The Development of a High Electrical Conductivity and High Heat Resistance Copper Alloy EFTEC-550

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ABSTRACT With coming of the next generation automotive technology revolution such as EV and the development of computer network, a high current and a high voltage electric circuit for the electric motor, a power supply for the PC server and others have been progressing. Also the terminals, the connectors, the relays and others, which are current-carrying material, the reduction of the power loss or the self-heating and further, maintaining the reliability of the good electrical contact even under the high temperature environment due to the heat generation are required. Therefore, a high electrical conductivity and an excellent stress relaxation resistance are required for the conductive material. This time, we worked on the development of a high electrical conductivity and high heat resistance copper alloy strip EFTEC-550, which is better performing than the existing copper alloy on the stress relaxation property and the connection reliability. By dispersing high-density and fine Cr precipitates in the copper matrix, the strength and the electrical conductivity of this developed product is well balanced. Also, a better stress relaxation property has been achieved by adding a small amount of Mg.

1. INTRODUCTION

In recent years, a high voltage and a high current of vehicle-mounted power supply system circuit due to the spread of the next generation vehicles, a large capacity of data communication and a compact size and a high current of the electrical devices have been progressing. And in these applications, the increase of the heat generation amount at the time of the energization becomes a problem. Also, in the spring contact part, because the stress relaxation is progressing due to the heat load of the automotive high temperature environment, the heat generation by a large current and others, the decrease in reliability is concerned. From these circumstances, a material having both high electrical conductivity and good stress relaxation properties desired. However, because the additive amount of an element is limited for the high electrical conductivity copper alloy, it is difficult to achieve both a high electrical conductivity and a high stress relaxation resistance at the same time. We have been manufacturing EFTEC-3 (C14410), EFTEC-64T (C18045) and others. As shown in previous reports[1), 2), 3)], these alloys have a variety of excellent properties in addition to the high electrical conductivity. However, because these products don't meet the requirements of the market in the aforementioned applications with respect to the stress relaxation property, we began the development of the new alloy EFTEC-550 which has both high electrical conductivity and a high stress relaxation resistance at the same time. In this report, the development content of EFTEC-550 and the material properties are reported.

2. EVALUATION METHOD

Various material properties are evaluated by the method below.

2.1 Electrical Conductivity Measurement

The electrical conductivity was calculated by measuring the electrical resistivity using the four probe method in accordance with JIS H 0505. The test samples were taken to the direction parallel to the rolling direction as longitudinal in the dimensions of width 10 mm and length 145 mm. The distance between voltage terminals was 100 mm and the energizing current was 100 mA.

2.2 Tensile Test

Tensile test was performed in accordance with JIS Z 2241 and tensile strength, elongation were measured. The test sample was JIS #5. Longitudinal direction is parallel to the rolling direction. Gauge length was 50 mm and tensile speed was 10 mm/min.

2.3 Bending Test

In accordance with JCBA T 307, W-type 90° bending test was performed. The test was performed for both directions where the bending axis was perpendicular to the rolling direction (Good-way) and parallel to the rolling direction (Bad-way). After the test, the surface of the outside bending portion was observed using microscope

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and the test samples were classified into five categories of (A) no wrinkle, (B) small wrinkle, (C) large wrinkle, (D) small crack and (E) large crack. The ratio of the minimum bending radius (*R*) where the crack doesn't occur and the sheet thickness (*t*), *R/t*, was estimated. The bending workability performance is inversely proportional to the value of the ratio *R/t*. The ratio of the width of the test sample (*W*) and the sheet thickness (*t*) is defined as *W/t* and the relationship between *R/t* and *W/t* is summarized. In general, if the sheet thickness is same, the bending workability becomes better as the value of *W/t* is reduced (The sheet width is narrow.). The schematic diagram of the bending direction and the bending test sample is shown in Figure 1.

