. **Incomes:** Internal databases information; Internal storage methods information; Manufacturing & handling methods information; Terminals and crimping machines producers technical acknowledge information; Crimping center, Laboratory and R&R office information simulations and validations. **Measure / Detect:** • Validation Testing and Simulation (Destructive and Non Destructive Testing). • Terminals Technical Definitions (Material & Design). • Manufacturing Process Parameters and Methodologies.

3.3.1. Terminal Characterization – Case Investigation



Picture 36 | Male Terminal A technical drawing

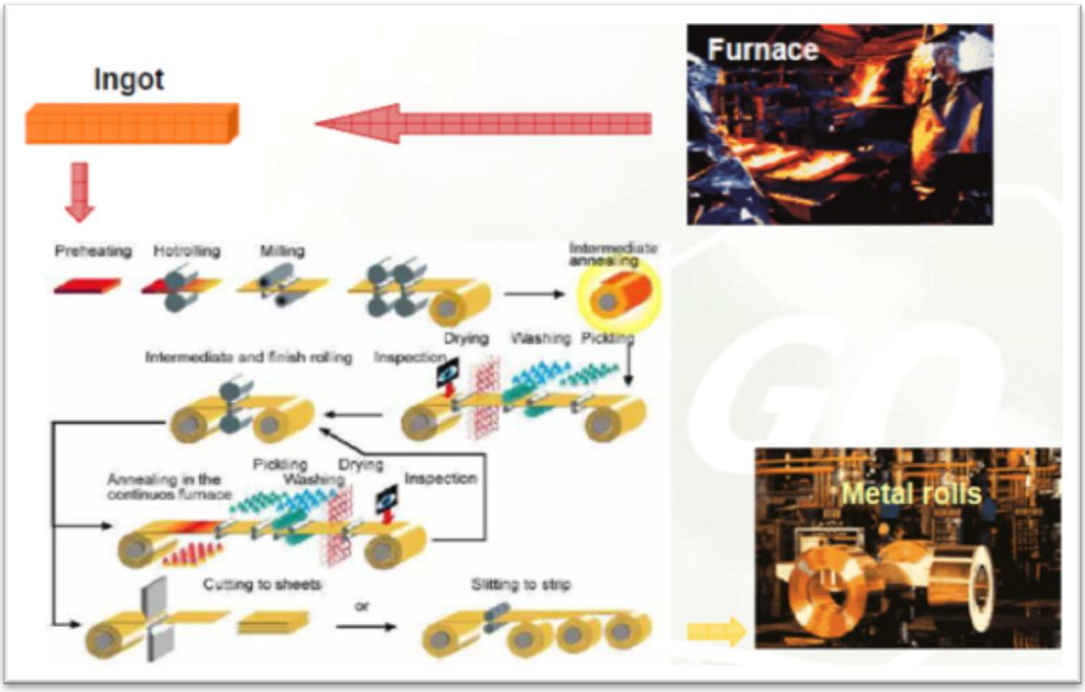


Picture 37 | Female Terminal B technical drawing

3.3.2. Study materials kinds characterization and its selection for testing

The main source of terminal raw material is cooper alloy rolls. In order to get there, a complex process takes place in the background, not often visible on this industry and many times rather impossible to get in. From the information that was possible to collect, the following picture presents a brief process description.

All starts, evidently, by the process of furnace to get the material ingot. After a previous pre-heating, begins the process of reducing its cross-sectional area by compression performed by two driven cylinder tools that rotate in opposite directions and have one or more matching grooves in each roll. The principle involved in reducing the cross-sectional area of the metal in roll forging is essentially the same as that employed in rolling mills to reduce billets to bars. After several forging and annealing steps, roll is supplied for terminal production.



Picture 38 | Cooper alloy sheets and rolls manufacturing process

Copper and copper alloy forging[15]

Copper and Copper alloy forgings offer a number of advantages over parts produced by other processes, including high strength as a result of mechanical working, closer tolerances than competing processes such as sand casting, and modest overall cost.

The most forgeable Copper alloy, forging brass (alloy C37700), can be forged into a given shape with substantially less load than that required to forge the same shape from low-carbon steel.

A less forgeable Copper alloy, such as an aluminum bronze, can be forged with approximately the same load as that required from low-carbon steel.

[15] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993

Copper and most Copper alloys are readily formed at all sheet gages. The Copper alloys commonly formed are characterized by strength and work-hardening rates between those of steel and aluminum alloys.

The combination of moderate to high strength, high electrical and thermal conductivity, the modest cost, and the good corrosion and stress-corrosion resistance, with ease of joining, and coupled with good formability are the main aspects to be taken into account for the use of Copper and Copper alloys in a wide range of applications. The forming operations used for electrical terminals in these kinds of alloys are listed below.

Table 6 | Terminals manufacturing main forming operations

Application	Forming Operations
electrical terminals and connectors	bending, stretch forming, blanking, coining, drawing

Effects of Composition, Cold Work, and Heat Treatment on Formability[16]

Copper alloys are primarily strengthened by cold work or by alloying additions that solid solution strengthen and enhance strain hardening. A finely dispersed second phase is sometimes used as a grain refiner to maximize strength/ductility combinations and/or as a means of ensuring good surface finish after forming. Precipitation hardening is important to a small but important class of alloys, most notably, the beryllium Copper alloys.

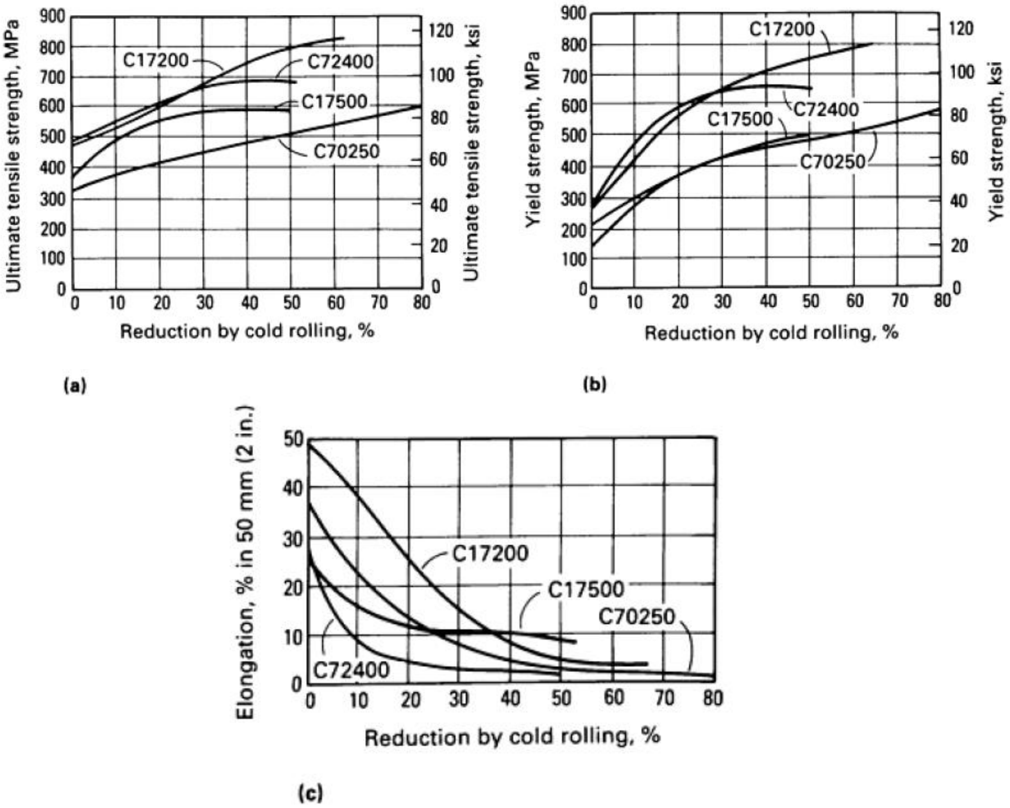
Copper-nickel-aluminum and Copper-nickel-silicon alloys are also commercially important precipitation-hardenable alloys. Spinodal and/or precipitation hardening are available in the Copper-nickel-tin and Copper-nickel-chromium systems. Hardening by martensite transformation is available in the Copper-aluminum system, but is rarely used commercially.

Precipitation Hardening and Cold Working[13]

Precipitation-hardenable alloys offer the opportunity to form parts in the maximum-ductility (solution-annealed) condition and then harden the formed part to maximum strength with a precipitation heat treatment. However, fabrication requirements may preclude this option. Forming can be preceded by aging or follow it. The choice is based on property and formability requirements. In many cases, volume changes that accompany aging, or other manufacturing constraints, preclude aging treatment of the formed part, and the precipitation-hardened alloys are therefore provided in mill-hardened tempers. Mill-hardened alloys are either solution annealed or cold rolled before being given an aging treatment at the mill to produce a specific set of final properties.

[16] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993

Mill-hardened tempers are designed to balance the requirements of strength and formability. They are of particular importance for intricate parts such as electronic connectors, where elimination of customer heat treatment and cleaning steps are important to the economics and/or part fabrication. Products that require hard bends operations or maximum formability capacity should be formed from annealed status or rolled tempers status before final aging in order to reach to the desired mechanical behavior. Mill-hardened tempers are much stronger than unaged rolled tempers, but compromise some formability compared to the rolled tempers in favor of avoiding customer aging and cleaning.



Graphic 11 | Copper Material Mechanical characterization graphs: (a) Ultimate Tensile strength (MPa) versus Reduction by cold rolling (%); (b) Yield strength (MPa) versus Reduction by cold rolling (%); (c) Elongation (%) versus Reduction by cold rolling (%).

Graphics above represent the work-hardening behavior of four precipitation-hardening Copper alloys in the solution-annealed condition: Effect of cold work by rolling reduction on (a) Ultimate Tensile strength, (b) Yield strength and (c) Elongation.

The main characteristics definition of the chosen terminals for the metallographic analysis can be seen on the next table. Is worth note, Terminal A is the description of a real broken terminal received from a real Quality Customer Complaint and Terminal B is a different gender terminal but as well its material was identified as one of top10 of the most problematic for breakage.

Table 7 | Chosen terminals for metallographic analysis definition

Reference	Gender	Material	Name	Coating	Lances
Terminal A	Male	CuSn 0,1	SICMA 3	Sn 1 to 3 µm	N
Terminal B	Female	CuFe 2P	SICMA 3+	Sn 1 to 3 µm	N

It is very important to know and understand the main characteristics of each material presented. Next, a summary is presented for Terminal A and Terminal B materials.

Terminal A body material (by *KME STOL®80*, commercial closet is CuSn0,15)

STOL®80 is a low Tin (Sn) special Copper alloy that combines low cost with highest conductivity. The cost for finish products is often equal to brass due to excellent conditions for stamping processes. Typical applications are male terminals and fuse boxes.

Chemical Composition (weight percentage)

- Sn | 0,1 .. 0,20
- Other | max. 0,1
- Cu | Balance

Note: This alloy is in accordance with RoHS 2002/96/CE for electric & electronic equipment and 2002/53/CE for automotive industry.

Main Applications

The main applications of this alloy are Automotive Switches and Relays, Contacts, Connectors, Terminals, Electrical Switches and Relays, Contacts, Terminals, Components for the electrical industry, stamped parts and Semiconductor Components.

Preferred Applications

The preferred applications are Connector Pins, Fuse Boxes and Busbars.

Physical Properties (Typical values in annealed temper at 20 °C)

- Density | 8,93 g/cm^3
- Electrical Conductivity | 48 MS/m
- Modulus of Elasticity | 120 GPa

Note: 1 MS/m = 1 m/(Ω mm²), i. e. is the resistance of a conductor of 1 m length and 1 mm² cross-sectional area.

Mechanical Properties (EN 1652)

Table 8 | CuSn0,15 mechanical properties (EN1652)

Termper	Tesile Strength Rm	Yield Strength Minimun $Rp_{0,2}$	Elongation Minimum A_{50mm}	Hardness HV*
	MPa	MPa	%	HV
R360	360 .. 370	310	7	110 .. 130
R420	420 .. 490	370	5	120 .. 150
R460	> 460	410	4	> 135

*Only for information

Corrosion Resistance

Relatively to corrosion resistance, CuSn0,15 has a good resistance in natural and industrial atmosphere (maritime air too). Industrial and drinking water, aqueous and alkaline solutions (not oxidizing), pure water vapor (steam), non-oxidizing acids (without oxygen in solution) and salts, neutral saline solutions. Material can be heat-treated in reducing atmosphere. This alloy is practically resistant against stress corrosion cracking. It is not resistant to: Oxidizing acids, solutions containing cyanides, ammonia or halogens, hydrous ammonia and halogenated gases, hydrogen sulfide, seawater.

Terminal B body material (by *KME STOL®194*, commercial closet is CuFe2P)

STOL®194 is a medium strength Copper alloy, with fine Fe precipitations. It combines high conductivity with medium strength and good relaxation properties.

Chemical Composition (weight percentage)

- Fe | 2,1 .. 2,6
- Zn | 0,05 .. 0,2
- Other | < 0,2
- Cu | Balance

Note: This alloy is in accordance with RoHS 2002/96/CE for electric & electronic equipment and 2002/53/CE for automotive industry.

Main Applications and Properties

This alloy is usually used in automotive applications such as Fuel Injectors, Electrical Connectors-Automotive, and electrical components such as Circuit Breaker Components, Electrical Connectors, Electrical Springs, Terminal and other industrial parts such as Welded Condenser Tubes, Gaskets, Eyelets, Flexible Metal Hose, and Stamped parts.

Preferred Applications

The preferred applications are basically Leadframes for Semiconductors and Current Carrying Capacity.

Physical Properties

- Density | 8,8 g/cm^3
- Electrical Conductivity | 35 MS/m
- Modulus of Elasticity | 125 GPa

Note: 1 MS/m = 1 m/(Ω mm²), i. e. is the resistance of a conductor of 1 m length and 1 mm² cross-sectional area.

Mechanical Properties (EN 1652)

Table 9 | CuFe2P Mechanical Properties (EN1652)

Temper	Tensile Strength Rm	Yield Strength Minimum $Rp_{0,2}$	Elongation Minimum A_{50mm}	Hardness HV*
	MPa	MPa	%	HV
R430	430 .. 510	380	10	130 .. 150
R510	510 .. 560	430	7	140 .. 160
R530	> 530	470	4	> 140

* Only for information

Corrosion Resistance

Relatively to corrosion resistance, CuFe2P has a good corrosion resistance in natural atmosphere (also sea air) and industrial atmosphere. In different waters and neutral saline solutions, it shows better resistance to corrosion through abrasion and pitting than SF-Cu.

CuFe2P is insensitive to stress corrosion cracking.

Notes: For information the source of this information:

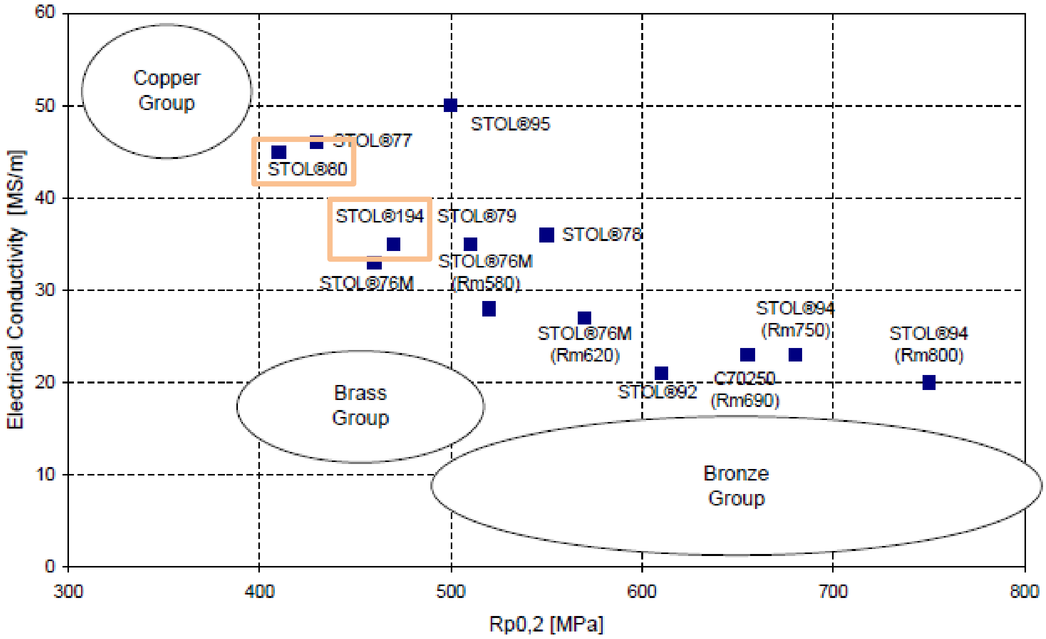
KME STOL®80[17]

KME STOL®194[18]

[17] [10] Dr. Warnecke, "STOL80 ENCuSn0,15 UNSC14410", by KME AG & Co, Germany, 2010
[18] [11] Dr. Warnecke, "STOL194 ENCuFe2P UNSC19400", by KME AG & Co, Germany, 2010

Yield strength versus electrical conductivity of selected alloys[19]

As can be seen on the next picture, from the quick comparison between both alloys results that CuSn0,15 has more Electrical Conductivity and lower Yield Strength that CuFe2P.



Picture 39 | Yield strength versus electrical conductivity of selected alloys

3.3.3. Terminal manufacturing process and its sequence

A brief introduction about formability of Copper alloys will be performed and terminals manufacturing will come just after.

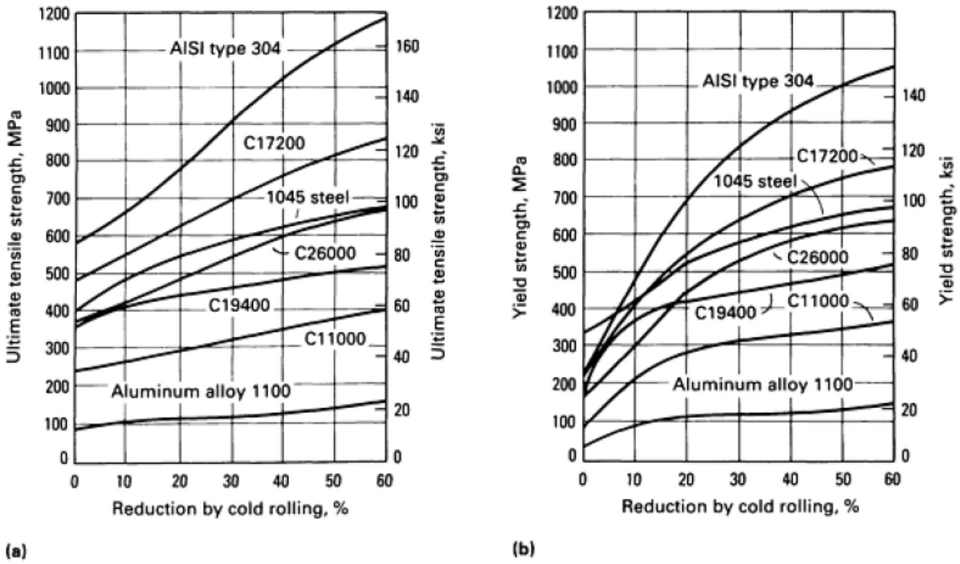
Formability of Copper Alloys versus Other Metals[20]

Attending the forming process of a given product, no single material property completely defines its formability. Formability can best be rationalized in terms of the strength, work hardening, and ductility of a Copper alloy, but these parameters do not allow direct correlation with formability.

Picture below show the work-hardening behavior of Copper alloys versus low-carbon steel, austenitic stainless steel, and aluminum. There, we can observe (a) the effect of cold work by rolling reduction on ultimate tensile strength and (b) the effect of cold work on yield strength.

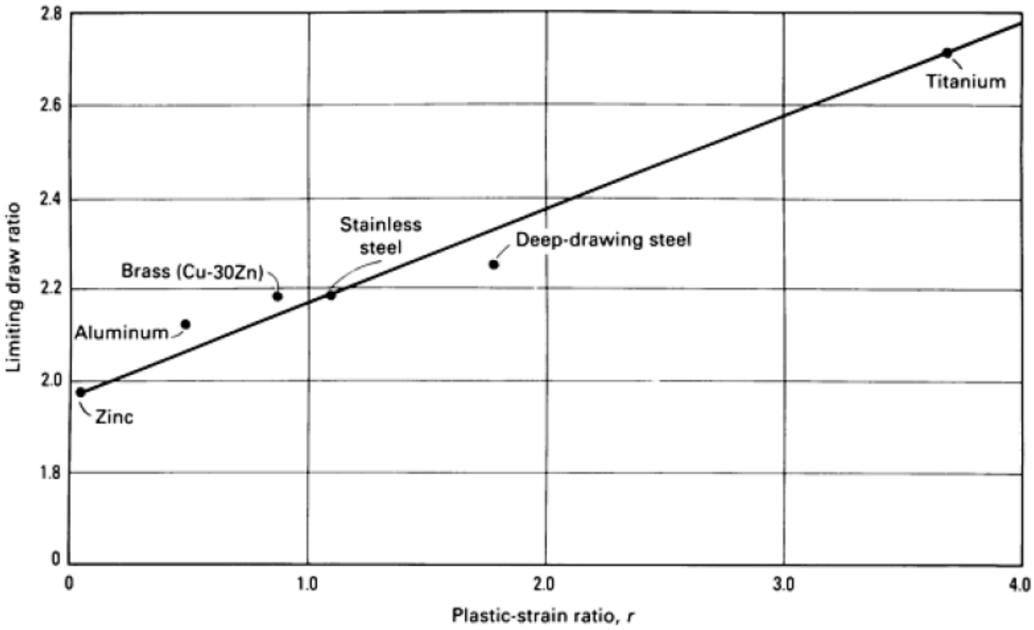
[19] [7] Udo Adler, Josef Mommertz and Dr. Holder Warnecke, "Technical Manual Strips of copper and copper alloys plain and tinned", by KME AG & Co, Germany, 2010

[20] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993



Picture 40 | Formability of Copper Alloys versus Other Metals

In general, Copper alloys offer better strength/formability combinations than most other alloy systems. The choice of material system is usually based on economics, including material and other fabrication costs as well as properties.



Picture 41 | Formability of Copper Alloys versus Other Metals

Many electrical terminals are fabricated additionally by simple bending operations. Bending is where a blanked coupon is wrapped, wiped or formed over a die. Bend formability is usually expressed as a minimum bending radius in terms of strip thickness and is the smallest radius to which the strip can be bent without cracking.

Materials main characteristics which influence formability

Ductility is the principal materials factor that determines bend formability. The ductility factor of first order of importance is the ability of a material to distribute strain in a highly localized region, that is, necking strain. The necking strain available depends on alloy composition and temper. As strength increases by cold work, the ability of an alloy to distribute necking strain decreases.

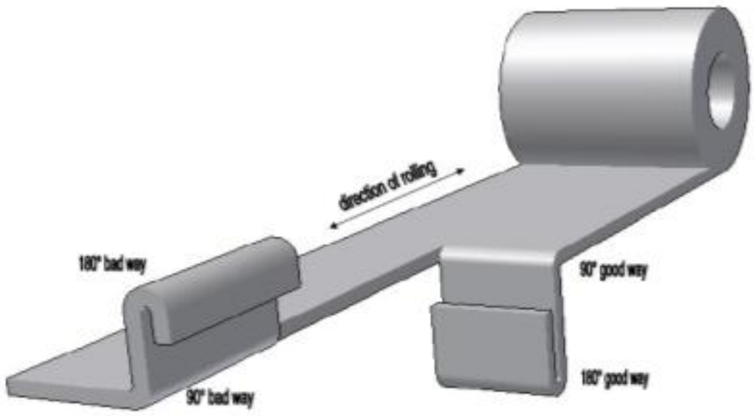
Bend formability decreasing with the growing of the strength depends on the alloy composition and the strengthening mechanism. Conventional tensile elongation cannot be used to predict bend formability, because it doesn't contributes adequately for necking strain.

The practice of cold rolling to increase strip temper degrades bend formability. However, it is often used because most alloys still exhibit useful bend formability at modest cold-rolling reductions. Product applications that require both high strength and good bend performance are usually satisfied by selecting Copper alloys that are precipitation and/or solute strengthened with element additions that greatly increase the work-hardening rate and thus minimize cold-rolling requirements to achieve the desired strength.

Bend formability is typically dependent on bend direction with respect to strip-rolling direction. All cold-rolled materials exhibit anisotropy. The extent of bend directionality varies from alloy to alloy, but always increases with increasing cold reduction. Bend directionality results from the development of strong textures during rolling (grains elongation and alignment).

Critical Points are:

- Marks
- Metal thickness
- The "nerves"
- (Lamination sense)



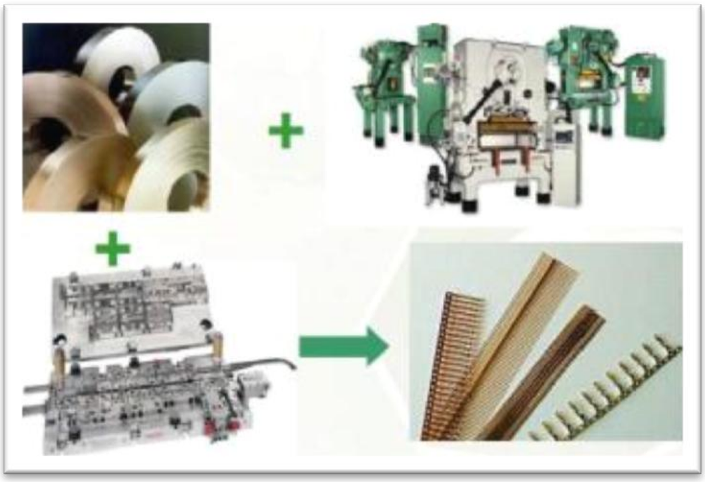
Picture 42 | Cold-rolled copper alloy anisotropy

Note: Forming along the longitudinal direction (correct way) is better than in cross direction.

Bend formability of Copper alloys is a function of the rolling direction. Bends with the axis transverse to the rolling direction are termed good-way bends; bends with the axis parallel to the rolling direction are bad-way bends.

As a generic presentation of terminals manufacturing process, below picture presents the forging and forming (bending) integrated operations.

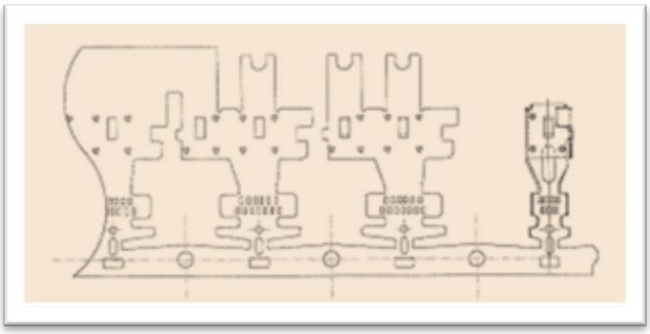
Material roll is fed into very heavy machinery for high load punching and bending operations and a very unique and singular sequence (each product reference has its own sequence) is respected until final product is finalized. Then, final product (terminals) coils are ready to be pass to the next stage in their production, surface treatment.



Picture 43 | Terminals manufacturing process flow

Cold forming processes impact resume

Strength, work hardening and ductility all play an important role. Copper alloys use alloying additions that enhance strain hardening and provide strength. Grain-size is controlled by annealing process or a finely dispersed second phase helps to maximize strength/ductility combinations and ensures good surface finish.



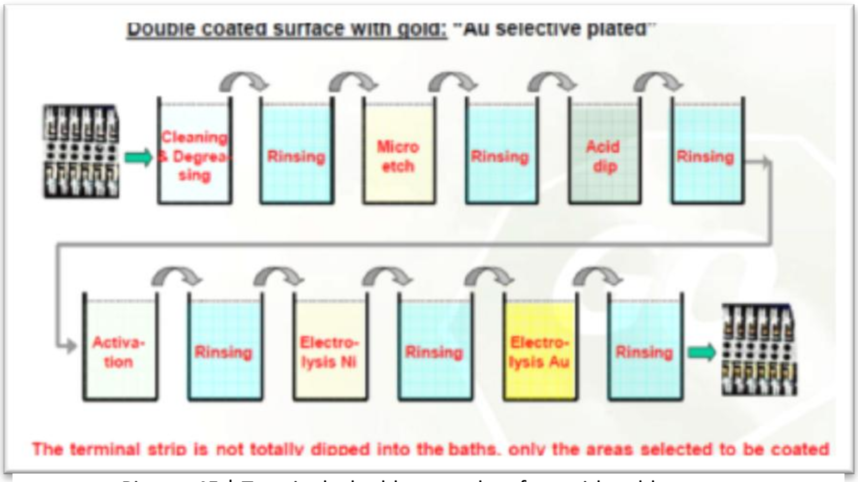
Picture 44 | Terminals forming process example

Compared with other materials, the formability of Copper alloys lies intermediate between that of aluminum and stainless steel, with a range of work hardening rates available.

Surface treatment[21]

Surface treatment is made by electro deposition. Metal is dissolved in the anode and deposited in the cathode.

The coat thickness depends on electrical current and the time that the metal is submerged in the bath.



Picture 45 | Terminals double coated surface with gold process

Main reasons to apply a surface treatment:

- Protect the contact spring from corrosion and oxidation;
- Surface appearance, low mating and unmating loads and cost reduction.

The two major classes of surface treatment are:

- Noble metal (gold, palladium and alloys of these metals);
- Non noble (primarily tin or tin/lead).

Tin Plating

Tin plating is usually a mix of Tin and Lead. The alloy with Lead makes it a natural lubricant and helps to reduce the terminal insertion loads or if the terminal must be soldered, Lead helps Tin to melt. Since 2005 Lead is not allowed in Tin plating because its toxicity and difficulty to recycle. The standard thickness is about 2 to 3 µm.

Gold Plating

Gold plating is recommended when the expected current through the terminal is very low, typically lower than 10 mA.

[21] [6] Robert S. Mroczkowski, "Connector Design/Materials and Connector Reliability", by AMP Incorporated, Harrisburg (USA), 1993

If an oxide layer is present, the current is not strong enough to pass through this layer and provide continuity. Gold is always used for critical applications such ABS and Air/Bag. In these cases, standard thickness is about 1 to 1.5 µm.

Both classes differ in the requirements for film management

Noble finishes minimize film formation, while for tin finishes the surface oxides are easily disrupted. Film management for noble metals requires preserving the nobility of the finish from external sources of degradation.

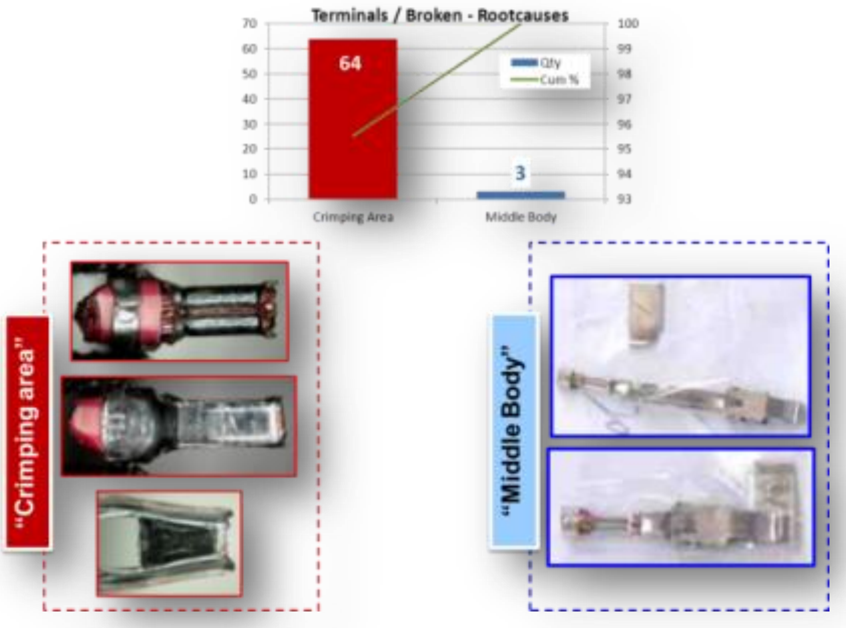
For Tin finishes mechanical displacement of the Tin oxide is required and mechanical stability of the interface must be maintained to minimize the potential for re-oxidation.

3.3.4. Identification and characterization of the investigation

From the previous presented graphics, defects nature can be divided in two major groups, damage and broken terminals. The most critical defect for customers and, in my perspective, superficially explored by YAZAKI wiring harness production is the broken terminal defect. Damage terminals defect is well understood and its internal sources were deeply investigated. They depend mainly in the most production influent factor in wiring harness manufacturing, man-power operation skills! Wiring harness production is mainly a manual manufacturing process, except its heart added-value operation, crimping. On this process, is concentrated one of the biggest and deepest know-hows from YAZAKI.

Thus, taking the critical defect (broken terminals) as base for this investigation, the next step is understand if we are facing a “Ductile” or a “Brittle” fracture and also which mechanism cause effectively this phenomenon. Theoretically, ductile and brittle fracture depends upon whether or not the material exhibits the ability to undergo plastic deformation. That characteristic makes the difference. For instance, a completely brittle material would fracture almost at the elastic limit[22]. By definition, simple fracture is the separation of a body into two or more parts in response to an applied stress that is static (constant) or not (cyclical). In order to investigate terminals failure mechanism and fracture modes, the following steps will focus on TERMINALS / BROKEN Root-causes.

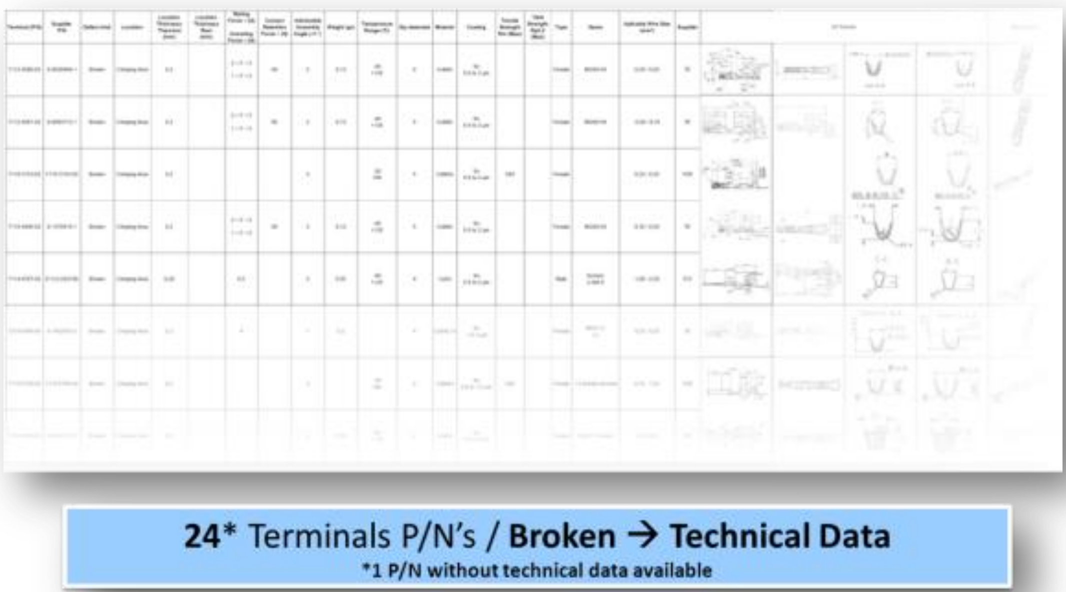
[22] [12] George F. Dieter and David Bacon, "Mechanical Metallurgy SI Metric Edition", by McGraw-Hill Book Company, Singapore, 1988



Graphic 12 | Terminals / BROKEN Root-causes Pareto and example pictures

3.3.5. Investigation critical analysis

From the initial 184 quality customer complaints, 64 complaints are related with BROKEN defects. From those 64, deeper analysis was performed, information was filtered and a list of 25 terminal different references was obtained as outcome. After, terminals technical information such as material, physical and mechanical characteristics, gender and wire section application range was collected from different internal databases and external supplier's sources.



Picture 46 | Quality Customer Complaints with terminals technical information database

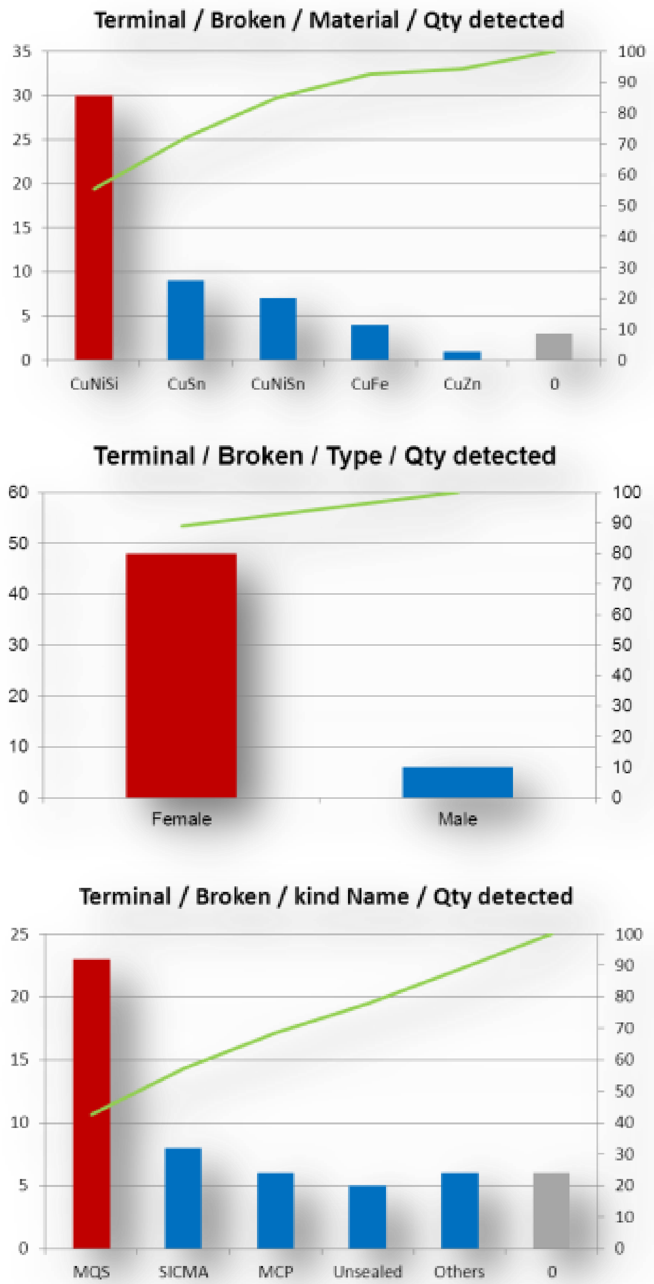
Indeed, it was very difficult for many terminals references to find the required technical information. The main reason for that is, for mostly of the terminal manufacturers, material information is confidential. It is considered that they “tune” their own raw material to achieve specific characteristics (know-how) and better economical rates. Obviously, this immediately means as well that trying to establish a relationship between the supplier materials information, material datasheets (required by automotive industry specification), and material information available on the related market, from *KME* for instance, it is very difficult.

