Developments and Future Trends in Copper Alloy Strip for Electronic Equipment and in Copper Tube for Air Conditioners

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The Kobe Steel group has the largest share in Asian market for high performance copper alloy strips for electronic equipment and for air conditioning copper tubes. Our high performance copper alloy strips and copper tubes meet diverse needs of our customers. This article summarizes the present and future technology trends of copper strips and tubes, and our latest products.

Introduction

Our group owns the largest share of copper alloy strips for electronic equipment and of copper tubes for air-conditioners in Asia. We have developed copper products in response to various needs of the time.

Lately, electronic equipment has changed dramatically. The cellular phones have gone through downsizing, upgrading of performance and digitization to own capabilities including clock, camera, TV and e-mail. The modern automobiles have various electric components including the ABS for safety and CCD cameras for rear and side monitoring. The engines are controlled by computers for energy saving and for optimum performance.

We have developed innovative copper alloy products having good balance of conductivities and strengths, and our products are becoming indispensable electronics materials. We are a unique manufacturer of copper strips with our main focus on electric equipment and 97% of our products are for electronic applications.

In addition, copper tubes are used in many applications including heat-transmitting tubing for heat exchangers, because of their excellent thermal conductivities, formabilities and corrosion resistance.

Recent needs for energy-saving, high-performance and cost-reduction have led the manufacturers of heat exchangers of residential- and commercial-air conditioners to employ inner grooved tubes having a number of fine grooves on the interior surfaces of the tubes. Also, the rapid growth of the Chinese economy drove up the bare copper price and there is an increasing interest in thinner-wall tubes using higher strength copper alloys for cost reduction.

In April 2004, Kobelco & Materials Copper Tube, Ltd. (KMCT) was established as a joint-venture between Kobe Steel Ltd. and Mitsubishi Materials Corporation, providing a manufacturing base for high quality products with strong technical resources.[1)] The company mainly produces grooved tubes for air conditioners and finned tubes for refrigerators, and is the only company in the industry that can supply heat-resistant, high-strength and corrosion-resistant copper alloy products.

1. Development of copper strip products

1.1 Market trend of copper strips for electric equipment

1.1.1 Downsizing of electronic equipment

Electronics equipment is becoming thinner and smaller with larger capacities and higher performance, and copper alloys are required with higher-strength, higher-reliability (thermal resistance and stress-relaxation resistance) and better bending formability. This trend will increase more in the future. **Figure 1** shows the downsizing trend of terminals and connectors.[2)]

To respond to the downsizing requirements, various next-generation materials are being

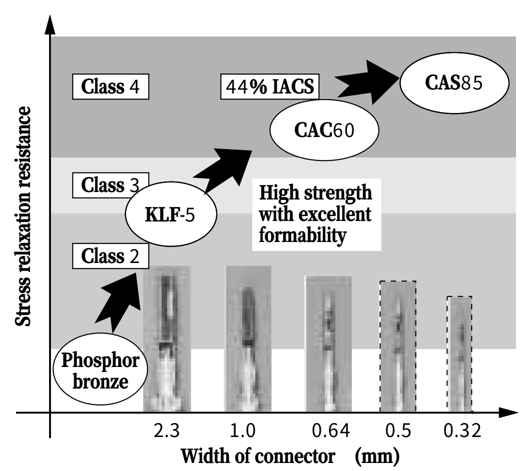

Fig. 1 Trend of connector shape and demanded characteristic

studied. The strengthening of copper alloys includes refinements of grain size and precipitate size, optimization of manufacturing processes and characteristics control by addition of trace elements. Basic research on strengthening mechanisms and microstructure control has led to the development of copper alloys with high conductivities and with high strengths.

1.1.2 Shift of production to Asian countries

The manufacturers of terminals are shifting their production to China and it is becoming necessary not only to establish the production bases, but also to supply products with high performance such as strength and thermal resistance at lower costs. There is a strong demand for alloys having designed-in characteristics of low-cost and recyclability.

