Copper-Coated High-Strength Electrical Wire

Kenta MATSUOKA*, Akihito HOSHIMA, and Daigo SATO

In an advanced information society where IoT and drones will widespread and in the near future where multitasking robots will be active due to the declining birthrate and aging population, there will be a greater need for stronger and lighter communication wires more than ever. The Special Steel Wire Division has developed thick copper covered (TCC) wire, which is a conductor composite material in which a high-strength steel wire is coated with a thick copper layer. TCC wire has higher strength than other copper alloy and composite material wires, and is particularly superior in flexibility. This paper reports on the characteristics of TCC wire.

Keywords: coating with copper, high-strength electrical wire, flex resistance, diameter reduction, corrosion resistance

1. Introduction

This paper is a follow-up to "High-Strength and High-Conductive Material to Replace Beryllium-Copper Alloys" which appeared in SEI Technical Review No. 84 (April 2017). In the initial report, the authors discussed this material with the expectation that it would be used for conductive springs. However, contrary to this expectation, we received many inquiries about the use of this material for high-strength electrical wires. Wires that are laid along the joints of drones and robots are required to be highly flexible, and are also required to be increasingly thin as the number of wires used for wiring sensors and other devices increases. In addition, the spread of electric vehicles has accelerated the electrification of in-vehicle heating. With increasing demand for heater wires, they are required to be strong enough to prevent combustion attributable to breakage. In order to meet the above requirements, the Special Steel Wire Div. took advantage of the electrical wire technology of the Sumitomo Electric Group to develop thick copper covered (TCC) wire whose strength level cannot be achieved by copper alloys. The Division has started to use TCC wire in harsh environments.

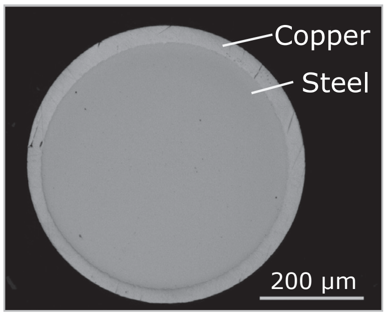


Photo 1. Cross-sectional view of TCC wire

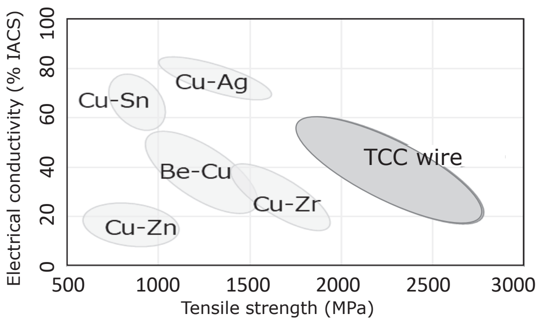


Fig. 1. Relationship between electrical conductivity and tensile strength

2. Features of TCC Wire

TCC wire is an element wire that makes up an electrical cable. This wire is made of a composite material composed of copper and steel, and its strength is higher than that of beryllium copper and other copper alloys. Photo 1 shows a cross-sectional view of TCC wire.

(1) Electrical conductivity versus tensile strength

When considering the use of TCC wire, it is necessary to determine the strength level from the electrical conductivity or resistance value required, or to determine the electrical conductivity required for achieving the target strength. The electrical conductivity of TCC wire ranges from 20 to 60% International Annealed Copper Standard (IACS)*[1], and can be used for a wide range of purposes by changing the strength and material of the core. Figure 1 shows the relationship between the electrical conductivity and tensile strength of TCC wire whose core is a piano wire.

(2) Wire diameter

Reducing the diameter of TCC wire by taking advantage of its high-strength property is an effective means of saving wire weight and wiring space. The diameter of TCC wire can be selected in the range of φ 0.03 to 0.4 mm according to the purpose of use. Wiring electrical devices using TCC wire in place of conventional copper alloy wire makes it possible to reduce the wire diameter while maintaining the same strength, as well as to improve the design of the housing and reduce its size by saving wiring space.

(3) Core

In place of steel wire, stainless-steel wire can be selected for the core of TCC wire to cope with a use environment requiring higher corrosion resistance.

3. Properties of TCC Wire

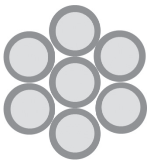
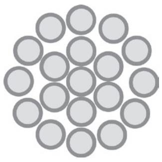
3-1 Flex resistance

(1) Stranded TCC wire

The flex resistance of an electrical wire is improved by twisting the element wires into a single strand. In general, the flex resistance of a stranded wire increases as the number of the element wires increases and their diameter decreases. In addition, an electrical wire having extremely high flex resistance can be obtained by using high-strength TCC wire as the element wire.