To be stated later on.

From this information, several, important and interesting Pareto’s graphics could be raised, some for company internal usage only, some others completely related with this investigation, now presented.

Head of Pareto’s resume:

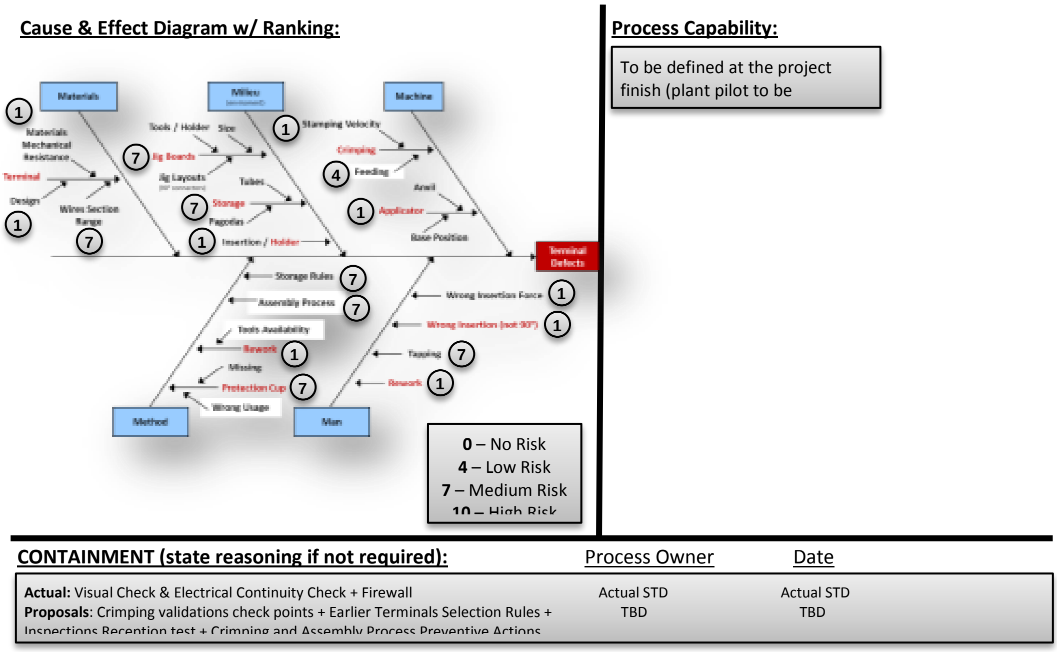
- Terminal Material: CuNiSi;
- Terminal Kind: Female;
- Terminal Kind: MQS (terminal assembled body).



Graphic 13 | Terminal Broken defects Pareto graphics

This information indicates us which are the most “sensitive” characteristics to pay attention to when terminals usage analysis takes place, in serial production or in early stages.

DMAIC+R – Measure



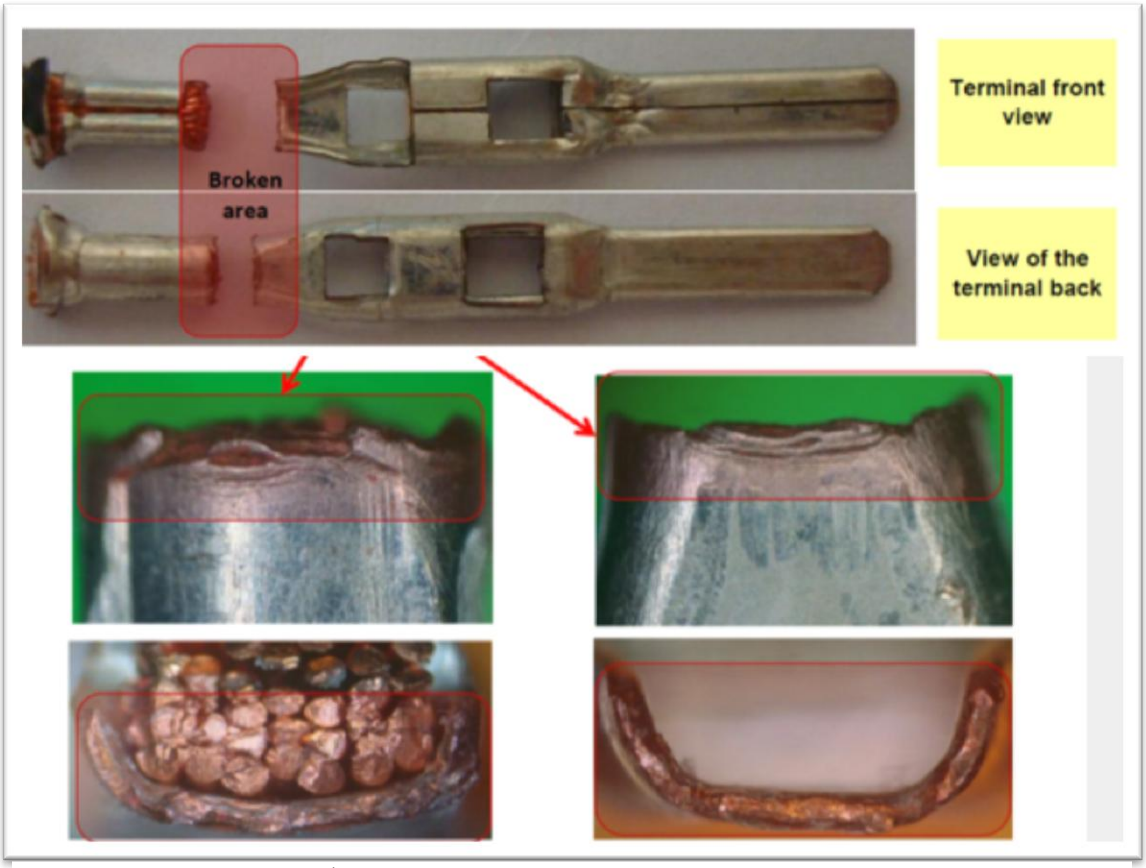
Picture 47 | DMAIC+R Methodology Measure step definition

Taking the information resulting from all Pareto graphics already presented and Ishikawa diagram as a guide line, a complete strategy was outlined for a complete evaluation. The sequence of the next steps will allow us to understand the influence of the root-causes pointed.

I. Selection and identification of real broken samples received from European manufacturing plants, which result from customer quality complaints;
II. Virtual Simulations (VS) (components design critical areas – stress concentration critical areas);
III. Preliminary examination of OK and BROKEN terminals by Nondestructive Testing (NDT)
IV. Determination of fracture mechanism (Fracture, Fatigue or Creep) and fracture modes (Ductile or Brittle) by Metallographic Examinations (ME);
V. Identifying failure mechanism and facture mode real production situation simulations in laboratory environment by Destructive Testing (DT);
VI. Terminal Design analysis (TD);
VII. Terminal Crimping Process analysis (TC);
VIII. Investigation of the components Ductile / Brittle behavior under identified failure mechanism and facture mode rules. → Expectation: Fragile/Robust terminals classification matrix / methodology.

3.3.6. Main process risk factors identification

Firstly, it was done the selection and identification of real broken samples received from group manufacturing plants, which result from real Quality Customer Complaints.



Picture 48 | Quality Customer Complaint sample received identification

Another noteworthy, after nearly four weeks of intense communication with all European plants Quality Leaders, only one real sample[23] was received. The terminal has the following characteristics:

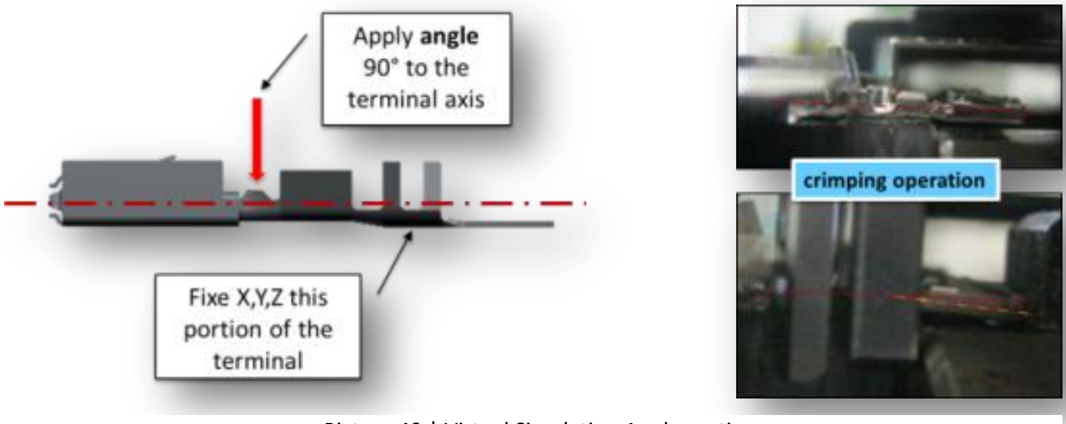
Table 10 | Quality Customer Complaint sample received characteristics

Terminal (P/N)	Gender	Material	Name	Coating	Lances
A	Male	CuSn0,1	SICMA 3	Sn 1 to 3 µm	No

In the meanwhile, **Virtual Simulations** (II) was carried out (components design critical areas – stress concentration critical areas).

[23] [13] Miguel Lopes and Claudia Laranjeira, "LKE-Z13-002695", by YAZAKI Europe Limited, Ovar (Portugal), 2013 [internal document]

Simulation A - Crimping operation



Picture 49 | Virtual Simulation A schematic

The main goal was to identify critical areas (concentration of higher efforts) during crimping operation on the terminal body.

All virtual simulations were performed by an internal Company office specialized in terminals conception and the following terminal characteristics extracted from Supplier database (3D module) are present hereunder in form of tables at each step, starting by Simulation A.

Table 11 | Terminal characteristics used on Virtual Simulation A

Terminal (P/N)	Complaints Qty	Material	Kind	Lances
A	6	CuNi1Si	Assembled	Y

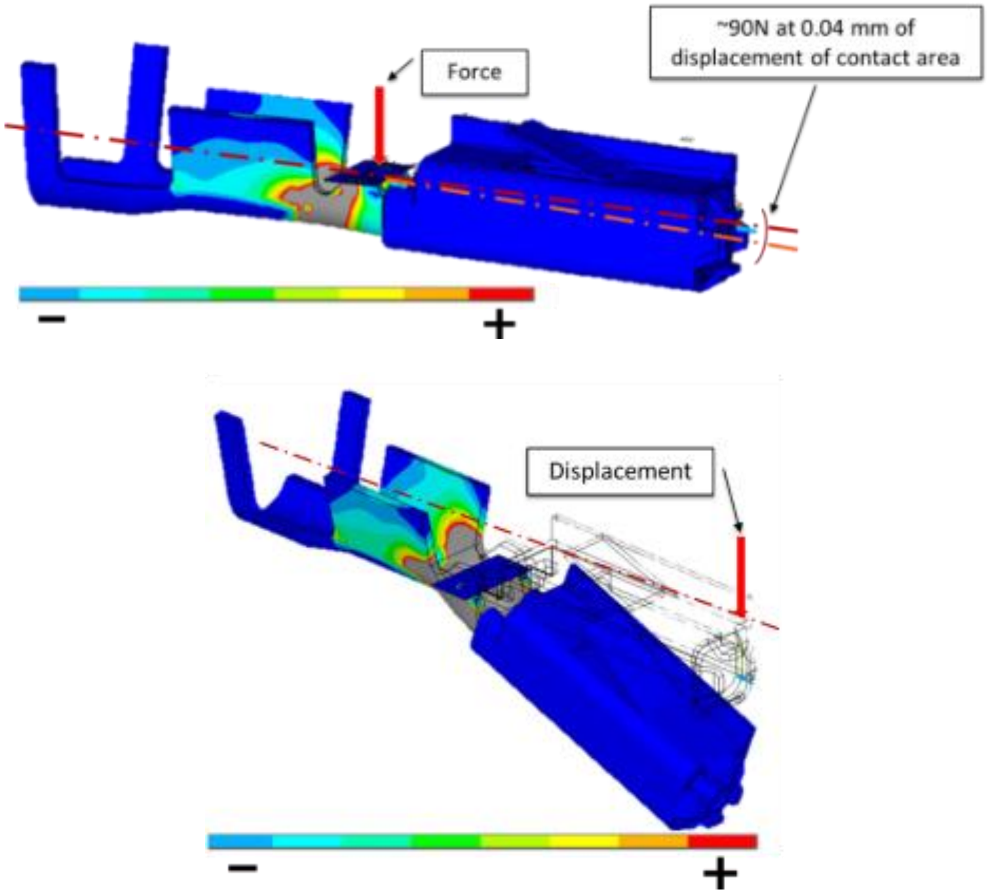
Simulation A - Conditions and Observations:

a) Terminal simulation performed by body displacement.

It was observed that a high displacement of contact area causes relatively small reaction load.

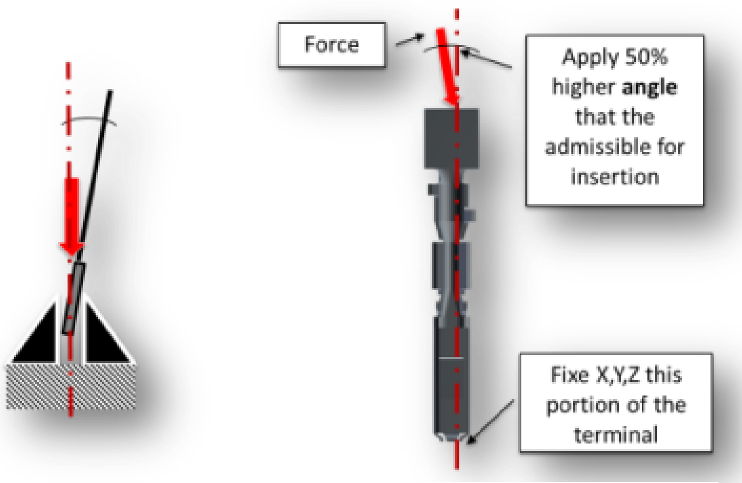
b) Terminal simulation performed by load application on body.

It was observed that the elastic / plastic deformation point occurred at ~90 N.



Picture 50 | Virtual Simulation A results

Simulation B - Insertion of Terminal in Connector cavity operation



Picture 51 | Virtual Simulation B schematic

The main goal was to identify the critical areas (concentration of higher efforts) during insertion of terminal in connector cavity operation.

Next are presented the Simulation B terminal characteristics:

Table 12 | Terminal characteristics used on Virtual Simulation B

Terminal (P/N)	Complaints Qty	Material	Kind	Lances
A	6	CuNi1Si	Assembled	Y

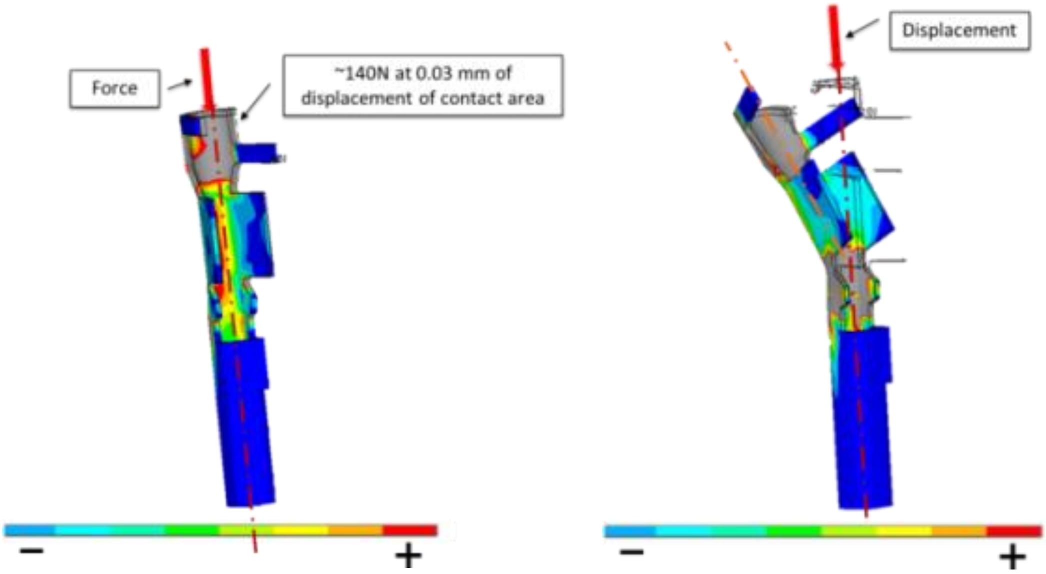
Simulation B Conditions and Observations:

a) Terminal Simulation performed by body displacement.

It was observed that a small displacement of contact area causes relatively high reaction load.

b) Terminal Simulation performed by load application on body.

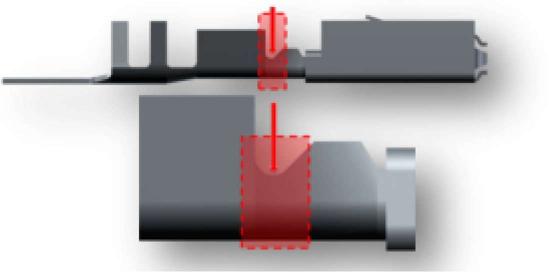
It was observed that the elastic / plastic deformation point occurred at ~140 N.



Picture 52 | Virtual Simulation B results

Preliminary conclusions:

- Virtual Simulation indicates the most critical area on the terminal (stress concentration);
- During crimping operation this area is potentially weakened by the effort and displacement involved (residual stress);



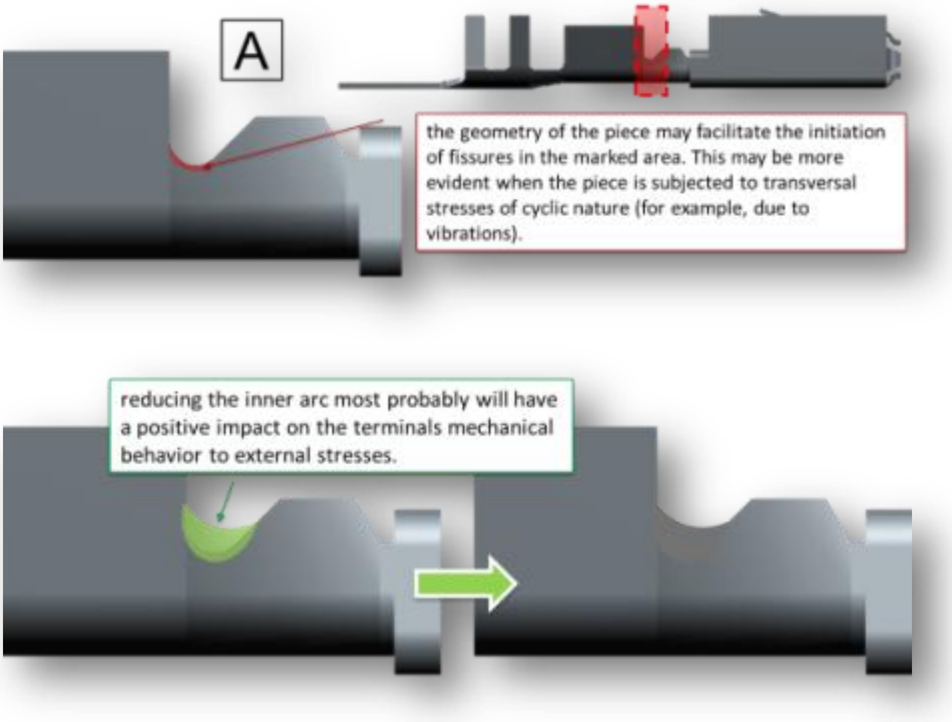
Picture 53 | Terminal transition critical area

- Terminal design has a strong influence on the terminal mechanical resistance to external efforts application.

Improvement Proposal

During the development of the several and different methodology items listed previously, root-causes are explored and explained, added-value information and improvement ideas are described and proposed.

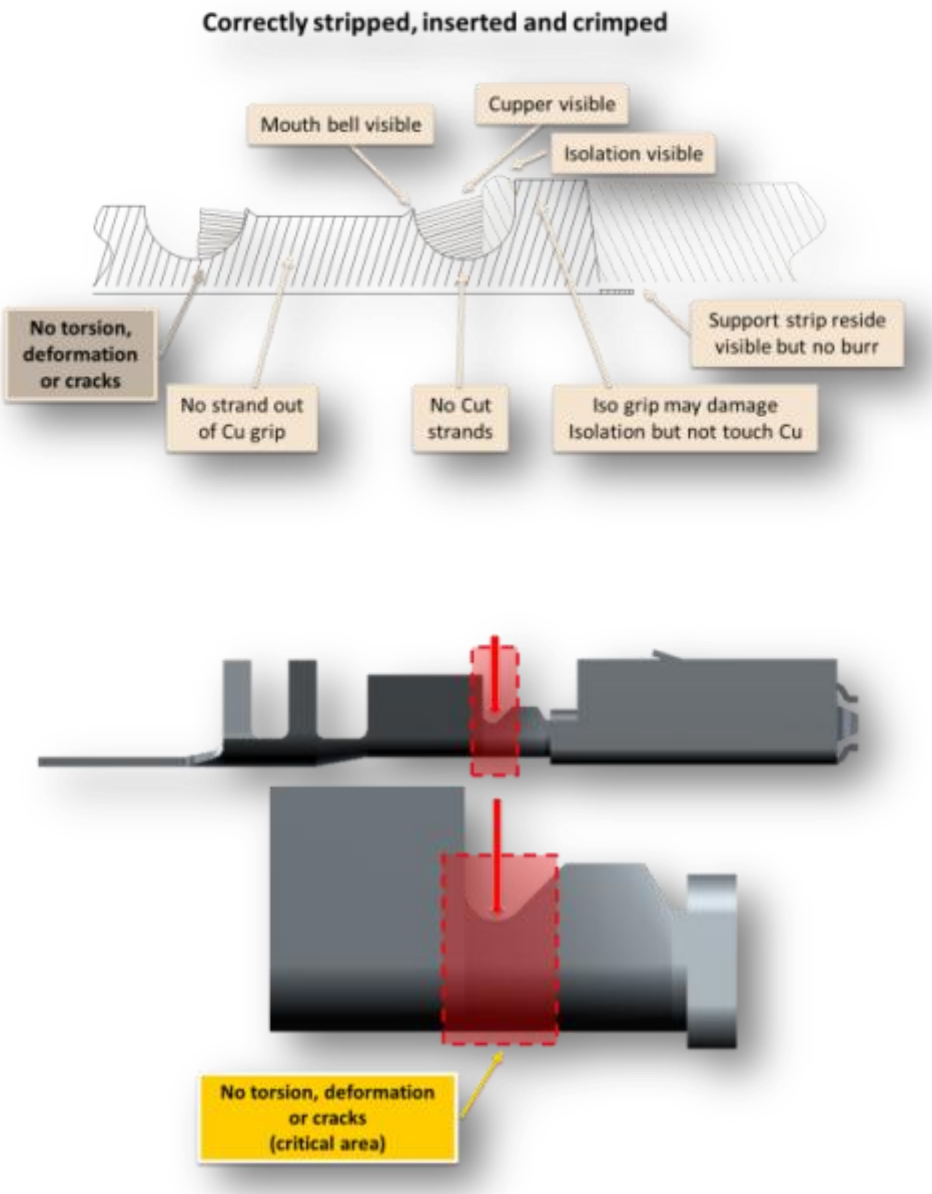
On this case, it was demonstrated that design has an important role on terminal mechanical behavior during usage. One proposition to blays its performance globally is to reduce the inner arc on the critical transition area. Please check the next pictures for a better understanding. Of course, this needs to be further investigated to confirm its effectiveness.



Picture 54 | Virtual Simulation – Improvement Proposal

In parallel to the Virtual Simulations (II) just explored, the **Preliminary Examination** (III) of OK and BROKEN terminals was performed. Visual Inspection (VI) is very common and known method and is used in a regular basis so once again was choose at this stage on the investigation. In the other hand, Nondestructive Testing (NDT) methods will be tried as well to check their applicability on this kind of products. Selected methods will be explored with the support on an external entity, *Universidade do Minho*, Material department.

First, it was necessary to understand where to look; secondly, what can be considered correct against the internal Company specification to know exactly what to filter from OK to NOK.

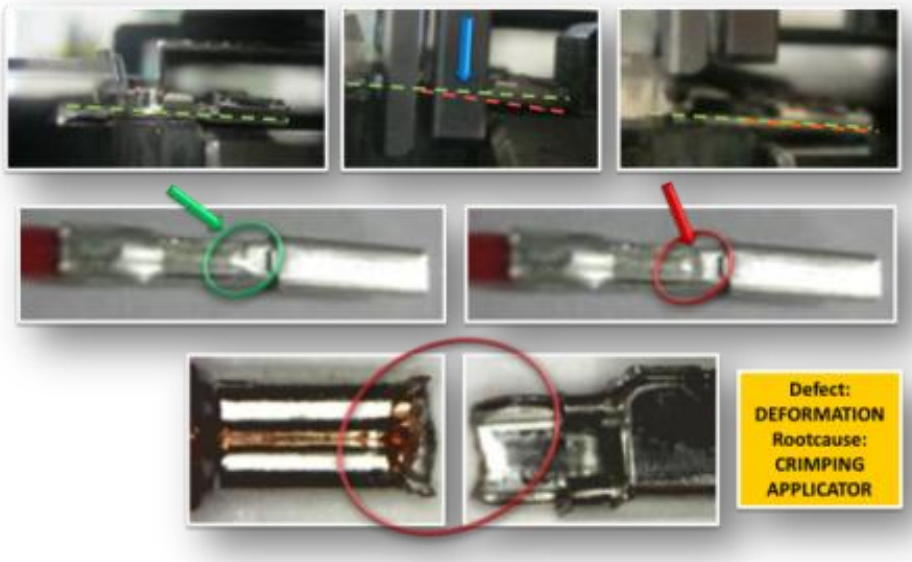


Picture 55 | Crimped Terminal Visual Inspection points

Visual Inspection (VI)

This method of verification and validation has an enormous role on the crimping process.
Very specific and important crimping parameters are controlled at 100% by poke-yoke gauges, for some other characteristics in crimp terminals, such as bending angles and presence of cracks, those automatic checkers are just not enough. To cover these areas, expertise of trained operators is call for duty and they are really needed.

For instance, next example is the perfect description of a real case where a specific kind of defect is present in the back side of a crimped terminal.



Picture 56 | Quality Customer Complaint analyze example

This broken terminal appeared in at Customer plant which resulted in an official Quality complaint for the Company. This was not detected at Company plant manufacturing process checking areas because of two main reasons: One, poke-yoke gauges are not able to detect this kind of surface defects if crimping areas dimensions are not changed. Two, was not detected by the operator because the internal visual checking standard do not consider the back of the terminal as a checking point.

For information, this kind of defect was caused by a missdisplacement of the terminal body on crimping applicator base (tool matrix).

Nondestructive Testing (NDT)[24]

As a tentative of finding a Nondestructive method that could allow the detection in early stages (terminal crimping validations in laboratory environment, per example) of superficial and/or under surface (microns) fissuring's, two methods were chosen and tryout on this kind of components, Dye Penetrant Testing (PT) and Radiographic Testing (RT).

Obviously, other methods were though but for some identified reasons, they were early filtered and rejected from this investigation.

The next table resumes all the criterions and results of the tests performed.

Table 13 | Nondestructive tests criterions and results description

Test	Visual Inspection	Dye Penetrant	Radiographic	Magnetic Particles	Ultra-Sound
Results Timing	High	Small wait	Medium wait (except digital)	Small wait	Immediately
Failures Kind	Superficial	Superficial	Almost all	Superficial or near	Internal
Sensitivity	Low	Medium	Low	Low	High
Data Registry	Only pictures	Only pictures	Medium	Rare	Rare
Material kind	All	Few	Almost all	Only magnetic	Almost all
Test Capability	Only cracks	Only cracks	Cracks and measuring	Only external superficial defects	Composition analysis and thickness measure
Investigation Testing performance result	Applicable for major superficial defects detection. (magnifying glasses usage)	**Result:** Not possible because components are too small.	**Result:** Not possible because components are too small.	**Result:** Not possible because components are too small.	**Result:** Not possible because components are too small.

The Radiographic (X-Ray) method tests were performed in OK terminals (not BROKEN). Hereunder the description of the terminal sample submitted to the testing:

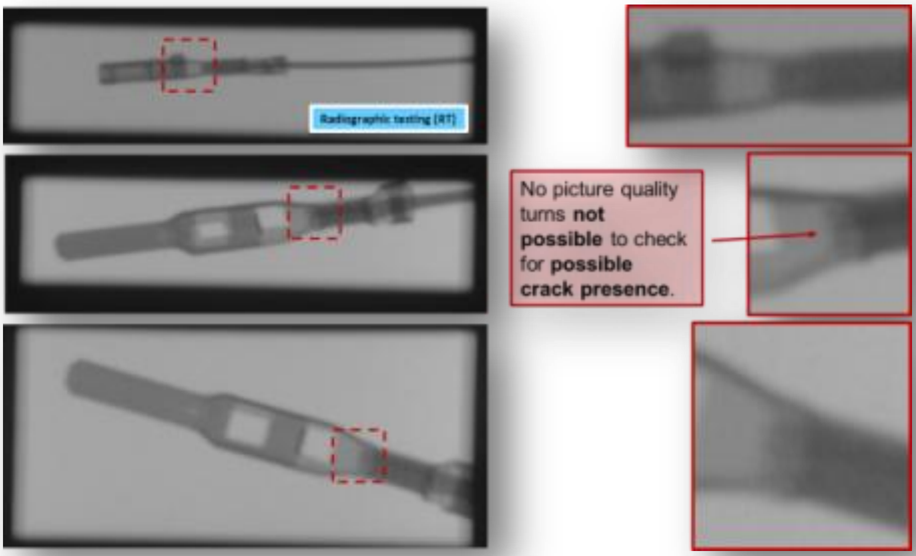
[24] [13] Miguel Lopes and Claudia Laranjeira, "LKE-Z13-002695", by YAZAKI Europe Limited, Ovar (Portugal), 2013 [internal document]

Table 14 | Terminal Not Broken submitted to the X-Ray test definition

Terminal (P/N)	Gender	Material	Name	Coating	Lances
A	Male	CuSn0,1	SICMA 3	Sn 1 to 3 µm	N

The expectation on this test was to identify critical areas on terminal body (internal or external cracking resulting from crimping operation, per example).

The next pictures are very clear about the result observed, which was already presented on the previous table. The industrial radiology equipment used was a DüRR HD-CR 35 NDT (radioactive sources: Selenium 75, Iridium 192, low energy X-Ray (<75 kV) and average energy X-Ray (>75 kV and <300 kV)).



Picture 57 | Terminal Not Broken submitted to the X-Ray test result

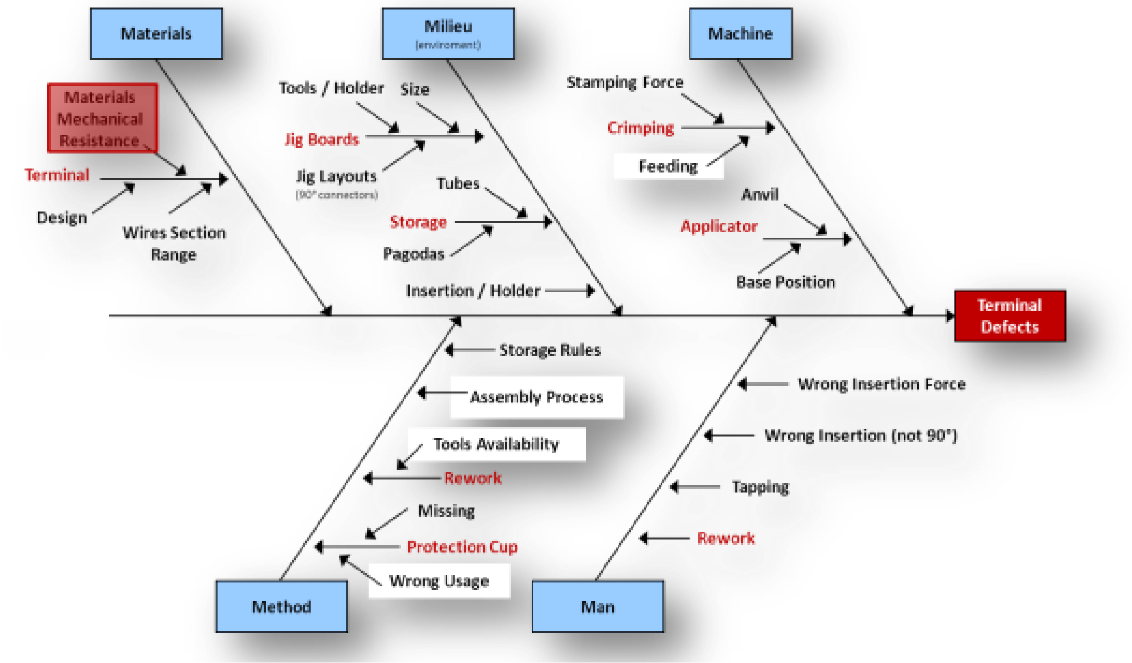
Preliminary Conclusion

Equipment availability in the Company laboratory to test performance and most importantly Universidade do Minho Material Department Professor opinion allow to filter some testing methods in early stage of this step, such as Dye Penetrant, Magnetic Particles and Ultra-Sound. At the end, only Visual Inspection (VI) was choose considering that all others were rejected by the components size in evaluation and resources requirements (per example, SEM / EDS exam is possible with good results but they present moderate time and costs consumption). Another filter option that was taken into account was the applicability in the Company Manufacturing Plants, costs and time consumption need to be very well managed, answering to a real Customer Quality complaint has a very limited time frame.

Later on this investigation, at metallographic examination step, further information will be added about this topic.

Next step is determination of fracture mechanism and fracture modes by **Metallographic Examinations** (ME), position IV on the established strategy.

During the following steps of the strategy the Ishikawa diagram will present pointing which area in being analyzed. This step will focus on Material Mechanical Resistance.



Picture 58 | Terminals Defects Root-causes Ishikawa diagram, Material field highlighted

The Company has a straight cooperation with *Universidade do Minho*, which made possible the metallographic examination of the BROKEN terminal received from a real Quality Customer Complaint and two OK others, quicker, cheaper and most importantly with result guaranties for a strong recognition by internal Company structure.

Metallographic Examination (ME)[25] was performed on the following methodologies:

- Chemical analysis of the base metal by X-ray fluorescence spectrometry;
- Micro-hardness Vickers in a transversal section;
- Metallographic observation by scanning electron microscopy.

[25] [13] Miguel Lopes and Claudia Laranjeira, "LKE-Z13-002695", by YAZAKI Europe Limited, Ovar (Portugal), 2013 [internal document]

Following the samples categorization:

- Male Terminal A was in OK status;
- Male Terminal A was in BROKEN status (resulting from a Customer Quality complaint);
- Female Terminal B was in OK status.

Table 15 | Metallographic examination samples characteristics (technical drawings extracted values)

Terminal (P/N)	Gender	Material	Name	Coating	Lances
A	Male	CuSn 0,1	SICMA 3	Sn 1 to 3 µm	N
B	Female	CuFe 2P	SICMA 3+	Sn 1 to 3 µm	N

Next are described how the testing samples were prepared:

- Samples were coated with an Au/Pd thin film, by sputtering; using the Module Sputter Coater equipment (SPI Supplies, Inc., USA company) with 15 mA electrical current;
- Samples were ground with SiC grinding paper (220, 500, 800 and 1200 mesh) followed by diamond powder polishing until 1 µm. The etching process was made passing lightly a solution of Ferric Chloride on the samples polished surface.

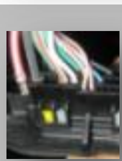
And which testing equipment was used:

- The SEM / EDS observation was performed using a High Resolution (Schottky) Environmental Scanning Electron Microscope with X-Ray Microanalysis and Electron Backscattered Diffraction analysis: Quanta 400 FEG ESEM / EDAX Genesis X4M;
- Philips X-ray fluorescence spectrometry, model X' UNIQUE II;
- The observation was made using a NIKON ECLIPSE 600 optical microscope provided with image record software using different magnifications (between x25 until x80 000);
- Micro-Hardness measured in a SHIMADZU, model Nº 4451 respecting the following parameters: normal load used 980,7 mN (corresponding to $HV_{0,1}$); Time at maximum load was 10 s.

Next two pages present Quality Customer Complaints related with both Terminals A and B, for information only.

Brief graphical description of the quality customer complaints related with the terminal A:

Table 16 | Terminal A Quality Customer Complaints examples

N°	Affiliate Supplier	Defect	Location	Details (photos)
#1	BU	Broken	Crimping Area	
#2	BU	Broken	Crimping Area	
#3	BU	Broken	Crimping Area	
#4	TU	Broken	Crimping Area	
#5	BU	Broken	Crimping Area	

Brief graphical description of the quality customer complaints related with the terminal B:

Table 17 | Terminal B Quality Customer Complaints examples

N°	Affiliate Supplier	Defect	Location	Details (photos)
#1	MU	Broken	Crimping Area	
#2	MU	Broken	Crimping Area	

The first action on the **Metallographic Examination** (IV) that was performed was the Chemical Analysis of the Terminals A and B base material by X-ray fluorescence spectrometry.

Presenting, measurement results for samples Terminal A kind:

Table 18 | Terminals A Broken and OK chemical analysis measurements results

ID	Terminal	Material	Cu (wt.%)	Sn (wt.%)	Fe (wt.%)	P (wt.%)	Al (wt.%)
(a)	A OK	CuSn0,1	Balance	0,26 ± 0,02	0,054 ± 0,005	0,031 ± 0,003	-
(b)	A BROKEN	CuSn0,1	Balance	0,36 ± 0,05	0,15 ± 0,02	0,038 ± 0,003	0,9 ± 0,1

Picture 59 | Examination area identification

Important Note:

For avoid as much as possible wrong interpretations about all possible events that can happen that would origin the contamination of the BROKEN terminal with *Al* element, the chemical analysis was performed in an area where no tool touches in a "normal manufacturing process", rather during the crimping process or a rework operation (such a brief note to state that the rework tools are made from stainless steel). The measured results, table above, when compared against the commercial alloys chemical composition specification (per example *KME*) one of the point that be noticed immediately is that there is no straight correspondence between them, meaning, Terminal A is made of CuSn0,1 and on the market are available the following cooper alloys, as shown on the table below.

Copper Alloy Supplier standard (*KME*):

Table 19 | Terminal A Copper alloy supplier standard chemical information

Terminal	Material	Cu (wt.%)	Sn (wt.%)	Fe (wt.%)	P (wt.%)	Pb (wt.%)
A	CuSn0,15	Balance	0,1 .. 0,2	Max. 0,1		-
A	CuSn2Fe0,1P	Balance	1,7 .. 2,3	0,05 .. 0,15	0,025 .. 0,4	-

As previously stated on this document, common sense among wire-harnesses producers, alloys chemicals compositions are one of "know-how's" for terminals producers, this fact seen here somehow demonstrate just that. More important than the previous point is the comparison of the measured results against terminals supplier submitted material specification (every supplier must submit a full package of documents. This is one of them, to see their product approved by its Customer). Specification values are demonstrated on the following table.