1.2 Development of copper strips with higher performances

1.2.1 Copper alloys for large-current applications and alloys for semiconductors and LEDs

The goals of developing copper alloys for electronic applications are 1) to increase the alloy strength without sacrificing the electrical and thermal conductivities and 2) to establish the manufacturing process of the alloy. For the strengthening of copper alloys, we have consistently pursued a mechanism combining precipitation hardening and solid-solution hardening by alloying elements.

For many years we have developed and supplied the KFC (Kobe Ferrous Copper) which is now regarded as the global standard of copper alloys for electronic applications. The KFC has a combination of high-strength around 500 MPa and excellent electrical- and thermal- conductivities of 90% IACS, both properties brought about by Fe_2P precipitates.[3]

White LEDs, which are finding more applications in traffic signals and automotive lights, generate significant amounts of heat and the electrode materials used for white LEDs are required to have thermal-resistance along with high conductivities. At the same time, superior press formabilities and bending capabilities are required for the materials to increase the productivity of end products.

To satisfy those demands for LED, we have recently developed KLF2, having conductivity of 75% IACS and strength of 600 MPa, by adding solid solution elements. The alloy also has good press formability and bending capability.

1.2.2 Copper alloys for mini-transistors and IC

Productivity and formability are important characteristics, as well as electrical characteristics, for mini-sized semiconductor parts. More numbers of process steps are involved in the production of mini-transistors, making their lead-frames subject to more soldering steps. Such lead frames are required to have good solder-wetability, reflow-soldering resistance, resin-adhesion, resin de-burring and spot-weldability.

We have developed a new heat-treatable KLF125 alloy by clarifying the effect of alloying elements on the above characteristics and by optimizing property balances.[4]

Occasionally small parts are made by etching. Residual stress can warp the products especially in the case of a half-etching process in which only half of the thickness is etched away. We have developed products with low residual stress for such applications.[5] A lot of products are first made by etching processes and then subsequently by press forming for high volume production. For those materials, both press formability and etchability are required. The KLF170 has been developed for this purpose by refining precipitate size.

Figure 2 shows the positions of our copper alloys for semiconductors in the 2-dimensional map with coordinate-axes of electrical conductivity and tensile strength.

1.2.3 Next generation terminals

Many electronics components are placed in the engine compartment to save space in the driving

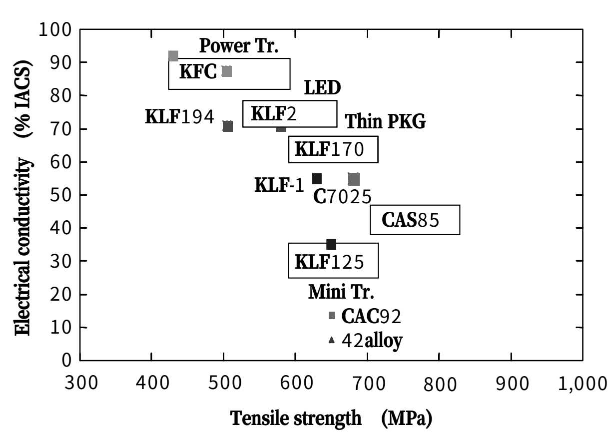

Fig. 2 Position of new copper alloys for semiconductor and electrical circuit

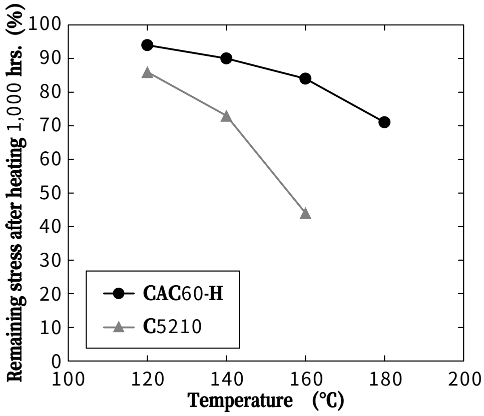

Fig. 3 Remaining stress after heating 1,000 hrs.

