Development of High-Strength HCL®307 Copper-Alloy Strip for Electrical Components

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ABSTRACT: The use of connectors in automobiles and consumer appliances such as cellular phones and PCs has been increasing. In addition, connectors smaller than conventional ones are now required. Novel connectors have been actively developed by connector manufacturers in response to this trend. Meanwhile, higher strength and electrical conductivity are required for Cu-alloy strips as connector materials. Against this background, we have improved a Corson alloy, HCL305, which is currently in mass production for lead-frame application, by equipping it with properties suitable for connector application. Additionally, we have developed HCL307, a Cu-alloy coil strip with still higher strength, using HCL305 as a base material. The developed material has high strength as well as excellent bending workability. We expect it will be widely utilized as a material to replace phosphor bronze and low-beryllium copper alloy.

[1] Introduction

Although brass and phosphor bronze are heavily used in connectors, the use of various Cu-alloy strips is becoming popular because of a requirement for higher functionality. Of these alloys, a Cu-Ni-Si-based alloy known as a Corson alloy is widely used because of its good balance between strength and electrical conductivity. In response to the above needs, we studied the process of optimized production of the Corson alloy HCL305, which was originally developed for a lead-frame application. As the result of our study, a material with improved properties, including strength and bending workability, was developed and placed on the market.

Beryllium copper alloy is generally known as an even stronger material. However, because it is expensive and there is concern about its recyclability and environmental impacts because of its widespread use, development of a replacement is needed.[1)]

In light of these developments, as a next-generation connector material with a still-higher strength that will be required in future and as a replacement for existing high-strength materials (low-beryllium copper alloy), we have developed a Corson alloy, HCL307, with improved properties by increasing Ni and Si amounts with the Ni/Si ratio kept in a predetermined range in comparison with those of HCL305.

Various properties of both the HCL307 high-strength Cu-alloy strip and HCL305 for connector application are introduced here.

[2] Corson alloy

The Corson alloy is a precipitation-hardening-type alloy with a Cu-Ni-Si system as its main composition. Fine and uniform precipitation of Ni_2Si through a heat treatment process-solution followed by ageingenables simultaneous attainment of high strength and medium-level electrical conductivity. HCL307 includes Zn, Sn, and P as additives to the basic Cu-Ni-Si composition. Higher strength and improvement in stress-relaxation resistance properties and anti-migration properties[2)] can be expected through addition of moderate amounts of Sn and Zn.

[3] Properties required for connector materials, and methods of evaluating these properties

Connector materials require various properties, including responsiveness to formation of complexes peculiar to connectors; initial strength to reach contact pressures above certain levels in contact areas; and ability to maintain these pressures in the long term. Specific properties are: (1) strength; (2) electrical conductivity; (3) stress-relaxation resistance; and (4) bending workability. Each property is explained below.

(1) Strength

High spring strength is required to obtain high contact pressures; the index of this is tensile strength. Because function as a spring is endowed by properties in the elastic deformation region, it is desirable to evaluate the stress at which a permanent set occurs, i.e. 0.2% yield strength. Generally speaking, since 0.2% yield strength increases with increasing tensile strength, evaluation using tensile strength is acceptable in practice. In addition to tensile strength, spring-bending elastic limit and Vickers hardness can be used for evaluating spring strength properties.

A tensile test was performed to evaluate the tensile properties in accordance with JIS Z 2241 using an Autograph (Model AG-I 50kN) manufactured by Shimadzu Corporation. A spring-bending elastic-limit testing machine manufactured by Akashi Corporation was used to measure spring-bending elastic limits.

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A model MVK-G2 Vickers hardness tester was used to measure hardness.

(2) Electrical conductivity

The electrical conductivity of Cu alloys is expressed in terms of % IACS (International Annealed Copper Standard). When a current, I, is applied to a Cu alloy with a current-carrying length of L, a cross-sectional area of S, an electrical conductivity of Ec, a thermal conductivity of κ, and a volume resistivity of ρ, then ΔT, the temperature rise due to heat generation, is approximated by:[3)]

$$\Delta T \fallingdotseq (\rho I^2 L^2)/(2 \kappa S^2)$$

When a connector is downsized, the cross-sectional area of the current-carrying portion becomes smaller and ΔT tends to increase. Temperature rise has the potential to cause a reduction in the contact pressure due to stress relaxation. Consequently, electrical conductivity becomes a more important property with downsizing of connectors.