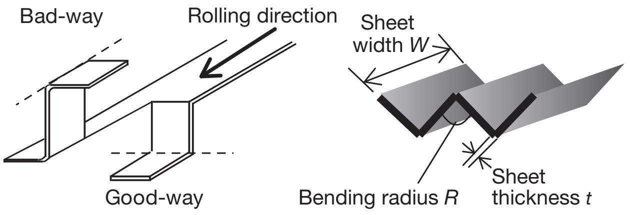
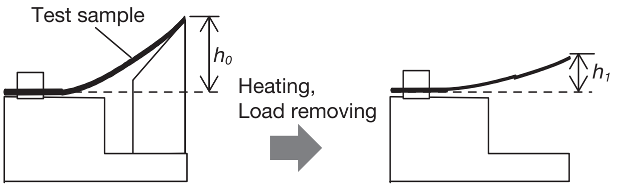


Figure 1 **The schematic diagram of the bending test.**

2.4 Stress Relaxation Test

In accordance with JCBA T 309, the stress relaxation ratio was measured. The longitudinal direction of the test sample is parallel to the rolling direction. The initial maximum load stress to the test sample is 80% of yield strength and the test samples were heat-treated for 1,000 hours in an air bath at the predetermined temperature. The stress relaxation ratio was calculated from the amount of deformation of the test sample at the predetermined time intervals. The stress relaxation property performance is inversely proportional to the value of the ratio R/t. The schematic diagram of the stress relaxation test is shown in Figure 2.



Stress relaxation (%) = $(h_1/h_0) \times 100$

Figure 2 **The schematic diagram of the stress relaxation test.**

2.5 Softening Property Measurement

The test samples were heated at the predetermined temperature in a salt bath and then water-quenched. The Vickers hardness was measured in accordance with JIS Z 2244. The hardness measurement was carried out in the test force of 2.942 N and the holding time of 15 seconds.

2.6 TEM Observation

The precipitation state of Cr in EFTEC-550 was confirmed by TEM observation. A thin piece was prepared by polishing in mechanically and then electrolytically. Further, the surface polishing of the sample was performed by ion milling. The observation was carried out entering the electron beam from the direction (200) of copper matrix at an accelerating voltage of 300 kV.

3. STUDY OF ALLOY COMPOSITION

Cu-Cr-Mg was selected as the alloy system. Aiming the development goal shown in Figure 3 and 4, the adjustment of the compositions and the process conditions were carried out. Cr is an element which is effective to achieve both the high electrical conductivity and the strength by precipitating it in copper alloy and Mg is an element to improve the stress relaxation property. The targeted goal was set to the area where the tensile strength and the electrical conductivity are superior to our EFTEC-3/EFTEC-64T and C19210/C19400 products which are the existing high electrical conductivity alloys. Further, regarding the stress relaxation property, the ambitious goal of good area was targeted in comparison to the existing copper alloys having high electrical conductivity.

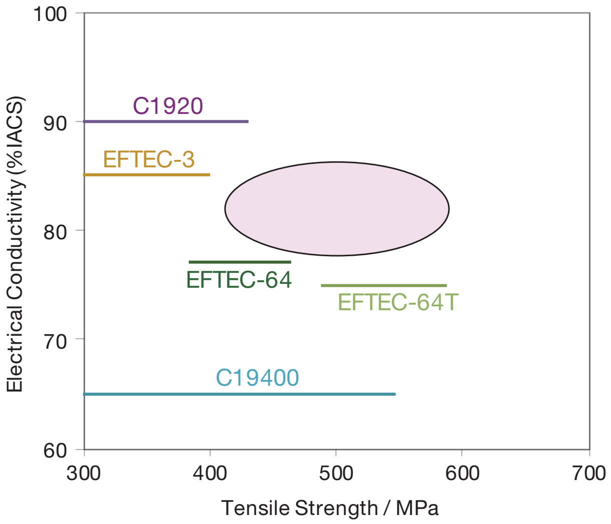


Figure 3 **Tensile strength vs. electrical conductivity of the existing alloy and the targeted area.**

The study results of the alloy composition are shown in Figure 5 and 6. Figure 5 shows the relationship between the additive amount of Cr and the tensile strength when the intermediate heat treatment is performed at the temperature of 400-600℃ and its heat treatment method is aging or annealing. Regardless of the heat treatment method, as the additive amount of Cr is increased, the tensile strength is increased. However, because the deterioration of the castability is concerned due to the excessive addition of Cr, the additive amount of Cr is determined as 0.25 mass%. Also, in Figure 6, the relationship between the additive amount of Mg for each manufacturing method and the stress relaxation ratio and the electrical conductivity is shown. By adding Mg, the stress relaxation property is improved remarkably, but as the additive amount is increased, the electrical conductivity is decreased. In order to achieve both a high electrical conductivity and a good stress relaxation property, the additive amount of Mg is determined as 0.1 mass%.