Terminal A Supplier material specification report[26]:

Table 20 | Terminal A supplier chemical information

Terminal	Date	Cu (wt.%)	Sn (wt.%)	Fe (wt.%)	P (wt.%)	Pb (wt.%)
A	14/02/2013	99,8 .. 100	0,1 .. 0,2	0 .. 0,05	0,005 .. 0,02	0 .. 0,05

Terminal A material Chemical Analysis preliminary conclusions:

- Comparing the chemical composition between (a) and (b) terminals important differences are evident on the elements *Sn* (~0,1) and *Fe* (~0,096) contents.
- Elements % content higher in the (b) terminal.
- Comparing the chemical composition of (a) and (b) terminals against the supplier material specification important differences are evident on the elements *Sn*, *Fe* and *P* contents.
- (a) and (b) are judged as NOT CONFORM against the supplier material specification (**ORANGE** color cells).
- *Al* element does not appear on the supplier material specification report.
- The (b) sample presents on its alloy chemical composition an unexpected high *Al* content (**RED** color cell).
- *Al* content is responsible for hardening of the material (creating precipitations with other elements) what makes it more susceptible to a brittle behavior[27].
- The (a) sample present Fe % content CONFORM against the supplier material specification (**GREEN** color cell).

[26] Terminal suppliers material datasheets [Internal document]
[27] [14] "A Guide to Working With Copper and Copper Alloys", by Copper Development Association, Ltd, New York (USA), 2010

The measurement results for sample Terminal B kind are listed below:

Table 21 | Terminals B OK chemical analysis measurements results

Sample ID	Terminal	Material	Cu (wt.%)	Fe (wt.%)	Zn (wt.%)	P (wt.%)	Pb (wt.%)
(c)	B OK	CuFe2P	Balance	2,12 ± 0,04	0,23 ± 0,005	0,035 ± 0,003	-

Copper Alloys Supplier standard (*KME*) presents the following compositions:

Table 22 | Terminal B Copper alloy supplier standard chemical information

Terminal	Material	Cu (wt.%)	Fe (wt.%)	Zn (wt.%)	P (wt.%)	Pb (wt.%)
B	CuFe2P	Balance	2,1 .. 2,6	0,05 .. 0,2	Other <0,2	
B	CuFe0,1P	Balance	0,05 .. 0,15	*Other	0,025 .. 0,04	*Other <0,5

Terminal B Supplier material specification report presents the following composition[28]:

Table 23 | Terminal B supplier chemical information

Terminal	Date	Cu (wt.%)	Fe (wt.%)	Zn (wt.%)	P (wt.%)	Pb (wt.%)
B	14/07/2008	Reminder	2,1 .. 2,6	0,05 .. 0,2	0,015 .. 0,15	0 .. 0,05

A total different case, the measured results when compared against the commercial alloys chemical composition specification do not match between them meaning that Terminal B is CuFe2P and on the market is available the “same” cooper alloy, but with different chemical composition as shown on the table. This can means that terminals suppliers “tune” their one cooper alloys as well.

Terminal B material chemical analysis preliminary conclusions:

- By comparing the terminal (c) and terminal (b) material chemical composition measured weights against the material supplier specification a conclusion is reached, all measured elements are COMFORM (GREEN color cell).

[28] Terminal Suppliers Material Datasheets [Internal document]

Second action on the Metallographic Examination was to perform the Micro-hardness Analysis of the Terminals A and B base materials by Vickers methodology in terminals cross-section attending the minimum distance between indentations stated by the standards (ASTM E92: 2003, pp. 6), regarding the distance from the indentation to the terminal border and attending that this material was laminated, just a row of indentations has been done allowing to determine the hardness profile of the terminal.

The measurements results for samples Terminal A and B kinds:

Table 24 | Terminals A and B OK samples and terminal A BROKEN sample results obtained by Vickers micro-hardness methodology measurements.

ID	**Terminal**	**Material**	**HV (average value)**
(a)	A OK	CuSn0,1	144 ± 4
(b)	A BROKEN	CuSn0,1	151 ± 4
(c)	B OK	CuFe2P	149 ± 4

Terminal A and B material kind supplier information:

Table 25 | Terminal A and B material kind hardness information from suppliers

Date	**Material**	**HV**
12/02/2013	CuSn0,1	110 .. 140
14/07/2008	CuFe2P	140 .. 160

Copper Alloy Supplier standard (*KME* CuSn0,15):

Table 26 | Copper alloy CuSn0,15 information about mechanical characteristics

Temper	**Tensile Strength Rm**	**Yield Strength Minimum $Rp_{0,2}$**	**Elongation Minimum A_{50mm}**	**Hardness HV***
	MPa	MPa	%	HV
R360	360 .. 430	310	7	110 .. 130
R420	420 .. 490	370	5	120 .. 150
R460	>460	410	4	> 135

* for information only

Copper Alloy Supplier standard (*KME* CuFe2P):

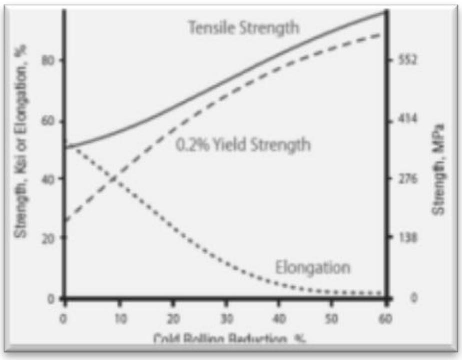
Table 27 | Copper alloy CuFe2P supplier information about mechanical characteristics

Temper	Tensile Strength Rm	Yield Strength Minimum $Rp_{0,2}$	Elongation Minimum A_{50mm}	Hardness HV*
	MPa	MPa	%	HV
R430	430 .. 510	380	10	130 .. 150
R510	510 .. 560	430	7	140 .. 160
R530	>530	470	4	> 140

* for information only

Terminals A and B micro-hardness analysis: preliminary conclusions

- Difference on material chemical composition elements percentage between (a) and (b) terminals A kind can explain the micro-hardness values difference presented;
- Material micro-hardness in (a) and (b) terminal A kind is NON CONFORM against the terminal supplier material specification datasheet (ORANGE color cells);
- Material micro-hardness in (c) terminal B kind is CONFORM against the terminal supplier material specification datasheet (GREEN color cells).



Graphic 14 | Strength versus Cold Rolling Reduction graphic

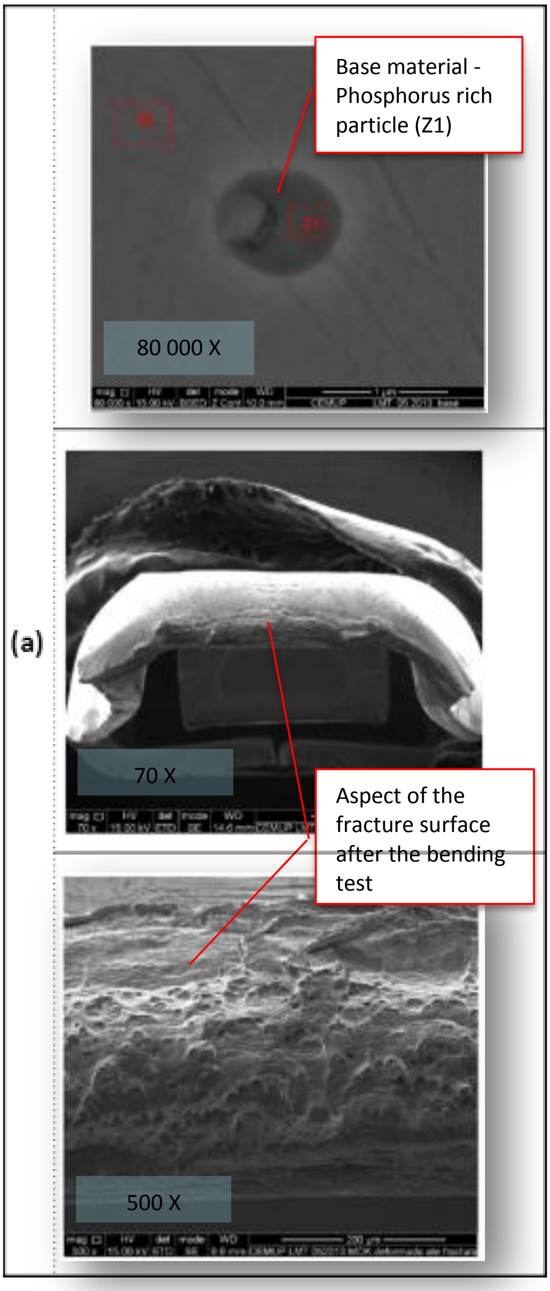
From the side graphic is read that material deformation capacity $A_{(50mm)}$ reduces when Hardness HV increases and consequently when Yield Strength $Rp_{0.2}$ and Tensile Strength increases as well. This means that when the micro-hardness values of the Terminal A BROKEN (measured) are compared against the material supplier (*KME*) micro-hardness values (standard) is immediately understood that the measured values are higher and can be considered as well that most probably are too high. Consequently, the material deformation ability is reduced significantly. Standard values (supplier catalog) indicate a really reduced working margin (from 10 to 7) too.

Improvement Proposition

Therefore is recommendable that Terminal A kind material needs to have a lower micro-hardness value, around 130 HV and like that achieve a safe A_{50mm} work margin.

Third step on the metallographic examination was to perform the **Metallographic Observation** of the Terminals A and B materials surfaces by scanning electron microscopy.

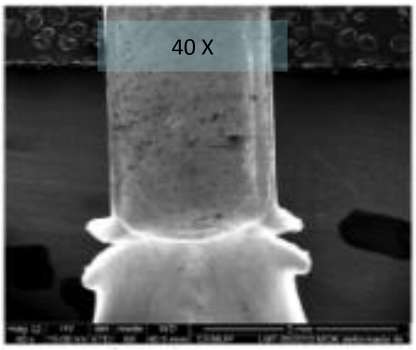
Table 28 | Metallographic Observation Terminal A OK



Sample (a), Terminal A kind, was the first of the three samples delivered to the *Universidade do Minho* to be subjected to the analysis, starting by a manual bending test, in alternate form. This simple test had the real intention to induce the sample initial cracking and its evolution and finally the complete fracture. The test goal was to obtain a fracture surface on an OK sample (a) in order to be analyzed and compared with a BROKEN sample fracture surface (b).

Manual Test Operation description

After 4 time's manual bending operation, it was verified that the material started to present cracking on both sides of the critical transition terminal body area.



Picture 60 | Terminal A manual bending test stage before complete rupture

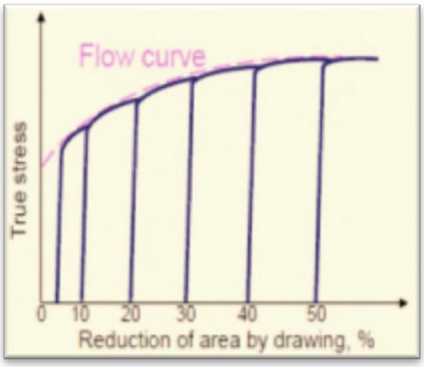
The manual bending operation was performed one time more and as results the terminal became completely broken (5 times total to fracture).

Terminal A OK sample (a) fracture surface observation

The morphology of the fracture terminal surface allowed concluding that the fracture mechanism is due to a cycle stress which indicated fatigue.

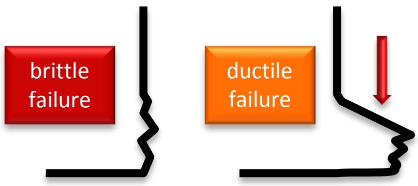
Hard inclusions (high phosphorus concentration) in the microstructure are most responsible for brittle behavior when subjected to mechanical stresses, especially of cyclic nature (strain-hardening).

“Copper is a relatively soft and malleable metal with excellent formability”[29]

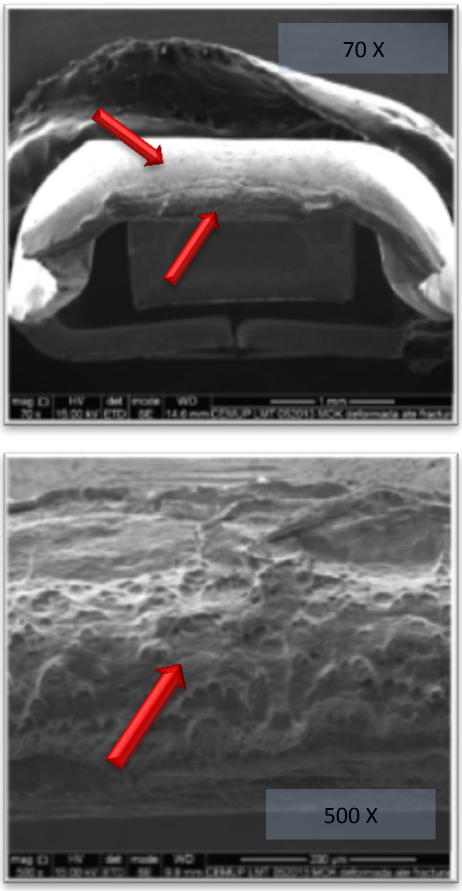


Graphic 15 | Material cycle stress representative flow curve

Copper alloys as other materials mechanical behavior depend on which chemical elements are present and its percentage. This is one of the most important conditions that will influence if a material is considered ductile or brittle. Observing the facture surface we can realize that the structure of the raw material show mostly a brittle behavior because there was no detection during fracture process of a reduction and consequently elongation of the terminal critical material transition section. Next sketch exemplifies exactly what is meant to be said.



Picture 62 | Brittle and Ductile difference behavior schematic



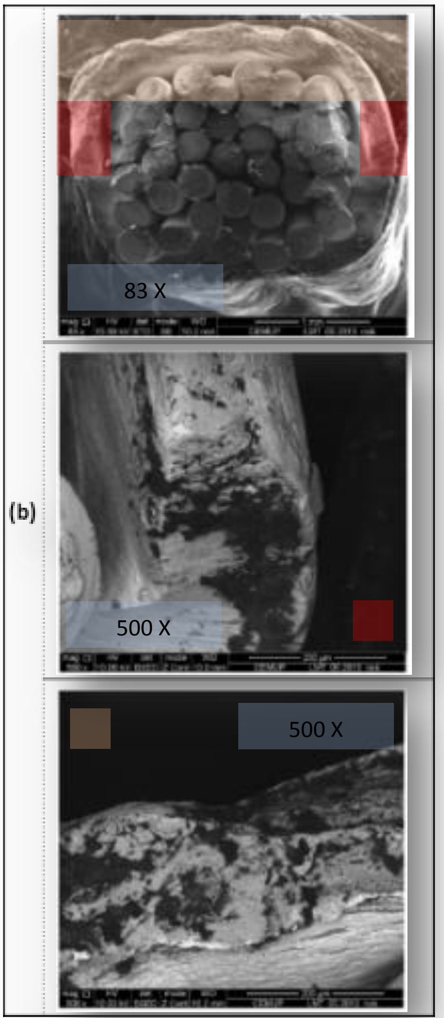
Picture 61 | Metallographic Observation Terminal A OK pictures

Pictures aside of the terminal A samples (a) surface demonstrate as well nearly the absence of a ductile deformation. Some of the surface is almost “polished”, strong indication of strong work hardening, high hardness and low ductility.

Analysis of the Terminal A BROKEN sample (b) was carried out on the sample surface in order to determinate the kind of failure mechanism is involved.

[29] [14] "A Guide to Working With Copper and Copper Alloys", by Copper Development Association, Ltd, New York (USA), 2010

Table 29 | Terminal A Broken (b) metallographic observation pictures

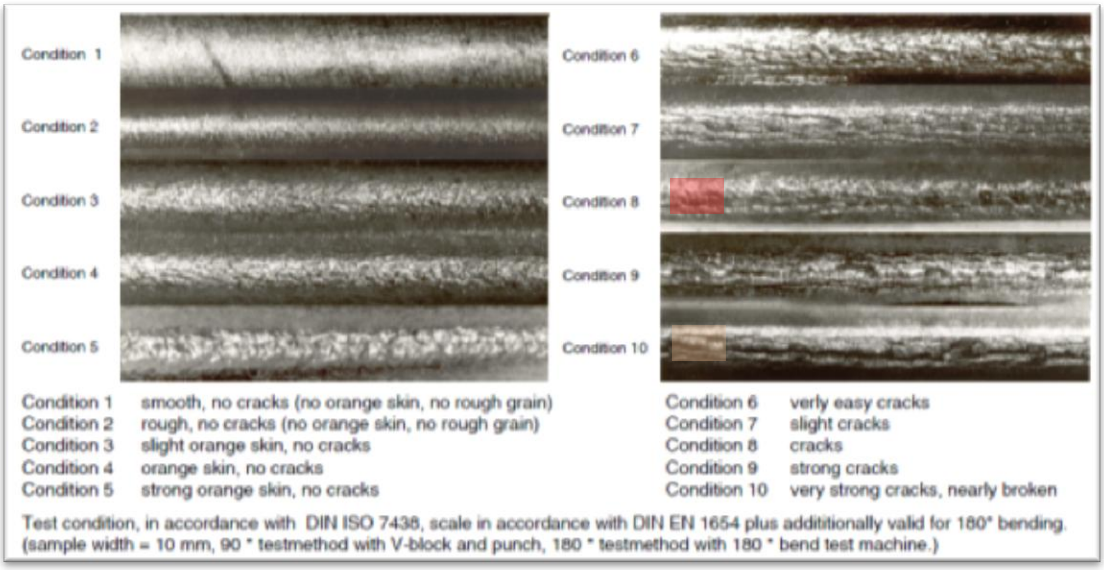


After a detailed observation focused on the corners of the terminal (RED identified areas) and the bottom area (ORANGE identified area) it was concluded that fracture mechanism was a fatigue failure process that advanced slowly sustained by the denoted small plastic deformation steps (waves) on the raw material structure. These strain-hardening steps were potentiated under cold work conditions, corresponding to different deformation stages during the crimping process, industrial manipulation, assembly process, and service, which are a strong indication of an increase of the mechanical strength and hardness of the raw material areas and a negative decrease of its ductility and ability to further plastic deformation. The corners surface suggests that were the first to fail (almost polished surface), being followed by the bottom one (wavier) where the mechanical resistance was unable to accommodate the stress and strain imposed, and consequently complete rupture took place by traction failure mechanism. Fatigue cracks spread until Cooper alloy's mechanical resistance limit was reached, and only then, the traction failure happened with a great influence by the diminution of the terminal resistant area.

Due to the traditional ductile behavior of this Copper based alloys, the fracture seems to follow a ductile pattern, being felt that material is in the frontier between the ductile and brittle behavior. Attending to the pictures, it was observed that there were some impurities on the surface, resulting of the manipulation, transport and atmosphere contact, which results on the surface oxides formation, which difficult somehow the observation.

Picture 63 | Terminal A sample (b)

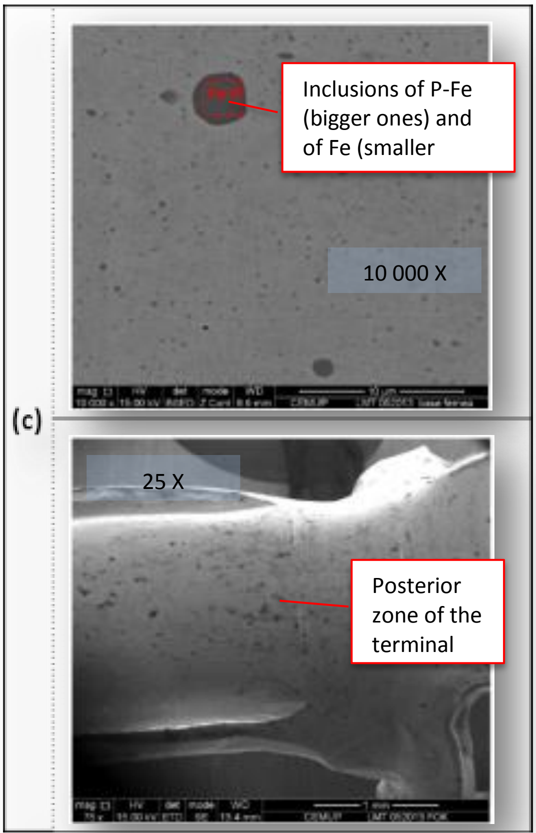
For information only, both previously identified areas as RED and ORANGE were classified according the following Scale of Bending (bending gallery)[30]



Picture 64 | Cooper alloy suppler bending classification gallery

ORANGE area was classified according to material supplier specification as 8 denoting cracks and RED area was classified as condition 10 denoting very strong cracks, nearly broken.

Table 30 | Terminal B OK metallographic observation



Finally, terminal B was observed. It is an OK terminal. In this sample (C), there was no interest to induce a fracture. The only terminal sample where this operation was performed was on the sample (A).

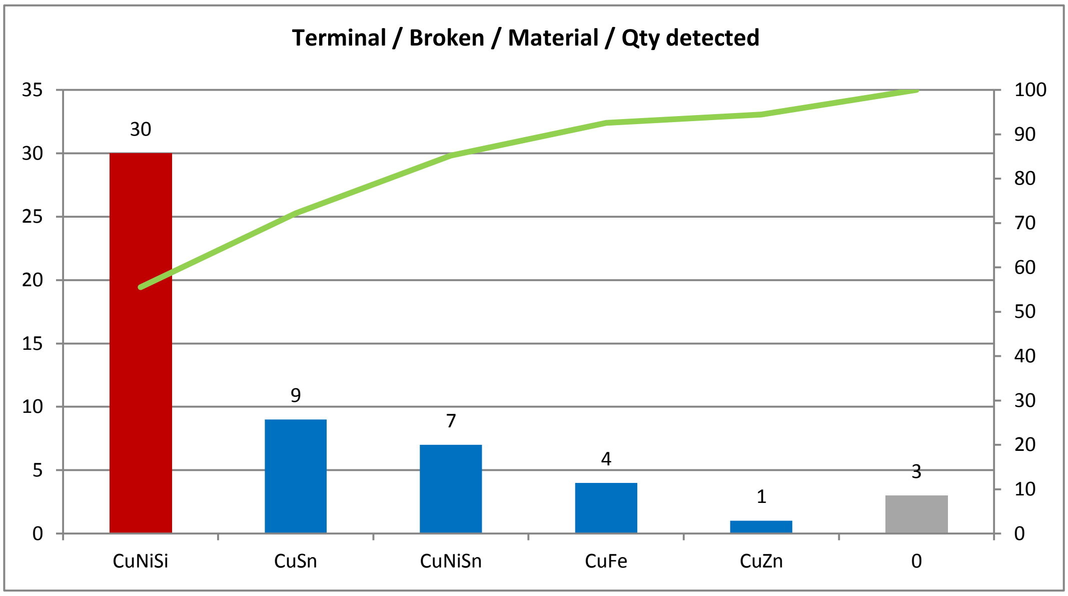
The chemical composition of the base material denotes a microstructure with a lot of Fe and Fe-P inclusions.

Both kinds of inclusions should contribute to the alloy hardness, increasing its susceptibility to brittleness, what can be less adequate for components subjected to vibrations or cyclic stresses.

[30] [7] Udo Adler, Josef Mommertz and Dr. Holder Warnecke, "Technical Manual Strips of copper and copper alloys plain and tinned", by KME AG & Co, Germany, 2010

Improvement Proposal - Metallographic Annealing[31]

Copper alloys are primarily strengthened by cold work or by alloying additions that potencies solid solution strengthen and enhance strain hardening (metallographic strain hardening)[32]. Precipitation hardening is important to a small but important class of alloys. Copper-nickel-aluminum and Copper-nickel-silicon alloys are also commercially important precipitation-hardenable alloys.



Graphic 16 | Terminal defect Material Pareto graphic

As can be easily confirmed on one of the Pareto graphics, CuNiSi is the cooper alloy related to the most of Company Customer Quality complaints on BROKEN terminals subject.

The favorable condition for precipitation hardening of this Copper alloy justifies, somehow, the observed surface conditions on samples (a) and (b), phosphorus and phosphorus/iron precipitations.

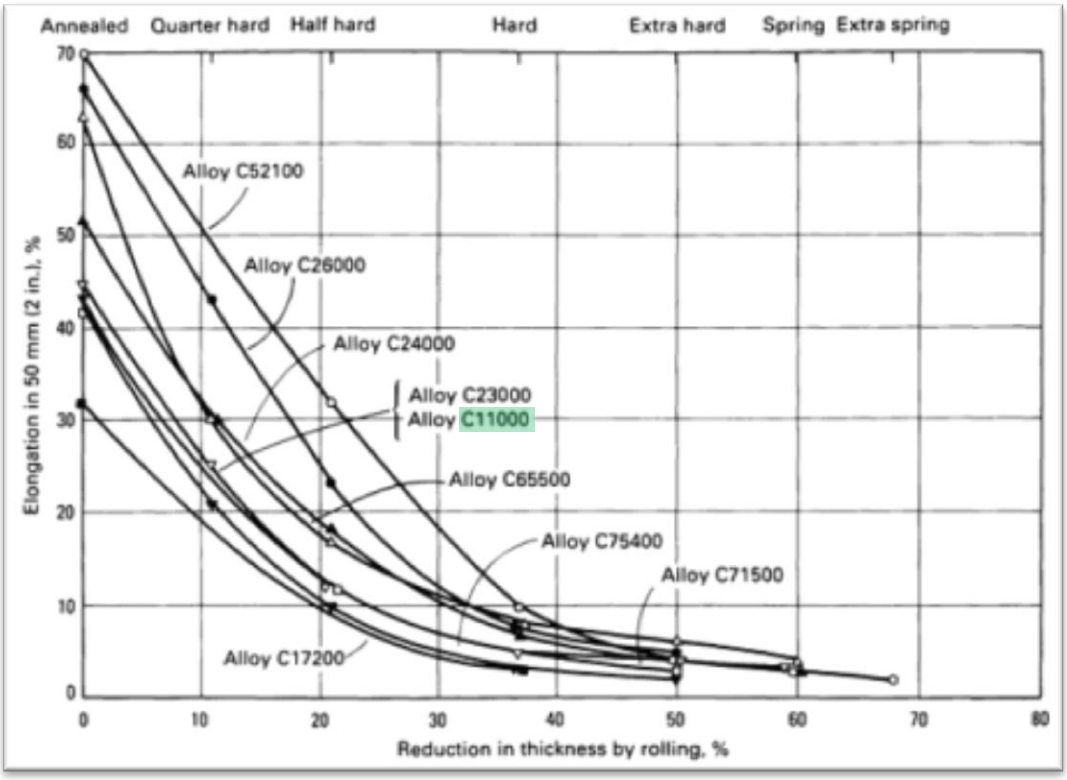
The relative work-hardening effects of various alloying elements are evident, the strong effect of aluminum is contrasted with the weak effect of nickel, with zinc and tin being intermediate. Ductility, as indicated by tensile elongation, decreases with cold reduction.

Is not known for sure if metallographic annealing solution is used by terminals manufactures after all the cold working process, however this was a subject for an improvement proposal study that will be presented next no this document, for Terminal A material kind only. Worked Copper can be recrystallized by annealing at temperatures as low as 250 °C, depending on the prior degree of cold work, time and temperature.

[31] [15] George E. Dieter (vol. Chairman), "Material Selection and Design Metals Handbook Vol.20", by ASM International, Maryland (USA), 1997

[32] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993

Even Copper alloys with large amounts of solution-hardening elements such as zinc, aluminum, tin and silicon, that show rapid work hardening, are readily commercially processed beyond 50% cold work, this means that a softening anneal is required to permit additional processing. The amount of cold working and the annealing parameters must be balanced to control grain size and crystallographic texturing and hardness.



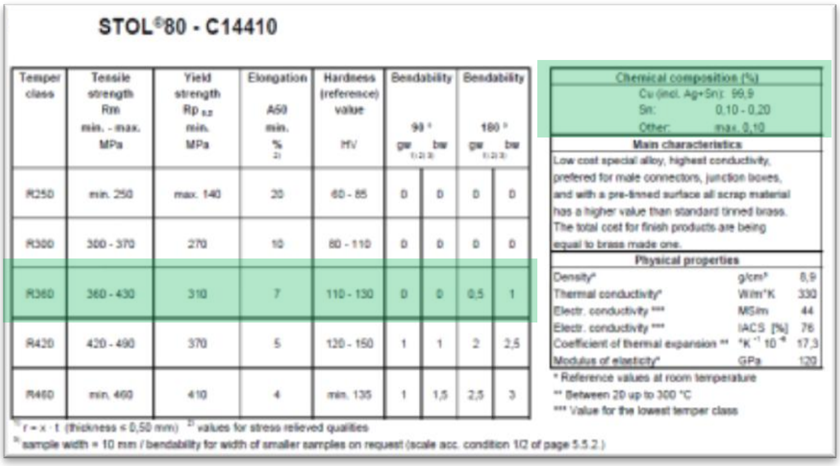
Graphic 17 | Copper alloy Elongation versus Reduction in thickness by rolling graphic

Another two important notes: the amount of cold deformation between softening anneals is usually restricted to 90% maximum to avoid excessive crystallographic texturing, especially in rolling of sheet and strip. Annealed performed between cold working forming steps should be performed within a temperature range of 375 to 650 °C, achieve as much as possible desired mechanical characteristics that will be fully operative for real service components.

To choose the annealing operation parameters for the Terminal A kind, the following steps were considered:

First, it was choose the best commercial Copper alloy[33] compromise according the mechanical properties comparative to the CuSn0,1 alloy used by the terminal supplier, *KME STOL®80 R360*.

[33] [7] Udo Adler, Josef Mommertz and Dr. Holder Warnecke, "Technical Manual Strips of copper and copper alloys plain and tinned", by KME AG & Co, Germany, 2010



STOL®80 - C14410

Temper class	Tensile strength Rm min. - max. MPa	Yield strength Rp 0,2 min. MPa	Elongation A50 min. % 2)	Hardness (reference) value HV	Bendability 90° gw 1) 2) 3)	Bendability 90° bw	Bendability 180° gw 1) 2) 3)	Bendability 180° bw
R250	min. 250	max. 140	20	60 - 85	0	0	0	0
R300	300 - 370	270	10	80 - 110	0	0	0	0
R360	360 - 430	310	7	110 - 130	0	0	0,5	1
R420	420 - 490	370	5	120 - 150	1	1	2	2,5
R460	min. 460	410	4	min. 135	1	1,5	2,5	3

1) r = x · t (thickness ≤ 0,50 mm) 2) values for stress relieved qualities
3) sample width = 10 mm / bendability for width of smaller samples on request (scale acc. condition 1/2 of page 5.5.2.)

Chemical composition (%)
Cu (incl. Ag+Sn): 99,9
Sn: 0,10 - 0,20
Other: max. 0,10

Main characteristics
Low cost special alloy, highest conductivity, prefered for male connectors, junction boxes, and with a pre-tinned surface all scrap material has a higher value than standard tinned brass. The total cost for finish products are being equal to brass made one.

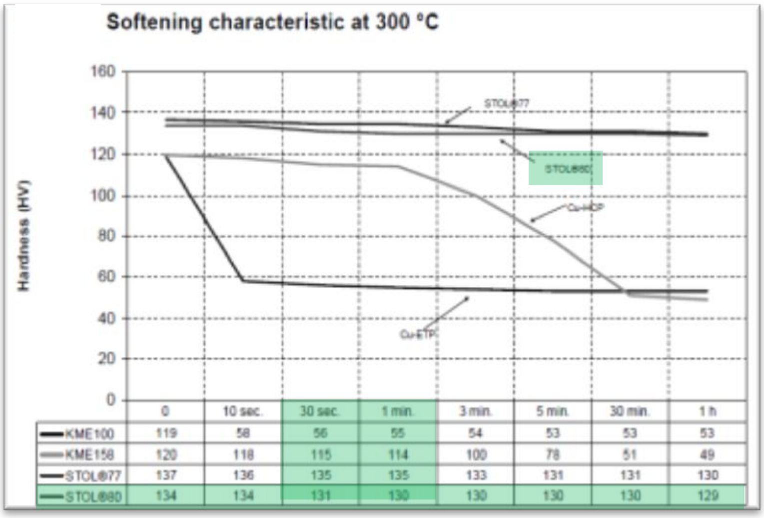
Physical properties

Density*	g/cm³	8,9
Thermal conductivity*	W/m°K	330
Electr. conductivity ***	MS/m	44
Electr. conductivity ***	IACS [%]	76
Coefficient of thermal expansion **	°K⁻¹ 10⁻⁶	17,3
Modulus of elasticity*	GPa	120

* Reference values at room temperature
** Between 20 up to 300 °C
*** Value for the lowest temper class

Picture 65 | CuSn0,1 cooper alloy supplier mechanical and chemical characteristics

Second, commercial cooper alloy supplier recommendation for temperature level is 300 °C, in order to achieve the 130 HV Vickers Hardness (recommended) without too much impact in the process tack-time, an operation time that takes around 30 seconds is enough.



	0	10 sec.	30 sec.	1 min.	3 min.	5 min.	30 min.	1 h
KME100	119	58	56	55	54	53	53	53
KME158	120	118	115	114	100	78	51	49
STOL®77	137	136	135	135	133	131	131	130
STOL®80	134	134	131	130	130	130	130	129

Picture 66 | CuSn0,1 cooper alloy supplier annealing parameters

Another proposition is, this treatment should be performed at terminal supplier manufacturing process because at Company process there is the presence of the Copper wire insulation, main base in vinyl material (very low resistance to high temperatures) and, of course, terminal supplier is the material expert, this task should be under its responsibility.

As previously demonstrated on this document, terminals are the product of several cold work operations, executed in several and sequentially separated steps. A positive way to implement this annealing operation is to perform intermediate annealing treatments steps during the complete terminals manufacturing process. This thermal treatment depends as well on terminal design geometry and the work-hardening rate of each particular Copper alloy.

Cooling Process[34]

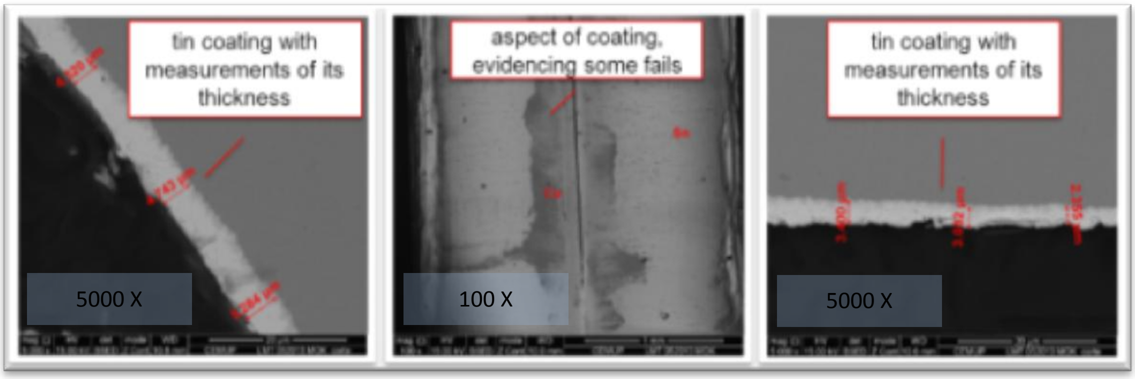
Successful heat treating requires that the material be quenched at the highest possible rate from the solution-treating temperature. It is therefore necessary to provide both rapid transfer from furnace to quench tank and an efficient quenching medium. Delays sufficient great to cause the loss of temperature before the correct quench process could allow the adulterated Copper intermetallic γ phase formation, and consequently, reducing the effectiveness of the entire thermal treatment.

The quenching medium, which is generally water, must be sufficiently cold and agitated to maintain a rapid cooling rate to below the 200 °C (400 °F) level to ensure that no premature spinodal hardening occurs. In some circumstances, particularly with the low-tin alloys, oil, air, or cold-gaseous medium quenching may be used for small parts or very thin sections, but a careful evaluation of these methods should be conducted to ensure the adequacy of the quench.

Terminal Coating Analysis

The coating is one of the terminal characteristic that was not analyzed so far. It is important to realize if its conformity has influence on the terminal mechanical behavior.

On the Terminal A and B kind, samples (a), (b) and (c) correspondently, all have tin (Sn) coating between 1 to 3 µm of thickness by technical definition. Therefore, by scanning electron microscopy methodology, were chosen samples (a) and (c) to be observed and verified their coating conformity. Next are demonstrated the terminal A OK, sample (a) verification results:

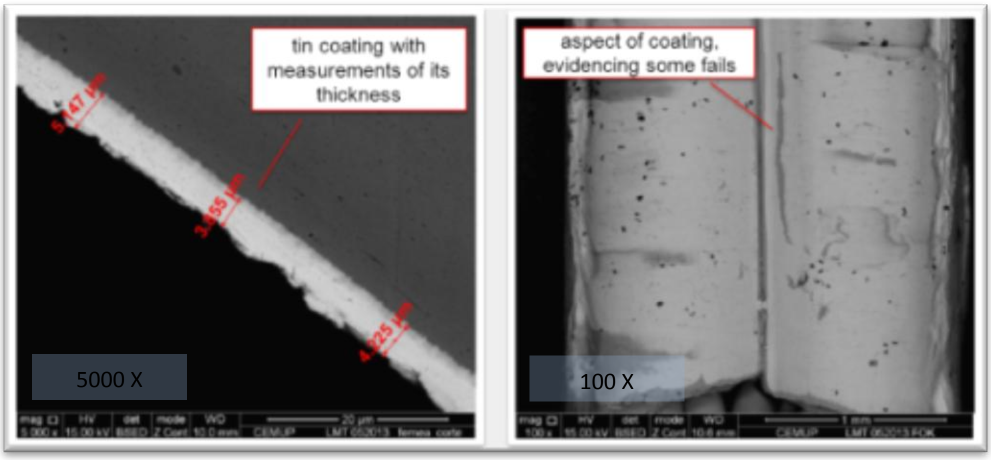


Picture 67 | Terminal A OK coating verification pictures

Resuming, coating has a regular thickness but NOT CONFORM in some areas because its outside from specification, measure around 4,7 µm against 3 µm defined by specification.