Table 1 shows a few examples of stranded TCC wire configuration. An optimum strand configuration can be selected according to the required flex resistance and the purpose of use. Photo 2 shows the external appearance of a stranded TCC wire.

Table 1. Configuration and cross-sectional view of stranded TCC wire

Strand configuration	Cross-sectional view
1 × 7	
1 × 19	
7 × 7	

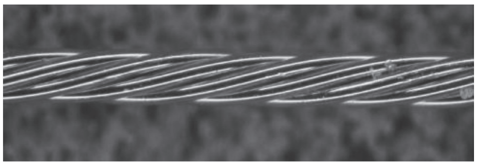


Photo 2. Stranded TCC wire (1 × 7)

(2) Evaluation of flex resistance

Electrical wires are exposed to various external forces such as bending and twisting depending on the place where they are used. Reproducing the load conditions of electrical cables and estimating their service life is important for determining the service life of the machine (robot). In this study, the flexing test shown in Fig. 2 was carried out to evaluate the flexing properties of stranded TCC wire.

Table 2 shows the specifications of the conductors that were evaluated by the flexing test. A Cu-3%Sn alloy was tested for comparison. The test load and mandrel diameter*2 were set to 1.47 N and 10 mm, respectively.

Photo 3 shows the state of the stranded wires after

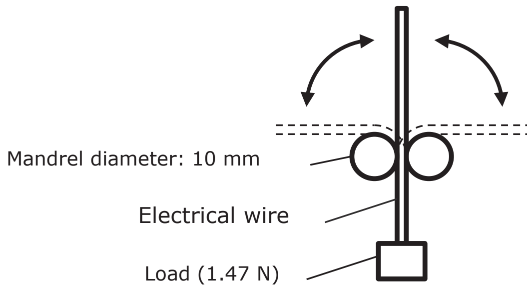


Fig. 2. Schematic illustration of flexing test

Table 2. Specifications of conductors used for flexing test

	TCC (30%IACS)	Cu-3%Sn alloy
Strand configuration	1 × 65/φ 0.05 mm	7 × 20/φ 0.03 mm

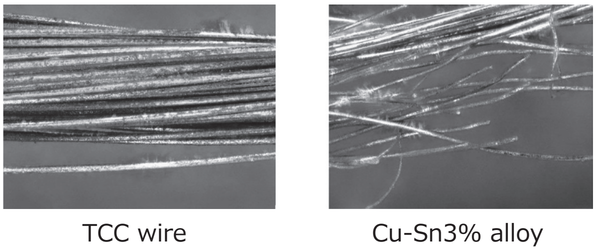


Photo 3. State of stranded wires after 10 million cycles of flexing test

being subjected to 10 million test cycles. Approximately 20 to 30% of the Cu-3%Sn alloy element wires broke, while the element wires of the stranded TCC wire did not break. The test was continued under severer conditions by setting the mandrel diameter to 5 mm. In this test, the stranded TCC wire did not break even after 13 million cycles of flexing. This result is an example verifying that increasing the strength of the element wires is more effective for improving the flex resistance of a stranded wire than increasing the number of smaller diameter element wires.

3-2 Connectivity to terminal

When wiring electronic devices, crimping or other mechanical pressing method is often selected to connect the wires to the terminals. Such a method is required to ensure sufficient connection strength and conductivity. Figure 3 shows a cross-sectional image of a press-deformed TCC

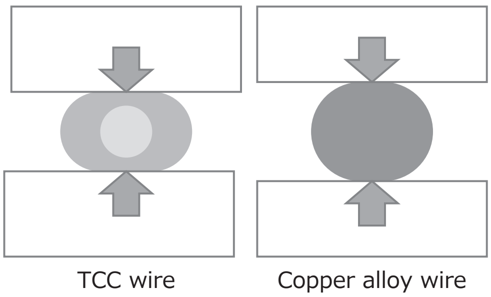


Fig. 3. Deformation image of conductors when pressed

wire and copper alloy wire. The copper alloy wire, the entire part of which is a hard conductor, does not deform easily enough to dig into the terminal. In contrast, the TCC wire, which is coated with soft copper, has an increased contact area with the terminal by deforming moderately. As a result, the TCC wire exhibits high conductivity.

