Development of Low-cost Contact Wire for High-speed Lines

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Chromium-zirconium precipitation-hardened copper alloy (PHC) contact wire was developed for high speed lines to address issues relating to cost and the environment. However, the problem with PHC contact wire is that it is not easily produced in small quantities, to meet the demand for small lots from railway operators. Therefore, the authors of this paper developed a new contact wire, Cobalt-phosphorus precipitation-hardened copper alloy (CPS) contact wire which can be produced in smaller quantities. The resulting low-cost CPS contact wire has the same strength and electric conductivity as PHC contact wire. This paper describes results from performance tests conducted with the CPS contact wire.

Keywords: contact wire, high-speed lines, low-cost, CPS contact wire, PHC contact wire

1. Introduction

Chromium-zirconium precipitation-hardened copper alloy contact wire (hereinafter referred to as PHC contact wire) was developed as a contact wire for high-speed contact lines, because it possesses both the strength and electrical conductivity required for high-speed contact lines [1]. The PHC contact wire has been in use on Japan’s Shinkansen since 2011. However, PHC contact wire cannot easily be produced in small quantities for railway operators.

Therefore, the authors develop a new contact wire for high-speed lines which can be produced in smaller quantities. The new developed Cobalt-phosphorus precipitation-hardened copper alloy contact wire (hereinafter referred to as CPS contact wire) has the same mechanical and electrical performance as PHC contact wire, but is cheaper to produce than PHC contact wire. Stationary tests and field installation tests showed that CPS contact wire can be used instead of PHC contact wire.

2. Prototype CPS contact wire

2.1 Background of CPS contact wire development

Strict temperature control is required in the casting process for PHC contact wire. Therefore, casting and rolling cannot be done in a continuous process [2]. Figure 1 shows a schematic diagram of the manufacturing-process of PHC contact wire (wire rod before drawing). Strict temperature control is required in the casting process for PHC contact wire, because a stable quality of ingot must be manufactured at least 200 tons at a time, which means that at least 200 tons of PHC contact wire needs to be manufactured at one time (110 mm\(^2\) in cross-sectional area, about 200 km of contact wire). Therefore, supply of PHC contact wire is not a problem when a new line is being constructed and where there is a large demand for it. On the other hand, when contact lines need to be replaced with PHC contact wire on existing lines, supply tends to take a long time if the manufacturer does not have enough stock.

![Fig. 1 Overview of manufacturing-process for manufacturing wire rod for PHC contact wire](image)

2.2 Material composition and specifications

We selected cobalt-phosphorus precipitation-hardened copper alloy as a candidate material for new contact wire for high-speed electric railway lines. The name of CPS contact wire is derived from the initial letters of the main component symbols shown in Table 1 below. Since cobalt-phosphorus precipitation-hardened copper alloy forms precipitates between solutes, the reaction time during
produce in the smaller quantities required by railway operators for contact wire replacement work.

Table 1 shows the chemical composition (weight percent) of CPS contact wire, which is a copper alloy consisting of cobalt (Co), phosphorus (P) and tin (Sn) as main alloying elements. Figure 3 shows the appearance of the CPS contact wire.

Since the CPS contact wire was developed to replace the PHC contact wire, the performance specifications of the CPS contact wire are based on those of the PHC contact wire. Table 2 shows the specifications of CPS 110 mm² in cross-sectional area (hereinafter referred to as CPS110).

2.3 Material properties

The basic material properties of CPS contact wire were verified in the stationary tests described below.

2.3.1 Material composition and specifications

Tensile test and electrical conductivity test of CPS110 contact wire were carried out in accordance with JIS (JIS C 3002:1992, Testing methods of electrical copper and aluminium wires) [3]. The results are shown in Table 3, where the tensile strength and conductivity of the CPS110 contact wire were found to be above the specified values.