[34] [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993

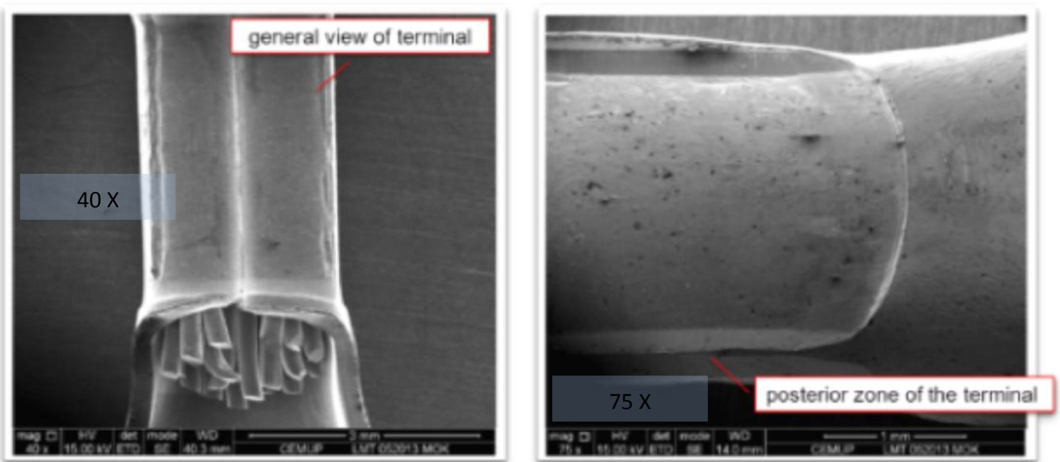
Some fails were distinguished, however, is thought that this has no negative impact on the terminal mechanical resistance or behavior. Those fails most probably were generated by the crimping operation itself. Next are demonstrated the terminal B OK, sample (c) verification:



Picture 68 | Terminal B OK (c) coating verification pictures

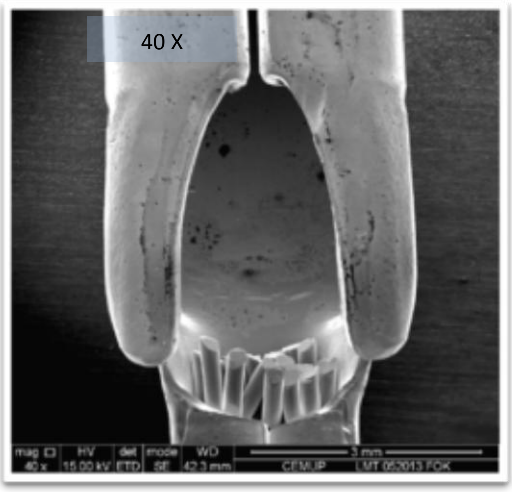
Coating has a regular thickness but still NOT COFORM in some specific areas. As observed on the sample (a) some fails were distinguished, however, is thought as well that this has no negative impact on the terminal mechanical resistance or behavior.

Previously, on the Non Destructive Tests, more specifically on Visual Inspection chapter, it was noted that there was better ways to perform the visual check of its conformity instead of the Ray-X tool, an example is the Scanning electron microscopy methodology however, isn't the first choice by the high time consuming and economic reasons. Hereunder are presented the results of the visual observation on terminal A OK, sample (a):



Picture 69 | Terminal A OK cracking presence verification pictures

The terminal presents a good finishing. No cracks on material have been detected.



Picture 70 | Terminal B OK cracking presence verification pictures

Hereunder are presented the results of the visual observation on terminal B OK, sample (c):

The terminal presents a good finishing. No cracks on material have been detected.

Customer quality complaint metallographic examination conclusion

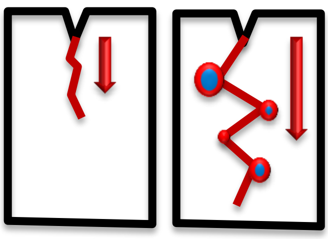
Terminal A BROKEN, sample (b) was fractured in service by a cracking mechanism induced by fatigue. This may be due to different factors, as per example the excessive hardness of base material, and the excessive percentage of certain chemicals elements or even and very important the presence of not defined chemical element in high percentage, which could be the main reasons of terminal failure. It is considered that Terminals coating have not a significant impact on failure mechanism in study.

Improvement Proposal | Micro-Hardness limit definition

This proposition is based on the Material Supplier specification information (Tensile and Yield strengths, material capacity of deformation given by A_{50mm} and HV hardness values) in straight relation with Tensile and Yield strengths specified by the Terminal Supplier.

Table 31 | Material Supplier specification information

ID	Terminal	Material	HV
(a) & (b)	A	CuSn0.1	110 - 130
(c)	B	CuFe2P	130 - 150



Picture 71 | Crack Initiation and propagation by microstructure inclusions explanation schematic

The base Copper alloy present in its microstructure inclusions of P-Fe, Fe and P that facilitate the initiation and following propagation of the fatigue induced cracks.

Improvement Proposition | Chemical Composition limits definition

Terminal material quality is critical so it can correspond with a correct mechanical behavior to all requested external solicitations. In order to achieve this it is recommended that the material present a well limited chemical composition, as specified by material suppliers.

It is highly recommended that the Company shouldn't allow the presence of terminals which chemical compositions are out of specification as confirmed previously. One of the most serious consequences is the presence of chemical precipitations and not expected elements. Material becomes harder and consequently as a brittle behavior.

For Terminal A and B, samples (a), (b) and (c), hereunder the specified chemical composition:

Table 32 | Specific Chemical composition improvement proposal values

ID	Terminal	Material	Chemical (wt.%)
(a) and (b)	A	CuSn0.1	Cu: Balance Sn: 0,10 – 0,20 Other: max 0,10
(c)	B	CuFe2P	Cu: Balance Fe: 2,1 – 2,6 Zn: 0,05 – 0,2 Other: max 0,2

Also recommendable is that the Company could chemically analyze, periodically, the terminals stocks that receive in their manufacturing plants. With this real information (evidences) could be possible to alert and put in motion real corrective actions plans, whenever needed, at the correspondent terminal manufacturing suppliers.

Another proposal in order to reduce as much as possible all hard inclusions presence (consequently hardness increase effect in the material) and residuals stress / strain hardness (accumulated for example, on terminals manufacturing process at suppliers side), is the application of a thermic treatment on terminals (Recrystallization Annealing for Homogenization) at supplier manufacturing process.

Table 33 | Specific Thermic treatment improvement proposal parameters

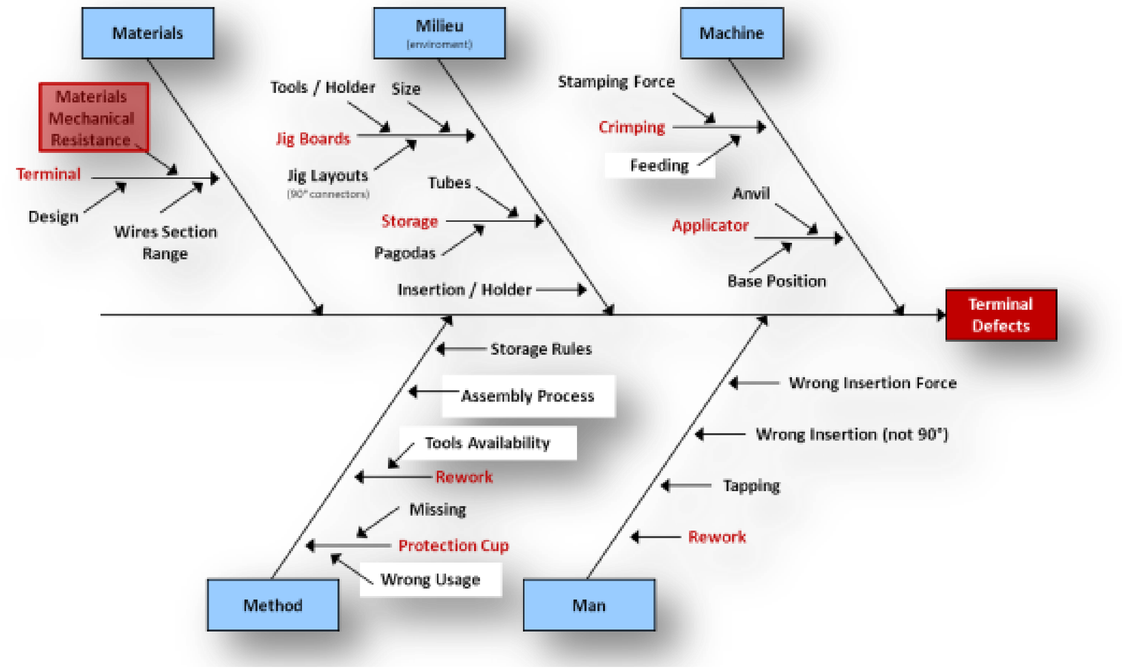
ID	Terminal	Material	Softening Annealing
(a) and (b)	A	CuSn0.1	T: 300°C Time: 30s - 60s Freq: intermediate
(c)	B	CuFe2P	T: 500°C Time: 10s – 30s Freq: intermediate

Other proposals are presented as follows:

a) Introduce sampling HV measurement as an internal manufacturing plants standard operation for lote classification at inspection reception areas. Subject to presented in detail later on this document.

b) In case of real cases (Customer Quality Complaints) introduce the chemical and metallographic analyses as normal analyze methodology.

Next step was to identify the failure mechanism and the facture mode by real production situation simulations in laboratory environment. In order to achieve this, new **Destructive Testing** (DT) were developed and performed. This step occupies the position V.



Picture 72 | Terminals Defects Root-causes Ishikawa diagram, Material field highlighted

Tests in laboratory environment were initially though "only" to confirm what the metallographic observation revealed, the failure mechanism and fracture mode.

During the destructive tests preparation with the Company internal laboratory staff, was concluded that much more information could be extracted from these tests, information that can result in potential future investigations, such as ergonomic improvements on the shop-floor manufacturing gauges allowing terminals insertion on the connectors operations improvements and another example is the orientation (angle) of connector holders and its correct placement on the assembly tables for a tapping operation that could not produce so much stress on the wires and indirectly on terminals, which can reduce theirs lifetime.

As mentioned, some simulations where initially though, they were identified on this document as A, B and C, which needed to be different (more realistic, simulations of real shop-floor events) from the ones already performed respecting Customers specifications for product validation requirement “only”. This explains what can be seen on the next pages, RED crossed pictures are shown next the new simulations A, B and C descriptions.

An additional outcome expected was the development of “new” test methods to simulate, in laboratory environment, real production operations that can have an important influence in terminal BROKEN defects, such as, handling operations, insertion load / angles and reworks actions (occurrence root-causes information extracted from Company internal databases).

Tests where developed and performed in the following sequence:

Table 34 | Destructive Testing list and description

N°	Test Name	Description
1	Angle definition for crack appearance.	Starting from 35° and decreasing until cracks are not visualized.
2	Confirm terminal behavior in the specific angle.	For all tests it was defined a group of 5 samples per test which all will suffer a determinate bent action (in specific angle) and after it will be checked the existence of cracks.
A	Check the necessary load to bend the terminal positioned at 20°.	Before this test, it was checked the maximum angle that would allow the correct terminal insertion into the connector. After this definition, terminals were prepared in epoxy resin with the same defined angle (20°). Tests with a more representative sample group will be performed => 10 samples per terminal kind (5 samples OK + 5 samples previously bent (terminal deformation)).
B	Check terminal behavior when inserted in the connector with a certain angle.	Test setup: check maximum angle which allows terminal insertion into the connector. This angle will also be used to verify the necessary load to bend terminals.
5	Confirm terminal behavior during connector insertion in a specific angle.	For all tests was defined a group of 5 samples per test, the connector will be rotated (in a specific angle) and then will be checked the behavior of the terminal when inserted when respecting a vertical motion.
C	Pull test (PT).	Check terminal behavior when submitted to a systemic tension.

Brief note: preparative tests (1, 2 and 5) had to be involved for correct performance of the A, B and C simulations. This is the reason why on the previous table, the numbering is atypical.

Following on the established internal procedure, the testing samples were defined. Terminal samples material information used on the tests are described on the following table.

Table 35 | Destructive Testing samples identification

Reference		Terminal Raw Material
Terminal ID	**Connector ID**	
Terminal A	Con1	CuSn
Ter2	Con2	CuNiSn
Ter3	Con3	CuNiSi

Once again the numbering on the table was atypical. On this case, "Terminal A" term was kept to maintain the association that these samples had the same kind of definition that previously in order steps of this investigation and the others were not.

Background of representative sample size definition

1st criteria for selection – Material Pareto created during the investigation:

- Ter3: CuNiSi – 1st position
- Terminal A: CuSn – 2nd position
- Ter2: CuNiSn – 3rd position

2nd criteria for selection – Terminal Gender:

- Terminal A: Male
- Ter2: Female
- Ter3: Female

3rd criteria for selection:

Terminal A, represents the only real part received from manufacturing plants for the time period defined for this investigation.

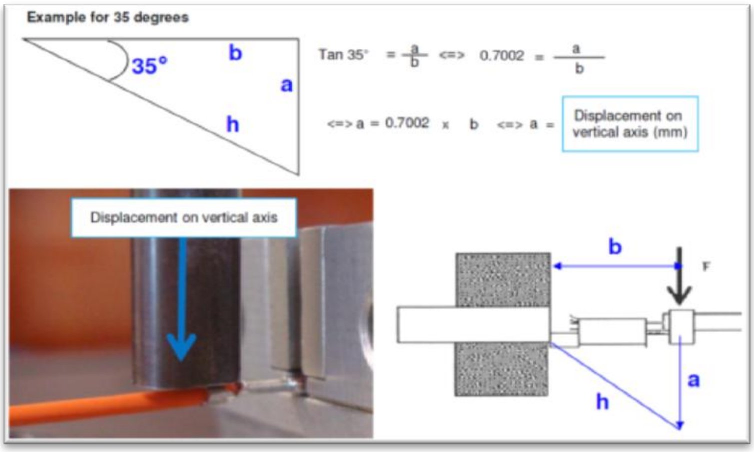
4th criteria for selection:

Number of samples fast availability for testing performance.

Next, all simulations and preparative test will be described in detail.

Test1 | Angle definition for crack appearance (angle range definition)

Method of calculation of the displacement on vertical axis required to bend the terminal:



Picture 73 | Method of calculation of the displacement on vertical axis

Performed operations for test set-up:

- Fixing sample on equipment base, according above pictures;
- Calculation of the displacement (force measures is not important at this stage) distance on vertical axis for different bending angles, starting in 35 °. In case of cracking appearance, a new sample is tested by decreasing the angle in 5 °. This operation will stop when the cracking is no longer present;
- Test motion speed: 8,3 x10^{-4} m/s (50 mm/min).

After test performed, measurements results were obtained as follows:

Table 36 | Test1 measurements (a) and (b) results

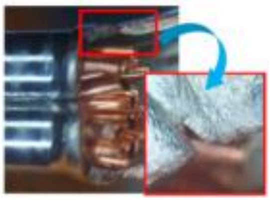
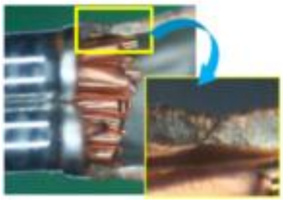
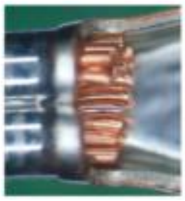
Terminal	(b) Distance (mm)	Distance (a) to bend the terminal according to the angle (mm)					
		35°	30°	25°	20°	15°	10°
A	7,237	5,067	4,178	3,375	2,634	1,939	1,276
Ter2	5,233	3,664	3,021	2,440	1,905	1,402	0,922
Ter3	4,845	3,392	2,797	2,259	1,763	1,298	0,854

In order to achieve a bending angle of 20 ° degrees the displacement that need be performed is around 2,6 mm (example of terminal A, for the others terminal kind is even smaller), after load released the material naturally recovers (not 100%) becoming the bending angle and the correspondence displacement distance even smaller. Important information must be distinguished: it is considered that is very difficult to human eye to detect these kinds of deformations and its very serious consequences (crack presence).

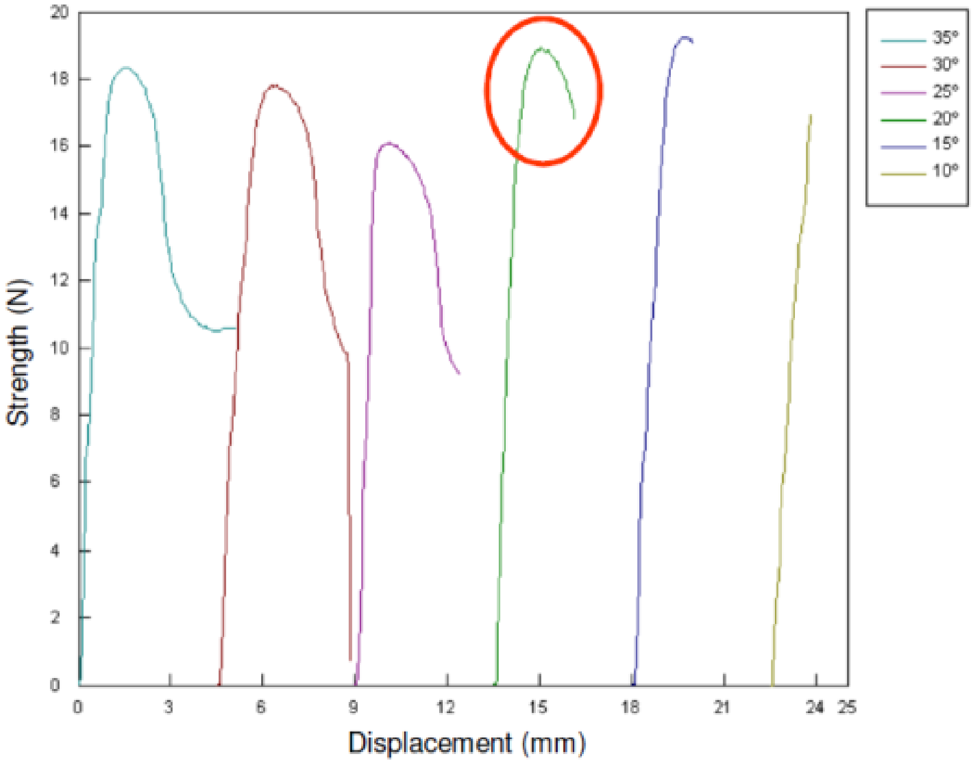
For better understanding of the material deformation progress during test performance, the following tables were formulated for each terminal sample. Angle range for crack initiation was also defined. Failure existence is also perceptible on the correspondent Strength (N) / Displacement (mm) graphics.

Check the existence of cracks in a specific angle range – Terminal A:

Table 37 | Test1 existence of cracks in a specific angle range – Terminal A

	Angle of Deformation					
A	**35°**	**30°**	**25°**	**20°**	**15°**	**10°**
	Y	Y	Y	Y	N	N
Crack Result						

Graphic for the different bending angles on the terminal A samples:

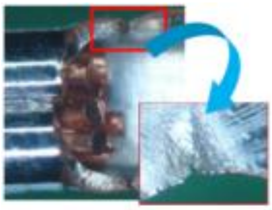


Graphic 18 | Test1 graphic for the different bending angles on the terminal A samples

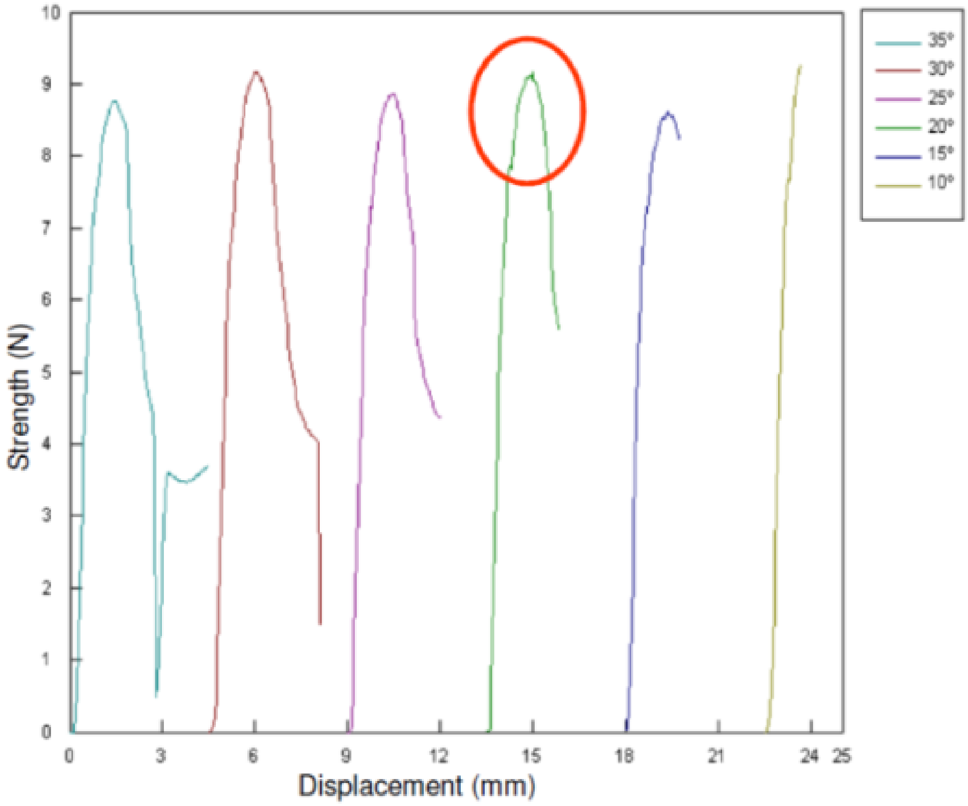
With a 20 ° deformation bending angle, external cracks were visualized.

Check the existence of cracks in a specific angle range – Terminal Ter2:

Table 38 | Test1 existence of cracks in a specific angle range – Terminal Ter2

	Angle of Deformation					
Ter2	**35°**	**30°**	**25°**	**20°**	**15°**	**10°**
	Y	Y	Y	Y	N	N
Crack Result						

Graphic for the different bending angles on the terminal Ter2 samples:

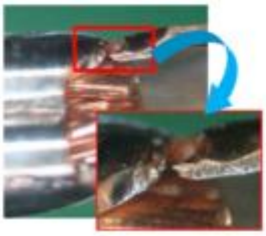
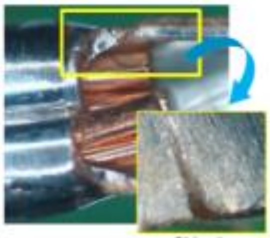


Graphic 19 | Test1 graphic for the different bending angles on the terminal Ter2 samples

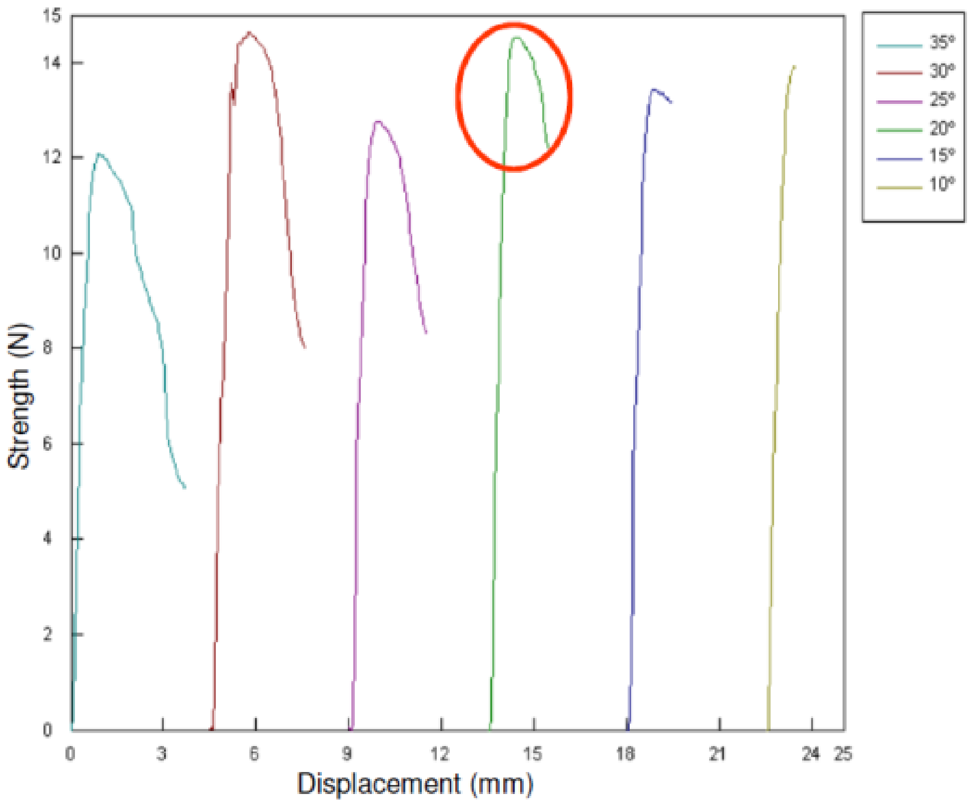
With a 20 ° deformation bending angle, external cracks were visualized.

Check the existence of cracks in a specific angle range – Terminal Ter3:

Table 39 | Test1 existence of cracks in a specific angle range – Terminal Ter3

	Angle of Deformation					
Ter3	**35°**	**30°**	**25°**	**20°**	**15°**	**10°**
	Y	Y	Y	Y	N	N
Fissure Result						

Graphic for the different bending angles on the terminal Ter3 samples:

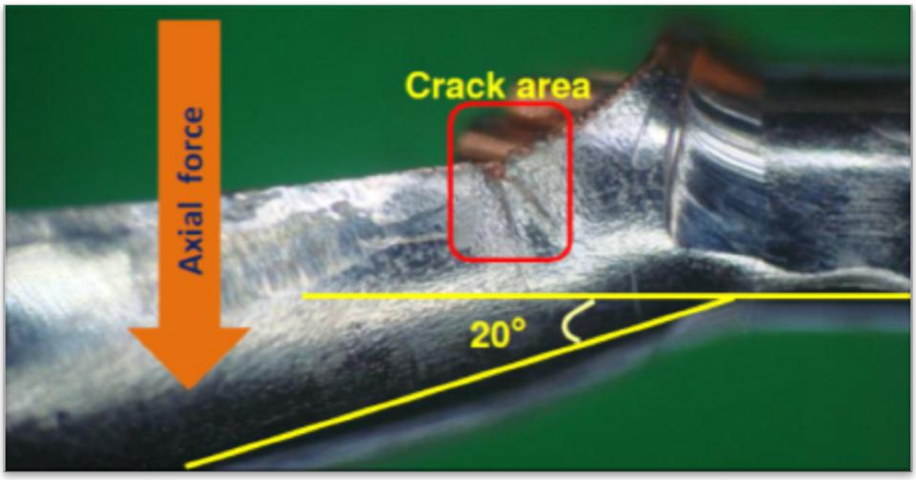


Picture 74 | Test1 graphic for the different bending angles on the terminal Ter3 samples

With a 20 ° deformation bending angle, external cracks were visualized.

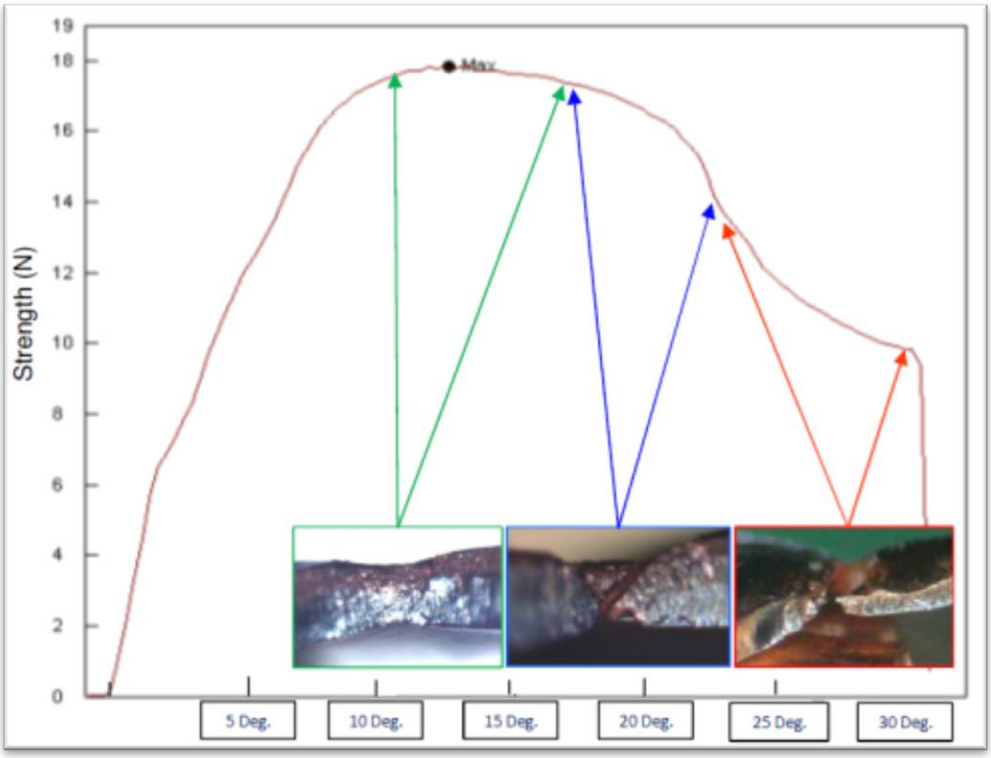
Test1 Preliminary Conclusions:

In all three samples, with different materials characteristics among them, cracking were visualized at angle range of 20 °. With this test Company acknowledges as well, for the first time, terminal cracking appearance definition angle range.



Picture 75 | Terminal cracking appearance definition angle range

A very interesting graphic is presented next for a visual understanding of the behavior of the terminal at different degrees of deformation.

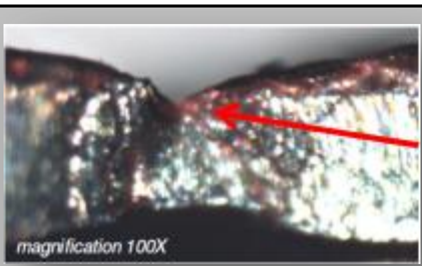
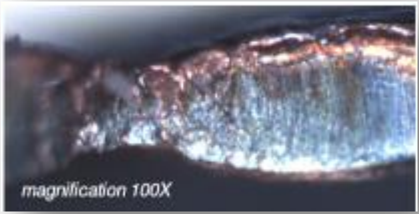


Graphic 20 | Behavior of the terminal at different degrees of deformation

Test2 | Confirmation of the terminal behavior in a specific angle (20 °) with a more representative sample group

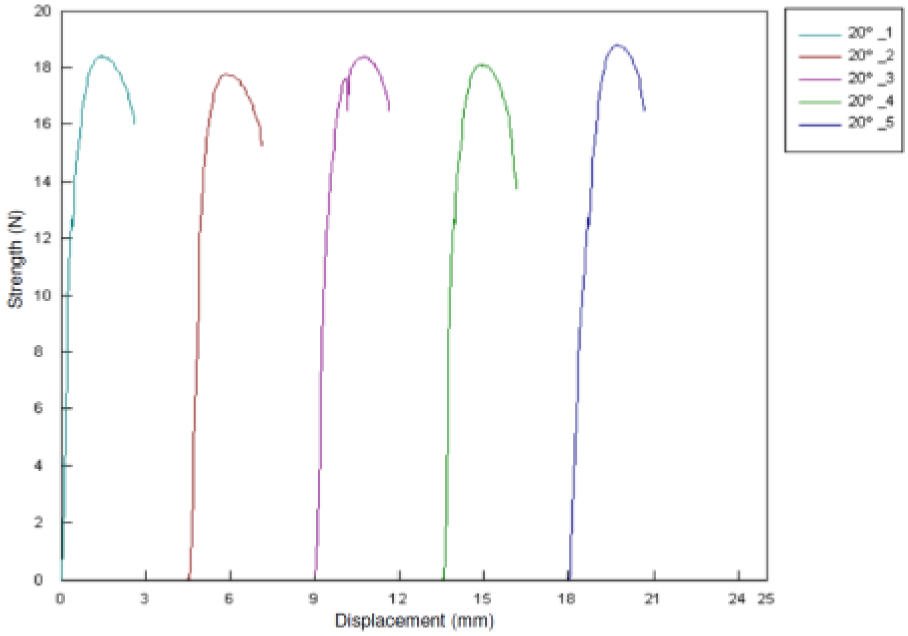
Crack analysis in 5 Terminal A samples after application of a bending angle of 20 °:

Table 40 | Test2 crack analysis in 5 Terminal A samples after application of a bending angle of 20 °

Sample	Wall Top View	Comments	Wall Side View
1		Crack *magnification 100X*	
2		Grooves *magnification 100X*	
3		Crack *magnification 100X*	
4		Crack *magnification 100X*	
5		Crack *magnification 100X*	

All 5 samples present fissuring initiation or cracking formation.

Graphic for the different bending loads on 5 Terminal A samples:



Graphic 21 | Test2 graphic for the different bending forces on 5 Terminal A samples

5 Terminal A samples bending loads measurements results to achieve 20 ° bending angle:

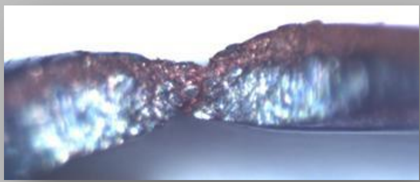
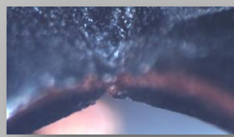
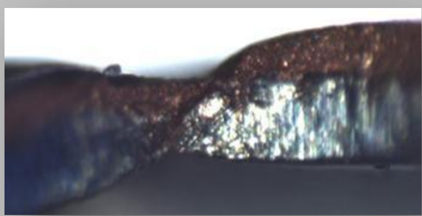
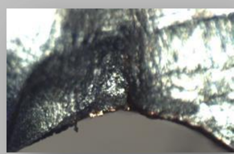
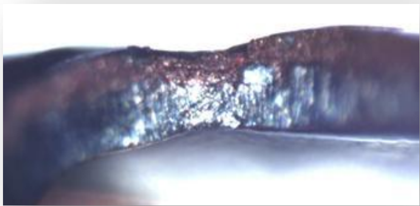
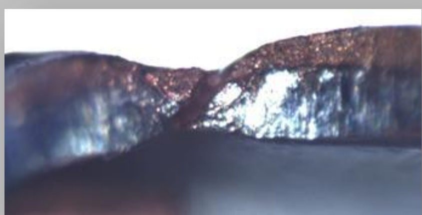
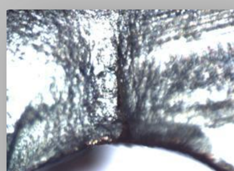
Table 41 | Test2 5 Terminal A samples bending loads measurements results to achieve 20 ° bending angle

Samples	Peak load results (N)	Average (N)
1	18,45	
2	17,83	
3	17,40	18,13
4	18,15	
5	18,83	

The average terminal strength to a bending load is 18,13 N, which means that is near to this value that the crack could appear when submitted to a load in the same conditions as mentioned above.

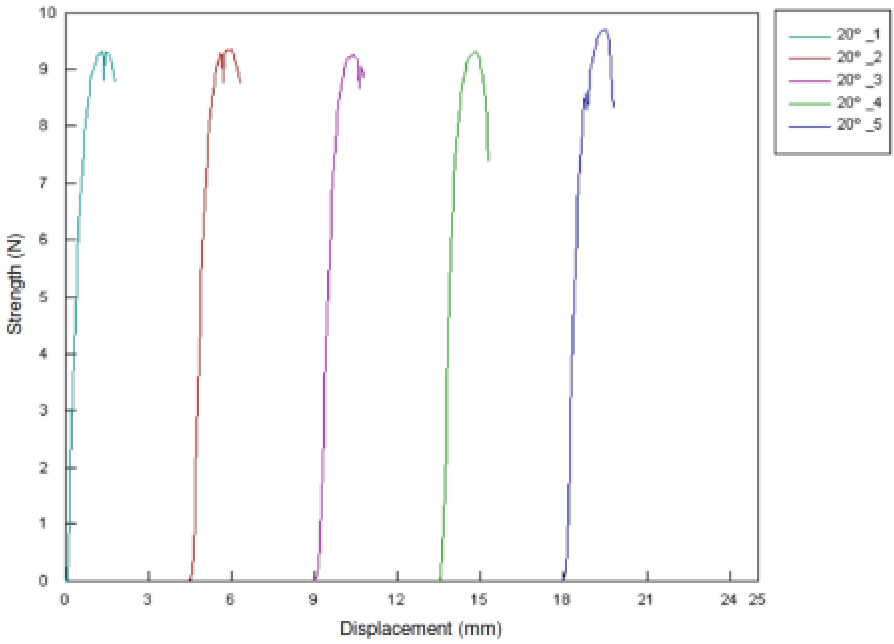
Crack analysis after applied a bend angle of 20 ° on the Terminal Ter2:

Table 42 | Test2 crack analysis after applied a bend angle of 20° on the Terminal Ter2

Sample	Wall Top View	Comments	Wall Side View
1		Crack *magnification 100X*	
2		Grooves *magnification 100X*	
3		Crack *magnification 100X*	
4		Grooves *magnification 100X*	
5		Crack *magnification 100X*	

All 5 samples present cracking initiation or cracking formation.

Graphic for the different bending loads on 5 Terminal Ter2 samples:



Graphic 22 | Test2 graphic for the different bending forces on 5 Terminal Ter2 samples

5 Terminal Ter2 samples bending loads measurements results to achieve 20 ° bending angle:

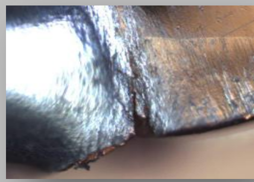
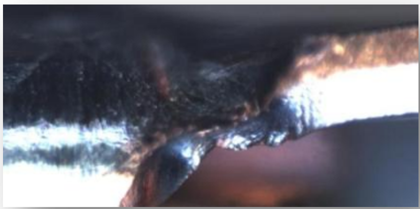
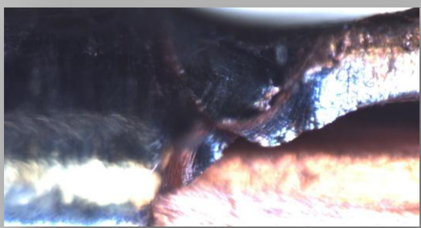
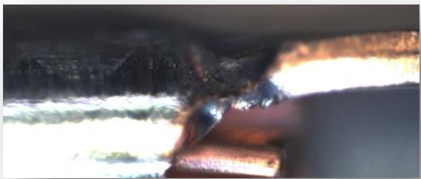
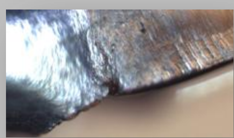
Table 43 | Test2 5 terminal Ter2 samples bending loads measurements results to achieve 20° bending angle

Samples	Peak load results (N)	Average (N)
1	9,32	
2	9,38	
3	9,27	9,40
4	9,32	
5	9,73	

The average terminal strength to a bending load is 9,40 N, which means that is near to this value that the crack could appear when submitted to a load in the same conditions as mentioned above.