Electrical conductivity was measured with a model Sigmatest D, manufactured by Foerster Instruments Incorporated.

(3) Stress-relaxation resistance

Stress relaxation is the phenomenon of gradual reduction in the stress generated in a material with time under a fixed strain (deformation). A major accelerating factor is temperature. When in use, a connector is always subject to a constant strain due to contact pressure. When its stress-relaxation resistance property is poor, the contact pressure decreases with time, sometimes leading to malconduction. Connectors can be exposed to high temperatures, in automotive applications in particular, and careful selection of materials is required in such severe environments.

For evaluation of stress-relaxation resistance, a deflection is given to the sample such that the maximum surface stress is 80% of a 0.2% yield strength, and the sample is held at high temperatures under a given constraint condition. The degree of degradation from the initial state is calculated by measuring the displacement caused by the permanent deflection generated by the stress relaxation after the sample has been held at a given temperature and the deflection is released.

(4) Bending workability

Samples taken in directions parallel to, and perpendicular to, the rolling direction are called "good-way" (= G.W.) and "bad-way" (= B.W.) samples. Generally, the bending workability of B.W. samples is inferior when the metallographic structure obtained by cold rolling becomes the structure of the material to be worked on. However, because of the complexity of their shapes, connectors need to be subjected to extreme bending, and excellent bending workability is necessary in various bending directions. Consequently, improved bending workability and suppression of anisotropy to low levels are required for connector materials. Elongation was calculated from an evaluation index. However, evaluation of the appearance and cross-section after actual bending work has been performed, is reliable.

An evaluation method of 90° W-bending is generally employed. This is followed by observation of the degree of occurrence of crack(s) and wrinkle(s) on the surface.

Furthermore, we studied softening properties in addition to the above items. The samples were heated at predetermined temperatures for 1 hour and then water-quenched. Their Vickers hardnesses were then measured with a Model MVK-G2 micro-Vickers hardness tester, manufactured by Akashi Corporation.

[4] Properties of the new alloy

Tables 1, 2, and **3** show the chemical compositions, physical properties, and mechanical properties, respectively, of HCL307. They include data on phosphor bronze (C5191), phosphor bronze for springs (C5210), and low-beryllium copper alloy (C17510) for comparison. **Figure 1** shows the metallographic structure.

Table 1 Chemical compositions.

	Ni	Si	Zn	Sn	P	Be	Cu
HCL307	3.0	0.7	1.7	0.3	0.02	−	Bal.
HCL305	2.5	0.5	1.7	−	0.02	−	Bal.
C5191	−	−	−	6.0	0.19	−	Bal.
C5210	−	−	−	8.0	0.19	−	Bal.
C17510	1.8	−	−	−	−	0.4	Bal.

(mass%)

Table 2 Physical properties.

		HCL307	HCL305	C5191	C5210	C17510
Specific gravity	g/cm^3	8.9	8.9	8.8	8.8	8.8
Coefficient of linear expansion	$\times 10^{-6}/K$	17.4	17.4	17.6	17.6	17.6
Thermal conductivity	W/m·K	165	178	60	55	232
Electrical conductivity	%IACS	35	42	14	13	55
Volume resistivity	$\times 10^{-8} \Omega m$	4.54	4.10	12.3	13.3	3.14
Modulus of longitudinal elasticity	GPa	125	125	110	110	132

Table 3 Mechanical properties.

Alloy		HCL307			HCL305			C5191	C5210	C17510
Temper		H		SH	H		SH	H	H	HT
Direction		G.W.	B.W.	G.W.	G.W.	B.W.	G.W.	G.W.	G.W.	G.W.
Tensile strength	MPa	750	735	820	685	650	730	640	650	860
0.2% yield strength	MPa	700	690	770	600	575	700	600	600	740
Elongation	%	13.5	14.5	3.0	14.5	17.0	5.0	15	30	12
Spring-bending elastic limit	MPa	710	730	770	590	610	650	530	540	690
Vickers hardness	Hv	240		250	220		240	200	220	250

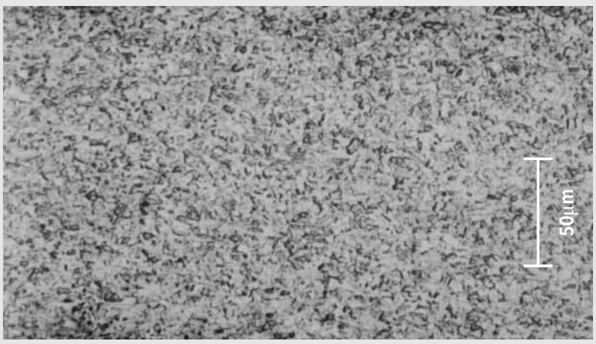


Fig. 1 − Microstructure of HCL307.