room, and are therefore subjected to severe conditions which require copper alloys to have higher thermal resistance. Some parts, such as connectors, are required to have extremely high long-lasting reliabilities at elevated temperatures as high as 120 to 165℃. Stress relaxation resistance is becoming indispensable for those alloys. In response to this requirement we have developed various alloys for different applications.[6)]

Japanese Automobile Standards Organization (JASO) classifies the copper strips for electronic connectors used in automobiles based on their characteristics (JASOD620). The standard ranks the alloys having 20-50% IACS and less than 15% stress relaxation at 150℃, 1,000 hrs as the highest in the stress relaxation characteristics. We have developed copper alloys with such small stress relaxation by controlling the densities of precipitates and dislocations and by optimizing the manufacturing process.

Figure 3 shows the residual stress after heating at each elevated temperature for 1,000 hrs. The CAC60 alloy retains good spring pressures at elevated temperatures in exothermic conditions.

1.2.4 Copper alloys for distribution circuit

Distribution circuits of automobiles, such as junction blocks (JB) and bus-bars, require alloys with good conductivity and bending formability. Strength is not usually an issue, because the parts are usually designed to be thick enough to allow high electrical current.

We have been supplying various copper alloys with higher than 60%IACS for those applications; however, the requirement for bending formability is becoming stricter as the part-size becomes smaller. In order to respond to this requirement, we have developed alloys with higher than 60%IACS and R/t = 0.5 (R: bending radius, t: thickness). The alloys CAC12, 16, 17, 19 have won good reputations[7)] with their good bending-formability, which is a result of fine grain-sizes brought about by the combination of precipitation annealing and high-temperature short-time annealing.

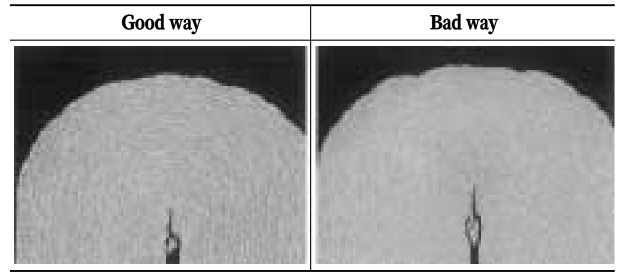

Photo 1 Cross-section of U bend (CAC19 alloy, 0.5R)

Photo 1 shows the cross-sections of U-bent samples of the CAC19 alloy. No cracks are observed either parallel or perpendicular to the rolling direction.

1.2.5 Micro terminals

The small terminals which are increasingly used for automobiles have width of mainly 0.64 mm. The width is becoming smaller and widths of 0.5 mm and 0.32 mm have already been discussed for applications. At the same time, the numbers of poles are increasing to 140. The CAC60, which we produce in volume for 0.64 mm width terminals, has good stress relaxation resistance, 45% IACS, tensile strength of 650 MPa and is capable of complete fold bending.[8)]

The micro terminals in the next generation will require copper alloys with higher strength. We have developed the CAS85 which has tensile strength of 750 MPa with improved conductivity and formability.[9)] **Figure 4** shows the portfolio of our copper alloy products for terminals and

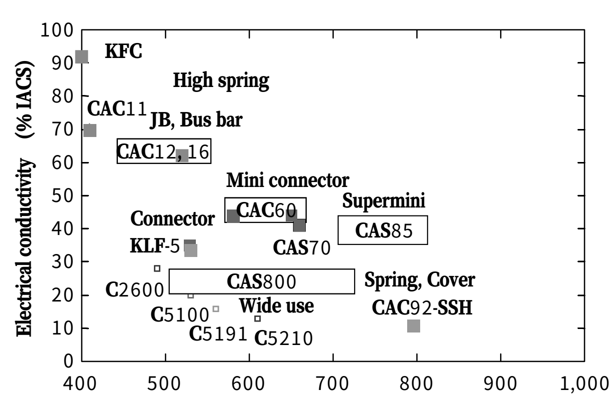

Fig. 4 Position of new copper alloys for terminal and connector

connectors.

