

# Contact Wire for High-Speed Dedicated Freight Corridor in India

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As part of its overseas business, Sumitomo Electric Industries, Ltd. has been providing contact wires for the high-speed dedicated freight corridor that is being constructed in India. To enter the Indian contact wire market, it was necessary to satisfy the specifications required by the local customer, such as high conductivity and high tensile strength based on overseas standards. Taking advantage of our accumulated expertise in copper-tin alloys, we achieved the required properties by adjusting the tin and oxygen ratio in material casting and by improving the drawing process of contact wire. This paper introduces our technical development.

Keywords: contact wire, high conductivity, high tensile strength, copper-tin alloy

## 1. Introduction

A number of large railway construction projects are currently underway in regions such as Southeast Asia and India, where the economy and railway sector are rapidly growing. Sumitomo Electric Industries, Ltd. received an order for contact wires, the total length of which is approximately 3,400 km, for a section (See Fig. 1, an approximately 1,500 km railway section between Delhi and Mumbai) of the Dedicated Freight Corridor, which is being constructed by the Dedicated Freight Corridor Corporation of India Limited (DFCCIL), a subsidiary of India's Ministry of Railways. We are producing and shipping contact wires, the volume of which is the largest in our

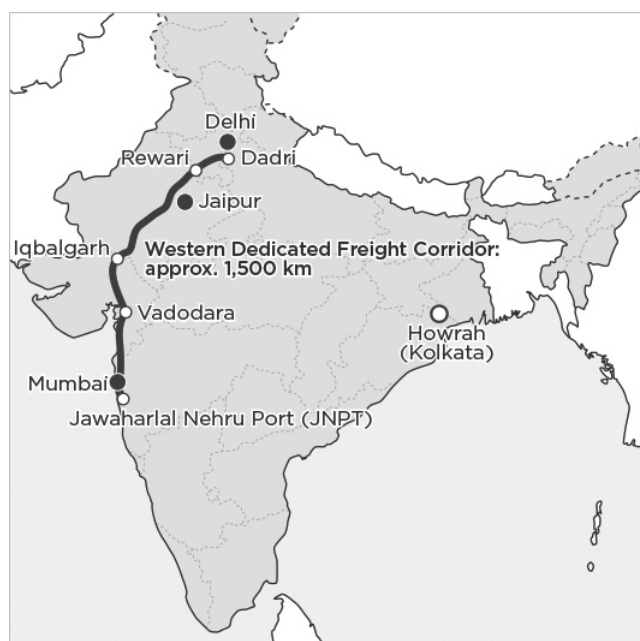


Fig. 1. India's Dedicated Freight Corridor (DFC) for which Sumitomo Electric received an order

overseas railway-related business. This was the first entry of our division into the Indian contact wire market, and we had to fulfill DFCCIL's requirements for this project, which were based on the European Standards (EN) rather than the Japanese ones. This paper reports on our development of unprecedented contact wires that fulfill customer requirements, such as high conductivity and high tensile strength, through the design of the manufacturing process based on our contact wire development experience that has been nurtured over time.

## 2. Contact Wire

Contact wires are electric wires used to supply power to railway vehicles, as shown in Fig. 2 via pantographs. To reduce power transmission loss, the metallic material of contact wires is copper with high conductivity, and adding tin or silver to the copper as needed improves tensile strength, fulfilling the particular requirements of each customer. Sumitomo Electric has contributed to the devel-

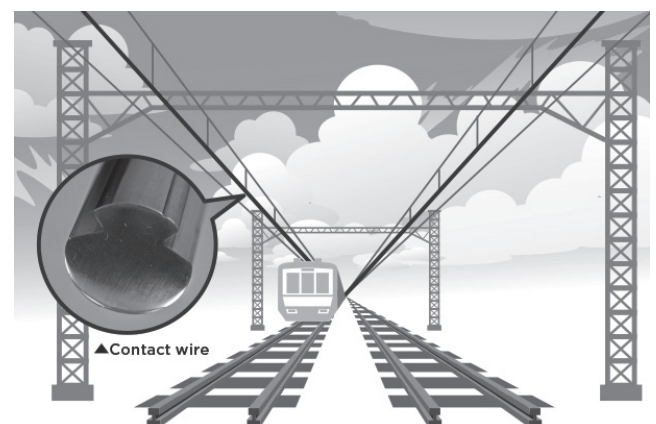


Fig. 2. Role of contact wires (power supply lines)

opment of Japan's railway networks of JR conventional lines, Shinkansen bullet train lines, and private railways by delivering various types of contact wires.