The relationships between the connection strength and conductivity of TCC wire and that of copper alloy wires are shown in Fig. 4. Compared with Cu-Sn alloy, Cu-Ag alloy ensures higher connection strength since this alloy has higher conductor strength and can be pressed with larger force. However, Cu-Ag alloy's conductivity deteriorates since the conductor does not deform as much. On the other hand, TCC wire achieves a good balance between connection strength and conductivity since the high-strength core of the wire ensures the required conductor strength and the copper coating deforms moderately.

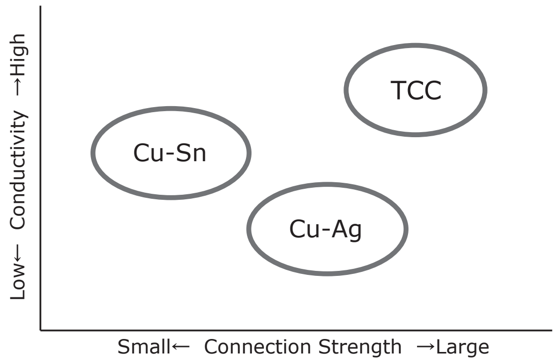


Fig. 4. Relationship between connection strength and conductivity

3-3 Transmission characteristics

The evaluation results for TCC wire are described below. Table 3 and Fig. 5 show the construction and cross-section of the sample cable used for the evaluation, respectively. The length of the sample cable was 10 m and the range of the measurement frequency was 1 to 100 MHz. The following four evaluation items were selected from the CAT5e channel specifications specified in the standards for the transmission characteristics of LAN cables.

- Insertion loss*[3]
- Return loss*[4]
- Near-end crosstalk attenuation*[5]
- Far-end crosstalk attenuation*[6]

Figures 6 and 7 show the evaluation results for the insertion loss and return loss characteristics of TCC wire, respectively. Pairs ①, ②, and ③ represent small, medium, and large twist pitch*[7], respectively. With regard to the return loss characteristics shown in Fig. 7, the return increased on the low frequency side since no impedance design was conducted in the evaluation and this increased the return to a level equivalent to the value specified in the standard. However, it was confirmed that the insertion loss of TCC wire shown in Fig. 6 satisfies the LAN standard value as long as the wire length is 10 m or less. The near-end crosstalk attenuation and far-end crosstalk attenuation

Table 3. Construction of sample cable

Item		TCC conductor 3 pair cable
Conductor	Size (Copper cross-sectional area)	AWG28
	Configuration	7 × 7 / φ 0.05 mm
	Outer diameter (mm)	0.45
Pair twist	Outer diameter (mm)	1.7
	Twist pitch	Small, Medium, Large
Assembly	Number of pairs	3 pairs

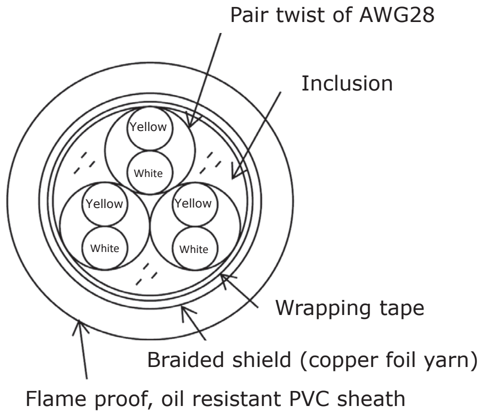


Fig. 5. Construction of sample cable

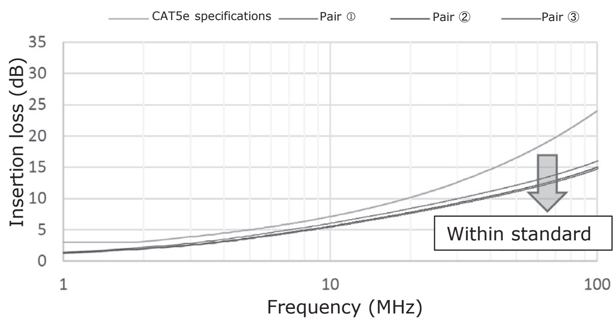


Fig. 6. Insertion loss characteristics

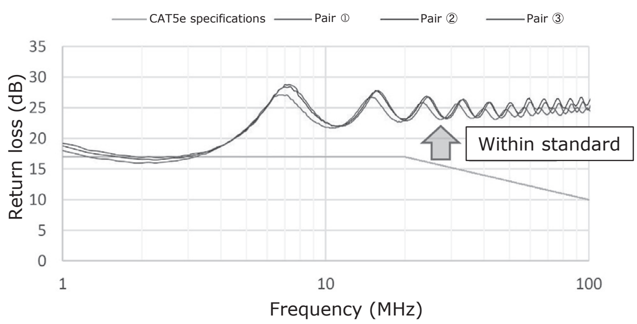


Fig. 7. Return loss characteristics

were also within the values specified in the standard, and the transmission characteristics of TCC wire were confirmed to be comparable to those of generally used soft copper and copper alloys.

