Precipitation hardened high copper alloys for connector pins made of wire

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Summary
A new generation of high performance copper alloy wire is attracting the attention of the electronic industry. The excellent material properties are due to the effect of precipitation hardening. The alloys are known in the electronic industry as precipitation hardened copper alloy strip for connectors and electrical contacts. Now these alloys are available as wire which is often further processed to square shaped connector pins. The properties of wire for connector pins made of the precipitation hardened alloy Wieland-K55 (UNS C 70250) are presented in comparison to other common connector pin materials. The combination of electric conductivity and mechanical strength as well as stress relaxation resistance data and further processing properties are discussed.

Key words:
Connector pins, wire, high copper alloys, precipitation hardening.

1. Introduction

Pure copper is the optimum material for electric current conductors. It combines high electric conductivity and a reasonable price. But many wire and cable applications require a strength which exceeds the strength attainable with pure copper wire, e.g. connector pins. In these cases the use of copper alloys becomes necessary.

Strength increase in alloys is possible by two different metallurgical effects, the solid solution hardening and the precipitation hardening. Brass and bronze are widely used solid solution hardened alloys. Certain high copper alloys with low contents of alloying elements, e.g. Ni, Si, Cr, are precipitation hardened and offer an interesting combination of high strength, good electrical conductivity and relaxation resistance. These alloys are predestined for application as connector pins in rough environment.

2. Solid solution hardened copper alloys

The copper lattice is able to dissolve a certain amount of atoms of other metals, e.g. Sn, Zn and Mg. This atoms take the lattice sites of copper atoms which is called a solid solution. The copper lattice in the vicinity of the atoms is distorted by expansion if the atoms are bigger than a copper atom, e.g. Zn and Mg, see scheme in fig. 1a. If the atoms are smaller than copper, e.g. Sn, Ni and Al, the lattice distortion is a contraction, see Fig. 1b. In both cases the resistance of the material against deformation is increased compared to pure copper, in other words: the material becomes harder. This kind of alloys is called "solid solution hardened alloys".

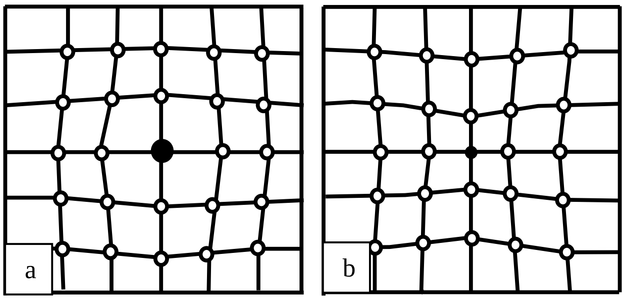

Fig.1: solid solution (schematic) of a) atoms with bigger size and b) atoms with smaller size than the lattice atoms.

Some elements can be dissolved in copper in high percentages. According to the equilibrium phase diagrams the maximum solubility of Zn is 39.0 % and of Sn is 15.8 % [1]. Standard brasses with 30 or 36 % Zn and bronzes with 5, 6 and 8% Sn are often applied in the electronic industry if the strength of pure copper is not sufficient.

To achieve a high strength wire in addition to the solid solution hardening effect a high degree of cold drawing deformation is necessary. Thin wires of phosphor bronze easily achieve strength values of 1000 MPa due to cold drawing.

But lattice distortion due to alloyed elements decreases electrical conductivity [2]. The disadvantage of solid solution hardened alloys is the low electrical conductivity, e.g. of about 25 % IACS (brass CuZn36) and about 14 % IACS (phosphor bronze CuSn6). This decrease of electric conductivity is due to the lattice distortion caused by the alloyed atoms.

In order to minimize the drop in electrical conductivity and to increase strength, solid solution hardened high copper alloys with low content of alloyed elements are applied. Examples are CuSn0.15, CuSn0.3 and CuMg0.1.

A weakness of all solid solution hardened alloys is their insufficient relaxation resistance at slightly increased service temperatures [3] beginning at about 60°C. To overcome this, the application of precipitation hardened alloys becomes necessary.