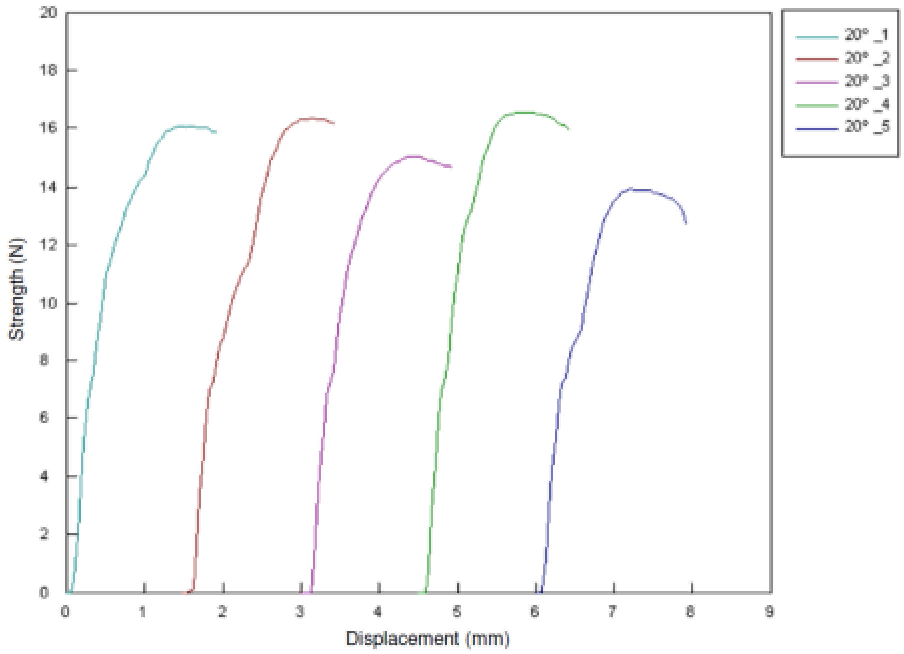
Crack analysis after applied a bend angle of 20° on the Terminal Ter3:

Table 44 | Test2 crack analysis after applied a bend angle of 20° on the Terminal Ter3

Sample	Wall Top View	Comments	Wall Side View
1		Crack *magnification* *100X*	
2		Crack *magnification* *100X*	
3		Crack *magnification* *100X*	
4		Crack *magnification* *100X*	
5		Crack *magnification* *100X*	

All 5 samples present cracking initiation or cracking formation.

Graphic for the different bending loads on 5 Terminal Ter3 samples:



Graphic 23 | Test2 graphic for the different bending forces on 5 Terminal Ter3 samples

5 Terminal Ter3 samples bending loads measurements results to achieve 20 ° bending angle:

Table 45 | Test2 5 terminal Ter3 samples bending loads measurements results to achieve 20° bending angle

Samples	Peak load results (N)	Average (N)
1	16,10	15,63
2	16,38	
3	15,07	
4	16,60	
5	13,98	

The average terminal strength to a bending load is 15,63 N, which means that is near to this value that the crack could appear when submitted to a load in the same conditions as mentioned above.

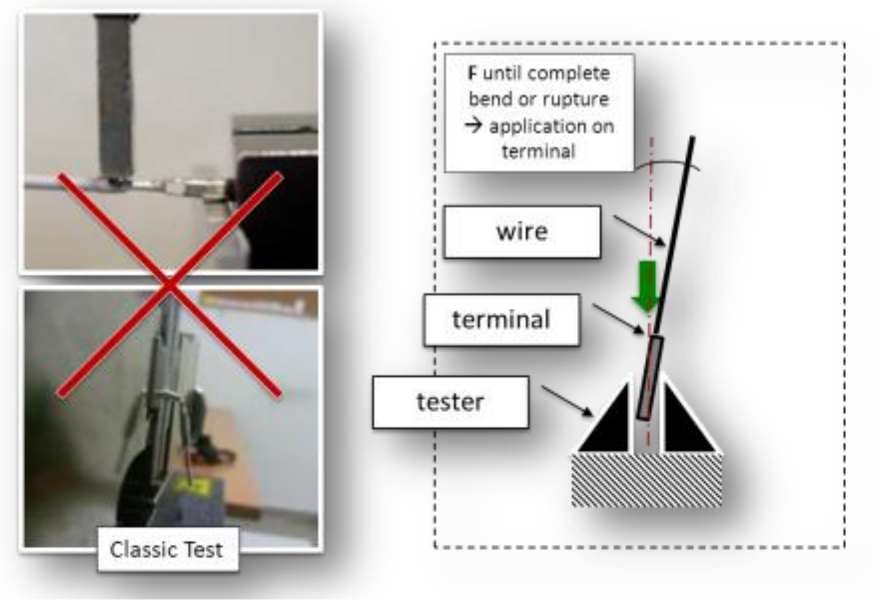
Test2 Preliminary Conclusions:

20 ° angle range is confirmed as cracking formation in all samples testing terminals, located in terminal design critical transition area.

Test A | Bend Test (BT): Check the necessary load to bend the terminal positioned at 20 °.

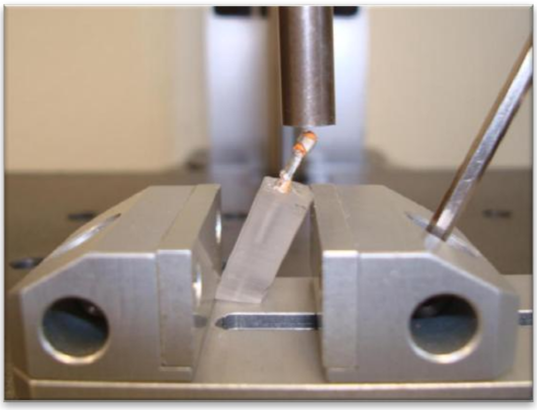
The previous tests should be faced mainly as preparation for the following Tests A and B. This Test A, was though and designed with propose of defect simulation by "wrong" insertion operation condition. Also as stated before, standard Customer specification tests are considered to not fully cover real shop-floor conditions.

Next picture on the right, demonstrate a classic test performance which allows analyzing the necessary load to bend the terminal. In a real shop-floor, applying a perpendicular load to the terminal body is not "natural" to happen, rather, the test conditions demonstrated on the picture on the left (Test A), applying load, not in a perpendicular direction, during a terminal insertion movement, which is performed "always" on this condition because is handmade. It worthy note, it is difficult to assure the reproducibility of this operation.
The direct load application on the body terminal back side was on propose because one of the real intents of this test A is to understand the real behavior of the terminal material (by bending). A real simulation terminal insertion movement was performed on test B, where the load is applied, as it is on real shop-floor condition, directly on the wire. To be check later on this document.



Picture 76 | TestA explanation schematic

Following picture demonstrate the real Test A conditions in Company internal laboratory environment.



Picture 77 | TestA holding jig

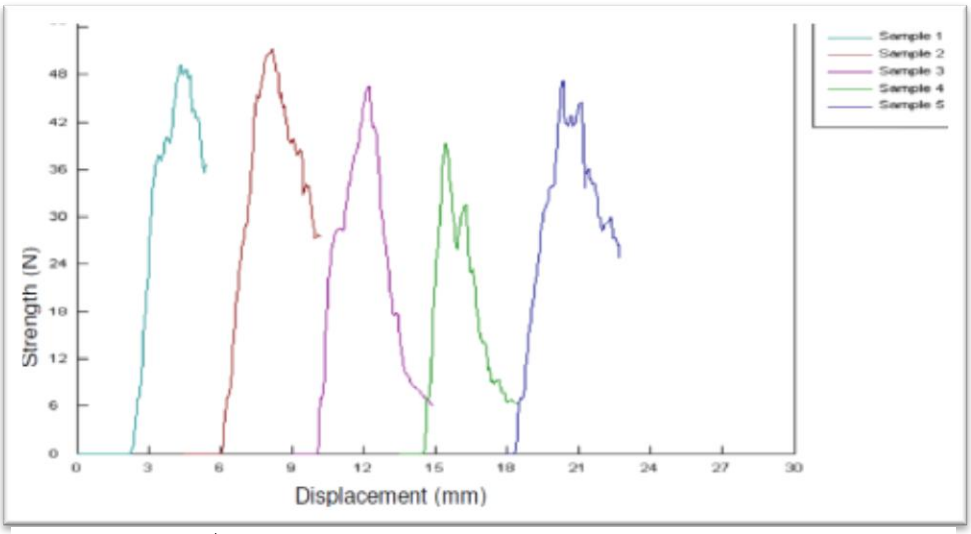
TestA preparation operations and conditions:

- 10 samples were prepared and hold by its head in epoxy resin;
- 5 at virgin condition state;
- 5 at changed state (terminal were 20 ° bent at Test1 conditions and turned back to its initial position);
- The epoxy bases were polished to a 20 ° +/-2 ° (maximum inclination defined angle for terminal insertion on the connector);
- Test motion speed: 8,3 x10^{-4} m/s (50 mm/min).

Note: 20 ° angle was used on this test because as verified on the Test1 and confirmed on Test2 cracks appear at this angle range.

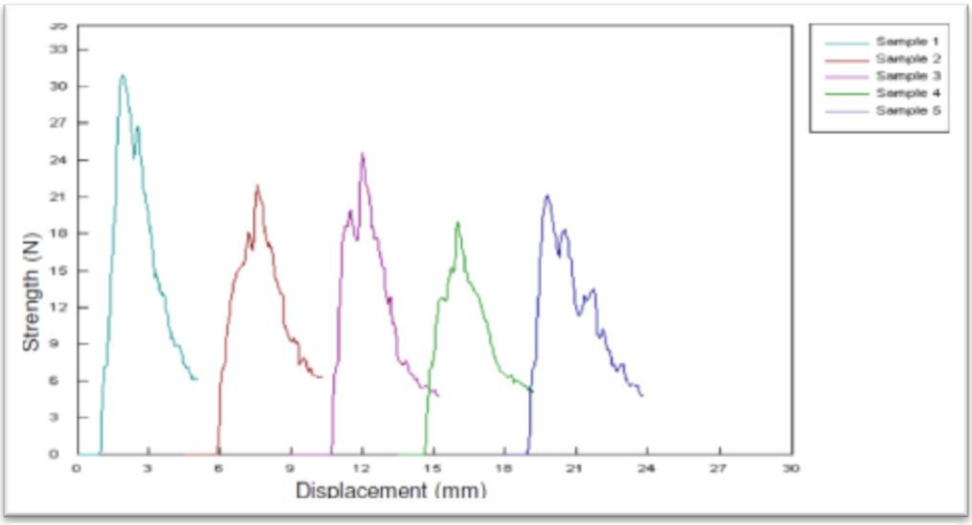
The Strength (N) versus Displacement (mm) graphics and Bending Load (N) tables are presented next.

Test A results for Terminal A - Terminal samples in virgin condition:



Graphic 24 | TestA results for Terminal A - Terminal samples in virgin condition

Test A results for Terminal A - Terminal samples in changed condition:



Graphic 25 | TestA results for Terminal A - Terminal samples in changed condition

Test A results for Terminal A - Bending Loads (N):

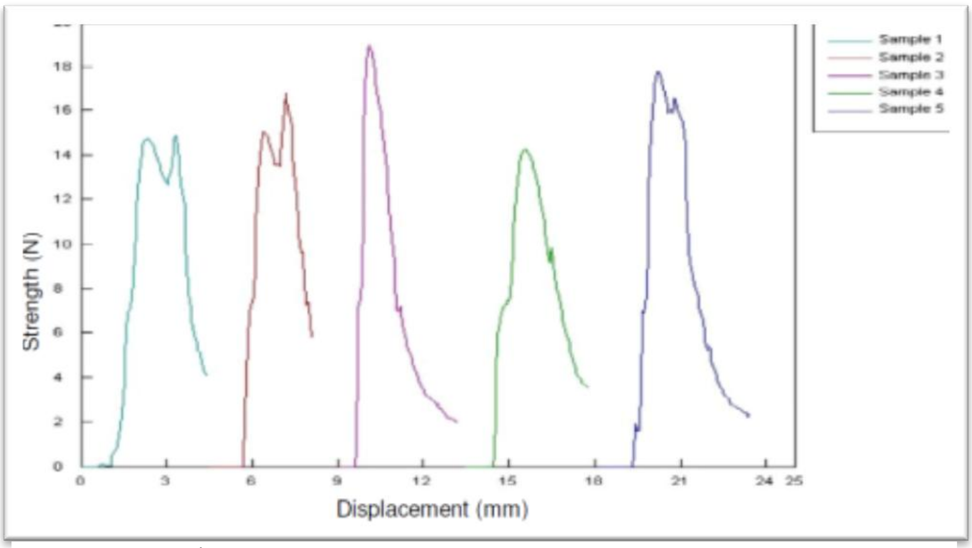
Table 46 | TestA results for Terminal A - Bending Loads (N)

Samples		1	2	3	4	5	Average (N)
Peak load results (N)	**Virgin**	49,38	51,45	46,63	39,40	47,23	46,85
	Changed	30,98	22,10	24,73	19,15	21,23	23,64

Test A | Terminal A samples Preliminary conclusions about Bending behavior:

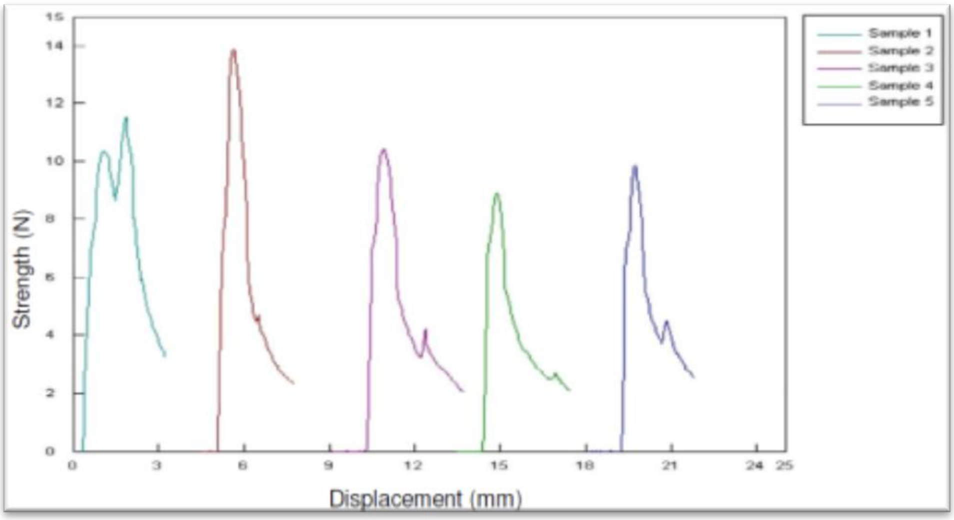
The terminals that were previously bent at 20 ° showed results around 50% of peak load lower than the others which represent a very important weakening, a real potential risk of terminal breaking.

Test A results for Terminal Ter2 - Terminal samples in virgin condition:



Graphic 26 | TestA results for Terminal Ter2 - Terminal samples in virgin condition

Test A results for Terminal Ter2 - Terminal samples in changed condition:



Graphic 27 | TestA results for Terminal Ter2 - Terminal samples in changed condition

Test A results for Terminal Ter2 - Bending Loads (N):

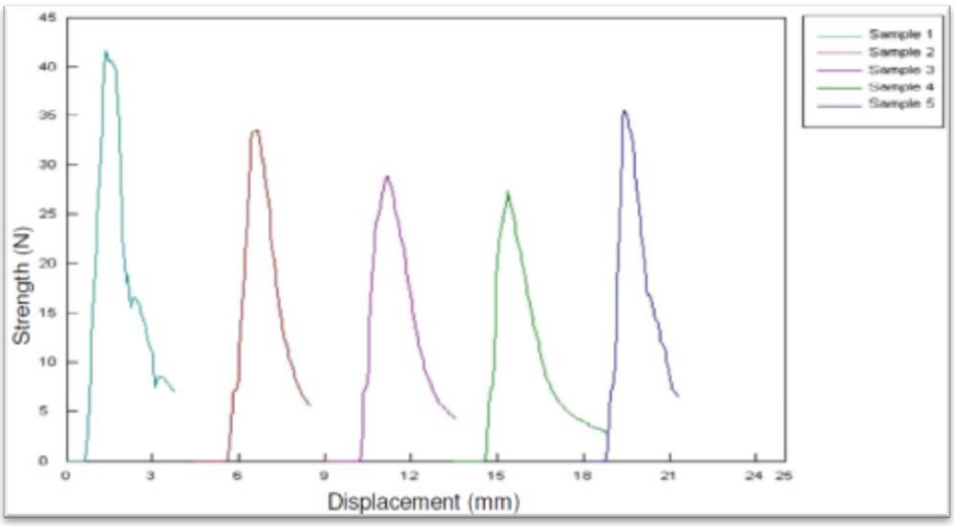
Table 47 | TestA results for Terminal Ter2 - Bending Loads (N)

Samples		1	2	3	4	5	Average (N)
Peak load results (N)	Initial	14,88	16,80	19,02	14,30	17,80	16,56
	Previously	11,55	13,93	10,45	8,95	9,90	10,96

Test A | Terminal Ter2 samples Preliminary conclusions about Bending behavior:

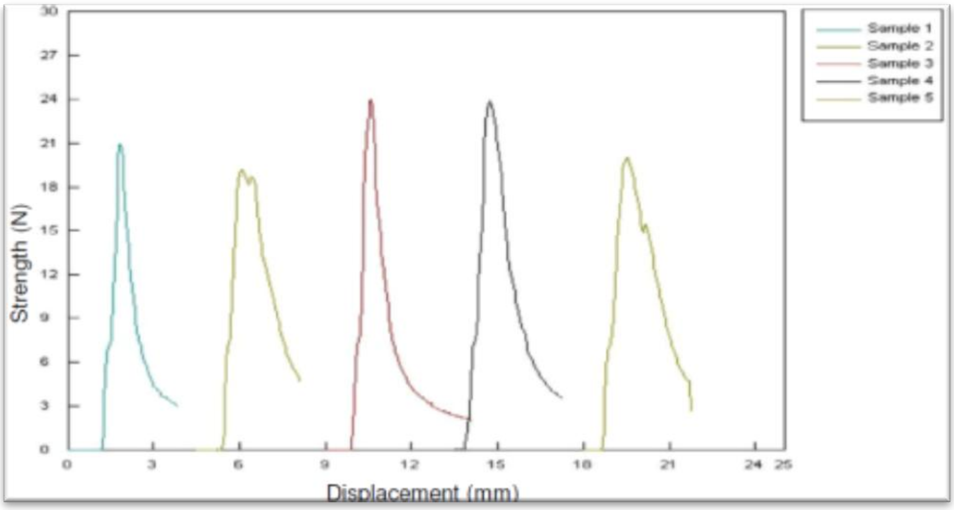
The terminals that were previously bent at 20 ° showed results around 34% of peak load lower than the others which represent a very important weakening, a real potential risk of terminal breaking.

Test A results for Terminal Ter3 - Terminal samples in virgin condition:



Graphic 28 | TestA results for Terminal Ter3 - Terminal samples in virgin condition

Test A results for Terminal Ter3 - Terminal samples in changed condition:



Graphic 29 | TestA results for Terminal Ter3 - Terminal samples in changed condition

Test A results for Terminal Ter3 - Bending Loads (N):

Table 48 | TestA results for Terminal Ter3 - Bending Loads (N)

Samples		1	2	3	4	5	Average (N)
Peak load results (N)	Virgin	41,63	33,55	28,90	27,48	35,60	33,43
	Changed	20,98	19,20	24,05	23,95	20,05	21,65

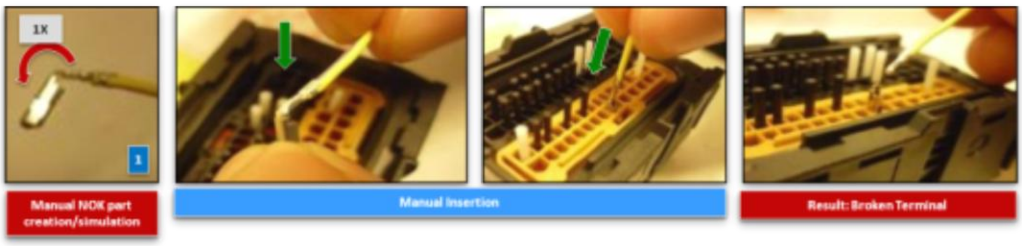
Test A | Terminal Ter3 samples Preliminary conclusions about Bending behavior:

The terminals that were previously bent at 20 ° showed results around 35% of peak load lower than the others which represent a very important weakening, a real potential risk of terminal breaking.

Test B | Push Test (PT): Terminal behavior when inserted in connector at different angles.

Once again, is just not possible to assure at 100% of the times that the insertion of the terminal into a connector is always performed in a "perfect" condition (90 ° angle).

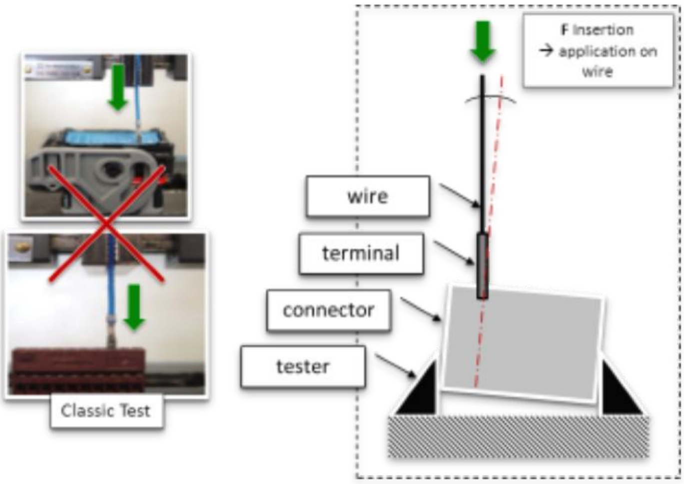
Handmade actions have a really high importance role on the wiring harness manufacturing process. So again, classic test methodology does not simulate exactly real situations.



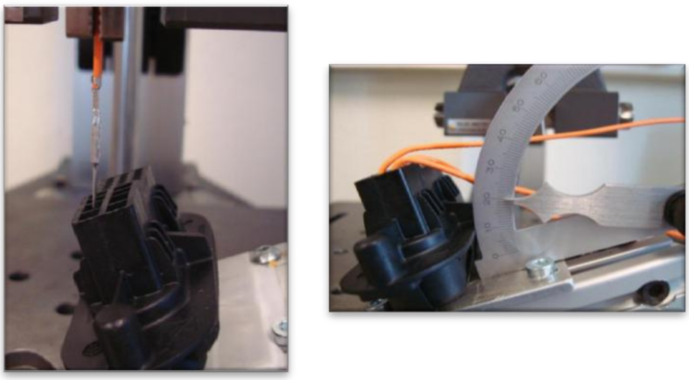
Picture 78 | TestB defect simulation

The previous pictures represent a real situation that was performed in one manufacturing plant. It is basically BROKEN terminal defect root-cause investigation. In a few words, terminal is manually bent, and then turned back to its original position. Next, this changed state terminal was inserted into the connector. During this movement, it became broken.

Test B was then though and design to simulate the terminal real insertion (load application on the wire) into a connector operation in the Company laboratory environment. The real intention on this test performance is to understand terminal's material behavior in different conditions.



Picture 79 | TestB simulation description



Picture 80 | TestB holding jig

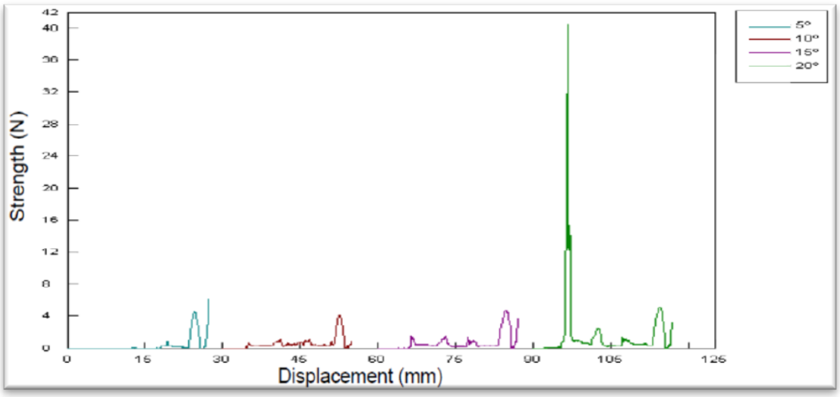
Test B preparation operations and conditions:

- Holding the connectors samples, in a base jig, according above picture;
- The connector holding jig inclination angle degree was measured with a goniometer;
- Starting the terminal, in virgin state, insertion operation with 5 ° jig inclination;
- If the terminal is inserted than a new sample is tested by incrementing the inclination angle in 5 ° until a defined limit of 20 °;
- Test motion speed: 8,3 x10^{-4} m/s (50 mm/min).

Note: 20 ° angle was used as limit on this test because as verified on the Test1 and confirmed on Test2 cracks appear at this angle range.

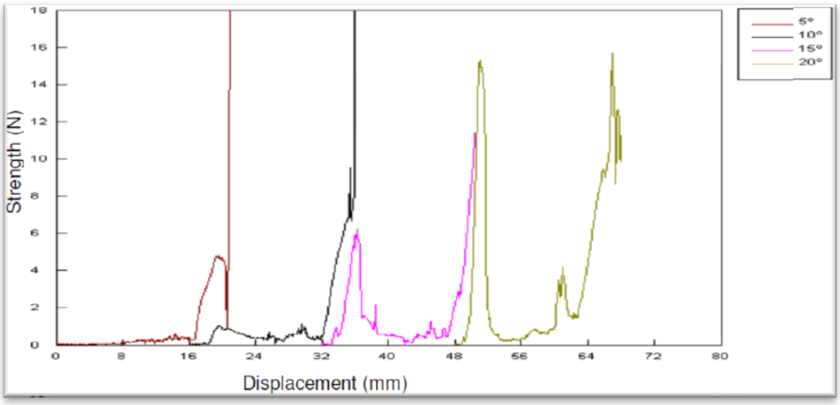
The Strength (N) versus Displacement (mm) graphics and Insertion Loads (N) table are presented next.

Test B graphic for Terminal A – Terminal samples inserted at different inclination angles:



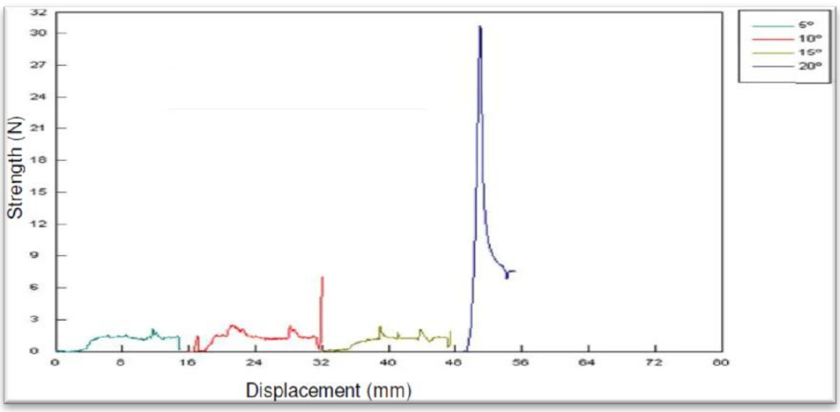
Graphic 30 | TestB results for Terminal A samples inserted at different inclination angles

Test B graphic for Terminal Ter2 – Terminal samples inserted at different inclination angles:



Graphic 31 | TestB results for Terminal Ter2 samples inserted at different inclination angles

Test B graphic for Terminal Ter3 – Terminal samples inserted at different inclination angles:



Graphic 32 | TestB results for Terminal Ter3 samples inserted at different inclination angles

Test B results for all terminal samples insertion loads (N):

Table 49 | TestB results for terminal insertion loads

Peak load results (N)					
Degrees		**5°**	**10°**	**15°**	**20°**
Samples	**Terminal A**	4,55	4,22	4,82	40,53
	Ter2	2,22	2,53	2,40	30,77
	Ter3	0,63	1,08	6,25	15,27

Test B | Preliminary Conclusions:

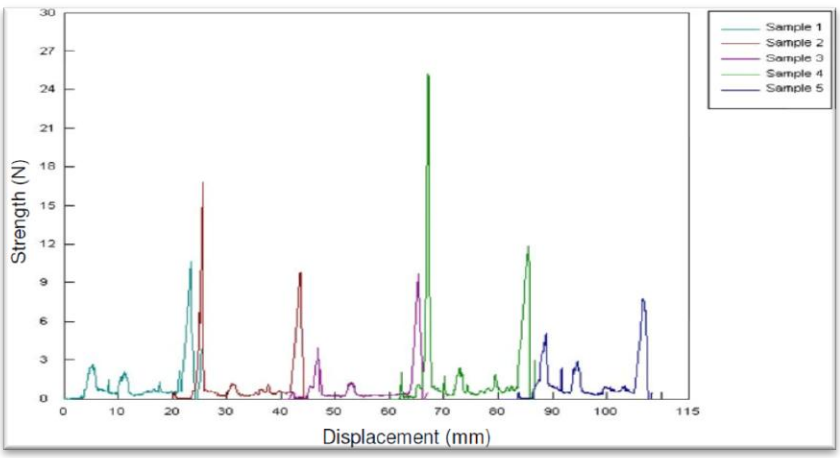
Insertion loads applied in terminals at 20 ° angle represent a real potential risk of terminal breaking. Terminal A insertion load at 20 ° is almost 9x higher than the average of the previous three defined angles degrees. Ter2 is almost 13x higher and Tre3 is almost 6x higher. 20 ° test results highlighted in **RED** color because of their importance.

Test 5 | Push Test (PT): Terminal behavior when inserted in connector at 20 °.

The Test 5 is an extension of the Test B, the difference is on the terminals samples preparation. Main objective of this test is to compared and analyze the terminal behavior difference in variation preparations status. Test 5 preparation operations and conditions:

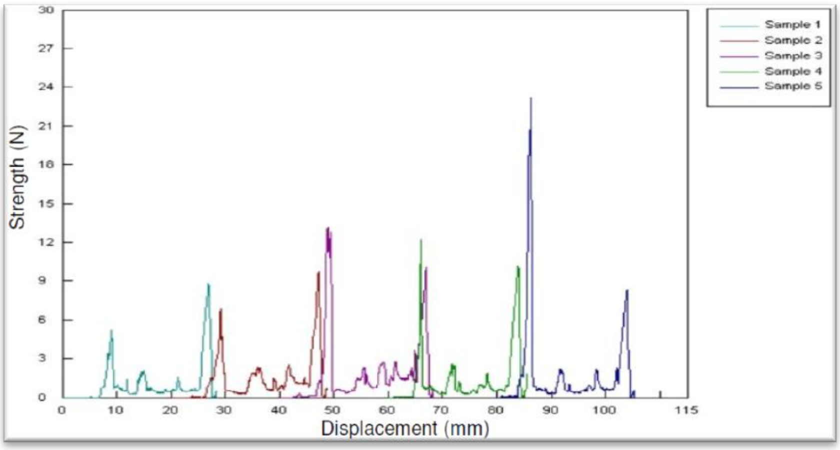
- Test B operations and conditions;
- 5 samples at virgin condition state;
- 5 samples at changed state (terminal were 20 ° bent at Test1 conditions and turned back to its initial position);
- Test motion speed: 8,3 x10^{-4} m/s (50 mm/min).

The Strength (N) versus Displacement (mm) graphics and Bending Load (N) tables are presented next. **Test 5 results for Terminal A** - Terminal samples in virgin condition:



Graphic 33 | Test5 results for Terminal A - Terminal samples in virgin condition

Test 5 results for Terminal A - Terminal samples in changed condition:



Graphic 34 | Test5 results for Terminal A - Terminal samples in changed condition

Test 5 results for Terminal A - Insertion Loads (N):

Table 50 | Test5 results for Terminal A insertion loads

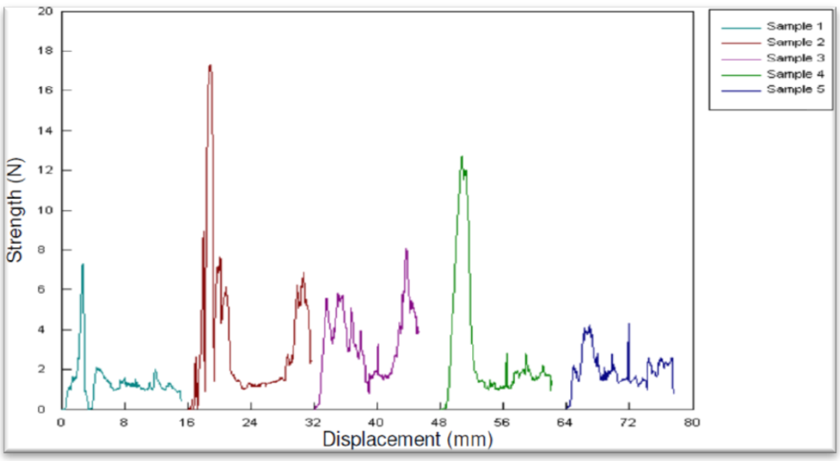
Samples		1	2	3	4	5	Average (N)
Peak load results (N)	**Virgin**	10,75	16,88	9,70	25,33	7,85	14,10
	Changed	8,88	9,82	13,18	12,27	23,23	13,48

Test 5 | Terminal A samples Preliminary Conclusions:

Similar average peak load values between both terminals preparations (virgin / changed).

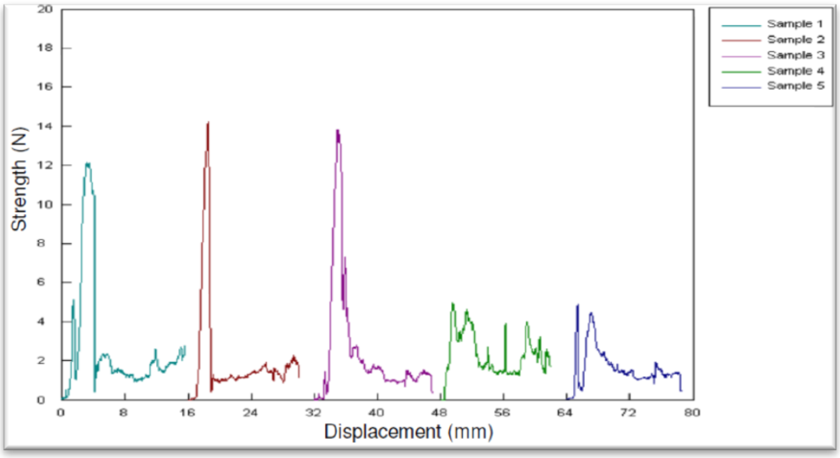
Is worthy note, for the terminals that were previously bent at 20 °, any deformation was detected during the terminal insertion.

Test 5 results for Terminal Ter2 - Terminal samples in virgin condition:



Graphic 35 | Test5 results for Terminal Ter2 samples in virgin condition

Test 5 results for Terminal Ter2 - Terminal samples in changed condition:



Graphic 36 | Test5 results for Terminal Ter2 samples in changed condition

Test 5 results for Terminal Ter2 - Insertion Loads (N):

Table 51 | Test5 results for Terminal Ter2 insertion loads

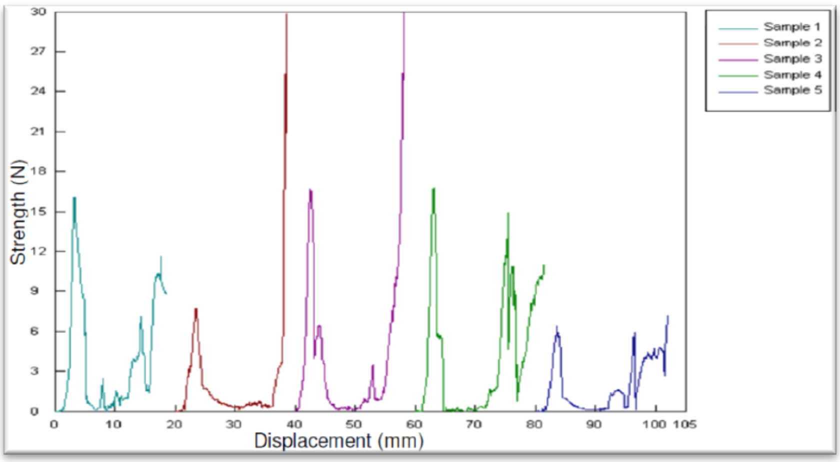
Samples		1	2	3	4	5	Average (N)
Peak load results (N)	Virgin	7,35	17,35	8,15	12,75	4,35	9,99
	Changed	12,20	14,27	13,85	5,03	4,95	10,06

Test 5 | Terminal Ter2 samples Preliminary Conclusions:

Similar average peak load values between both terminals preparations (virgin / changed).

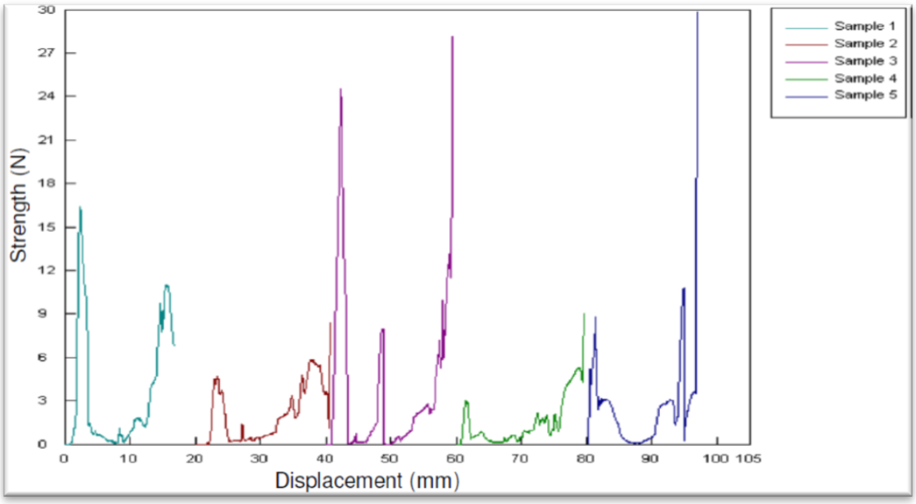
Is worthy note, for the terminals that were previously bent at 20 °, any deformation was detected during the terminal insertion.

Test 5 results for Terminal Ter3 - Terminal samples in virgin condition:



Graphic 37 | Test5 results for Terminal Ter3 samples in virgin condition

Test 5 results for Terminal Ter3 - Terminal samples in changed condition:



Graphic 38 | Test5 results for Terminal Ter3 samples in changed condition

Test 5 results for Terminal Ter3 - Insertion Loads (N):

Table 52 | Test5 results for Terminal Ter3 insertion loads

Samples		1	2	3	4	5	Average (N)
Peak load results (N)	**Virgin**	16,10	25,4	25,42	16,77	6,45	18,03
	Changed	16,42	5,90	24,58	5,35	10,88	12,58

Test 5 | Terminal Ter3 samples Preliminary Conclusions:

Similar average peak load values between both terminals preparations (virgin / changed).

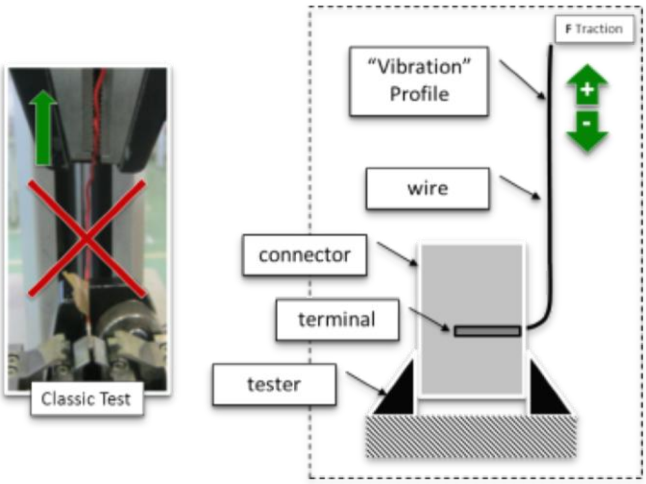
Is worthy note, for the terminals that were previously bent at 20 °, any deformation was detected during the terminal insertion.