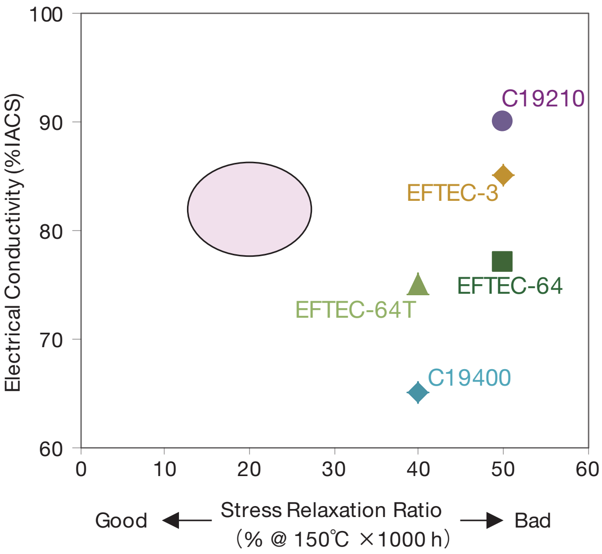


Figure 4 Stress relaxation ratio vs. electrical conductivity of the existing alloy and the targeted area.

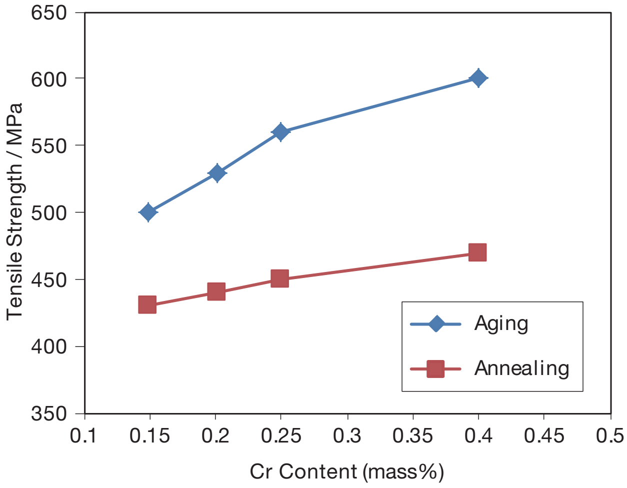


Figure 5 The effect of Cr content on the tensile strength.

In consideration of these facts, the target composition of Cu-0.25%Cr-0.1%Mg was determined. EFTEC-550T with an emphasis on the tensile strength and EFTEC-550E with an emphasis on the electrical conductivity were developed by controlling the state of precipitation of Cr while adjusting each process and its condition. In Figure 7, the precipitation state of Cr for each product is shown. In case of EFTEC-550T, the tensile strength was increased by precipitating Cr more densely and finely. In case of EFTEC-550E, the electrical conductivity is increased by growing the precipitate and increasing the amount of the precipitate.

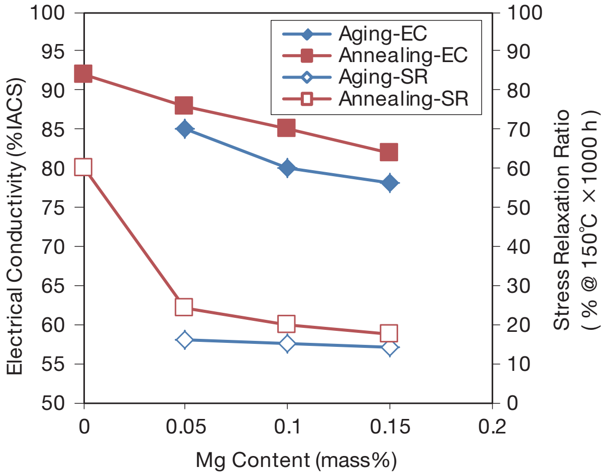
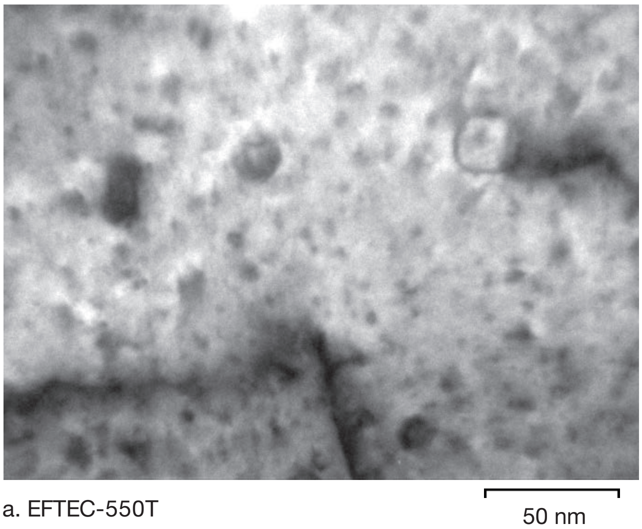
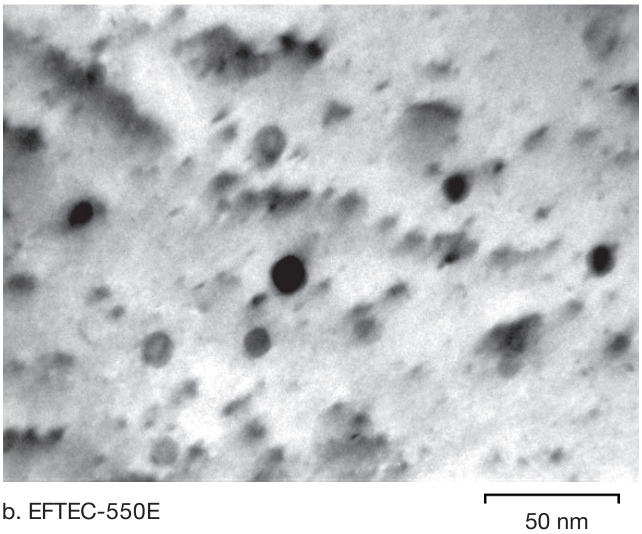