3. Precipitation hardened high copper alloys

The ability to dissolve other types of atoms in general is increased at elevated temperatures. If temperature decreases the limit of solubility is undershot. This fact may be utilized to generate precipitations by an annealing procedure at temperatures below the solubility limit. The atoms form precipitations, a second phase, an intermetallic. The size of these particles usually is lower than 100 nm. As the atoms leave the lattice, the lattice distortion is undone and the electric conductivity of the material increases. Fig. 2 shows a scheme of a precipitation inside the copper lattice. Cold deformation after the solution annealing but previous to the age annealing supports the formation of small-sized and homogeneously distributed precipitations.

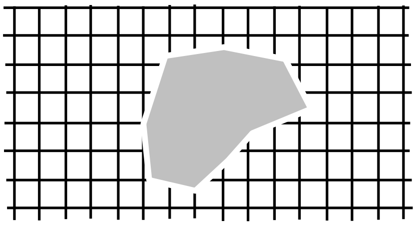

Fig.2: precipitation inside copper lattice (schematic)

On the other hand the precipitates increase the base strength of the material and influence the strengthening behaviour. They harden the material. For this reason such kind of alloys are called “precipitation hardened alloys”.

A big advantage of precipitation hardened alloys is their relaxation resistance. If the material is exposed to elevated service temperatures the precipitates do not dissolve and the increased base hardness is maintained.

Wieland produces several precipitation hardened alloys, see table 1, which are all candidates for connector pin material. Wire of two alloys, Wieland-K65 (CuFe2P) and Wieland-K55 (CuNi3SiMg), are already used for connector pins.

Table 1: precipitation hardening alloys for wire (round wire properties)

Wieland-designation	UNS-number	composition	Achievable tensile strength (MPa)	electrical conductivity (%IACS)
K55	C70250	CuNi3SiMg	> 800	45 - 55
K88	C18080	CuCrAgFeTiSi	> 650	75 - 85
K65	C19400	CuFe2P	> 600	max. 60
K80	C19210	CuFeP	> 600	max. 94

As the content of alloyed elements in these alloys is low, these alloys are classified as high copper alloys. They are called “ precipitation hardened high copper alloys”.

4. The choice of connector pin material

In comparison to connector pins made by stamping out of strip, connector pins made of wire offer a lot of advantages. Square shaped wire exhibits symmetrical shape, precise edge radius, coating on all surfaces, optimum grain orientation [4] as well as minimized scrap during processing.

The choice of the alloy is made according to different requirements of different industries. The advantages of the different alloys are listed in table 2.

Table 2: Advantages of different square wire materials

Alloy:	*Advantage:*
Brass	cheap alloy
Bronze	corrosion resistant alloy
CuMg	high conductivity
Wieland-K65	high strength + high conductivity + relaxation resistance
Wieland-K55	high strength + reasonable conductivity + high relaxation resistance
Wieland-K88	highest conductivity + high relaxation resistance
CuBe2 *	very high strength

* not produced by Wieland

5. Mechanical and electrical properties of square wire

After manufacturing the round-shaped semi-finished product “redraw wire” the next step is the production of square wire. The usually achieved combination of mechanical and electrical properties of square wire made of different copper alloys is shown in figure 3. The property combination achieved by Wieland-K55 square wire fits into the pattern of the other materials. The electrical conductivity reaches minimum values of 45% IACS. The softer conditions even reach values up to 55% IACS. The property data of Wieland-K88 is prospective as K88 square wire is in a project state.