Test C | Pull load Test (PT): Check terminal behavior when submitted to a systemic tension

This was the third test designed with one specific propose, to simulate real assembly operations, in a laboratory environment, that cause oscillation movements on the terminals by the pull and push loads produced. Following pictures demonstrate another terminal defect root-cause investigation in one of Company manufacturing plants. Resuming, terminal sample was manually bent (1) and then turned back to its original position (2), then inserted in a 90 ° wire angle connector (3) and (4). Wires were stretched (5) and protection was add (6) and (7). During all operations were performed causing oscillation movements and inherent pull and push loads. Wiring Harness was electrically tested and considered OK (8). At the end the terminal was dissembled and found BROKEN.

Picture 81 | TestC defect simulation

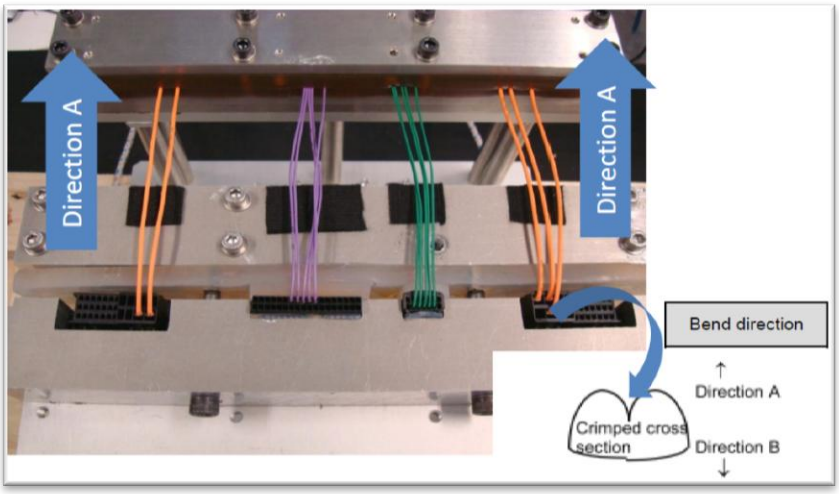
Standard pull load test determinate the terminal/wire combinations pull load value. This classic test is mainly used to validate the terminal crimping machine/applicator setup at each daily/shift manufacturing start up. Test C methodology as a different goal.



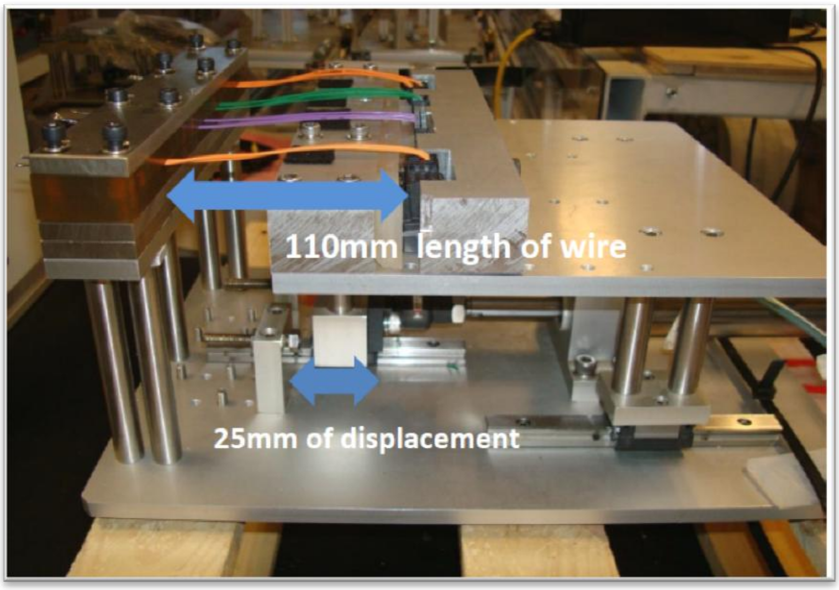
Picture 82 | TestC explanation schematic

Conditions and operations for Test C preparation:

- 10 samples were tested per connector;
- 5 samples in virgin state;
- 5 samples in changed state (prepared respecting Test1 conditions);
- Tests performed according samples different conditions;
- Total 10 000 cycles, at 4 Hz of frequency;
- Total displacement of 25 mm;
- Each terminal sample have 110 mm of wire length;
- Continue monitoring for each terminal and data acquisition at a frequency of 1 Hz;
- Wires push/pull load application in the crimping direction (terminal orientation inside the connector).

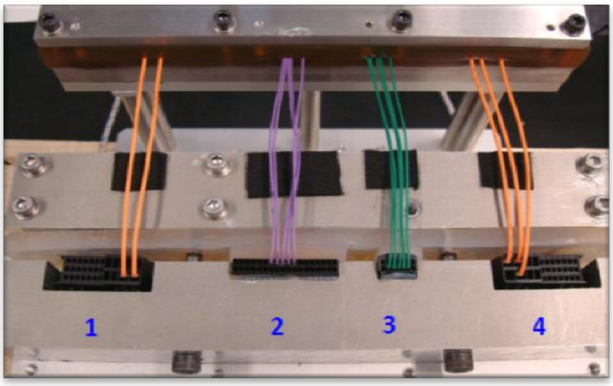


Picture 83 | TestC test jig movement sense explanation



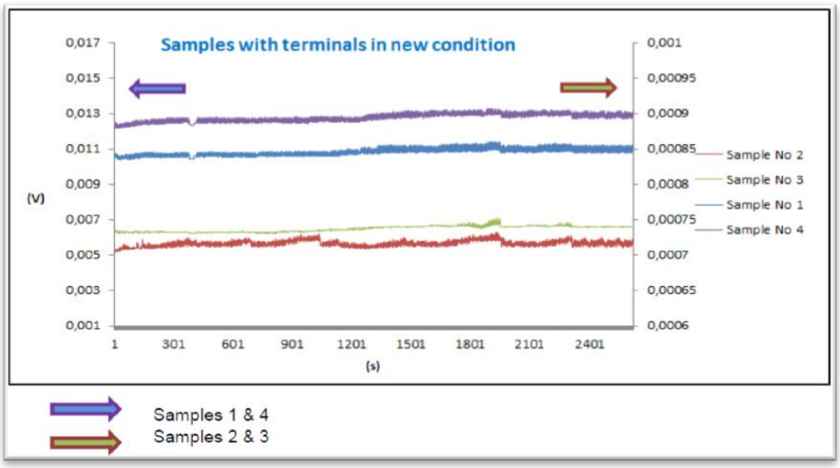
Picture 84 | TestC test jig movements distances explanation

Testing Samples Identification:



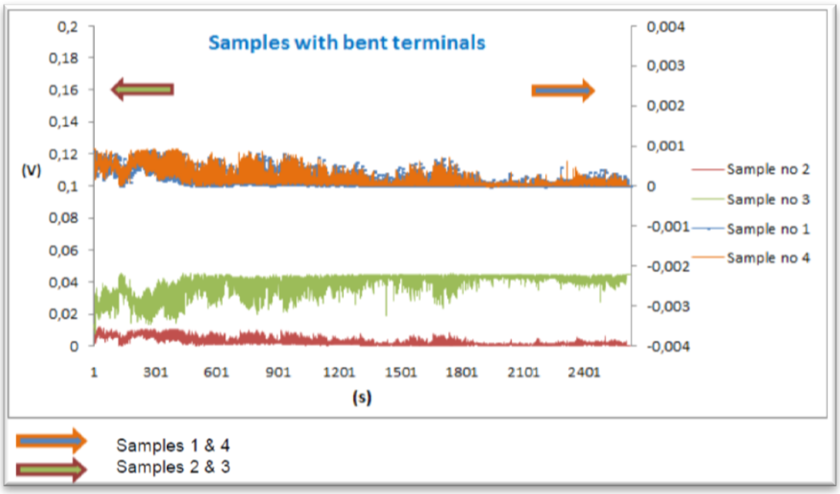
Picture 85 | TestC test samples identification

Test C results - Terminal samples in virgin condition:



Graphic 39 | TestC results terminal samples in virgin condition

Test C results - Terminal samples in changed condition:



Graphic 40 | TestC results terminal samples in changed condition

Test C | Preliminary Conclusions:

For both terminals states, no continuity loss was detected during testing. After the test ending, terminals were removed and visual inspection was done. No broken terminals were detected.

It is concluded that terminals, even the most fragile ones after the 20° bent operation, do not become broken during a strong wire oscillation movement (terminal moves inside the connector cavity), this suggests that terminals breakage happens during insertion on the connector at an inclination angle equal or higher than 20 ° degrees and also that in real shop-floor, most probably terminals bending operation doesn’t happen exactly as Test 1 defined conditions, bending movements should be more than just 1x and/or bending angle should be higher.

Test C contributes with a good approach of what is inducing a terminal breakage, but not the complete picture. It's necessary more research, per example, to define exactly the critical bend angle. In order to do that, hereunder is presented a proposal for future tests:

- Microscope analysis to verify crack area of bent terminals used in pull load test;
- Measure necessary load to bend the terminals with a crack from 20° to 90° (10° steps);
- Measure the load of terminals previously bent (from 20 ° to 90 °) and then re-submit to pull load test- Submit bent terminals from 20 ° to 90 ° with steps of 10 ° to a pull load test with connectors positioned in axis (extreme test conditions);

Notes:

- Presented jig was completely developed specifically for this Test C methodology;

Now available at Company Laboratory for future test performances;

- Is worthy note, this jig is completely adaptable for other kind of components testing.

Destructive Testing (DT) – Test Results and Conclusions Overview

Test 1

Table 53 | Test1 results overview

Terminal	Crack Initiation Result Deformation angle degree range					
	35°	**30°**	**25°**	**20°**	**15°**	**10°**
A	Y	Y	Y	Y	N	N
Ter2	Y	Y	Y	Y	N	N
Ter3	Y	Y	Y	Y	N	N

Note: **Y** = Yes (Crack was initiated); **N**=No (Crack was not initiated)

When applied a bend load to promote an angle of 20 °, occurs the loss of the terminal mechanical resistance due to crack initiation in the terminal design transition critical area.

Test 2

Table 54 | Test2 results overview

Terminal	Average results of bend (N)
A	18,30
Ter2	9,40
Ter3	15,63

The terminal Ter2 is significantly less resistant than the other two terminals.

Test A

Table 55 | TestA results overview

Terminal	Peak load (average) results (N)		Loss of terminal resistance (%)
	Virgin	Change	
A	46,85	23,64	50,00
Ter2	16,56	10,96	34,00
Ter3	33,43	21,65	35,00

The terminals that were previously bent at 20 ° showed losses of resistance higher than 34%.

Test B

Table 56 | TestB results overview

		Peak load result (N)			
Degrees		**5°**	**10°**	**15°**	**20°**
Samples	**A**	4,55	4,22	4,82	40,53
	Ter2	2,22	2,53	2,40	30,77
	Ter3	0,63	1,08	6,25	15,27

After the connector was positioned at 20 ° degrees, was discovered that is very difficult to insert the terminal on the correspondent cavity.

Test 5

Table 57 | Test5 results overview

Terminal	Peak load (average) results (N)	
	Virgin	**Changed**
A	14,10	13,48
Ter2	9,99	10,06
Ter3	18,03	12,63

The peak load during the insertion of terminals occurred during the first phase of insertion (connector entrance) although no major difference was detected between terminal different states on these test conditions.

Test C

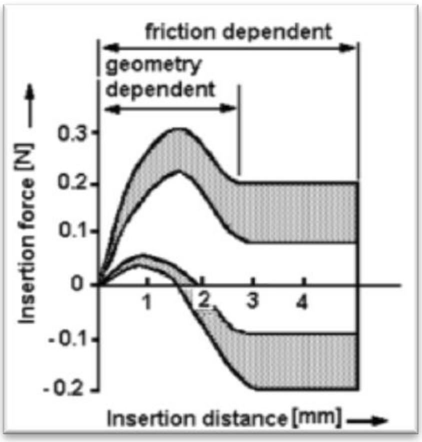
Terminals at different stats do not become broken during a strong wire oscillation movement.

Destructive Testing (DT) – Generic Conclusions

There exist no well-defined limits for parameters like load, stress, plating thickness, roughness and number of mating cycles because the validity of all the results of research experiments is limited and the experimentation and interpretation of the results can be very complex.

The maximum insertion load is dependent in two important factors, see below picture[35]:

- The geometry of terminal head and connector cavity entry shape and its nominal / tolerances dimensions;
- The friction coefficient between terminal cooper alloy surface and connector plastic cavity surfaces.

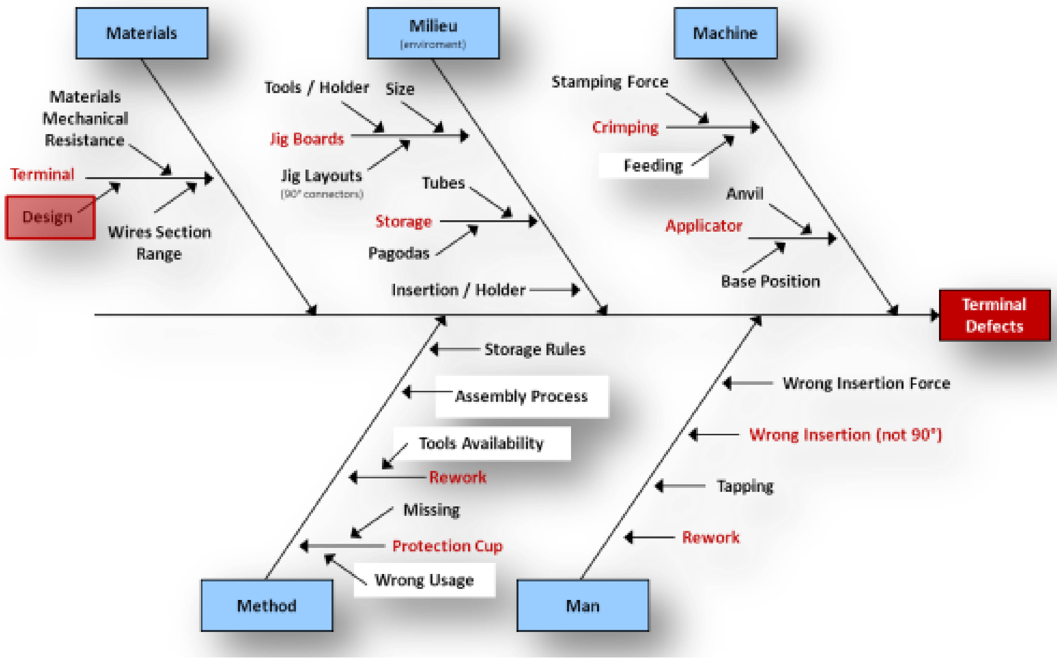


Picture 86 | Terminal's insertion force versus insertion distance

Both factors need to be in tight control in order to keep the insertion load within its design limits. This explains as well the different values (registered among 3 terminals at TestB) between TestB and Test5.

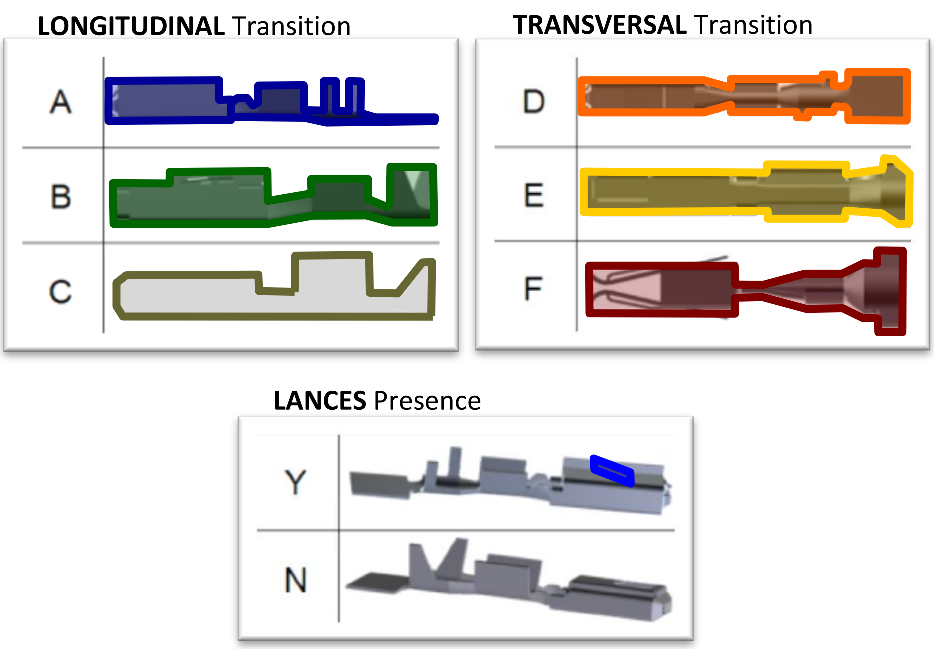
[35] [16] Piet van Dijk, "Critical Aspects of Electrical Connector Contacts", Abstract, Netherlands, 2002

When information is available, what is needed to be done is work it in order accomplishes, as much as possible, our goals. Keeping that in mind, **Terminal Design** analysis (VI), was done following a very empirical way: the main rule that was imposed on this methodology was to establish a terminal design family's classification according to their unique characteristics.



Picture 87 | Terminals Defects Root-causes Ishikawa diagram, Material field highlighted

The main objective of this analysis is making possible to understand its relation/influence on the current BROKEN Terminal defects in analysis. Terminals transitions were categorized:



Picture 88 | Terminals transitions categories

Terminal References List establishment

On the defined monitored period, total terminal defects complaints were 184. 67 of those were related to BROKEN kind (crimping area and middle body) and the others DAMAGE kind. 64 complaints were directly related to crimping area broken location, which means 25 terminal different references (in order to know the terminal reference connect with each complaint was established contact with all Company European manufacturing plants quality leaders. 3 didn't answer, meaning, the investigation continue considering 61 complaints, from this moment). From the 25 terminal identified references (25 -1 = for one of them was no possible to find information), all technical information was collected for a total occurrence frequency of 54 different terminals were categorized (should be 54 total amount of real broken terminals but in the end 53 were counted because no technical information available for one of them). Most important, this list can be considered as the **sensitive terminals list**, to which all Company European plants need to avoid of apply extra attention to. Hereunder the list, terminals presented without some confidential information and already categorized:

Table 58 | Sensitive terminals list

Reference	Qty detected	Material	Name	Lances	Longitudinal	Transversal
X	7	CuNi1Si	MQS	Y	A	E
X	6	CuNi1Si	MQS	Y	A	D
X	5	CuNiSn	0,64 II	N	B	D
X	5	CuNi1Si	MQS	Y	A	D
Terminal A	5	CuSn 0,1	SICMA 3	N	C	D
X	4	CuSn 0,15	MCP 1,2 LL	Y	B	D
X	2	CuNiSn	1,5	N	B	D
X	2	CuNi1Si	0,64 III	N	C	D
X	2	CuNi1Si	MQS	Y	A	E
Terminal B	2	CuFe 2P	SICMA 3+	N	A	F
X	1	CuNi1Si	MQS	N	A	D
X	1	CuNi1Si	clean body	N	A	E
X	1	CuNi1Si	RH 0.64mm	Y	B	E
X	1	CuZn 15	SICMA 2,8	N	B	D
X	1	CuFe 2P	SICMA 2,8	N	B	D
X	1	CuNi1Si	MQS	Y	A	E
X	1	CuNi1Si	MQS	Y	A	E
X	1	CuNi1Si	unsealed	N	C	D
X	1	CuSn	CTX150	N	C	E
X	1	CuNi1Si	MCP 2,8	N	A	F
X	1	CuFe 2P	Power Timer 2	Y	B	F
X	1	CuNi	Micro Timer 2	Y	A	F
X	1	CuSn	1,5 System	N	C	D

From this step forward, individual analyses were performed centered in terminal categorized and defect's detection frequency. Terminals were grouped by Name and/or Material for simplification of next tables.

1st analyses | Classification was verified and judged under the terminology:

HIGH is RED, MEDIUM is **ORANGE** and LOW is PINK.

Objective: Terminals transitions, kind and material were classified, from higher to low, in quantity detected importance basis.

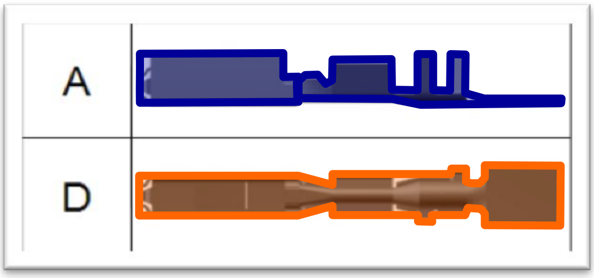
Table 59 | 1st Analyses terminals transitions, kind and material classification

	Name	Material	Lances	Longitudinal	Transversal	Qty detected
1	MQS	CuNiSi	Y	A	D	11
			Y	A	E	11
			N	A	D	1
2	SICMA 3	CuFe	N	B	D	1
		CuSn	N	C	D	5
		CuZn	N	B	D	1
3	0,64 II	CuNiSn	N	B	D	5
4	MCP	CuSn	Y	B	D	4
		CuNiSi	N	A	F	1
5	1,5	CuSn	N	C	D	1
		CuNiSn	N	B	D	2
6	0,64 III	CuNiSi	N	C	D	2
7	SICMA 3+	CuFe	N	A	F	2
8	Clean Body	CuNiSi	N	A	E	1
9	RH 0,64	CuNiSi	Y	B	E	1
10	Unsealed	CuNiSi	N	C	D	1
11	CTX150	CuSn	N	C	E	1
12	Power Timer	CuFe	Y	B	F	1
13	Micro Timer	CuNiSi	Y	A	F	1
					Total	53

1st Preliminary Result:

It was identified the terminal that represent higher potential risk of breakage are "A" and "D" individual transitions, CuNiSi material and MQS kind.

Transitions
HIGHER RISK OF BREACKAGE



Terminal Kind: **MQS**
Terminal Material: **CuNiSi**

Picture 89 | 1st design preliminary result

2^{nd} analyses | Classification was verified and judged under the terminology:

HIGH is **RED**, MEDIUM is **ORANGE** and LOW is **PINK**.

Objective: Terminals transitions, kind and material were classified, from higher to low, in quantity detected importance basis and additionally Y & N = with and without lances.

Table 60 | 2^{nd} Analyses terminals design transitions, kind and material classification tables

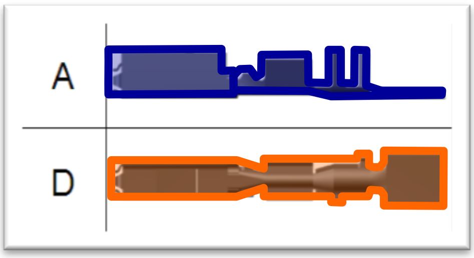
Longitudinal	A	B	C	
CuNiSi	27	1	2	30
CuNiSn	0	7	0	7
CuSn	0	4	7	11
CuFe	2	2	0	4
CuZn	0	1	0	1
	29	15	9	53

Transversal	D	E	F	
CuNiSi	15	13	2	30
CuNiSn	7	0	0	7
CuSn	10	1	0	11
CuFe	1	0	3	4
CuZn	1	0	0	1
	34	14	5	53

Y & N	AD	AE	AF	BD	BE	BF	CD	CE	CF	
CuNiSi	12	12	2	0	1	0	3	0	0	30
CuNiSn	0	0	0	7	0	0	0	0	0	7
CuSn	0	0	0	4	0	0	6	1	0	11
CuFe	0	0	2	1	0	1	0	0	0	4
CuZn	0	0	0	1	0	0	0	0	0	1
	12	12	4	13	1	1	9	1	0	53

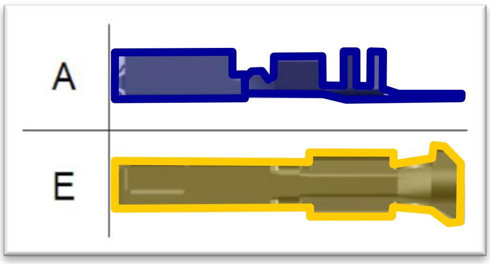
2^{nd} Preliminary Result:

Transitions
HIGHER RISK OF BREACKAGE



Terminal Lances: **Yes & No**
Terminal Body Material: **CuNiSi**

Combination
HIGHER RISK OF BREACKAGE



Terminal Lances: **Yes & No**
Terminal Body Material: **CuNiSi**

Picture 90 | 2^{nd} design preliminary result

It was identified the terminal that represents higher potential risk of breakage are “A” and “D” individual transitions, A and E combination transitions, CuNiSi material.

3rd analyses | Classification was verified and judged under the terminology:

HIGH is **RED**, MEDIUM is **ORANGE** and LOW is **PINK**.

Objective: Terminals transitions, kind and material were classified, from higher to lower, in quantity detected importance basis and additionally only with lances.

Table 61 | 3rd Analysis terminals design transitions, kind and material classification tables

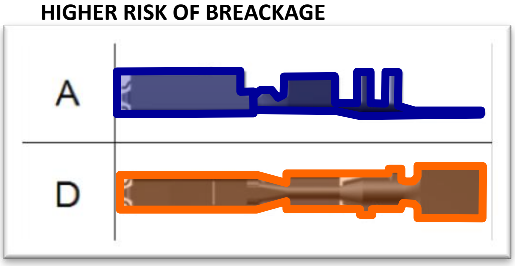
Y	A	B	C	
CuNiSi	23	1	0	24
CuNiSn	0	0	0	0
CuSn	0	4	0	4
CuFe	0	1	0	1
CuZn	0	0	0	0
	23	6	0	29

Y	D	E	F	
CuNiSi	11	12	1	24
CuNiSn	0	0	0	0
CuSn	4	0	0	4
CuFe	0	0	1	1
CuZn	0	0	0	0
	15	12	2	29

Y	AD	AE	AF	BD	BE	BF	CD	CE	CF	
CuNiSi	11	11	1	0	1	0	0	0	0	24
CuNiSn	0	0	0	0	0	0	0	0	0	0
CuSn	0	0	0	4	0	0	0	0	0	4
CuFe	0	0	0	0	0	1	0	0	0	1
CuZn	0	0	0	0	0	0	0	0	0	0
	11	11	1	4	1	1	0	0	0	29

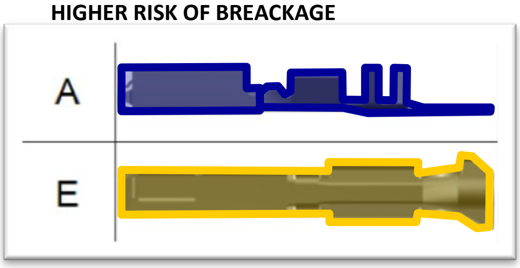
3rd preliminary result:

Transitions
HIGHER RISK OF BREACKAGE



Terminal Lances: **Yes**
Terminal Material: **CuNiSi**

Combination
HIGHER RISK OF BREACKAGE



Terminal Lances: **Yes**
Terminal Material: **CuNiSi**

Picture 91 | 3rd design preliminary results

It was identified the terminal that represent higher potential risk of breakage are “A” and “D” individual transitions, A and E combination transitions, CuNiSi material with Lances.

4th analyses | Classification was verified and judged under the terminology:

HIGH is **RED**, MEDIUM is **ORANGE** and LOW is PINK.

Objective: Terminals transitions, kind and material were classified, from higher to low, in quantity detected importance basis and additionally only without lances.

Table 62 | 4th analyses Terminals design transitions, kind and material classification tables

N	A	B	C	
CuNiSi	3	0	3	6
CuNiSn	0	7	0	7
CuSn	0	0	7	7
CuFe	2	1	0	3
CuZn	0	1	0	1
	5	9	10	24

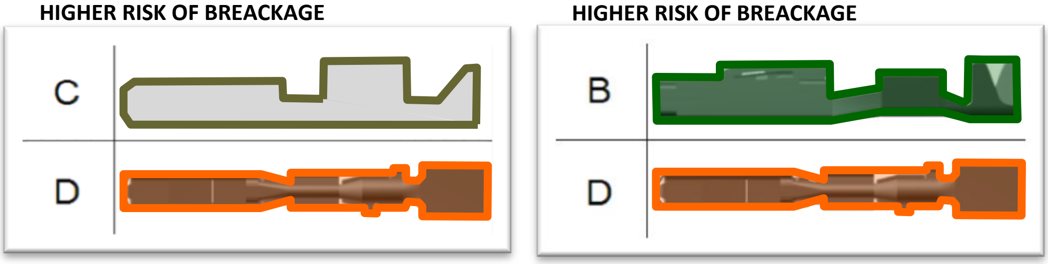
N	D	E	F	
CuNiSi	4	1	1	6
CuNiSn	7	0	0	7
CuSn	6	1	0	7
CuFe	1	0	2	3
CuZn	1	0	0	1
	19	2	3	24

N	AD	AE	AF	BD	BE	BF	CD	CE	CF	
CuNiSi	1	1	1		0	0	3	0	0	6
CuNiSn	0	0	0	7	0	0	0	0	0	7
CuSn	0	0	0	0	0	0	6	1	0	7
CuFe	0	0	2	1	0	0	0	0	0	3
CuZn	0	0	0	1	0	0	0	0	0	1
	1	1	3	9	0	0	9	1	0	24

4th Preliminary Result:

Transitions
HIGHER RISK OF BREACKAGE

Combination
HIGHER RISK OF BREACKAGE



Terminal Lances: **No**
Terminal Material: **CuNiSn**

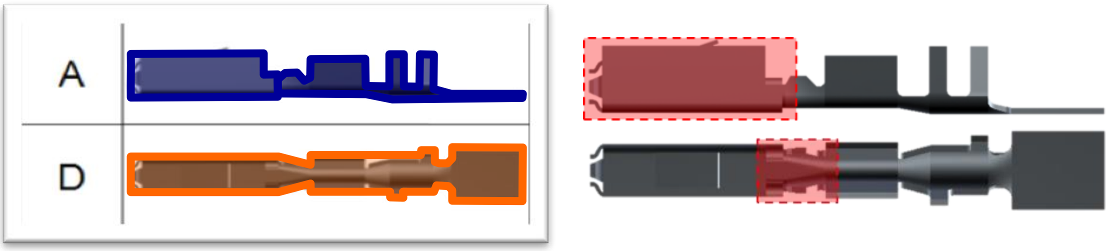
Terminal Lances: **No**
Terminal Material: **CuNiSn**

Picture 92 | 4th design preliminary results

It was identified the terminal that represent higher potential risk of breakage are "C" and "D" individual transitions, B and D combination transitions, CuNiSn material without Lances.

1st Terminal Design Preliminary Conclusion: Transitions and Combinations

Transitions & Combination
HIGHER RISK OF BREAKAGE

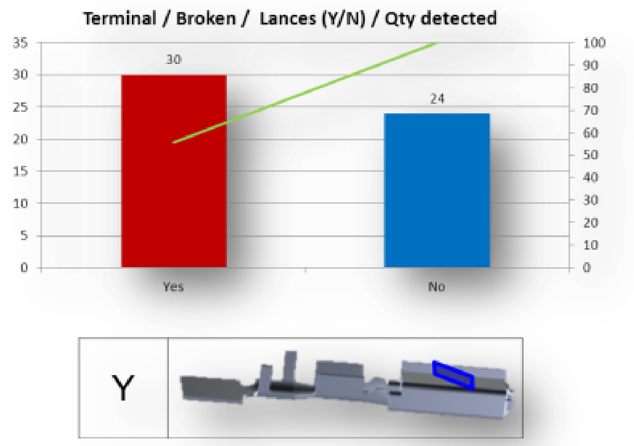


Terminal Kind: **MQS**
Terminal Lances: **Yes**
Terminal Material: **CuNiSi**

Picture 93 | 1st Terminal Design Preliminary Conclusion for Transitions and Combinations results

Identified as the terminal transitions that represent higher potential risk of breakage are “A” and “D” individually and “A” and “D” as a combination, also combined with CuNiSn material, MQS kind and terminal with Lances.

2nd Terminal Design Preliminary Conclusion: Terminal with Lances



Graphic 41 | 2nd Terminal Design Preliminary Conclusion for Terminal with Lances

Lances represent higher influence/importance for terminal breakage.

Improvement proposal – Critical terminals design families’ classification

Critical Level	Longitudinal	Transversal
1st	A	D
2nd	A	E
3rd	B	D
4th	B	E
5th	A	F
6th	C	D
7th	C	E

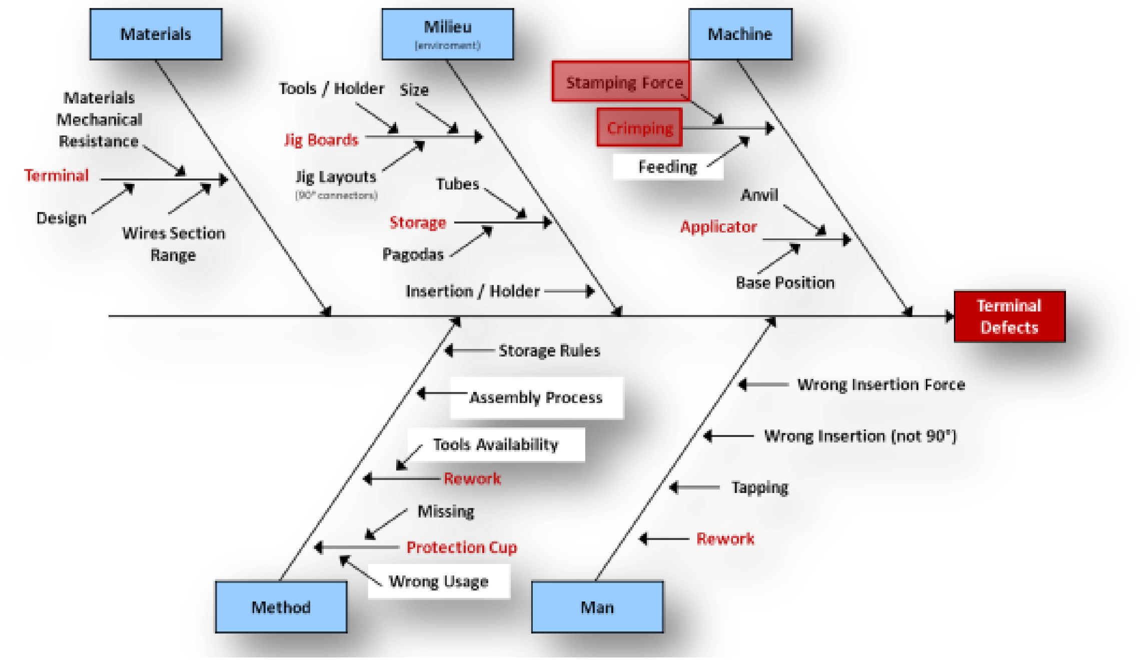
Picture 94 | Design classification

In earlier stages, in wiring harness engineering study, this classification table can be consulted in order to identify if the chosen terminals represent higher quality risk, in a design point of view, and consequently announce to manufacturing plants the alert so all necessary preventive actions can be taken.

Terminal **Crimping Process** Analysis (VII) is treated next.

This process can be considered the heart of the wiring harness product. Of course, not all details about it will be discussed here but some very interesting subjects were chosen, considered added value to the terminal BROKEN defect investigation.

The objective of this chapter is to understand the importance of those steps and parameters on the process and demonstrate that they can be checked in different perspectives.



Picture 95 | Terminals Defects Root-causes Ishikawa diagram, Machine field highlighted

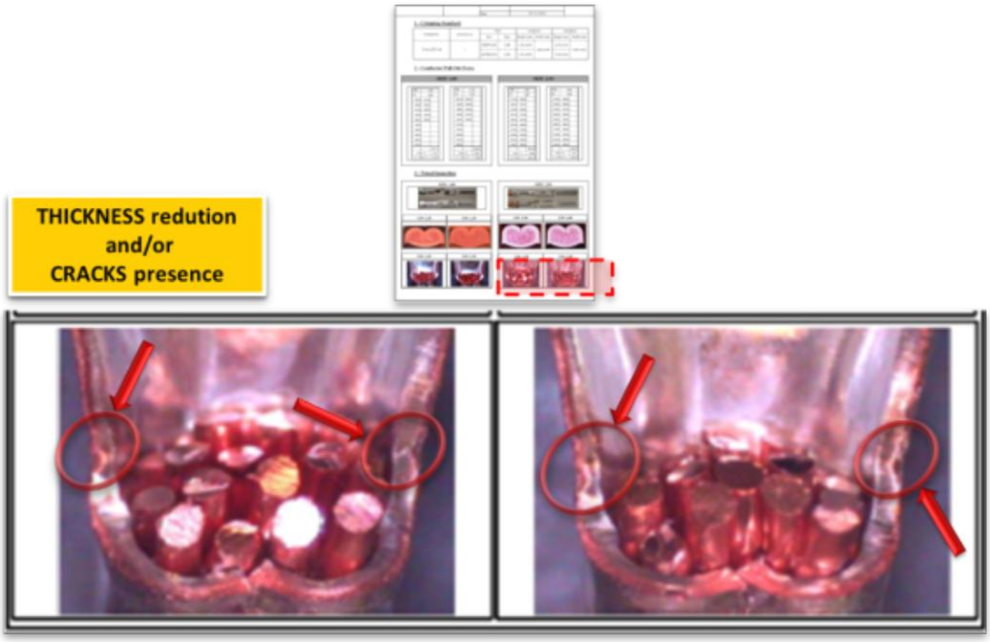
Inspection of Crimped Terminals

In order to understand the next step on this analysis, the inspection will focus in a macro and micro perspectives of the terminals crimping, it is desirable to refresh the crimping terminal checking standard ("what and where to check") previously present on the chapter "2.3.3 Terminals Crimping Method, Equipment and Evaluation" on this document.

Were received, from an internal engineering center for the terminal crimping standards development, crimping validations reports for the top 10 terminals references previously identified on the list for the most sensitive. All cases were inspected. Some were chosen to be presented. Next pictures will demonstrate the most important and relevant cases found among them. Despite of their validation they present necking, fissuring and internal defects areas on the material structure influencing not only terminals mechanical behavior but also terminals' main function: electrical signal continuity. In this perspective, added value recommendations will also be presented next.