1.2.6 Tin-plated material

We also supply tin-plated copper alloy products. As the numbers of connections and fitting forces of connectors increase, the connectors are required to have smaller insert force for better workability and productivity.

We have achieved 25% reduction of insert force without sacrificing the electrical reliability and corrosion resistance. The alloy has 3 layers of tin-plate on a Ni plate layer which prevents diffusion of alloying elements into the tin layer.[10)]

The soldering temperature for electronic equipment has been risen to above 250℃ to accommodate the lead-free soldering required for environmental protection. Our tin-plated copper alloy has good solderability for lead-free solders and will find more applications in the future.[11)]

1.3 Summary of copper strip products

Our copper group has developed new copper alloys and tin-plated products matching the needs of the market. We will strengthen the position of our products in the global market by establishing production bases overseas and making alliances with foreign companies.

2. Development of copper tube products

2.1 Development of high performance copper tube products

2.1.1 Copper tube for air conditioners

For further energy-saving and cost-reduction, the copper tubes are required to be lighter and to have good thermal conductivities in circulating coolant. Our study has revealed that lower fin-heights with larger lead-angles are effective for the new coolant R410A. The new design concept based on this study enabled us to develop a new high-performance tube product with large lead-angle with no increase of weight.

KMCT has test benches for the production and evaluation of heat-exchangers, and not only develops tubes, but also makes proposals on processing techniques and performance improvements by applications of the grooved tube for return bend. We are also studying the future technology of reducing contact thermal-resistance between the copper and aluminum tubes. Products using carbon oxide as natural coolant are expected to increase rapidly and we have started studying the thermal conductance of inner grooved tube under supercritical conditions.

2.1.2 Heat transmitting copper tube for compression type refrigerator

Traditionally, improvements of heat transmission performance of a tube have been achieved by the increase of surface areas, however, the approach tends to result in increases of cost and weight per length. We have achieved high performance by analyzing the flow of coolant using a high speed camera and by reflecting the result in the thin-precision forming of semi-hard material.

The TOPCROSS CHT34-N2 developed for condensers has a superior condensability on the exterior surface of the tube due to its open fin shape, and the sharp edge of the fins allows quick release of condensed fluid.[12)]

The TOPCROSS EHT34 developed for evaporators has good resistance against smudge with its open shape unlike other cavity-type boiling structure. **Photo 2** and **Photo 3** show the appearances of TOPCROSS CHT34-N2 and TOPCROSS EHT34 respectively. **Figure 5** and **Figure 6** show the condensing and evaporating properties of the respective tubes.

2.1.3 Heat transmitting copper tube for absorption refrigerator

Absorption refrigerators are widely used for air-conditioning in Japan and in other Asian countries because of their Freon-free, environmental-friendly features. An absorption refrigerator mainly consists