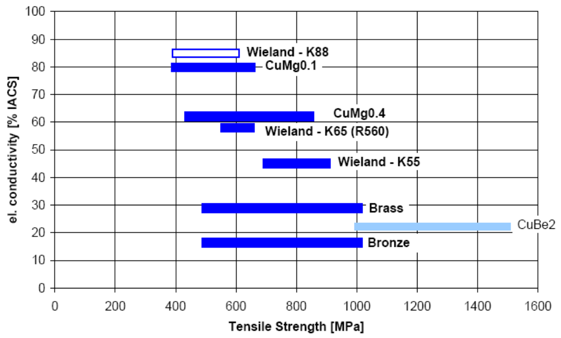

Fig. 3: Properties of square wire made of different copper alloys, dimension 0.63 x 0.63 mm. Square wire properties by courtesy of Richard Stenzhorn GmbH, Velbert-Langenberg, Germany. The data of K88 is prospective.

6. Relaxation resistance – an important property

Rough service conditions require high performance materials e.g. if automotive industry designs connectors in the vicinity of the engine:

- Impacts require high strength and ductility
- Vibrations require high fatigue strength
- Elevated temperature requires relaxation resistance
- Dirt requires corrosion protection

A high degree of relaxation resistance is only guaranteed by precipitation hardened alloys. Fig. 4 compares the precipitation hardening alloys Wieland-K55, Wieland-K65 and Wieland-K88 with phosphor bronze, a typical solid solution hardened alloy.

The strength of solid solution hardened alloys is due to the lattice deformation during the cold drawing process. During exposition to elevated temperatures the deformation thermally recovers (relaxes) and the strength is decreasing towards the value of the material’s base strength. As this base strength is low, the solid solution hardened alloys suffer from severe relaxation.

In principle the precipitation hardened alloys are subjected to the same material-internal procedures. But their base strength is much higher. So they exhibit a good, some alloys even a very good relaxation resistance [3, 5, 6].

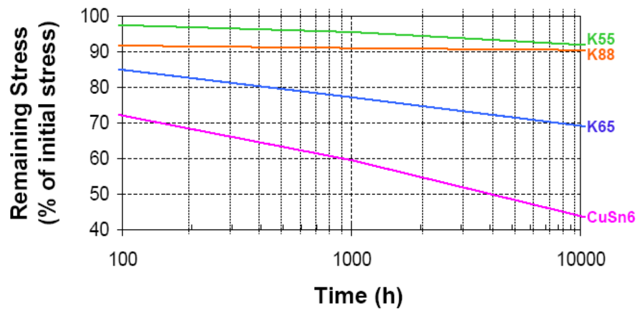

Fig. 4: Relaxation resistance data of precipitation hardened alloys K55, K65, K88 and bronze (CuSn6), measured at 150°C on thermally recovered strip with comparable loads (about 0.5 times of yield strength).

7. Further properties of Wieland-K55 square wire

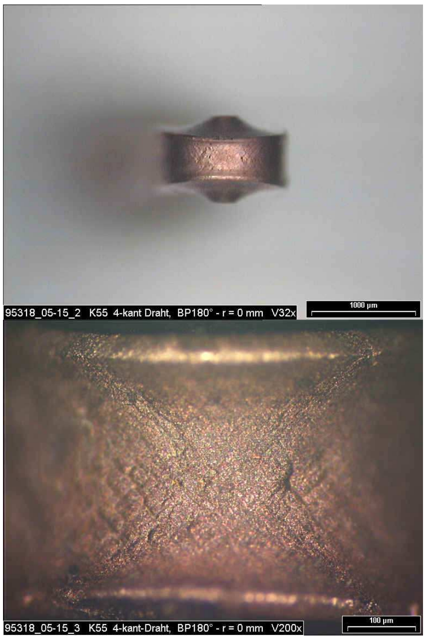

Fig. 5: Bending test with K55 square wire 0.63 x 0.63 mm, bending angle = 180°, bending radius = 0 mm. K55 material properties: tensile strength Rm = 782 MPa, elongation A100 = 1.2 %, electrical conductivity = 47% IACS. Bending test result: no cracks occurred, only ductile folds and orange peel.

Beneath mechanical, electrical and relaxation data further properties of the wire are important and were investigated. Galvanizing of K55 square wire has been proved to be as easy as strip galvanizing. Bending tests with K55 square wire were made. The results show a very good bendability (see Fig. 5). Additionally the production process of square wire must ensure that there is enough capacity for formability which is required by embossing, a highly challenging step during pin production as it generates large local strains.