Figure 6 The effect of Mg content on the stress relaxation ratio and the electrical conductivity.



a. EFTEC-550T



b. EFTEC-550E

Figure 7 The precipitation state of Cr for EFTEC-550T/E.

4. MATERIAL PROPERTY EVALUATION

In this section, the material properties for EFTEC-550T/E are reported.

4.1 Chemical Composition and Physical Property

Table 1 shows the chemical composition of EFTEC-550. For both EFTEC-550T and E, a representative composition is Cu-0.25% Cr-0.1% Mg. Also in Table 2, the physical properties of EFTEC-550 are shown. EFTEC-550T has a high electrical conductivity of about 80% IACS and EFTEC-550E has a high electrical conductivity of approximately 85% IACS. It is expected that the heat generation suppressing effect becomes large when a large current is injected.

Table 1 The chemical composition of EFTEC-550.

Elements	Cr	Mg	Cu
Content (mass%)	0.25	0.1	Remainder

4.2 Mechanical Property

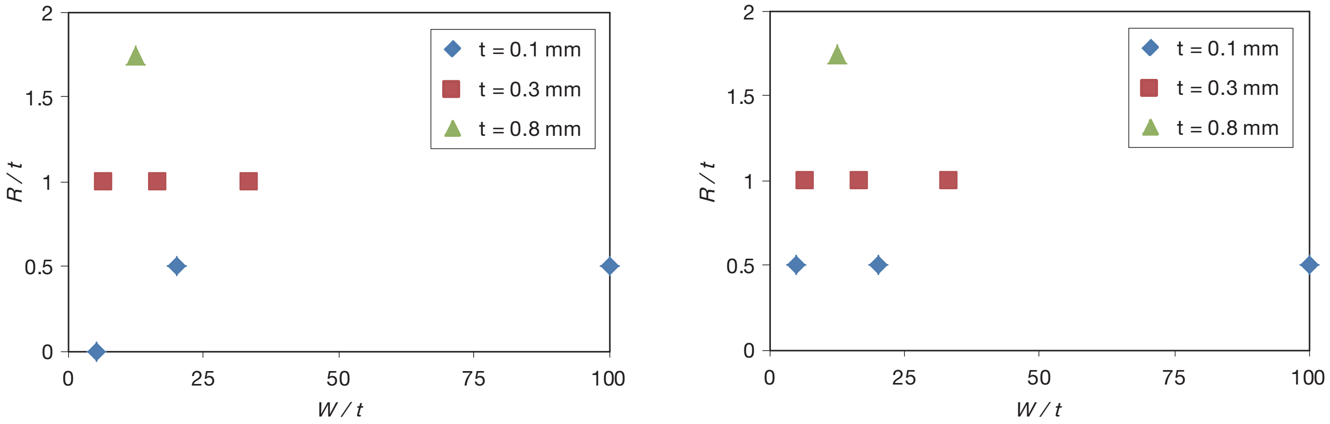
The mechanical properties of EFTEC-550 are shown in Table 3. EFTEC-550T has a tensile strength of about 550 MPa and EFTEC-550E has a tensile strength of approximately 450 MPa. EFTEC-550 has achieved the high tensile strength and the high electrical conductivity at a higher level in comparison to the existing high electrical conductivity copper alloy.