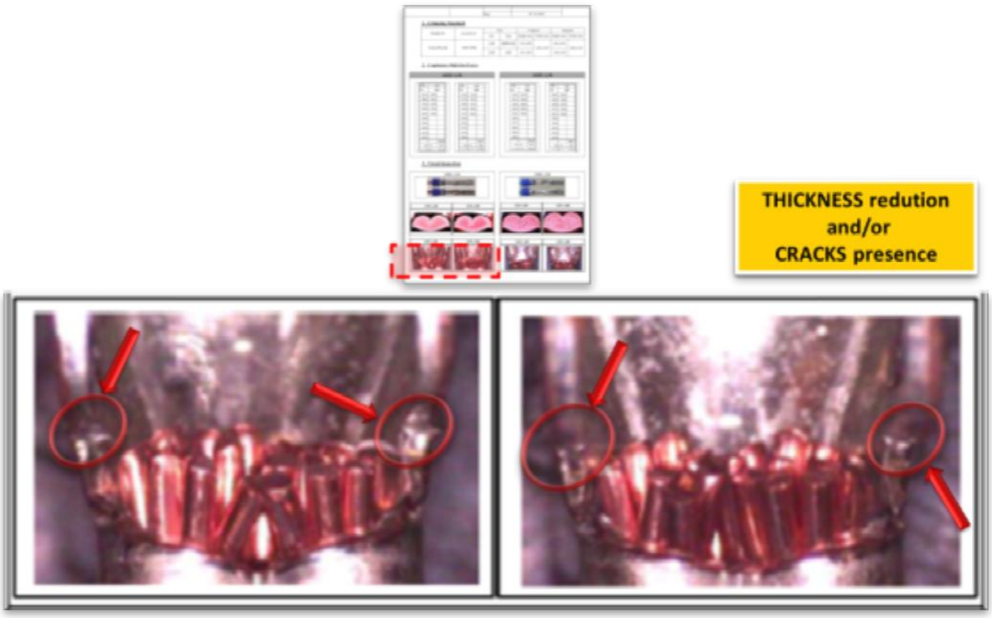
Terminals crimping validation reports – cases observation

Case #1 - Terminal A



Picture 96 | Case #1 - Terminal A crimping validation report

Case #2 - Terminal 1

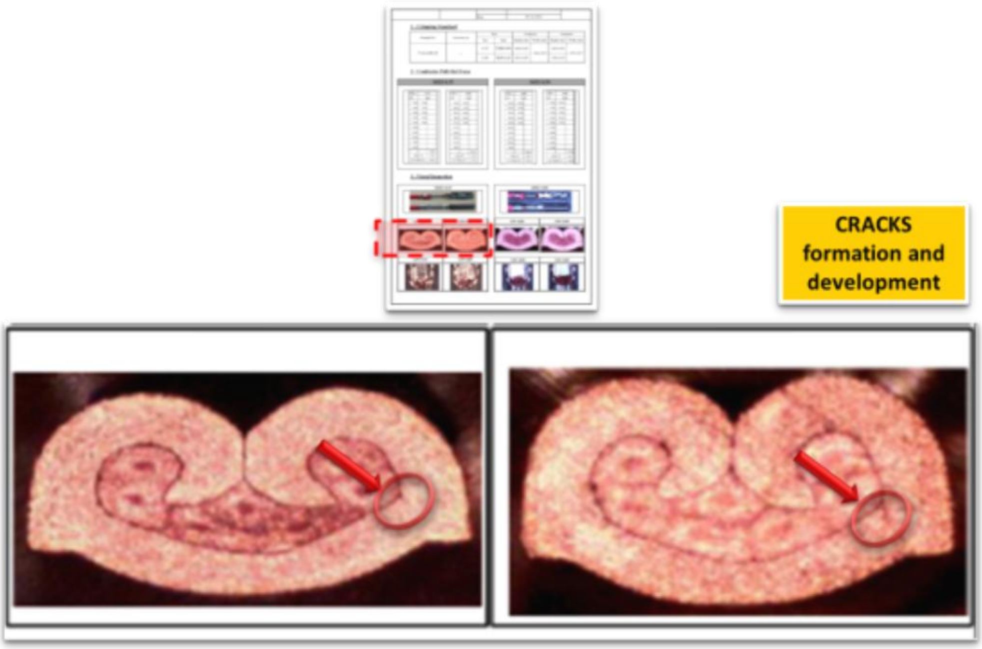


Picture 97 | Case #2 - Terminal 1 crimping validation report

Case #3 - Terminal 2

Picture 98 | Case #3 - Terminal 2 crimping validation report

Case #4 - Terminal 3

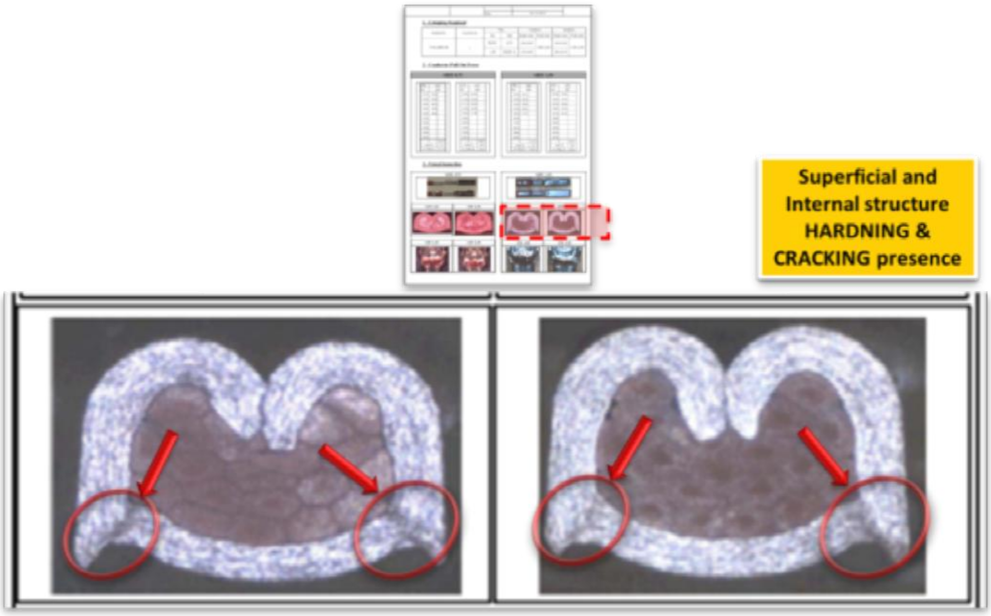


Picture 99 | Case #4 - Terminal 3 crimping validation report

Case #5 - Terminal 4

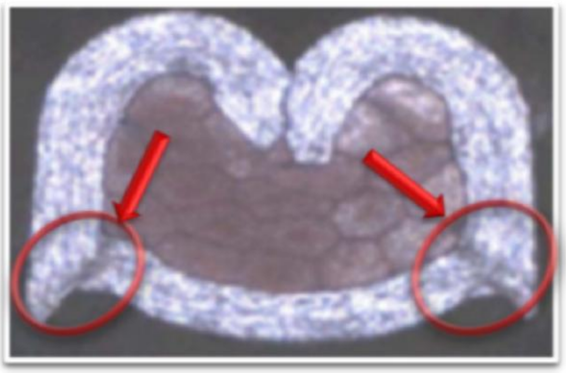
Picture 100 | Case #5 - Terminal 4 crimping validation report

Case #6 - Terminal 5



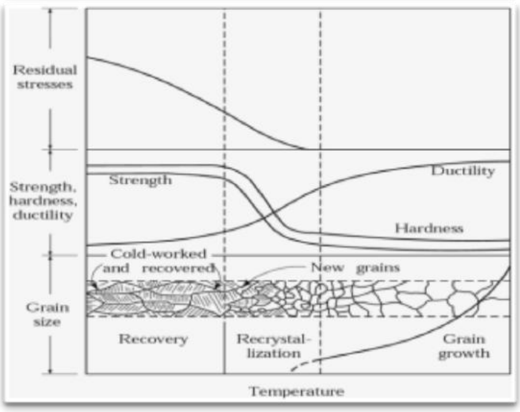
Picture 101 | Case #6 – Terminal 5 crimping validation report

Superficial and Internal structure defect: Grain Size Increase Impact and Edge Dislocations



Picture 102 | Superficial and Internal structure defect

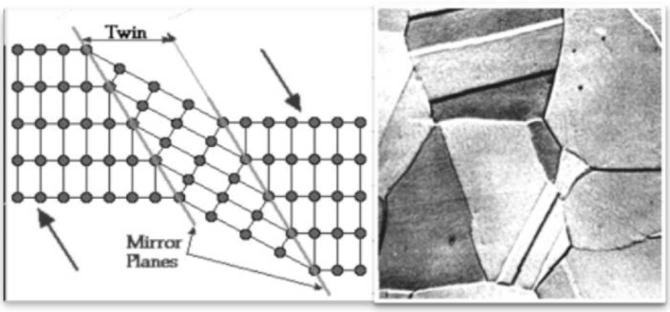
It was focus only on this last presented defect kind, as show on the picture aside, the grain is too much large, induced by the cold work forming. A Recrystallization Annealing for Homogenization performed at the right temperature allows a re-size (decrease) the grain, and recover the material tenacity and ductility, as already analyzed on this study.



Graphic 42 | Sizable grains relationship with hardness, ductility, strength and residual stresses

Sizable grains have a strong relationship with higher hardness, lower ductility, higher strength and higher residual stresses on the terminals. All characteristics mentioned potentiate the occurrence of BROKEN terminal defects. Please check picture aside for better understanding.

Grain Borders (Structure Defects): Edge Dislocations Explanation



Picture 103 | Material edge dislocations defect kind

At room temperature (or close), grain borders have a great negative impact on the material capacity for plastic deformation, since this kind of defect makes harder the internal movements on those regions (higher mechanical resistance).

Improvement Proposal

Additionally, it’s necessary to check on crimped terminals all areas with a High resolution microscope, finding cracks presence and major thickness reduction situation is the goal.

One of the very interesting parameters to be analyzed on the Crimping process is Velocity, meaning, velocity that press falls down over each terminal.

Two of the questions that lead to analyze this topic were: What happens if the press velocity is too high when compared against to the theoretically admissible terminal material deformation velocity? Is the standard velocity used in the Company press machines too high or not? The pursuit of an answer to the second question seems more important in a Company perspective and at this stage of this defect analyses although answers related to the first question will not be forgotten.

Adjust the crimping press velocity for dedicated terminal machines:

- General case (Company standard process): V ~ **0,8** m/s

Important Note: Information received from an international crimping machines supplier.

- Typical values for forming operations in Mechanical Press[36]: **0,06** to **1,5** m/s

Forging machine	Velocity range, ms-1
Gravity drop hammer	3.6-4.8
Power drop hammer	3.0-9.0
HERF machine	6.0-24.0
Mechanical press	0.06-1.5
Hydraulic press	0.06-0.30

Remark: HERF – High Energy Rate Forging

Picture 104 | Typical values of velocity for forming operations

- Typical values for forming operations in Hydraulic Presses[37]: **0,03** to **0,8** m/s

Table 2 Capacities of forging presses

Type of press	Force		Pressing speed	
	MN	tonf	m/s	ft/s
Mechanical	2.2-142.3	250-16,000	0.06-1.5	0.2-5
Hydraulic	2.2-623	250-70,000	0.03-0.8	0.1-2.5

Picture 105 | Capacities of forging presses

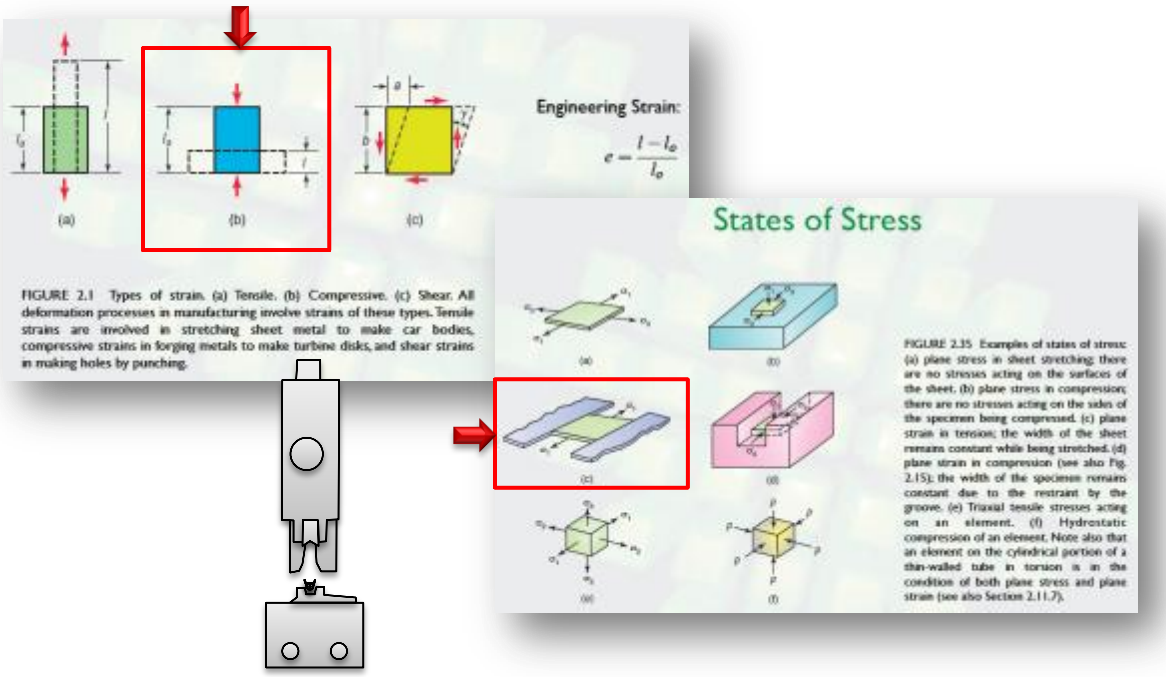
Effects of speed of deformation:

- High deformation speed (high strain rate) means high flow stress;
- If deformation velocity is too high means metal fissuring becomes highly possible;
- High material deformation velocity can cause plastic instability in cold working.

36 [17] "Fundamentalls of Metallworking-Chapter1", by Suranaree University of Technology, Tapany Udomphol (Thailand), 2007
37 [1] S. L. Semiatin (vol. Chairman), "Forming and Forging Metals Handbook Vol.14", by ASM International, Batelle Columbus, 1993

An immediate conclusion can be taken after reading the last statements: press velocity used in Company standard process is very near of the forging upper typical limit, for mechanical and hydraulic press machines. After this theoretical confirmation, another interesting question is: What can be the material plastic forming admissible velocity theoretically for this terminal case investigation?

First step: Terminal crimping involved deformations processes were identified[38]:



Picture 106 | Terminal crimping deformations processes identification

Identified kind of strain | Compressive: (b).

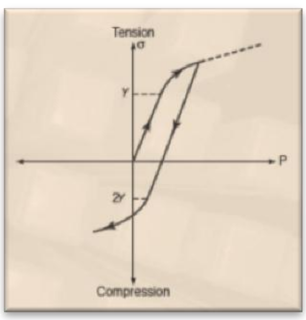
Crimping operation basis is a descending press hammer on top of the terminal crimping area.

Identified state of stress | Plan strain in tension: (c).

The width of the terminal remains constant while being stretched. There is always a plastic deformation on the terminal body never recovered, strain deformation.

Considering that this curve, picture aside, can demonstrate, theoretically, the material behavior during a crimping operation.

Arrows show load and unload paths. Note the decrease in the yield stress when compression is applied, followed by tension, whereby yield stress in tension decreases.



Graphic 43 | Typical tension versus compression graphic

[38] [18] Serope Kalpakjian and Steven Schmid , "Manufacturing Processes for Engineering Materials, 5th ed", by Pearson Education presentation, South Asia, 2008

As mentioned before, cooper alloys mechanical behavior information is not so easy to find freely, no so much as for steel alloys, nevertheless, the viscoplasticity theory can be used for the most of the materials.

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied.

Basically, this method will be used to calculate the Terminal A material kind deformation velocity theoretically admissible to be compared afterwards with the real standard crimping velocity used in the Company.

Second step: Terminal A mechanical, physical and chemical characteristics[39]

STOL®80 - C14410

Temper class	Tensile strength Rm min. - max. MPa	Yield strength $Rp_{0,2}$ min. MPa	Elongation A50 min. % 2)	Hardness (reference) value HV	Bendability 90 ° gw 1) 2) 3)	Bendability 90 ° bw	Bendability 180 ° gw 1) 2) 3)	Bendability 180 ° bw
R250	min. 250	max. 140	20	60 - 85	0	0	0	0
R300	300 - 370	270	10	80 - 110	0	0	0	0
R360	360 - 430	310	7	110 - 130	0	0	0,5	1
R420	420 - 490	370	5	120 - 150	1	1	2	2,5
R460	min. 460	410	4	min. 135	1	1,5	2,5	3

1) $r = x \cdot t$ (thickness ≤ 0,50 mm) 2) values for stress relieved qualities
3) sample width = 10 mm / bendability for width of smaller samples on request (scale acc. condition 1/2 of page 5.5.2.)

Chemical composition (%)	
Cu (incl. Ag+Sn):	99,9
Sn:	0,10 - 0,20
Other:	max. 0,10

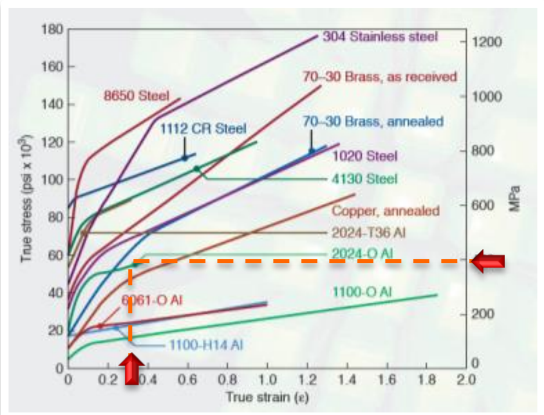
Main characteristics

Low cost special alloy, highest conductivity, prefered for male connectors, junction boxes, and with a pre-tinned surface all scrap material has a higher value than standard tinned brass. The total cost for finish products are being equal to brass made one.

Physical properties		
Density*	g/cm³	8,9
Thermal conductivity*	W/m°K	330
Electr. conductivity ***	MS/m	44
Electr. conductivity ***	IACS [%]	76
Coefficient of thermal expansion **	$°K^{-1}\ 10^{-6}$	17,3
Modulus of elasticity*	GPa	120

* Reference values at room temperature
** Between 20 up to 300 °C
*** Value for the lowest temper class

Picture 107 | Terminal A material supplier mechanical, physical and chemical characteristics



Graphic 44 | True Strain for Copper Alloys

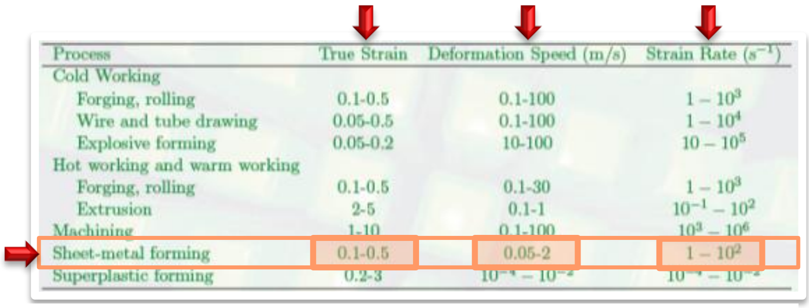
From this board is taken the Yield strength (YS) value = **310** MPa.

True Strain for Copper Alloys[40]

The true stress – true strain curves in tension at room temperature for various metals. The point of intersection at the ordinate is the YS, thus, the elastic portion of the curve is not indicated. The *K* and *n* values are determined from these curves.

[39] [7] Udo Adler, Josef Mommertz and Dr. Holder Warnecke, "Technical Manual Strips of copper and copper alloys plain and tinned", by KME AG & Co, Germany, 2010
[40] [18] Serope Kalpakjian and Steven Schmid , "Manufacturing Processes for Engineering Materials, 5th ed", by Pearson Education presentation, South Asia, 2008

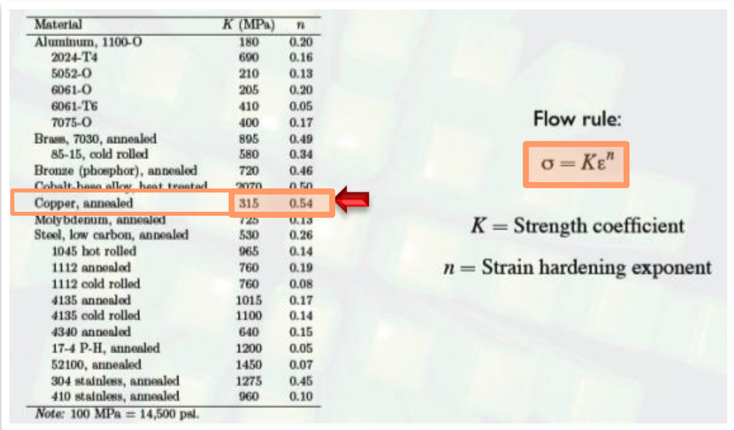
Third step: Intersecting YS = 310 MPa with the Copper annealed curve, the True Strain (ε) ~ **0,32**.



Process	True Strain	Deformation Speed (m/s)	Strain Rate (s^{-1})
Cold Working			
Forging, rolling	0.1-0.5	0.1-100	$1 - 10^3$
Wire and tube drawing	0.05-0.5	0.1-100	$1 - 10^4$
Explosive forming	0.05-0.2	10-100	$10 - 10^5$
Hot working and warm working			
Forging, rolling	0.1-0.5	0.1-30	$1 - 10^3$
Extrusion	2-5	0.1-1	$10^{-1} - 10^2$
Machining	1-10	0.1-100	$10^3 - 10^6$
Sheet-metal forming	0.1-0.5	0.05-2	$1 - 10^2$
Superplastic forming	0.2-3	$10^{-4} - 10^{-2}$	$10^{-4} - 10^{-2}$

Picture 108 | typical strain rates in metalworking for sheet-metal forming

Fourth step: From typical strain rates in metalworking for sheet-metal formin can be know the intervals for deformation velocity (V) = **0,05** .. **2** m/s.



Material	K (MPa)	n
Aluminum, 1100-O	180	0.20
2024-T4	690	0.16
5052-O	210	0.13
6061-O	205	0.20
6061-T6	410	0.05
7075-O	400	0.17
Brass, 7030, annealed	895	0.49
85-15, cold rolled	580	0.34
Bronze (phosphor), annealed	720	0.46
Cobalt-base alloy, heat treated	2070	0.50
Copper, annealed	315	0.54
Molybdenum, annealed	725	0.13
Steel, low carbon, annealed	530	0.26
1045 hot rolled	965	0.14
1112 annealed	760	0.19
1112 cold rolled	760	0.08
4135 annealed	1015	0.17
4135 cold rolled	1100	0.14
4340 annealed	640	0.15
17-4 P-H, annealed	1200	0.05
52100, annealed	1450	0.07
304 stainless, annealed	1275	0.45
410 stainless, annealed	960	0.10

Note: 100 MPa = 14,500 psi.

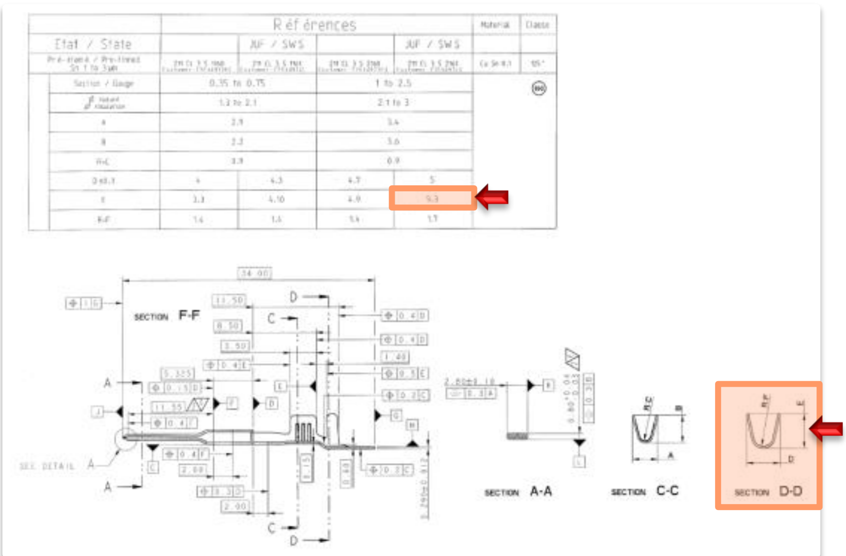
Picture 109 | Material power law flow rule

Fifth step: In order to know the theoretical value for the stress estimated the Power Law Flow rule[41] is used.

$\sigma = 315 * 0{,}32^{0{,}54}$.

σ ~ **170** MPa.

Sixth step: Strain rate in forming is defined by $\varepsilon^{*}=V/h$, where ε=true strain rate; *h*=instantaneous height of work piece being deformed and *V*=Velocity.



Picture 110 | Terminal A technical drawing extract

[41] [18] Serope Kalpakjian and Steven Schmid , "Manufacturing Processes for Engineering Materials, 5th ed", by Pearson Education presentation, South Asia, 2008

Seventh step: All combined, calculation is made:

Table 63 | Terminal A material forming velocity calculation

Flow Rule			
K	315	MPa	***
n	0,54		***
ε	0,32		*
σ	170	MPa	**

Strain Rate					
V	293,89	mm/s	0,29	m/s	**
ε̇	55,45	**			
h	5,30	mm	****		

Interpolation Linear Calculation			
x1	0,10	True Strain	*
X2	0,32	True Strain	*
X3	0,50	True Strain	*
Y1	1	Strain Rate (s^{-1})	*
Y2	55,45	Strain Rate (s^{-1})	**
Y3	100	Strain Rate (s^{-1})	*

Values Source:

* Graphic

** Calculated

*** Table

**** Drawing

Preliminary Results:

Copper alloy CuSn theoretical plastic admissible deformation velocity ~ **0,29** m/s.

Note: This calculation is an approach, gives estimation what could be the real value.

Actual press machines velocity is ~**2,8**x higher than material plasticity theory.

Other possible negative effects[42] are identified if the press velocity for a metal forming operation is higher than required, several changes can occur:

- Many materials are speed-sensitive and will behave differently at different speeds;
- Ductility may vary and many materials appear stronger when deformed at faster velocity.

Improvement Proposal:

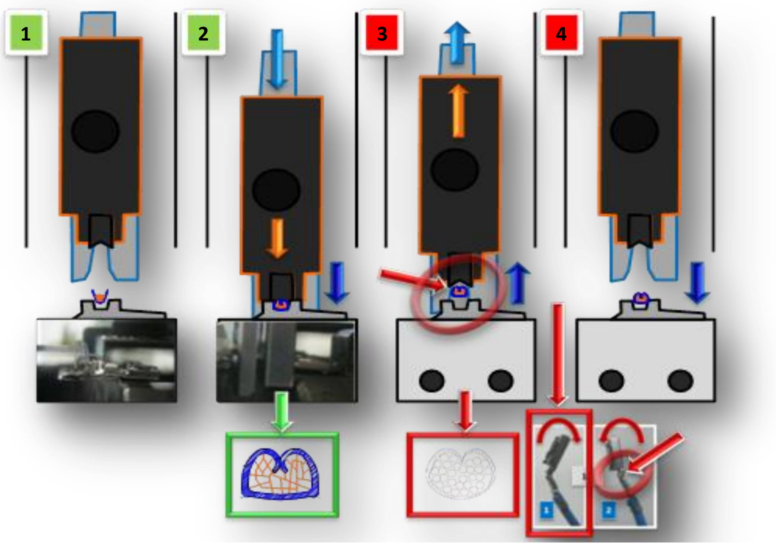
Promote the adaptability of terminal dedicated Press Machines crimping machines.

Two other interesting subjects that can be analyzed on the standard crimping process are the **Lubricant** usage and the **Cleaning** of the crimping applicators frequency. About those subjects there is not so much information available.

[42] [19] E. Paul Degarmo, J.T. Black, Ronald A. Kohser,"Materials and Process in Manufacturing, 9th", by John Wiley & Sons, Inc., New York (USA), 2003

Lubricant Usage

On terminal crimping process a no conform terminal crimped is usually and commonly call as "Bad Crimping". Of course, is a very generic definition, and this defect kind can be induced by many different means, however, the following analysis will focus specifically on the terminal behavior during the crimping tool relieve movement. Please check next picture.



Picture 111 | Terminal crimping process unstressed and bent defects kind

In the picture above, resulting from the second step (2), is considered as a "Good Crimping" and on the third step (3), considered as "Bad Crimping".

What happens between one and the other? Using real manufacturing plants definition, when the applicators unveil moves in the upper sense after crimping operation, terminal is unstressed, which means, crimping compression ratio disappears and that once was conform, becomes not conform. A better and different explanation can be as follows: it is considered that by friction loads between the applicator unveil internal surfaces and terminal side surfaces relieve of the crimping loads happens. Taking this into account the degree of deformation depends on the normal pressing tensions and the surfaces orientation in contact. The friction loads are directly related the involved loads magnitude, the surfaces state (ware and/or finishing) and the terminal base material hardness. The deformation through the induced friction leads to a microrelief formation on the crimping terminal area.

A second defect kind that can occur is what can be seen on the previous picture between step (3) and (4), the terminal becomes "slightly" bend when applicator unveil moves up.

Is considered in this movement that friction loads are involved, and so, after crimping operation the terminal goes up with unveil and becomes bent.

Immediately after the automatic crimping operation, the trained operator does a visual inspection on all terminals on its crimping areas. When a bend terminal is detected, his natural reaction is, wrongly, manually correct its alignment. This correction increases strain-hardening percentage on terminals transition critical area, increasing the risk of terminal breakage.

Improvement Proposal

With lubricant frequent usage, both situations happening frequency can be strongly reduce during crimping process for sensitive terminals.

It is worth note, for a very small terminal / wire combination list lubricant is already used internally, as preventive action against breakage. So, why not implement it for other kind of terminals, considered "sensitive" already identified on this document?

Lubricant usage could be initially implemented on the 25 terminals references identified, its evolution followed and registered in a Company pilot plant, then, after results analyzed and considered added value to the process improvement and this defect kind decrease than this kind of recommendation could be extended. Of course economic impact and production efficiency factors must enter in the final equation for a conclusive decision.

Lubricant kind recommendation[43]

Solid lubricant and electrical conductor: Graphite and Teflon - PTFE (powder spray).

Please find the next information as the supporting one for this kind of lubricant choice.

Process Advantages:

- Lower terminal insertion loads involved;
- Lower terminal crimping loads involved;
- Less unveil wear improvement (higher tool usage cycles);
- With special additives, less corrosion can be an achievement.

Some disadvantages can be present and need to be considered:

- Lubricated surface may retain more dust;
- Lubricants can polymerize and form insulators;
- Lubricant can creep to places where it is not wanted.

Proper and controlled application requires special attentions:

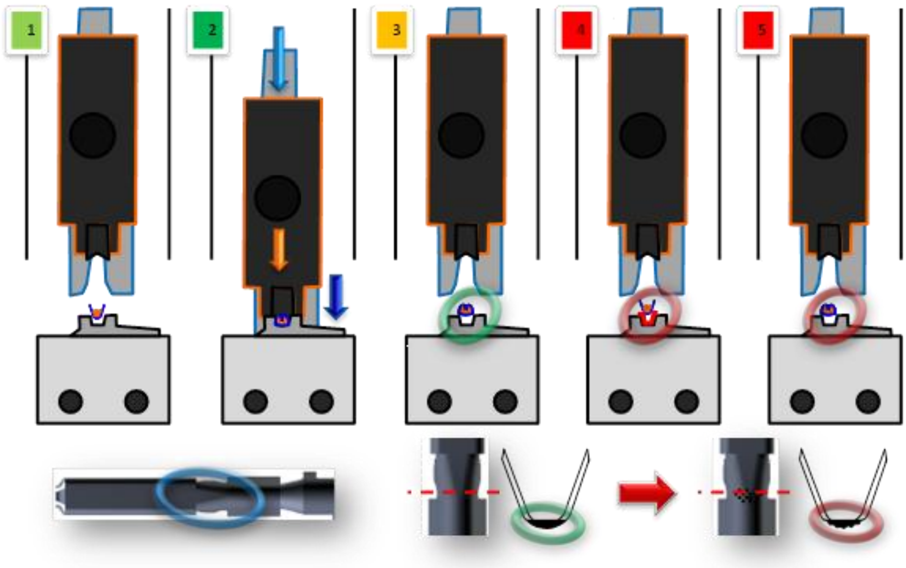
- Lubricant may be partly removed during the terminal and connector assembly process;
- Connectors and Packaging materials may become contaminated with lubricant;
- In general, they are effective on contacts which are not required to switch frequently at moderately high currents.

[43] [16] Piet van Dijk, "Critical Aspects of Electrical Connector Contacts", Abstract, Netherlands, 2002

Important Notes:

- Lubricants may be considered to be a part of the product surface finish;
- To be specified on the product drawing and subjected to the procedures of testing and quality control;
- Installation process should act as a spray application that operates automatically, timed with the applicator press strokes.

Cleaning Frequency



Picture 112 | Terminal crimping process irregular surface defect kind explanation

Cleaning can have an important effect on the terminal mechanical resistance during the complete process. As can be seen in the picture above, after N crimping cycles, the applicator matrix accumulates Sn residuals particles (source: terminal coatings), probably some Copper alloy particles as well, some surrounding environment residuals (dirty particles). All of this kind of not desired particles can increase the risk of damaging the terminal design critical transition area (mostly its base area) and raising the terminal breakage potential risk.

Actually, is up to the trained operator to clean its working space (machine included).

By establishing a more exigent method, with a higher frequency practice for the sensitive identified terminals, it is considered that this root-cause might be reduced as well.

Improvement Proposal

Cleaning higher frequency (reduces terminal damage risk and minimizes tool wear).

Preliminary Conclusions and Improvement Recommendations Resume

Terminal and wire combination Crimping Validation Process:

- For visual inspection procedure of crimped terminals it is important to focus on design critical transition area (necking and cracks);
- For visual inspection procedure on crimped terminal microcuts it is important to focus additionally on negative edge dislocations systems and internal cracks formation.

Terminal Crimping Production Area:

- Adjust the crimping press machine velocity (sensitive terminals adaptability);
- Lubricant usage on sensitive terminals (reduces terminal damage risk and minimizes tool wear);
- Cleaning higher frequency (reduces terminal damage risk and minimizes tool wear).

Fragile versus Brittle Terminals Classification Matrix and Methodology (VIII) is the final established step on this BROKEN terminal root-causes investigation strategy.

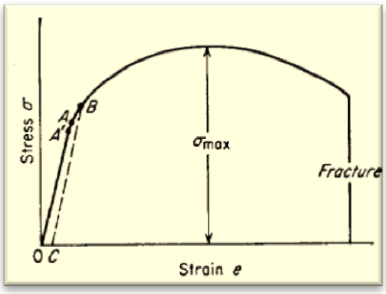
In this very important step the objective is to obtain a method which will allow to a trained operator to classify a terminal lote at the inspection reception area. According to the classification given, specific protection and handling rules are recommended to be applied.

As a preliminary condition to create this method was defined that it should be very practical and not just a theoretical principle, meaning, a manufacturing plant operator do not need to become a material expert in order to use it correctly.

During this investigation, one broken terminal received from a real Quality Customer Complaint was chemical and mechanical analyzed and declared no conform against related specifications. It was understood and confirmed as well that there is a strong relationship between the chemical composition and mechanical characteristics. Several parameters out of specification and high elements weight percentage mean high YS and UTS, also meaning higher Hardness. There is a straight relationship between material Hardness and YS or UTS, so: Why not raise a useful and simple method based in very important and real material characteristic measure? A method can be raised and supported around it, where the only actions required from the operator are to take some measurements and check the label conditional color presented (Visual Management), to know exactly what to do next.

First, the theoretical background is presented and afterwards the proposed methodology.

Tensile Deformation of Ductile Metal[44]



Graphic 45 | Typical Stress versus Strain curve

The initial portion of the curve OA is the elastic region within which Hooke's law is obeyed.

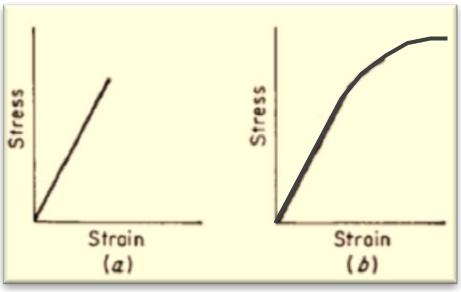
Point A is the elastic limit, defined as the greatest stress that the metal can withstand without experience a permanent strain when the load is removed.

The determination of the elastic limit is quite tedious, not at all routine, and dependent of the sensitivity of the strain-measuring instrument. For these reasons it is often replaced by the proportional limit point A'.

For engineering purposes the limit of usage elastic behavior is described by the yield strength (YS), point B. The YS is defined as the stress which will produce a small amount of permanent strain, or offset, is OC. Plastic deformation begins when the elastic limit is exceeded. Eventually the load reaches a maximum value. The maximum load divided by the original area of the specimen is the ultimate tensile strength (UTS).

For a ductile metal the diameter of the specimen begins to decreases rapidly beyond maximum load, so that the load required continuing deformation drops off until the specimen fractures.

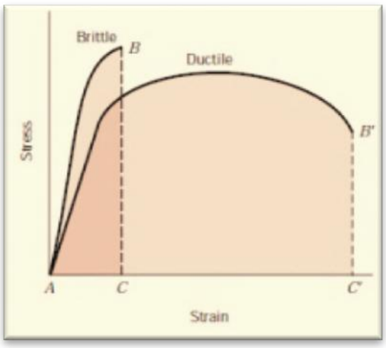
The general behavior of materials under load can be classified as ductile or brittle depending upon whether or not the material exhibits the ability to undergo plastic deformation.



Graphic 46 | Elastic region failure difference between a brittle and a ductile material

The previous picture illustrates the tension stress-strain curve for a ductile material.

A completely brittle material would fracture almost at the elastic limit (a), while a brittle metal shows some slight measure of plasticity before fracture (b).



Graphic 47 | Failure difference between brittle and ductile material

Adequate ductility is an important engineering consideration, because it allows the material to redistribute localized stresses.

[44] [12] George F. Dieter and David Bacon, "Mechanical Metallurgy SI Metric Edition", by McGraw-Hill Book Company, Singapore, 1988

In brittle materials, localized stresses continue to build up when there is no local yielding until finally, a crack forms at one or more points of stress concentration, and it spreads rapidly over the section. Even if no stress concentrations are present in a brittle material, fracture will still occur suddenly because the yield stress and tensile strength are practically identical.

Elements can fail to perform their intended functions in three general ways[45]:

1. Excessive elastic deformation

Two general kinds of excessive elastic deformation may occur:

- Excessive deflection under condition of stable equilibrium, such as the deflection of a shaft under gradually applied loads.
- Excessive elastic deformation of a machine part can mean failure of the machine. For example, a shaft which is too flexible can cause rapid wear of the bearing, or excessive defection of closely mating parts can result in interference and damage to the parts.

Failures due to excessive elastic deformation are controlled by modulus of elasticity, not by the strength of the material. The most effective way to increase the stiffness of a member is usually by changing its shape and increasing the dimensions of its cross section.