Table 1 shows the types and characteristics of our major contact wires. The type GT is short for grooved trolley wire, which has grooves designed to facilitate the installation of clamps. The letters following GT show added metallic elements. Alloying improves tensile strength and wear resistance, but at the expense of conductivity.\*1

Table 1. Types, characteristics, and typical use of our contact wires

Type	Material	Characteristics	Typical use
GT	Copper Cu		Conventional lines
GT-SN	Copper-tin alloy Cu-Sn	High strength, heat and wear resistance	High-speed lines, conventional lines
GT-SN-W	Copper-tin alloy Cu-Sn	High strength (improved), heat and wear resistance	Shinkansen, conventional lines
GT-AG	Copper-silver alloy Cu-Ag	High strength, heat and wear resistance	High-speed lines, conventional lines

Since Shinkansen and other high-speed railways require higher wire tension, the contact wires had to have a high tensile strength. To fulfill this requirement, we developed GT-SN-W, a contact wire made of copper-tin alloy in 1992.<sup>(1)</sup> With this development as a springboard, Sumitomo Electric has entered overseas markets, starting with the delivery of GT-SN-W contact wires to Taiwan High Speed Rail in 2004.

In the Japanese market, the number of new projects is decreasing and demand for contact wire is now mostly for replacement wire due to deterioration from wear and tear. In contrast, many new railway construction projects in overseas markets are being scheduled, especially new high-speed railway projects in Asia, and strong demand is expected to continue.

### 3. Development

#### 3-1 Required properties

Upon our entry into the Indian market, DFCCIL first required us to use copper-silver alloy and to fulfill the contact wire specifications that were based on EN Standards. Table 2 compares the specifications of conductivity and tensile strength among EN standards, customer requirements to be developed, and conventional wires. In Japan, copper-tin alloy is the predominant material for contact wires for high-speed railways, while in Europe, where EN standards are applied, copper-silver alloy with high conductivity is also used. However, copper-silver alloy has a disadvantage in terms of cost. We examined the use of copper-tin alloy while satisfying EN standards. The requirement from DFCCIL was 82% IACS in conductivity, which is higher than the EN standards. We were determined to develop a copper-tin alloy with a conductivity of 82% or more and a tensile strength of 420 MPa or more, which was customer requirement.

Table 2. Customer requirements and conventional wires

Applicable standard	Material, type	Conductivity [%IACS]	Tensile strength [MPa]	Cost
EN	Copper-silver alloy	97	360	High
EN	Copper-tin alloy	80	420	Low
Customer requirements	—	82	420	—
Conventional	Copper-tin alloy, GT-SN-W	70	430	—

#### 3-2 Details of the development phase

The manufacturing process for contact wires is shown in Fig. 3. The wire rod line consists of the casting process, where copper is melted in a melting furnace and additional elements are added, with casting being done by a continuous casting machine; and the rolling process, where the cast material is continuously hot-rolled by a rolling machine to produce wire rods. In the next drawing line, the wire rod is fed through a drawing machine to obtain contact wires with grooves. This drawing process is a cold working process. The tensile strength of the wires is increased due to work hardening\*2 during the wire drawing.

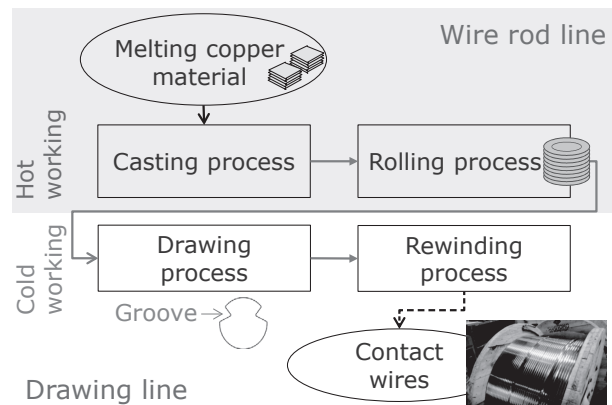


Fig. 3. Manufacturing process of contact wires

To optimize the tradeoff between conductivity and tensile strength, we designed a manufacturing process that includes a redesign of the alloy constituents on the basis of our conventional GT-SN-W contact wires, exploiting our experience in developing high-tensile strength copper-tin and copper-silver alloys.