Table 2 The physical properties of EFTEC-550T/E.

Property	EFTEC-550T	EFTEC-550E
Thermal Conductivity $W \cdot m^{-1} \cdot K^{-1}$	330	340
Electrical Conductivity % IACS	80 (≧ 75)	85 (≧ 80)
Electrical Resistivity $\mu\Omega \cdot cm$	2.16	2.03
Specific Gravity	8.9	8.9
Modulus of Elasticity GPa	140	130

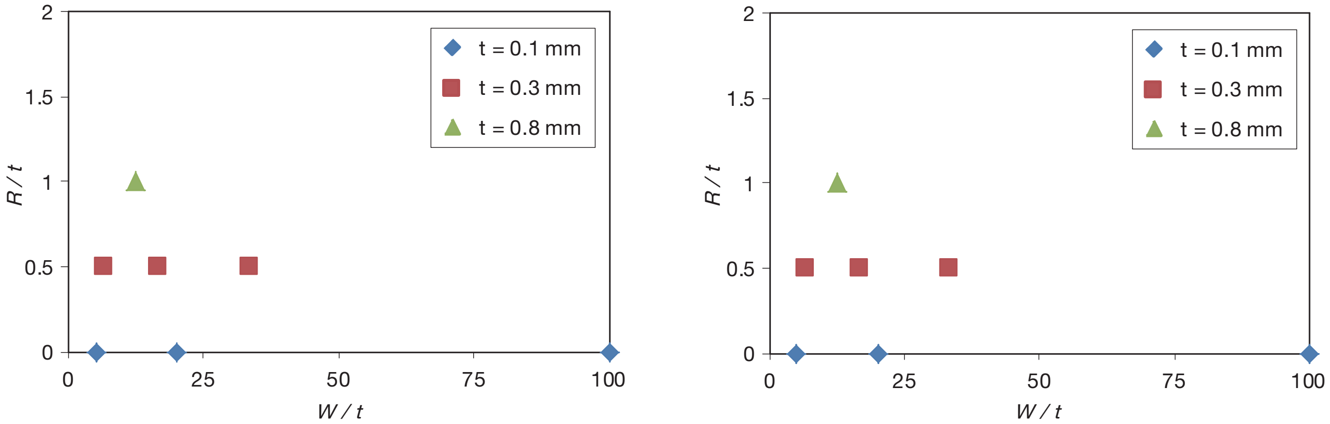
Table 3 The mechanical properties of EFTEC-550T/E.

Property	EFTEC-550T Temper：H	EFTEC-550E Temper：H
Tensile Strength MPa	550	450
Elongation %	10	10



a. EFTEC-550T Good-Way

b. EFTEC-550T Bad-Way



c. EFTEC-550E Good-Way

d. EFTEC-550E Bad-Way

Figure 8 The bending workability of EFTEC-550T/E.

4.3 Bending Workability

In recent years, a compact size and a complexity structure of electric devices have been progressing and the severer bending process for the materials is carried out in various directions. In Figure 8, W-type 90°bending workability is shown. If the sheet thickness of EFTEC-550T is less than 0.3 mm, and if the sheet thickness of EFTEC-550E is less than 0.8 mm, the processing with *R/t* ≦1 is possible. Also, for both EFTEC-550 T and E, *R/t* has small anisotropy to the bending direction.

4.4 Stress Relaxation Property

For the components used in the high temperature environment such as an automotive engine room and the components where the heat generation occurs due to the large current energization, it is of concern that the spring contact material causes a permanent plastic deformation due to the stress relaxation phenomenon and can lead to an electric failure. Therefore, the stress relaxation property is required for the material. In Figure 9, the stress relaxation property of EFTEC-550 is shown. Both EFTEC-550T and E have a significantly smaller stress relaxation ratio in comparison to C5210 which is widely used in the electrical devices and others. Also, as shown in Figure 4, the stress relaxation property is significantly improved in comparison to the existing high electrical conductivity alloy. Especially, the stress relaxation property of EFTEC-550T is equivalent or more in comparison to a general Corson alloy (Cu-Ni-Si).