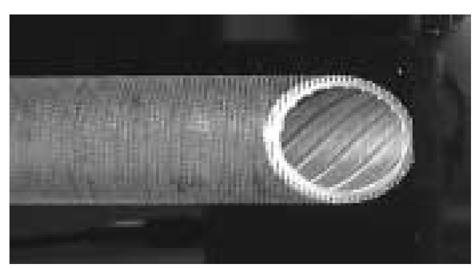

Photo 2 Overview of TOPPCROSS CHT34-N2

Photo 3 Overview of TOPPCROSS EHT34-N2

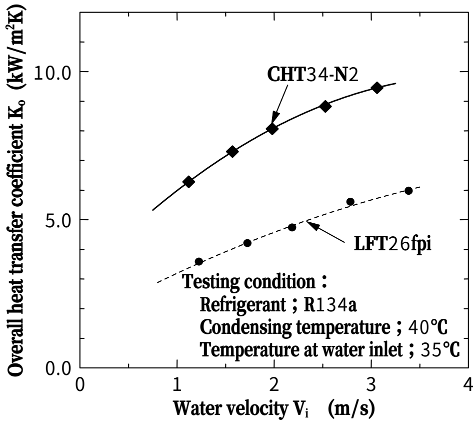

Fig. 5 Overall heat transfer coefficient vs. water velocity

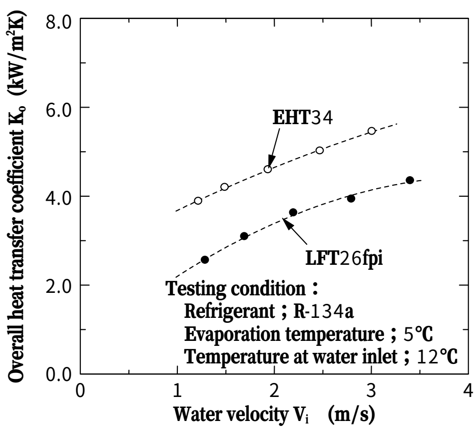

Fig. 6 Overall heat transfer coefficient of flooded type evaporator

of heat exchangers such as evaporators, absorbing circuits, condensers and regenerators. Each heat exchanger has different conductivity characteristics and requires different types of heat-transmitting tube.

We have developed thin-wall / high heat-transmitting tubes by precision forming of a semi-hard material. Further developments such as the VOF analysis[13] have brought approx. 80% share in the domestic market of the tubes.

An evaporator cools water by dripping water on the heat-transmitting tubes placed horizontally in a vacuum. Because of the mechanism, the wetability for water of the exterior surface of the tube affects the performance of the evaporator. Our ENDCROSS products have excellent evaporation capabilities, because the many independent protrusions on the exterior-surface improve water-wetability along the tube axis and make the fluid layer thin by the surface tension at the protrusion edges.

An absorbing circuit heats water by an exothermic reaction between high-concentration lithium-bromide solution and water vapor generated by the evaporator. Our ENDCROSS without inner rib is recommended for this application because the independent exterior protrusions stir the fluid and the rib-less interior wall prevents pressure-losses.[14]

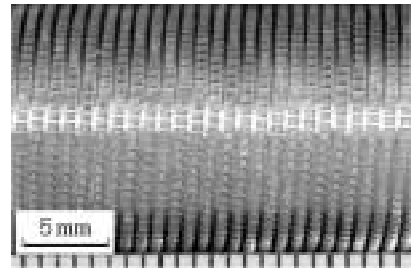

Photo 4 Overview of ENDCROSS

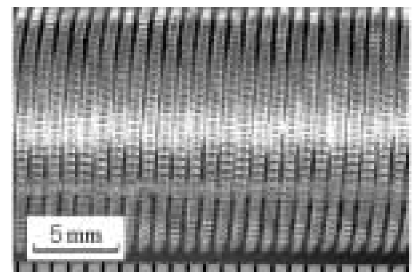

Photo 5 Overview of CONDCROSS

A condenser condenses water vapor generated by a regenerator and our CONDCROSS is recommended with its independent protrusions optimized for evaporation.[15]

A regenerator increases the concentration of the lithium-bromide solution diluted in the absorbing circuit by the water vapor running in the tube. The thermal conduction in the exchanger is close to the pool-boiling and forms lithium-bromide crystallites which causes plugging of the tube. Because of this, most regenerators today use low-fin type tubes with simple inner surfaces. We are developing new heat-transmitting tubes with better heat transmission for this application.

Photos 4 and **5** show the appearances of ENDCROSS for evaporators and CONDCROSS for condensers respectively.