2.3.2 Thermal softening characteristics

To estimate thermal-resistant of the contact wire, we conducted a thermal softening measurement. In the thermal softening test, the contact wire was held in an electric furnace at a predetermined temperature for one hour, then a tensile test was conducted at room temperature. The test results are shown in Fig. 4. For comparison, characteristics of PHC and SN contact wire, which are widely used today, are also shown. Figure 4 shows that the thermal softening characteristic of CPS contact wire is equivalent to those of PHC contact wire up to 500°C. However, note that at 600°C, PHC contact wire has better thermal softening property than CPS contact wire. As maximal permissible temperature in Japan, the maximum permissible temperature of contact wire is 90°C [4], regardless of the type of contact wire. In addition, the temperature to which contact wire was exposed in a tunnel fire accident (in 1972) was reported to be about 250 - 380°C [5]. On the basis of these facts, it was con-
2.3.3 Wear characteristics

The wear measurement of the contact wire is carried out under the conditions shown in Table 4. PHC110 in Table 4 refers to PHC 110 mm\(^2\) in cross-sectional area, and contact strip (T3-2) made of iron-based sintered alloy is used in Shinkansen.

Figure 5 and Fig. 6 show the wear characteristics of a contact wire and contact strips, respectively. When not energized (0 A), the amount of wear of CPS contact wire was equal to or slightly less than that of PHC contact wire. When energized with 200 A, the amount of wear of CPS contact wire was less than that of PHC contact wire. It can also be said that the amount of wear of the contact strip is the same as that of the contact wire.

Table 4  Wear test conditions

| Types of contact wire | CPS110, PHC110 |
|----------------------|----------------|
| Types of contact strip | Iron-based sintered alloy (T3-2) |
| Current (watering conditions) | 0 A (no watering) |
| | 200 A (watering (3 L/min)) |
| Contact force of contact strip | 74 N |
| Sliding speed of contact wire | 200 km/h |
| Time of examination | 2 hours |

2.3.4 Fatigue characteristics (CPS110 contact wire (new wire))

To obtain the fatigue characteristics of the CPS contact wire, we carried out fatigue measurements, shown schematically in Fig. 7. The excitation waveform was sinusoidal with frequency of 5 Hz [6], and the test tension was set at 14.7 kN in order to obtain the general fatigue characteristics of CPS contact wire.

The test results are shown in Fig. 8. The fatigue test results of the PHC contact wire (nominal cross-sectional area:110 mm\(^2\), tension:14.7 kN), which was tested for comparison, are also shown in Fig. 8. Note the arrows in Fig. 8 indicate that the test was terminated without breaking the contact wire.

Figure 8 demonstrates that when the same strain was applied to the contact wires, the number of cycles applied before fatigue rupture occurred in the CPS contact wire was higher than that of PHC contact wire. Therefore, CPS contact wire has better fatigue characteristics than PHC contact wire.
2.3.5 Verification of fittings compatibility

The CPS contact wire is intended to be used when replacing PHC contact wire that have reached the end of its service life, and the verification test was conducted because the fittings for PHC contact wire is used without modification when replacing the wire. The tested fittings are pull-off arm, dropper ear and double ear. From the test results, we concluded that the fittings for PHC contact wire could be used to fasten the CPS contact wire.

3. Installation test (on-site-test)

3.1 Test overview

Installation test of CPS contact wire was examined on the main line (high-speed sections of the Shinkansen) under an operation at a maximum speed of 240 km/h. Table 5 shows an overview of the installation test. After a year of installation tests, no particular problems were encountered.

3.2 Wear measurement and observation of contact surface

Table 6 shows the results of wear measurements immediately after the start of the installation test and before the end of installation test of the CPS contact wire and the CS contact wire. The CS contact wire is a contact wire for high-speed lines, one generation before the PHC contact wire, with copper around the steel core. Note that the CS contact wire was installed before the CPS contact wire installation test (adjacent to the CPS contact wire, with the steel core unexposed). From Table 6, it is found that the wear cross-sectional area of CPS contact wire is less than one-third of that of the CS contact wire.

Figure 9 shows the condition of the CPS contact wire contact surfaces observed immediately before the end of installation test. All the surveyed surfaces were smooth and there was no abnormal wear such as local wear.

3.3 Dynamic characteristics

To estimate dynamic characteristics of the CPS contact wire at supporting points, we measured the uplift and the strain of the contact wire at a supporting point during the installation test. For comparison, we also conducted the same measurements for PHC contact wire at same point. The maximum values for each measurement item are shown in Table 7. Table 7 shows that the uplift and the strain of CPS contact wire are almost the same as those of PHC contact wire. We also found that the measured values were lower than the guide value of 100 mm and the guide value of 500 × 10⁻⁶ [7], respectively. Therefore, we concluded that the guide value of uplift and strain (positive) of the CPS contact wire would not pose a problem in use on the main line where the tests were conducted.
3.4 Survey of removals

Table 8 shows the measured results on the CPS contact wires following their removal after installation tests against manufacturer specifications. All the items used in the tests were verified after testing, to ensure that they still met the required specifications.