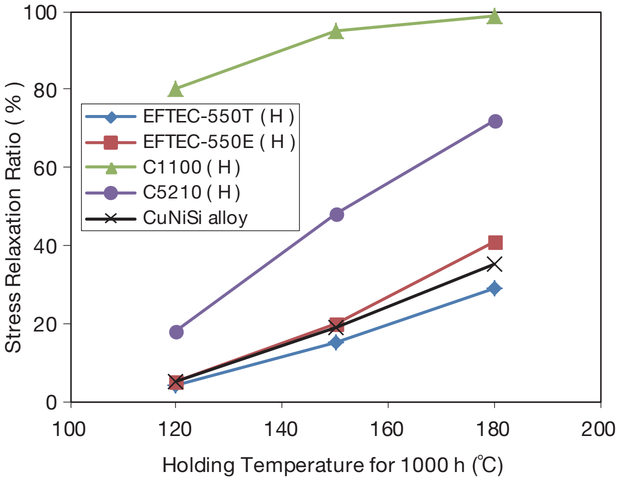


Figure 9 The stress relaxation property of EFTEC-550T/E.

4.5 Softening Resistance

When manufacturing and mounting the electric devices, the soldering and its reflow treatment is generally performed at the temperature range of 250-300℃. Therefore, the material is required not to soften at this temperature range. In Figure 10, the softening resistance of EFTEC-550 is shown. Both EFTEC-550T and E maintain the mechanical property after 30 minutes heat treatment at the reflow temperature range, and it is expected that both products also withstand the heating during component mounting.

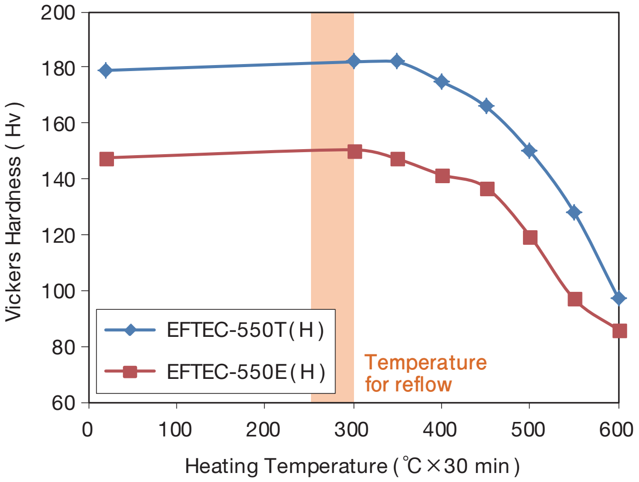


Figure 10 The softening resistance of EFTEC-550T/E.

4.6 Magnetic Property

If the material has a magnetic influence, there is a risk that a malfunction of the peripheral electronic devices, the motors and the semiconductor devices may occur. In the previous report, the specific magnetic permeability μ of the existing copper alloy is shown[2]. Our existing alloy product of EFTEC-3, EFTEC-64T have equivalent specific magnetic permeability to oxygen free copper (C1020) and there is almost no risk to reduce the system reliability due to the magnetic influence. EFTEC-550 has a similar alloy composition to EFTEC-64T, and EFTEC-550 is presumed to have the equivalent magnetic property. In contract, the specific magnetic permeability of C19210 and C19400 containing Fe in the alloy composition becomes large.

5. SUMMARY

The material properties of EFTEC-550 are summarized below.

(1) If compared to the existing high electrical conductivity alloy, the strength and the electrical conductivity are achieved at a higher level for the product of EFTEC-550 and the product also has a better stress relaxation property. EFTEC-550 with an emphasis on the strength, has the tensile strength of about 550 MPa and the electrical conductivity of about 80% IACS. EFTEC-550 with an emphasis on the electrical conductivity, has the tensile strength of about 450 MPa and the electrical conductivity of about 85% IACS.

(2) The stress relaxation property is significantly improved in comparison to C5210 which is mainly used for the electric devices and the existing high electrical conductivity alloy. Especially, EFTEC-550T has a stress relaxation property equal to or greater than the general Corson alloy.

(3) The risk of the material softening due to the heating such as a soldering or a reflow performed at the time of manufacturing and mounting of the electric devices is small.

(4) The specific magnetic permeability of EFTEC-550 is equivalent to C1020 and the risk of a reliability decrease under conditions such as a malfunction of the peripheral electric devices, the motors and the semiconductor devices due to the magnetic influence is small.

EFTEC-550 having these material properties can contribute to the control of the heat generation which is of concern in a high voltage and a high current of the vehicle-mounted power supply system circuit due to the spread of next-generation vehicles, in a large capacity of data communication and in a compact size and a high current of the electric devices and also to the improvement in reliability of the spring contact portion.

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