2.1.4 Copper alloy tube

We are the only manufacturer of copper alloy tubes in the industry and are developing new applications. The alloy tubes are classified either into the high-strength type or into the high corrosion-resistance type.

HRS35LT is a high strength alloy having thermal resistance at 1,000℃ despite its precipitation hardening feature and is used for in-

Table 1 Features of each copper alloy tubes

Alloy name	Function	Features	Application
HRS35LT	Precipitation hardening type	Super heat-resistant and strength	Heat exchanger for Eco-cute, 4 way valve
KHRT	Solid-solution hardening type	High heat-resistant and strength	Heat exchanger for air conditioner
MA5J	Precipitation hardening type	High strength (within JIS)	Home refrigerator, Heat exchanger for Eco-cute
PICOLESS	Corrosion-resistance copper alloy	Corrosion resistance toward type II corrosion	Insulated tube for piping
KALT	Corrosion-resistance copper alloy	Corrosion resistance toward ant nest type corrosion	Heat exchanger for heavy duty air conditioner

furnace brazing.[16)]

On the other hand, KHRT is a solid-solution hardening type and has a good formability with thermal resistance at 900℃ and is suitable for inner grooved tubes and complex shape parts.[17)] This alloy is the mainstream of high-strength alloys since it is castable in-house and lower in cost. The MA5J has high strength, although lower in thermal resistance, and its composition is in the JIS range. The alloy is suitable for products made through an automatic brazing line.[18)]

The corrosion resistant PICOLESS is used for our coated copper tubes. The Zr content in the alloy prevents type II corrosion occurring in the hot water piping. The KALT is used for the heat transmitting tubes of air conditioners installed in an oil-rich environment such as food processing factories and machine shops. The Mn content in the alloy prevents the ant-nest type corrosion.

Table 1 summarizes the properties of the alloys.

2.1.5 Development of heat exchangers based on a new concept

We are developing new heat-exchangers, using carbon dioxide coolant, based on our design and analysis technologies.

Heat-exchangers for carbon dioxide coolant have not yet been optimized and various developments are being made for practical applications such as refrigerators, vending machines, and air-conditioners. New-type heat exchangers such as solid-type brazed heat-exchangers are also being developed.

2.2 Summary of copper tube products

The shift to overseas production by air-conditioner manufacturers reduced the domestic demand for copper tubes, forcing us to establish KMCT. On the other hand, products using carbonic-gas coolant have increased dramatically, bringing us hope for new demand.

KMCT owns its original technologies such as inner-grooved tubes, high-performance finned-tubes, high-strength copper alloys and high corrosion resistance copper alloys, and contributes to society by providing products and services related to energy conservation and environmental protection.

3. Globalization of copper business

Our copper strip product group has its mother factory in the Chofu Plant, and slit processing centers in Thailand (KEMT: Kobe Electronics Material (Thailand) Co., Ltd.) and in China (Suzhou Kobe Copper Technology, Co., Ltd.). The SKPL (Singapore Kobe Pte. Ltd.) has capabilities of plating, shape rolling and slitting. The Kobe Leadmikk Co., Ltd. in Moji provides press forming and plating, and owns technologies such as nickel plating, silver plating and lead-free solder plating. The company also owns a plating factory in Wuxi China (Shinko Leadmikk (Wuxi) Co., Ltd.).

Our copper tube product group has KWCP (Kobe Wieland Copper Products, LLC) in the USA and KMCT (Kobelco & Material Copper Tube, Ltd.) in Malaysia and Thailand. We have established a robust supply system from Southeast Asia under the joint venture with Mitsubishi Material Corp. The Shinko Metal Products Co., Ltd. manufactures products including special alloy tubes and molds for continuous-casting.

Conclusions

To respond to the needs of the time, the copper product group has developed unique alloys and products such as strips for electronic equipment and tubes for air conditioners. The business is supported by our characteristic technologies and has grown into global scale to own the largest share in Asia.

We will continue basic research, and develop new materials and products by addressing the needs of the time.

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