4. Examples of the Use of TCC Wire

4-1 Use for high-strength, flex resistant cables

(1) Movable cable

Cables connected to movable devices such as air cylinders and industrial robot arms have a particularly high risk of wire breakage. Figure 8 shows the example of a cable connected to a movable device. In this example, the cable is bent every time the air cylinder moves from side to side and may finally break. The flexural life of the cable directly affects the life of the product.

For the same reason, cables that have been laid along industrial robot arm joints are exposed to a high risk of breakage due to repetitive bending. The service life of a product can be extended by using TCC wire whose flex resistance is higher than that of copper alloy wires.

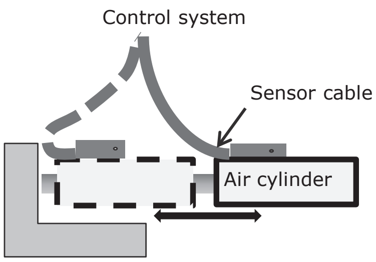


Fig. 8. Schematic illustration of the operation of air cylinder

(2) Automotive heater wire

The shift to electric vehicles has not only promoted more energy-efficient vehicle interior heating, but also the pursuit of comfort in the interior space. Under the above circumstances, demand is increasing for heater wires that directly heat passengers rather than for air conditioners that entail the drying of the vehicle interior air. On the other hand, heater wires used for directly heating passengers may break depending on the behavior of the passengers. To prevent such an incident, heater wires are required to have sufficient strength and flex resistance. Use of stranded TCC wire as heater wire can minimize the risk of wire breakage.

4-2 Use for thin, lightweight cable

With the shift to IoT, the length of cables for the internal wiring of information equipment and the complexity of wiring are expected to increase. Use of cables constructed of TCC wire, which is thinner than conventional wire, can save wiring space.

Another promising application of TCC wire is its use for wiring in drones and vehicles that are required to be more lightweight.

5. Conclusion

This paper described the use of TCC wire, which is a high-strength composite wire, as electrical wire. The significant advantages for increasing the strength of electrical wire are improvement in breakage resistance, weight reduction, and space saving. Recently, the antibacterial effect of copper is attracting attention, and weaving TCC wire in textiles is expected to expand. In parallel with this product, we have also succeeded in the commercialization of SUS-Coated Copper Wire*8 (tentative product name), which is copper wire coated with stainless steel. Tests are being carried for the application of this wire to conductive springs and for use in harsh environments where wear resistance is required. Meanwhile, from the standpoint of the depletion of copper resources, this product, which is constructed by covering steel with copper in only the area where conductivity is required, will help extend the minable years of copper. This product is expected to help build a prosperous and environment-friendly society.

Technical Terms

*1 IACS: An abbreviation for International Annealed Copper Standard. In this standard, the volume resistivity of standard annealed copper, which is 1.7241×10^{-2} μΩm, is defined to be 100% IACS as the reference value of conductivity.

*2 Mandrel diameter: The outer diameter to which the test sample wire is bent in a flexing test. The smaller the mandrel diameter, the more severe the test.

*3 Insertion loss: One of CAT5e specifications that is used to evaluate to what degree an input signal is attenuated at the output end.

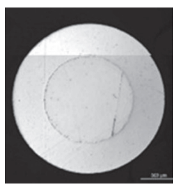
*4 Return loss: One of CAT5e specifications that is used to evaluate to what degree an input signal is reflected.

*5 Near-end crosstalk attenuation: One of CAT5e specifications that is used to evaluate to what degree an input signal is attracted to the input end of the other pair (near end).

*6 Far-end crosstalk attenuation: One of CAT5e specifications that is used to evaluate to what degree an input signal is attracted to the output end of the other pair (outer end).

*7 Twist pitch: The distance that is required for an element wire to make a 360-degree revolution of the strand.

*8 SUS-Coated Copper Wire (tentative product name): A composite wire made by coating a pure copper core with stainless steel. This wire is applicable to spring contacts, as well as heater wire and motor brushes that are required to be resistant to wear.



Reference

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Contributors

The lead author is indicated by an asterisk (*).

K. MATSUOKA*
• Special Steel Wire Division

A. HOSHIMA
• Assistant Manager, Special Steel Wire Division

D. SATO
• General Manager, Special Steel Wire Division