The cross-sectional shape of the contact wire satisfied the JIS (JIS E 2101:1990, Hard-Drawn Grooved Trolley Wires [8]) even after the installation test, and there was no change in the cross-sectional shape except for the wear caused by the sliding of the contact strip. There was no abnormal corrosion on the contact wire surface.

The metallurgical structures before and after the CPS contact wire was used in the installation test are shown in Fig. 10. From the viewpoint of the metallurgical structure observed after the installation test, there was no change in size and no abnormalities.

4. Conclusions

This paper describes the development of a new type of contact wire, called ‘CPS contact wire’, which has the same strength and conductivity as PHC contact wire. The developed contact wire is cheaper than PHC contact wire to produce and can be manufactured in smaller lots. The research results are as follows:

- Stationary tests were conducted to verify that the CPS contact wire had the same mechanical and electrical properties as PHC contact wire.
- Fittings for PHC contact wire can be used directly on CPS contact wires.
- One year after installing CPS contact wire test on a

### Table 7 Comparison of contact wire dynamics measurements (maximum values)

|                | Uplift | Strain(positive) |
|----------------|--------|-----------------|
|                | CPS    | PHC             | CPS       | PHC       |
| 35.0 mm (238.3 km/h) | 36.4 mm (237.8 km/h) | 247×10^-6 (238.3 km/h) | 264×10^-6 (232.5 km/h) |

*Figures in parentheses show the pantograph passes speed

### Table 8 Measurement results after the installation test

| Measurements             | Specifications                          | Before the test | After the test |
|--------------------------|-----------------------------------------|-----------------|---------------|
| Tensile resistance       | 47.2 kN for 3 minutes with no visual difference | OK              | OK            |
| Maximum Tensile Load     | ≥ 59.0 kN                               | OK (59.3 kN)   | OK (60.1 kN)  |
| Elongation               | ≥ 2.0%                                  | OK (3.8%)      | OK (4.1%)    |
| Conductivity             | ≥ 76% IACS                              | OK (79.8% IACS)| OK (79.8% IACS) |
main line, the following results were confirmed regarding the performance of CPS contact wire.

- The wear cross-sectional area is less than one-third of the wear cross section of CS contact wire.
- The contact line dynamics (uplift and contact wire strain) was equivalent to that of PHC contact wire at the same supporting point.
- There was no local wear or other abnormal wear on the sliding surfaces.
- There was no abnormal surface corrosion.
- The contact wire still satisfied the specification of the contact wire even after one year of installation test.
- There was no change in metallography.

These results demonstrate that CPS contact wire can be used as a replacement for PHC contact wire.

References

[1] Harada, S., Shimizu, M., Ikeda, K., Sato, J., Koyano, S., and Chikanari, K., “Development of Simple Catenary Equipment Using PHC Contact Wire for Shinkansen,” Quarterly Report of RTRI, Vol. 49, No. 2, pp. 96–102, 2008.

[2] Hattori, Y., Hori, K., and Wada, M., “Production of oxygen-free copper and copper alloy wire rod by SCR,” Journal of the Society for the Study of Copper Drawing Technology, Vol. 40, No. 1, pp. 153–155, 2001 (in Japanese).

[3] Japanese Industrial Standards, Testing methods of electrical copper and aluminium wires, JIS C 3002-1992 (in Japanese).

[4] Railway Technical Research Institute, Overhead contact line and pantograph characteristics, Railway Research-Culture Promotion Foundation, p. 150, 1993 (in Japanese).

[5] Japan Railway Electrical Engineering Association, Research on overhead contact line materials, p. 2, 1974 (in Japanese).

[6] Japanese Industrial Standards, Electric traction overhead lines-Fittings, JIS E 2201-2013 (in Japanese).

[7] Railway Technical Research Institute, Overhead contact line and pantograph characteristics, Railway Research-Culture Promotion Foundation, pp. 217–221, 1993 (in Japanese).

[8] Japanese Industrial Standards, Hard-Drawn Grooved Trolley Wires, JIS E 2101-1990 (in Japanese).

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