HCL305 has a higher electrical conductivity (above 40% IACS) than does phosphor bronze. HCL307 has a slightly lower electrical conductivity than HCL305 because of the higher rate of addition of elements. However, it still has 35% IACS, which is higher than that of phosphor bronze.

With regard to mechanical properties, the strength of HCL305 is not lower than that of phosphor bronze. The strength of HCL307 is further improved owing to the higher concentration of Ni_2Si caused by the addition of greater amounts of Ni and Si. The HCL307-SH shows a strength close to that of low-beryllium copper alloy. For elongation, the HCL307-H developed by our company shows values above 12% in both G.W. and B.W.

HCL307 has a fine spheroidized metallographic structure. Its anisotropy is small, and the difference in strength between G.W. and B.W. is comparatively small.

Figure 2 shows the stress relaxation properties at 150°C. The stresses applied were 80% of 0.2% yield strength. The materials developed by our company show stress-relaxation resistance properties better than those of phosphor bronze. Both HCL307 and HCL305 maintain more than 75% of initial contact forces in both the G.W. and B.W., even after 1000 hours. HCL307 shows better properties than HCL305. We consider the reason for this to be as follows: When elements with larger atomic radii than that of the solvent element (Cu in this case) are added, stress-relaxation resistance properties are improved;[2] hence the large radius of Sn added to the HCL307 improves the stress-relaxation resistance properties.

Figure 3 shows softening properties. Softening of phosphor bronze progresses markedly at 350°C, whereas HCL305 and HCL307 maintain more than 80% of their initial hardnesses up to 550°C, indicating good heat resistance.

Table 4 shows the bending workability of strips with a thickness of 0.2 mm, and **Figure 4** shows the appearances of the

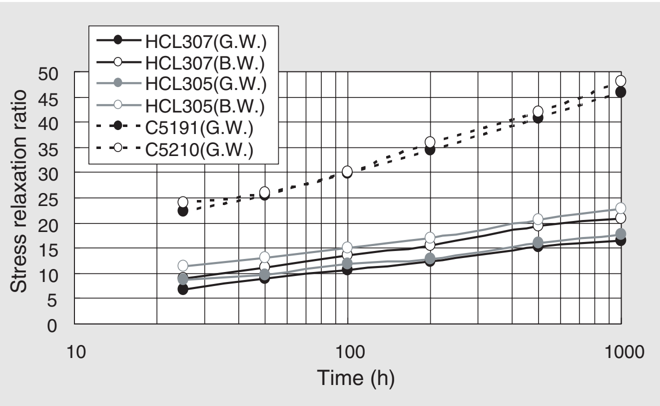


Fig. 2 – Stress-relaxation properties (temperature: 150°C, applied stress: 80% of 0.2% yield strength).

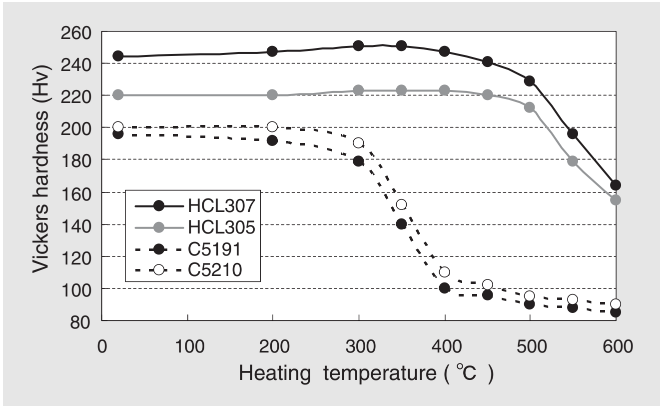


Fig. 3 – Softening properties (heating time:1h).