2. Yielding or excessive plastic deformation

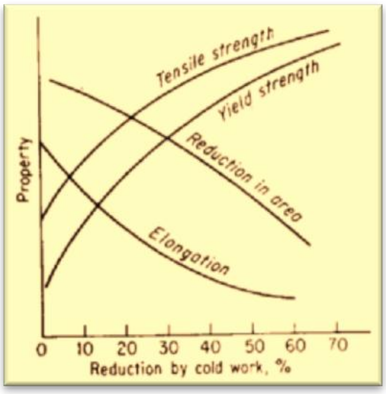
It occurs when the elastic limit of the metal has been exceeded. Yielding produces permanent change of shape, which may prevent the part from functioning properly any longer. In a ductile metal under conditions of static loading at room temperature yielding rarely results in fracture, because the metal strain hardens as it deforms, and an increased stress is required to produce further deformation. Failure by excessive plastic deformation is controlled by the yield strength of the metal for a uniaxial condition of loading.

3. Fracture

The formation of a crack which can result in a complete disruption of continuity of the member constitutes fracture. A part made from a ductile metal which is loaded statically rarely fractures like a tensile specimen, because it will first fail by excessive plastic deformation. However, metals fail by fracture in three general ways: (1) sudden brittle fracture; (2) fatigue, or progressive fracture; (3) delayed fracture.

[45] [12] George F. Dieter and David Bacon, "Mechanical Metallurgy SI Metric Edition", by McGraw-Hill Book Company, Singapore, 1988

Most fractures in machines parts are due to fatigue. Fatigue failures occur in parts which are subjected to alternating, or fluctuating, stresses. A minute crack starts at a localized spot, generally at the notch or stress concentration, and gradually spreads over the cross section until the member breaks. Fatigue failure is caused by a critical localized tensile stress which is very difficult to evaluate, and therefore design for fatigue failure is based primarily on empirical relationships using nominal stresses.

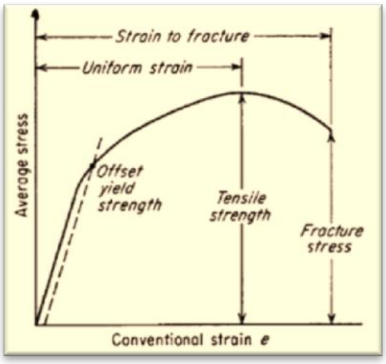


Graphic 48 | Typical variation of strength and ductility parameters with increasing cold-work amount

Figure shows the typical variation of strength and ductility parameters with increasing amount of cold-work.

Since in most cold-working processes one or two dimensions of the metal are reduced at the expense of an increase in the other dimensions, cold-work produces elongation of the grains in the principal direction of working. Several deformations produce a reorientation of the grains into a preferred direction. In addition to the changes in tensile properties shown in picture, cold-working produces changes in other characteristics. An appreciable decrease in electrical conductivity due to an increase number of scattering centers occurs. This leads to a general decrease in corrosion resistance and in a certain alloys introduces the possibility of the stress-corrosion fissuring.

The tensile test is widely used to provide basic design information on the strength of materials. In the tension test a specimen is subjected to a continually increasing uniaxial tensile load while simultaneous observations are made of the elongation of the specimen. An engineering stress-strain curve is constructed from the load-elongation measurements. The parameters which described the stress-strain curve of a metal are tensile strength, yield strength or yield point, percent elongation, and reduction of area. The first two are strength parameters and the last two indicate ductility. For ductile metals the tensile strength should be regarded as a measure of the maximum load which a metal can withstand under the very restrictive conditions of uniaxial loading. It is the base of the strength of members, suitably reduced by a factor of safety[46].



Graphic 49 | Engineering stress-strain curve

[46] [20] Budynas–Nisbett, "Mechanical Engineering Shigley's Mechanical Engineering Design, Eighth Edition", by McGraw–Hill Primis, United States of America, 2008

Note: All engineering materials show certain variability in mechanical properties, which in turn can be influenced mainly by changes on fabrication. Further, uncertainties usually exist regarding the magnitude of the applied loads. Thus, in order to provide a margin of safety and to protect against failure from unpredicted causes, it is necessary that the allowable stresses be smaller than the stresses which produce failure.

Since the material is ductile, that part can carry loads satisfactorily with no general yielding. In these cases it is considered factor of safety as geometric (theoretical) stress concentration factor *Kt*. The usual definition of geometric (theoretical) stress-concentration factor for normal stress Kt and shear stress Kts is, $\sigma_{max} = Kt*\sigma_{nom}$ (a) & $\tau_{max} = Kts*\tau_{nom}$ (b).

Brittle materials do not exhibit a plastic range so "feels" the stress concentration factor Kt/Kts.

The current trend is a more rational approach of basing the static design of ductile metals on the yield strength (YS). It is very useful identification of a material in the same sense that the chemical composition serves to identify a metal or alloy. Further, because is easy to determinate and is quite reproducible property, it is useful for the purposes of specifications and for quality control of a product.

Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often quite useful. For brittle materials, the tensile strength is a valid criterion for design.

Ductility is a qualitative, subjective property of a material. In general, measurements of ductility are of interest in three ways[47]:

- Indicate the extension to which a metal can be deformed without fracture in metalworking operations such as rolling and extrusion.
- Indicate to the designer, in a general way, the ability of the metal to flow plastically before fracture.
- Serve as an indicator of changes in impurity level or processing conditions. Ductility measurements may be specified to material "quality" even though no direct relationships exist between the ductility measurement and performance in service.

The convectional measures of ductility that are obtained from the tensile test are test engineering strain at fracture (usually called the elongation) and the reduction of area at fracture. Knowing that such measurements are dependent on the product length and its cross section dimensions to guaranty a localized and uniform extension, additionally product metallurgical condition, must be concluded that are not applicable for this investigation because of the uncertainly of their suppliers production (lack of information).

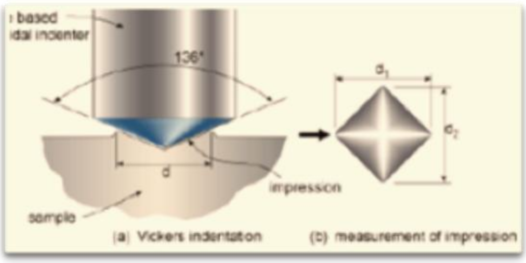
[47] [12] George F. Dieter and David Bacon, "Mechanical Metallurgy SI Metric Edition", by McGraw-Hill Book Company, Singapore, 1988

Hardness usually implies a resistance to deformation, and for metals the property is a measure of their resistance to permanent or plastic deformation.

There are three general kinds of hardness measurement depending on the manner in which the test is conducted. These are (1) scratch hardness, (2) indentation hardness, (3) rebound, or dynamic hardness. Only indention hardness is of major engineering interest for metals.

Vickers Hardness Methodology resume[48]

The Vickers Hardness test uses a square-base diamond pyramid as the indenter. Because of the shape of the indenter, this is frequently called the diamond-pyramid hardness test (DPH), or Vickers Hardness Number (VHN). The DPH or VHN is defined as the load divided by the surface area of the lengths of the diagonals of the impression.



Picture 113 | Vickers methodology indenter

In a very interesting document was found the solution to establish a correct relationship between hardness and YS or UTS values for Copper alloys. The content of this important document will be described briefly next.

Investigation[49] **background information**

Hardness and strength values of over 55 Copper alloys strengthened by solid solution, precipitation hardening, cold working, and dispersion strengthening were compiled. The yield strength (YS) and ultimate tensile strength (UTS) values of the Copper alloys examined ranged between 50 to 1 300 MPa and 200 to 1 400 MPa, respectively.

Least squares regression analysis was employed to establish correlations between strength and Vickers hardness values. Strain-hardening potential showed a significant effect on the correlations. In all the cases, a linear relation was obtained for both YS and UTS with hardness for the entire range of values under analysis. Simple empirical equations were proposed to estimate the strength using bulk hardness.

Ever since indentation hardness testing has come into existence, there were studies to estimate other mechanical properties especially ultimate tensile strength and yield strength from bulk hardness measurement.

[48] [12] George F. Dieter and David Bacon,"Mechanical Metallurgy SI Metric Edition", by McGraw-Hill Book Company, Singapore, 1988

[49][21] S.C. Krishna, N.K. Gangwar, A.K. Jha and B. Pant, "On the Prediction of Strength from Hardness for Copper Alloys - Journal of Materials", by Vikram Sarabhai Space Centre, Trivandrum (India), 2013

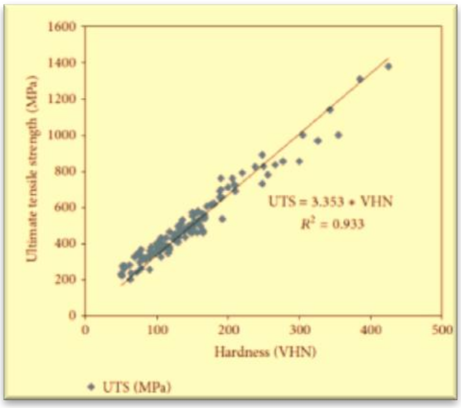
These relations are always attractive as they bring down the number of tests to be conducted to ensure the quality of the materials. As these methods are fast and relatively non-destructive in nature they are effectively used in failure analysis.

Least squares regression analysis was employed to obtain simple expressions, to predict the strength from hardness.
A linear correlation could be observed in most of the Hardness ranges of materials tested, except at low hardness. The linear trend line is made to pass through the origin as shown in picture. Regression analysis of the data points yielded a linear relation as,

UTS = 3.353 ∗ VHN

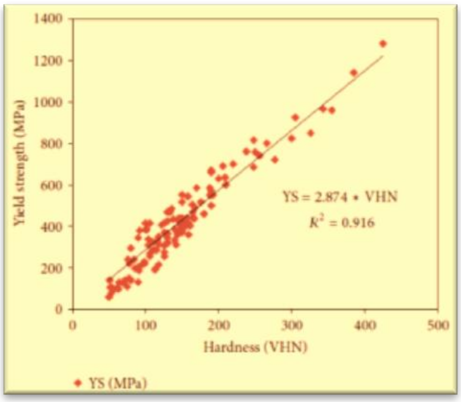
Ultimate tensile strength is in MPa and VHN is Vickers hardness number.

Regression analysis gives a coefficient of determination (R^2): 0.933.
Linear correlation has been obtained from the entire range of the hardness, a deviation was observed for hardness lower than 110 VHN.



Graphic 50 | Ultimate tensile strength regression analysis

Correlation obtained for yield strength and hardness values for Copper alloys also depicted a linear relationship as shown in the picture. Regression analysis of the data points gave a linear correlation for ultimate tensile strength as,



Graphic 51 | Yield strength regression analysis

YS = 2.874 ∗ VHN

Yield Strength is in MPa and VHN is Vickers hardness number.
Coefficient of determination (R^2): 0.916.
From the picture, it can be ascertained that yield strength has a linear correlation with hardness, with tendency to nonlinearity at hardness values less than 110 VHN.

An annealed material with high strain-hardening potential will become harder much more during the hardness test than a cold-worked metal. Therefore, cold-worked materials yield better correlations for hardness strength.

Alloys with lower hardness and strength have shown deviation from linear correlation.
It is concluded that these correlations can be used for predicting the strength of Copper alloys covering a wide range (YS-50 to 1 200 MPa and UTS-200 to 1 400 MPa).

Important Note: **If Vickers hardness methodology is not used is possible to be converted.**
Hardness conversion data have been determined experimentally and found to be dependent on material kind and characteristics. Detailed conversion tables for various other metals and alloys are contained in ASTM Standard E 140, ‘‘Standard Hardness Conversion Tables for Metals.’’

Hereunder the general view of the Classification Matrix method for manufacturing plants.

YAZAKI

Terminal Reference	Date
7114-4707-02	17/05/2013

Terminal reference and date info (Operator Manual Input)

Material	Plant	Lot
CuSn0,1	YBE	A

Material alloy, Plant and Lot references date info (Operator Manual Input)

	YS	UTS	Hardness
Min	330	370	110
Max	396	440	140
	MPa	MPa	VHN

Material alloy Data Sheet info (Specification)

YS	UTS	Hardness	Criterion	Behavior	Defect Risk
higher		higher	higher	Brittle	Critical
416,730	486,185	145	12%	Brittle	High
405,234	472,773	141	9%	Brittle	High
396,612	462,714	138	6%	Brittle	Medium
385,116	449,302	134	3%	Ductile	Medium
373,620	435,890	130	0%	Ductile	Low
362,124	422,478	126	-3%	Ductile	Medium
350,628	409,066	122	-6%	Unstressed	Medium
339,132	395,654	118	-9%	Unstressed	High
327,636	382,242	114	-12%	Unstressed	High
lower		lower	lower	Unstressed	Critical
MPa	MPa	VHN			

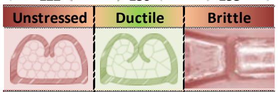
(UTS/YS)	
1,333	Specification Max
0,934	Specification Min
1,167	Measured Ration
Behavior	
15,8%	Measured Criterion
1,115	Strain Hardening Factor

Terminals Classification Matrix and Material Behavior parameters info

Terminal Measurement Classification		
YS	UTS	Hardness
433	505	151
MPa	MPa	VHN

122 ↔ 130 ↔ 138

Unstressed	Ductile	Brittle



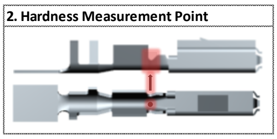
C H | M L M | H C

Reduced Terminals Classification Matrix

Terminals Classification Matrix work instructions (Operator Manual Input)

1. Choose 30 terminals for Hardness measurement from a recieved lote
Vickers Micro-Hardness Methodology Recommended
If other method used, **convert average** result to VHN by using the **ASTM spec.**

2. Hardness Measurement Point



4. Check for Final Classification
Result on the "Terminal Measurement Classification" board

5. Print out only the reduce result board and put it on the analyzed lote
Act according Reactivity Rule Board

6. Reactivity Rule Board

Criterion	Ductile	Brittle	Unstressed	Rule
L = LOW	X	-	-	OK for Production
M = Medium	X	X	X	Adapt Handling / Storage
H = Hard	-	X	X	Reject Lote / Alert Supplier

3. Lote Hardness Average

#	VHN
1	152
2	149
3	150
4	149
5	151
6	149
7	151
8	152
9	149
10	150
11	149
12	151
13	150
14	151
15	149
16	151
17	150
18	150
19	152
20	151
21	151
22	150
23	151
24	149
25	150
26	150
27	151
28	153
29	152
30	152
AVG	151
	VHN

Scope
Strength of copper alloys covering a wide range
(YS 50 to 1200 MPa and UTS 200 to 1400 MPa)
Deviations
UTS with less than 20% deviation at hardness lower than 150VHN
YS was estimated within 10%–25% with large deviation at hardness lower than 140VHN

Formulas	R^2
YS = 2,874 * VHN	0,916
UTS = 3,353 * VHN	0,933

Source
Hindawi Publishing Corporation, Journal of Materials, 2013, Article ID 352578
Materials Processing and Characterization Group, Vikram Sarabhai Space Centre
Received 23 November 2012; Revised 27 February 2013; Accepted 18 March 2013

Picture 114 | Classification Matrix method for manufacturing plants overview

Note: **ORANGE** indicates that operators need to input information. **BLUE** is only information.

Next, deeper explanations about this methodology are given.

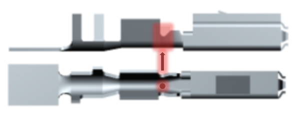
2. Hardness Measurements point
Terminal transition critical area were its recommended to realize the hardness measurement.

3. Lote Hardness Average
30 measures values, 1 average result.
(Operator Manual Input)

6. Reactivity Rule Board
According to the *Terminal Measurement Classification* board result actions are recommended. *LOW (L)* is normal handling and storage procedures active in the Company; *MEDIUM (M)* additionally adopting, as much as possible, this document described process improvement recommendations; *HARD (H)* reject the lote. Further analyses are recommended.

1. Choose 30 terminals for Hardness measurement from a recieved lote
Vickers Micro-Hardness Methodology Recommended
If other method used, **convert average** result to VHN by using the **ASTM spec.**

2. Hardness Measurement Point



4. Check Final Classification
Result on the "Terminal Measurement Classification" board

5. Print out only the reduce result board
and put it on the analyzed lote
Act according Reactivity Rule Board

6. Reactivity Rule Board

Criterion	Ductile	Brittle	Unstressed	Rule
L = LOW	X	-	-	OK for Production
M = Medium	X	X	X	Adapt Handling / Storage
H = Hard	-	X	X	Reject Lote / Alert Supplier

Scope
Strength of copper alloys covering a wide range
(YS 50 to 1200 MPa and UTS 200 to 1400 MPa)
Deviations
UTS with less than 20% deviation at hardness lower than 150VHN
YS was estimated within 10%–25% with large deviation at hardness lower than 140VHN

Formulas	**R^2**
YS = 2,874 * VHN	0,916
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Source
Hindawi Publishing Corporation, Journal of Materials, 2013, Article ID 352578
Materials Processing and Characterization Group, Vikram Sarabhai Space Centre
Received 23 November 2012; Revised 27 February 2013; Accepted 18 March 2013

3. Lote Hardness Average	
1	152
2	149
3	150
4	149
5	151
6	149
7	151
8	152
9	149
10	150
11	149
12	151
13	150
14	151
15	149
16	151
17	150
18	150
19	152
20	151
21	151
22	150
23	151
24	149
25	150
26	150
27	151
28	153
29	152
30	152
AVG	151
	VHN

Safety working area limits definition.
Specification Max: UTS (max value) / **YS** (min value)
Specification Min: UTS (min value) / **YS** (max value)

YS	UTS	Hardness
higher		higher
416,730	486,185	145
405,234	472,773	141
396,612	462,714	138
385,116	449,302	134
373,620	435,890	130
362,124	422,478	126
350,628	409,066	122
339,132	395,654	118
327,636	382,242	114
lower		lower
MPa	MPa	VHN

Criterion	Behavior	Defect Risk
higher	Brittle	Critical
12%	Brittle	High
9%	Brittle	High
6%	Brittle	Medium
3%	Ductile	Medium
0%	Ductile	Low
-3%	Ductile	Medium
-6%	Unstressed	Medium
-9%	Unstressed	High
-12%	Unstressed	High
lower	Unstressed	Critical

(UTS/YS)	
1,333	Specification Max
0,934	Specification Min
1,167	Measured Ration
Behavior	
15,8%	Measured Criterion
1,115	Strain Hardening Factor

Analyzed Lote **UTS/YS** ratio measured. *UTS* and *YS* from *Terminal Measurement*

Measured Criterion
Measured Lote Average Hardness against "ideal" *CuSn* copper alloy hardness value.

YS (*Yield Strength*) = (2,874 x Hardness column value)
UTS (*Ultimate Tensile Strength*) = (3,353 x Hardness column value)

Hardness
column Pre-defined values for *CuSn* copper alloy only. *130VHN* is considered the "ideal" value.

Criterion
column Hardness percentage pre-defined values for *CuSn* copper alloy **Behavior**.

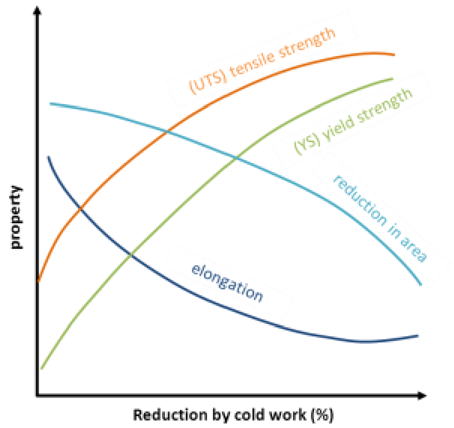
Defect Risk
column Pre-defined terminal defect risk classification stages according to *CuSn* copper alloy hardness level.

Strain Hardening Factor
= *σnom / σmax*
σnom value is calculated based on Linear Interpolation specification UTS values vs measured average VHN.
σmax value is calculated based on Linear Interpolation specification UTS values vs ideal VHN.

Picture 115 | Classification Matrix method deeper explanations

Taking the Terminal A, material CuSn0,1 as the base of this example, the classification matrix has the “target” hardness 130 VHN. As seen previously, this value was the recommend and defends on this investigation.

Upper limit and lower limit are defined supported in the hardness values, being the upper limit towards to brittle material behavior (higher hardness) and lower limit towards to unstressed material behavior (lower hardness).

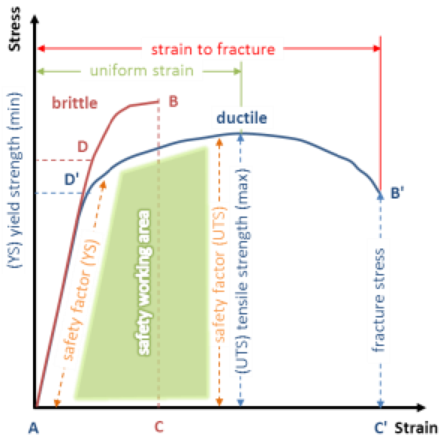


Graphic 52 | Material property versus reduction by cold work

By the graphic show aside, higher hardness means lower elongation and higher YS and UTS. For the lower hardness is the opposite. One more explanation about the terms used, been ductile the optimal material state for cold work operation, brittle state represents medium / high risk of breakage defect and unstressed state represents medium / high risk of not having a good terminal crimping (lower Copper compression ratio because of the forming loads relief).

Criterion is purely an empirical percentage of hardness to establish the behavior / defect risk definition steps and YS and UTS calculated by the previous presented formulas.

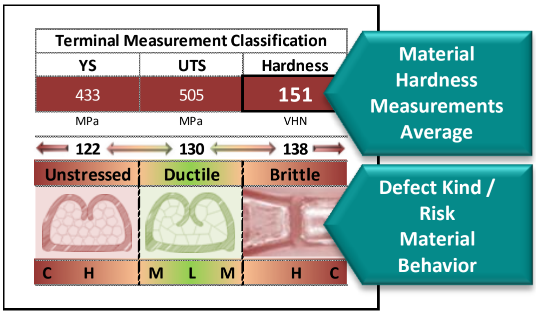
On the right side of the classification table is calculated as well the ratios UTS / YS which represent the safety working area definition. And for information only, is shown the measured criterion and the effect of cold working in the raw material, named strain hardening factor.



Graphic 53 | Safety working area definition

Considering that the material specification YS, UTS & VHN values send by terminal supplier are measures performed in raw material state. Terminals arrive to the Company manufacturing plants already with a strain hardening induced by the forming and forging operations related with terminals manufacturing which means that hardness that Company operators will measure on the batch received, most probably, does not have a straight relationship with the value present on the material sheet. The requisite to have an estimation of the effect of this cold work in the raw material was raised up. The calculation of this factor was based in the previously described “safety of factor”, σ_{max} = factor*σ_{nom}.

In this case, σ_{max} is the tension based in the hardness measured, a linear interpolation is used to calculate, as accurate as possible, the correspondent UTS value, the σ_{nom} in the tension based in the hardness target, 130 VHN, linear interpolation is used as well. The bases of the linear interpolation are the material specification UTS & VHN values send by terminal supplier.



Picture 116 | Terminal Measurement Classification

The operator just need to input 30 hardness measures, after this job is done, the average is automatically calculated and classified. The identification is done by colors, which can be easily associated to the identification matrix.

The terminal classification main function is to alert the plant services what to do with the analyzed lot, for that, the reactivity rule board was created.

6. Reactivity Rule Board				
Criterion	Ductile	Brittle	Unstressed	Rule
L = LOW	X	-	-	OK for Production
M = Medium	X	X	X	Adapt Handling / Storage
H = Hard	-	X	X	Reject Lote / Alert Supplier

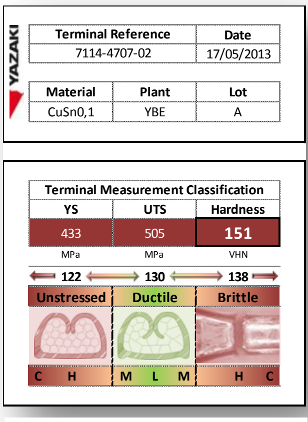
Picture 117 | Reactivity Rule Board

LOW = OK for production. Normal handling and storage restrictions are recommended.

MEDIUM = Adapt Handling / Storage procedure. Sensitive terminals, special cares need to be took accordantly (handling and storage) as per example the application of investigation proposed press velocity reduction, lubrication usage and higher cleaning frequency.

HARD = Reject Lote / Alert Supplier. Those are the immediate actions to be taken.

Aside is presented the Lote print out label format of the Terminal Classification Matrix.



Picture 118 | Terminal Classification Matrix label

4. Conclusions

It is considered that these investigation outcomes are important steps forward towards the understanding one of the major Customer quality complaints fonts in the wiring harnesses automotive industry business, the terminals breakage.

The requirement of the Company management was that this investigation could achieve firm outcomes which could strongly contribute for the reduction of this undesirable defect consequence. Expectantly, successful interventions on the product definition and/or on the manufacturing process, based on these investigation outcomes, will have an image and economic benefit on the business among the Company demanding Customers.

In order to have a robust investigation base, real information and physical terminals were collected from all varieties of accessible fonts. All the information was compiled and treated.

A no-conform (broken) terminal was received from a real Customer quality complaint and many “new” others (not broken) were, prevenient from actual stock, were analyzed in this investigation, trying to identify the terminal failure causes. Metallurgical observation, Scanning Electron Microscopy, X-Ray fluorescence spectrometry and Vickers micro-hardness analyses were carried out in order to pursuit that goal.

Diverse possible terminals deformation stages during the assembly process, industrial manipulation, forming process (crimping) and service conditions were observed and cursorily analyzed in this investigation, attempting to identify the terminals failure main occurrence and outflow root-causes. Several technical improvements were proposed throughout the investigation progression. Analyzing the obtained results, the following conclusions and outcomes can be identified.

Internal databases information analysis conclusions and outcomes

- As background information outcome, terminals were presented as automotive industry products, its functions, its manufacturing process and material characteristics.
- Very interesting Pareto’s graphics showing the most influent defect occurrence dates, product production dates, impacted Customer and Company plants, impacted projects, Customer and Suppliers impacted and others topics. These were a direct product of collected data treatment. Some were presented on this document others weren’t because are confidential informations.
- All analyzed occurrence and outflow root-causes were crucial to generate the essential Ishikawa diagram. On this diagram can be found all the interesting areas to be investigated associated to this defect typology.

- A new perspective of analysis was announced to the Company teams. Additional analysis methodology allowing the comprehension of other not negligible failure root-causes.
- A total of 25 terminals references were listed up, in a Customer quality complaint frequency order, as the most sensitive. Is estimated that these terminals references represent the most problematic actually in production.
- An added-value but empirical study about terminals design was developed. Presented results suggest the reasons why female terminals gender have higher adverse impact on terminal broken defects frequency and to reconfirm that the current common design is not optimal against stress concentration induced by manufacturing process and industrial manipulations.

Nondestructive and destructive analysis conclusions and outcomes

- Initial nondestructive simulations in virtual environment were performed indicating a specific high stress concentration area on terminals design, firmly answering, why all the analyzed Customer quality complaints related with broken terminals have revealed as the most fragile terminal area.
- All nondestructive methods tryout were concluded not applicable or generally inconclusive because of terminal size (small component), except for visual inspection method, which is already performed in a mastered manner in Company plants.
- New destructive simulations methods, preparation tests and necessary holding jigs were developed for this investigation.
- The definition of the bending angle range of fissuring initiation; In a terminal that is submitted to a bending operation (angle of 20° degrees or more) is registered a huge loss of mechanical resistance which can reach nearly half of its initial value; One terminal with the previous described condition needs more axial load to be inserted into its connector cavity which represents higher quality risk because the operations is manually performed; It was confirmed that even when a fragile terminal (after bent at 20°) is tested under oscillation movement (assembly and/or car movement simulation) it doesn't break, meaning, is thought that it becomes broken in the exact instance of insertion in the connector cavity (peak of load) or by an unusual hand-made action (example: reworks operation). All of these conclusions and outcomes were achieved by destructive simulations performed in an internal laboratory environment.

Metallographic analysis conclusions and outcomes

- Terminals body materials are Copper alloys which are constituted essentially by Copper. A thin layer (around 2 µm thickness) of Sn is also present but there is not conclusive about the coating influence in this investigation. Otherwise, base material contents of Sn and P were found higher than supplier specified, smaller contents of Fe, not respecting supplier specifications were found as well, and non-desirable elements as Al. Some of these elements were concentrated in small clusters, which can work as heterogeneities/cracks generators and can also contribute to cracks progression.
- Consequently, the expected usual hardness for this kind of Copper alloys wasn't in its original grade and it denoted increase can be endorsed to the successive mechanical work at room temperature, causing strain hardening in two different steps: terminal formation and crimping process. Terminals conformation imposed an increase of the base material hardness due to work hardening. The average hardness measured is higher than usual for this kind of Copper alloys, allowing become conscious that some hardness has been attained by work hardening.
- Metallurgical observation, strengthened by internal terminal crimping validation reports verification, allowed observing that grain structure was strongly influenced by the terminal manufacturing process. Analyzing essentially the bottom corners of microcut terminals surfaces, the chains of grains can be clearly visible and even internal defects such as micro.-cracks. Being the terminal forming process performed at room temperature and being the Copper particularly sensible to work hardening, easily it can be expected both mechanical strength and hardness increase.
- The crimping process inflicts an additional terminal hardness increase, which is not good for the terminal mechanical behavior, reducing its ductility and toughness.
- Terminal failure surface reveals that fracture takes place in different stages (slow cycle fatigue effect) due to different fracture surface morphologies.
- Fracture surface morphology is ductile, but close to brittle behavior in some areas, mostly on the top corners of the terminal microcut surface. Copper just presents brittle behavior under very specific conditions.

Internal crimping process analysis conclusions and outcomes

- A calculation based in the viscoplasticity theory estimates that a specific terminal with Copper alloy, CuSn, as body material presents a theoretical plastic permissible deformation velocity nearly 0,29 m/s, which represents that, the actual press machines in the Company shop-floors are setup with a velocity nearly 2,8 times (reference value) higher that theoretically necessary.

- The deformation degree on the terminal crimping area during the rear movement of the crimping applicator unveil depends on the normal pressure and on the orientation of the friction surface relative to the principal crystal axis.

Terminals Classification Methodology outcome

- This methodology objective is allowing the classification of all terminal lots at their arrival in manufacturing plants inspection reception areas. All further decisions will be taken based in real hardness measurements assessment. This methodology was created with a clear intention to be robust, practical and easily used by the manufacturing plants inspection reception actual staff, nevertheless, its necessary to consider that responsible staff personal needs training and manufacturing plants needed to be equipped with hardness measurement gauges.

Interpreting all statements performed before, the following improvements can be proposed:

Internal databases information analysis improvement proposals

- Is advisable that the Company should highly care for the predominantly the Top10 references from 25 terminals references identified as most sensitive.
- Terminal design families' classes were defined. By accessing those in early engineering projects development stages, terminal design criticality can be defined and extra protective actions necessity can be preventively announced to manufacturing plants.

Metallographic analysis improvement proposals

- The terminals Copper alloy chemical composition and original hardness should be restrictively controlled on the suppliers' facilities.
- The terminal Copper alloy strip should be heated at moderate temperature immediately before mechanical conformation avoiding work hardening effect as much as possible at Company manufacturing plants crimping process areas.
- If the previous proposal is very difficult to implement, it should be considered to perform an annealing treatment in order to reduce the mechanical strength and hardness of the terminal after mechanical deformation, restoring the ductility and toughness desirable for the terminal, at supplier's facilities. Thermic treatment parameters were subject of study during this investigation.

Internal crimping process analysis improvement proposals

- The crimping press velocity should be reduced mainly for the identified sensitive terminals in order to avoid internal material defects, cracks initiation and progression, superficial necking effects and allowing a better material flow during the process as well as stress accommodation.
- Frequent lubricant usages as well a higher clean frequency are estimated to carry important benefits to avoid mainly further material strain-hardening effect and also a negative microrelief on the crimping compression ratio.
- Should be advised a design development to the terminals suppliers in order to minimize stress concentration in areas stricken by the cold work hardening effect.

5. Suggestions for future investigations

Further investigations are required to cover all aspects mention on the Ishikawa diagram presented on this investigation. Hereunder selected questions/ideas that can be considered as next steps proposals:

- What happen in the Customer plants during those high defects occurrence frequency dates?
- Correspondently, what happen in Company manufacturing plants during those high defects occurrence frequency dates?
- The Pareto' Top5 1st placed material has an important difference to the second placed, why?
- The defined angle degree range for fissuring initiation can be used for ergonomic assembly operations improvements and existing sub-assembly tools improvement.

The major reason why the methodology DMAIC+R was not completely presented on this document is because this investigation essentially focuses on the Define phase. Hopefully, these investigation achievements will result in real engagements. For sure, by Company Management decision, this will take place in the near future.

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ANNEX I

Material Specifciation Datasheets

Terminal Supplier - Terminal A – material specification datasheet

KME Germany GmbH & Co. KG

le 12.02.2013

FCI AUTOMOTIVE FRANCE

Z.I. DES LONGS REAGES

28230 EPERNON
FRANCE

page 1

certificat de recéption 3.1 EN 10204:2004	rouleau 185312S	Liste embal 902159	commande 840980 - 1	client 04065700

nombre roul 1 — poids net 674,00KG

Numéros de colis WC227207

Votre numéro de commande OP064
numéro d´article FM466 — no. article 7069645
STOL80 0,285 x 72 SN
FM 466 Ind. A

proprietes mecaniques		nominal min.	nominal max.	effectif min.	effectif max.
epaisseur	mm	0,275	0,295	0,28	0,282
largeur	mm	71,9	72,1	71,91	71,93
résistance à la traction	|| RM N/mm²	370	440	429	434
limite elastique	|| RP N/mm²	330		403	407
allongement	A 50mm || %	4		7	8
durete	*HV	110	140	129	129
essai de pliage	|| 180° r= 0.30mm BK :			sans fissures	sans fissures
essai de pliage	+ 180° r= 0.15mm BK :			sans fissures	sans fissures
fleche	mm/ 1000		2	0,02	0,08
couche d' etain	Sn pur etame a chaud	1	3	1,59	2,03

* valeur indicative

analyse chimique %	sans plomb
SN	0.1884
CU	99.7580
P	0.0099
AUTRE	reste

controle de conformité
l ' expert: M. Schwandner
(Ceci est une lettre électronique. Elle est valable sans signature.)

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KME Germany GmbH & Co. KG
Sitz / Registergericht:
Osnabrück HRA 200902
USt.-ID.-Nr.: DE257040788
St.-Nr. 66/208/10059

Persönlich haftende
Gesellschafterin:
KME Germany Bet. GmbH
Sitz/Registergericht:
Osnabrück HRB 19014

Geschäftsführer:
Egon Mackowiak (Vors.)
Heinz Klenen
Hans-Joachim Scheja
Aufsichtsratsvorsitzender:
Roelf-Evert Reins

Terminal Supplier - Terminal B – material specification datasheet

Approved Company
ISO / TS 16949 : 2009

Wieland

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Lieu de chargement/n° **:000051/20272747**

Wieland-Werke AG D-89070 Ulm

FCI AUTOMOTIVE FRANCE
RUE DES LONGS REAGES
28230 EPERNON
FRANKREICH

Votre commande n°	: OP063
Date de commande	:
V/matérill n°	: FM448 IND. C, 14.07.

Confirmation de cde. n°	**: 11251393 001**
N/commande de fabrication n°	: **36306554**
Lot de contrôle n°	: 40002576571
Notre bon de livraison	: 81026197 010
Quantité livrée	: 7.475,0 KG
Date	: 10.05.2011

Certificat de réception 3.1 selon EN 10204 : 2004

Produit:
230 Bande étamée SnPUR®
Matière:
Wieland K65 CUFE2P
État: 300 dur

Dimensions:

Dim A:	0,29 mm	-0,012	+0,012
Dim B:	52,7 mm	-0,1	+0,1
Dim C:			
Dim D:			

Spécification: Révision/Date d'emission
DIN 17 666

Note:
Votre code n°: FM448 IND. C, 14.07.08 IND. C, 14.07.08

Composition chimique **selon 3.1 EN 10204 : 2004**

Cu Cuivre *Fe Fer* *Pb Plomb*
P Phosphore *Zn Zinc*

Caractéristique contrôlée	CU	FE	PB	P	ZN
Unité	%	%	%	%	%
Minimum/Référence(R)		2,1		0,015	0,05
Maximum/Référence(R)		2,6	0,03	0,15	0,2

Valeurs mesurées:
Éprouvette (No.)

65882	reste	2,289	0,0003	0,023	0,127
65952	reste	2,288	0,0013	0,021	0,123
65962	reste	2,285	0,0014	0,022	0,125
65992	reste	2,295	0,0009	0,025	0,123

Approved Company
ISO / TS 16949 : 2009

Wieland

Page
2 de 3

Certificat de réception 3.1 selon EN 10204 : 2004

FCI AUTOMOTIVE FRANCE

Votre commande n°	: OP063
Date de commande	:
V/matérill n°	: FM448 IND. C. 14.07.

Confirmation de cde. n°	: **11251393 001**
N/commande de fabrication n°	: **36306554**
Lot de contrôle n°	: 40002576571
Notre bon de livraison	: 81026197 010
Quantité livrée	: 7.475,0 KG
Date	: 10.05.2011

Essais mécaniques

RP0,2 *Limite élastique à 0,2 %* ***RM*** *Résistance à la traction Rm*
A2" *Allongement de rupture A2"* ***HV3*** *Dureté Vickers HV3*

Caractéristique contrôlée	**RP0,2**	**RM**	**A2"**	**HV3**	
Unité	MPa	MPa	%		
Minimum/Référence(R)	420	430	4,0	140	R
Maximum/Référence(R)	470	500		160	R

Valeurs mesurées:
Éprouvette (No.)

N6588V1 _A	441	469	5,0	147
N6588V1 _E	441	469	5,3	147
N6588V2 _A	440	466	4,4	148
N6588V2 _E	444	467	4,6	148
N6596V1 _A	437	465	4,7	147
N6596V1 _E	444	472	5,5	150
N6596V2 _A	441	467	4,6	149
N6596V2 _E	445	473	4,9	151
N6599V1 _A	442	466	4,2	149
N6599V1 _E	447	472	4,2	149
N6599V2 _A	444	468	4,0	149
N6599V2 _E	446	471	5,2	150
U6595V1 _A	432	460	4,4	150
U6595V1 _E	442	469	4,4	149
U6595V2 _A	443	469	5,5	148
U6595V2 _E	441	468	5,0	149
U6596V1 _A	438	467	4,7	148
U6596V1 _E	441	471	4,8	150
U6596V2 _A	443	466	4,7	148
U6596V2 _E	449	476	4,1	150

Autres contrôles

Caractéristique contrôlée	Unité	Valeurs specifiés de référence (R)		Valeurs mesurées	
		Mini.	Maxi.	Mini.	Maxi.
Conductivité électrique	MS/m	35		36,68	37,51
Pliage à bloc parallèle	Résultat bon				
Pliage à bloc perpend.	Résultat bon				
Ep. du revêtement à l'étain pur	µm	1	3	1,5	3

ANNEX II

Terminals A and B technical drawings

(Links on the color letters)