The microstructure of K55 contains small precipitates embedded in the copper matrix as shown in the scheme in Fig. 2. The precipitations are nickel-silicides containing Ni, Si and Mg. The hardening particles are not visible in the optical microscope. Scanning electron microscope (SEM) is necessary to make them visible. Fig. 6 shows a SEM image of Wieland-K55 wire with small precipitates.

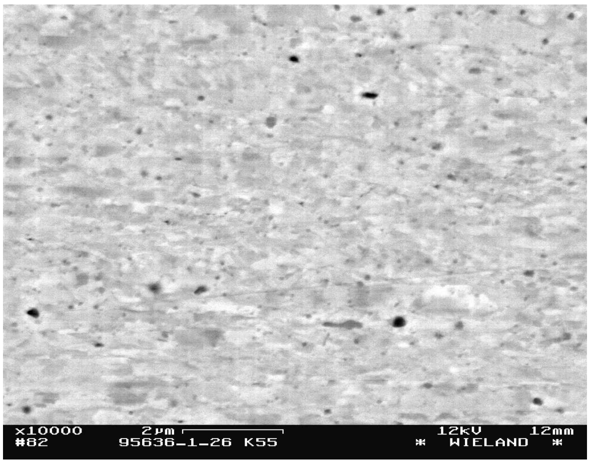

Fig. 6: SEM image of Wieland-K55 wire, longitudinal section, with precipitations (dark grey spots) in the copper matrix (fair grey). Wire drawing direction is horizontal.

8. Connector pins made of Wieland-K55

The production chain from casting to readily manufactured and mounted connector pins is long and material passes a lot of different workshops and even different companies. Fig. 7 shows the production chain.

Wieland-Werke AG has a long tradition in manufacturing precipitation hardening high copper alloys. The material Wieland-K55 has been commercially produced as strip for more than 15 years [3, 7]. The know-how of generating the optimum combination of good electrical conductivity and high strength has been successfully transferred to the product group "wire". Round-shaped wire made of Wieland-K55 is now commercially available in diameters of ≥ 0.3 mm.

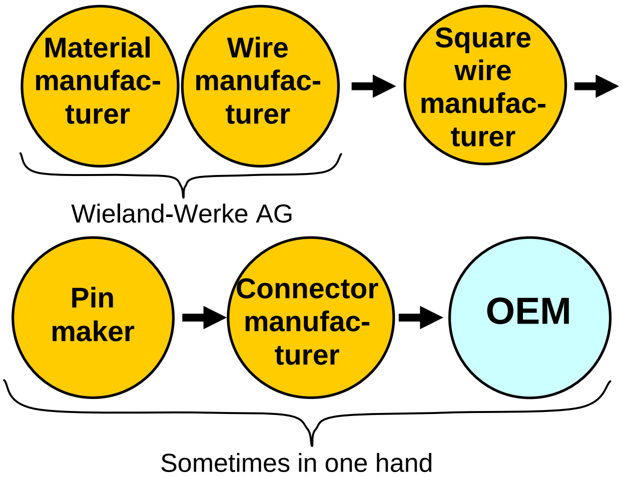

Fig. 7: Production chain of connector pin manufacturing in Europe

The further processing to square wire is made by redrawing companies which are highly specialized in order to fulfil the various customer requirements regarding geometry, surface and strength.

All subsequent production steps, e.g. galvanizing, pin making, embossing, bending and integration into the connector by plastic injection moulding are made by the connector manufacturers or their subcontractors.

9. Conclusions

Wire made of the precipitation hardened high copper alloy Wieland-K55, UNS C70250, more and more attracts the attention of connector designers. It is found to be suitable for application as square-shaped connector pin as it offers a lot of interesting properties:

- High strength (up to 900 MPa)
- Reasonable electrical conductivity (45 to 55 % IACS)
- High relaxation resistance
- Excellent bending properties
- Sufficient ductility for further processing
- Easy to galvanize

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