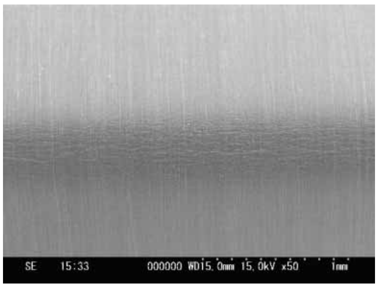
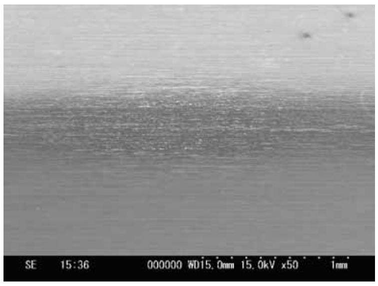
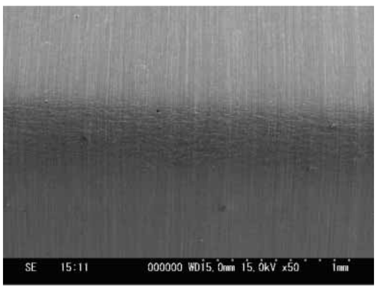
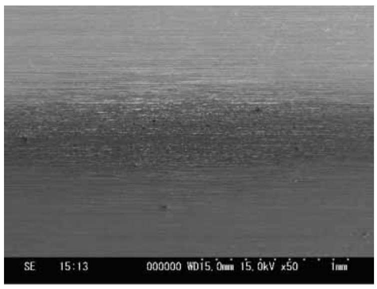
Bending direction	G.W.	B.W.
HCL307		
HCL305		

Fig. 4 – Appearances after 90° W-bending (strip thickness:0.2 mm, bending radius:0 mm).

Table 4 Bending workability (strip thickness:0.2 mm).

Alloy	Temper	Bending direction	Bending radius (mm)			R/t
			0(sharp)	0.1	0.2	
HCL307	H	G.W.	B	A	A	0
		B.W.	B	B	A	0.5
HCL305	H	G.W.	A	A	A	0
		B.W.	A	A	A	0
C5191	H	G.W.	A	A	A	0
C5210	H	G.W.	A	A	A	0

Evaluation criterion: A-sound, B-wrinkled, C-cracked

bent portions of strips with a thickness of 0.2 mm after bending with a radius, R, of 0 mm (i.e. sharp condition). Generally, when a material is made to be of a higher strength, its bending workability deteriorates. However, the "H" material of HCL307 has a large level of elongation. Although it shows a few wrinkles in B.W. bending, it shows approximately the same bending workability as that of HCL305. It also shows good values, 0 or 0.5, on R/t evaluation.

[5] Conclusions

We have developed HCL307 for effective application in connectors that require high strength. It is based on a Corson alloy and simultaneously attains high electrical conductivity, excellent stress-relaxation resistance, heat resistance, and bending workability, together with high strength.

Figure 5 compares the properties of the alloys developed by our company and various other alloys. The development of HCL307, together with HCL305, has enabled us to cover a wide spectrum of strength levels and meet a wide range of customer needs. In future, we hope to expand the applications of HCL307 as a next-generation connector material and a replacement for low-beryllium copper alloy, at the same time as we promote HCL305 for replacement of phosphor bronze and further sales for automotive application. We also hope to develop even higher-strength materials based on the present alloy by improving the additive elements and the production process.

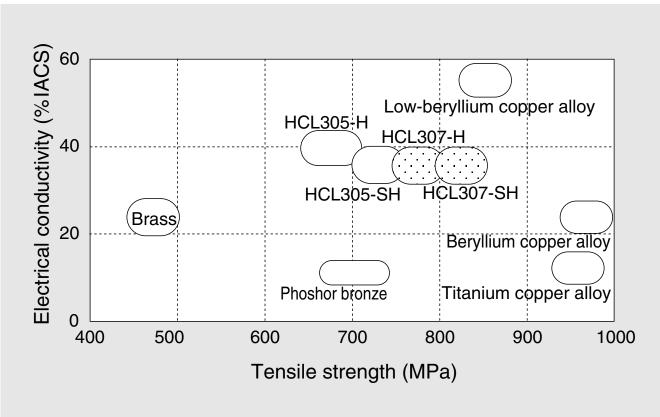


Fig. 5 − Comparison of properties of alloys developed by our company and various others.

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