Figure 4 is a conceptual diagram. An extension to GT-SN-W contact wires (1) increases conductivity by decreasing the tin content (additional element) but considerably decreases tensile strength. On the other hand, (2) tensile strength improves but conductivity decreases with an increase in the cold working ratio\*3 in the drawing process by increasing the wire rod diameter. This is because work hardening with plastic deformation in cold working accumulates distortion and causes a disorder of the atomic arrangement, leading to lower conductivity. Work hardening is known to improve tensile strength as the

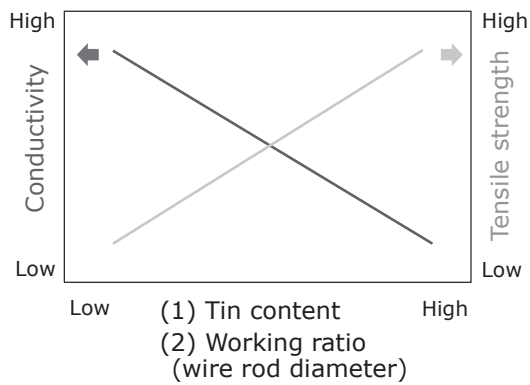


Fig. 4. Tradeoff between conductivity and tensile strength

tin content increases. This is a phenomenon where distortion accumulating in the solid-soluted tin atoms of copper-tin alloy, which is the solid-solution strengthened alloy,<sup>\*4</sup> causes work hardening to advance.

On the basis of the above, we had to improve conductivity without decreasing the tin content as much as possible in order to balance conductivity and tensile strength. To achieve this, we focused on the role of the oxygen in tough-pitch copper widely used as a conductive material. Tough-pitch copper generally contains 200 to 500 ppm oxygen, which exists in crystal grains and grain boundaries in the form of copper oxide particles. Other impurity elements in copper (several ppm or less), which are crystallized<sup>\*5</sup> with these copper oxide particles, will prevent the decrease in conductivity due to impurity elements, leading to higher conductivity. Against this backdrop, we tried to balance conductivity and tensile strength by controlling the oxygen concentration in copper alloy. When the oxygen concentration in copper alloy is high, tin will react with oxygen to form oxides, leading to lower properties. In contrast, when the oxygen concentration is low, other impurity elements in copper will affect the properties. When redesigning alloy constituents, we searched for the optimum constituent range by considering tin content along with oxygen concentration control. In addition, we evaluated the trial products with various wire rod diameters and drawing conditions while designing a manufacturing process to secure necessary tensile strength. We produced trial contact wires on an actual production line and established the contact wire manufacturing conditions that fulfilled the customer requirements.

#### 4. Development Results

Figure 5 shows the properties of conventional copper-tin alloy contact wires and developed contact wires produced using the redesigned manufacturing process. Through the redesign of the manufacturing process, we have established control methods for tin content and oxygen concentration in copper, and determined the wire rod diameter and drawing conditions by considering work hardening in the drawing process.

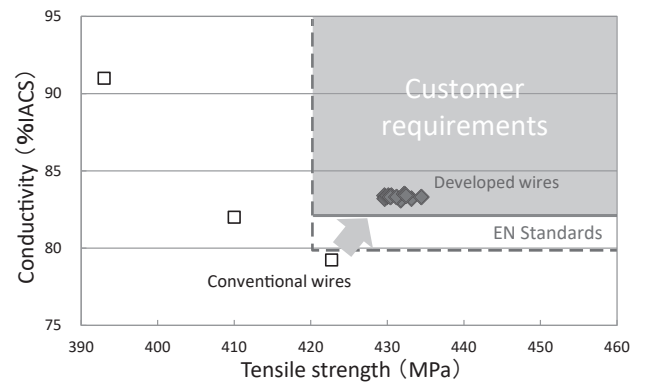


Fig. 5. Properties of conventional and developed contact wires

As a result, we have developed original and advanced contact wires that fulfill the specifications (a conductivity of 82% or more and a tensile strength of 420 MPa or more) required by the customer DFCCIL.

#### 5. Conclusion

While DFCCIL required high conductivity and strength based on overseas standards, Sumitomo Electric has developed contact wires that fulfill both requirements by exploiting our experience developing copper-tin alloy. By redesigning the manufacturing process, we have successfully established control methods for tin content and oxygen concentration, the optimum wire rod diameter, and drawing conditions. The developed contact wires satisfy the customer requirements and are now being produced and shipped.

#### Technical Terms

- \* 1 Conductivity: The conductivity of standard annealed copper is defined to be 100% IACS. IACS is the acronym for international annealed copper standard.
- \* 2 Work hardening: A phenomenon where strengthening of a metal occurs when a stress is applied due to the accumulation of distortion induced by plastic deformation.
- \* 3 Working ratio: A parameter defined by the initial cross-sectional area before wire drawing minus the final cross-sectional area after wire drawing divided by the initial cross-sectional area before wire drawing.
- \* 4 Solid-solution strengthened alloy: An alloy that is strengthened by solid-soluting (a phase where two or more elements are uniformly soluble in the solid state) additional elements in the parent phase.
- \* 5 Crystallized: A phenomenon where additional elements dissolved in a molten or solid metal in the atomic state form compounds different from the metal in the parent phase and are precipitated from the metal.

### Reference

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