

Terminal Plating to Lower Insertion Force of Multiway Connectors

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Recent advancements in automotive electronic control systems have led to an increase in the numbers of electronic control units and circuits, and accordingly the number of the necessary connectors and terminals has risen. Meanwhile, multiway connectors require high insertion force, which makes the assembly operation difficult. Therefore, demand has grown for terminal plating that lowers the insertion force. We have developed a tin (Sn) alloy plating technique to replace the widely-used Sn plating. The Sn alloy plating restrains abrasive wear during connector matching and successfully reduces the insertion force.

Keywords: low insertion force, low friction, contact resistance, plating, Sn-Pd

1. Introduction

Nowadays more and more car functions are controlled electrically in order to improve environmental performance, safety, and comfort. This means an increase in the number of electronic control units, which in turn increases the number of sensors and other devices connected to those units, and accordingly the number of circuits in individual units and the number of pins on the connectors. With multiway connectors, a greater force is required to mate the connector (connector mating force) in the process of attaching it to the vehicle, reducing the workability.

Conventionally, when the mating force increased, the connectors were split up or a lever structure was built in the connector to withstand the increased force. However, the installation space allotted to the electronic control units is shrinking to secure the comfort and convenience of the passengers, making these conventional solutions difficult as they require more space.

For this reason, there are increasing demands for the development of plating that reduces the insertion force and friction coefficient of the connector, so that the mating force can be kept low even if the number of pins increases.

Sumitomo Electric Industries, Ltd. has created a connector with an increased number of pins through the development of an original plating technology that lowers the insertion force of terminals, which accounts for the majority of the mating force of connectors.

2. Contact and Wear Mechanism

In contact between solids, there is always some roughness on the surface, and therefore the real contact area is much smaller than apparent contact area, as shown in Fig. 1 (a). The real contact area occurs between the tips of protrusions, as is shown in Fig. 1 (b). This means that the contact pressure becomes extremely high, and a strong bonding power is generated on the surfaces, increasing adhesion. When an external force is exerted on one of the two surfaces, the adhered part is peeled off and forms a new adhered part. The force required to repeat this is the adhesive friction force.⁽¹⁾

Conventionally, reflow tin (Sn) plating has been used for terminals. This involves the plating of Sn on to the copper alloy base metal and the use of a reflow treatment*¹ to melt the Sn and recrystallize it. In abrasion between two items that are the same material, the high level of affinity means that strong adhesion occurs and the frictional force increases.

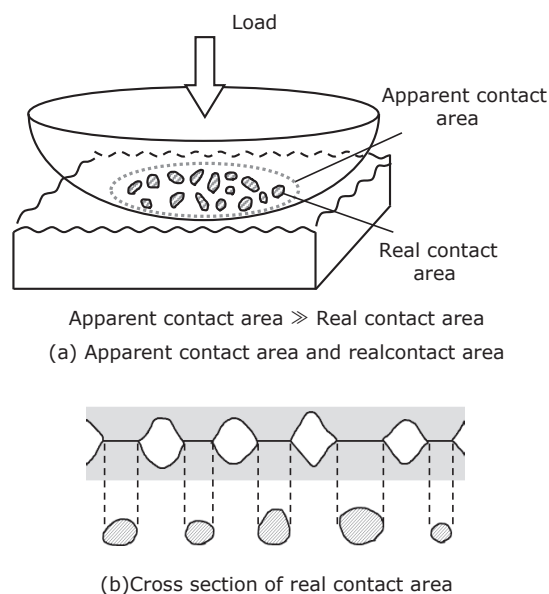


Fig. 1. Schematic drawing of the contact between solid surfaces

Also, because of the differences in the profiles of the two surfaces or other reasons, one of the surfaces is pushed into the other. As Fig. 2 shows, when one surface is spherical and the other is flat, and the two surfaces are slid against each other, the spherical surface will push into the flat surface. As the spherical surface being pushed in moves, the flat surface is dug up along with the forward face in the direction of movement. The force necessary for this digging is the ploughing friction force.⁽²⁾

The adhesive friction and ploughing friction described above also affect the abrasion between the two Sn-plated surfaces when a terminal is inserted. One previous method developed to reduce the insertion force is plating with a thinned Sn layers, such as the 3-layer plating shown in Table 1. By reducing the thickness of the Sn layer, the apparent hardness increases and the ploughing friction and surface deformation decrease. However, the friction coefficient reduction effect is limited to only around 20%.

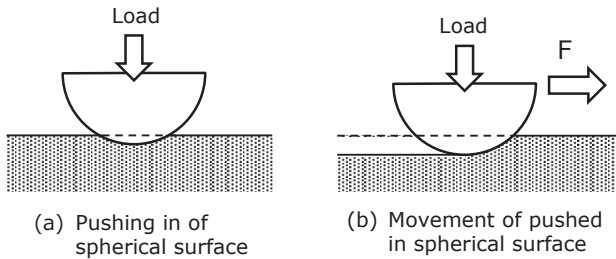


Fig. 2. Ploughing friction force

Table 1. Types of Sn plating (Representative example)

	Reflow Sn plating (IMC*/Sn)	3 layer plating (Ni/IMC/Sn)
Plating Structure		
Sn plating thickness	0.8 μm	0.3 μm
IMC thickness	0.4 μm	0.3 μm
Ni substrate plating thickness	—	0.5 μm
Reflow treatment	Applied	Applied
Reduction effect for Coefficient of friction	—	20%

To further reduce the friction, we considered the use of a plating structure with alternating soft and hard layers as shown in Fig. 3 to realize function-separated plating. This structure secures the contact resistance with the soft layers (Sn) and supports the load during the terminal insertion with the hard layers, to suppress the ploughing friction and adhesive friction forces.

With this structure as the ideal model, we focused on the fact that the intermetallic compound of Sn and palladium (Pd) (Sn-Pd alloy) is hard and forms a mesh pattern, and applied this to low insertion force plating. The plating structure developed is shown in Fig. 4. The feature of this plating is that the hard Sn-Pd alloy is formed in the thickness direction in the soft Sn plating and exposed at the outer surface. The amount of the Sn-Pd alloy depends on the Pd concentration and it is possible to adjust the amount of the alloy as necessary.

On the item developed, Ni, Sn, and Pd layers are formed to obtain an original structure shown in Fig. 4 in the alloying of the reflow treatment.

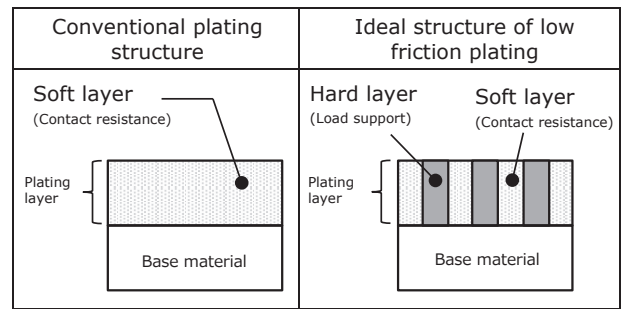


Fig. 3. Ideal structure of low friction plating

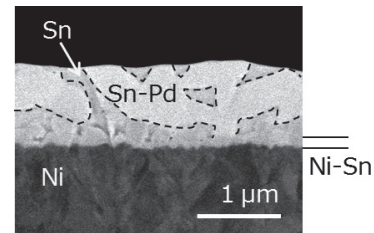


Fig. 4. Cross sectional structure of Sn-Pd plating

3. Sn-Pd Plating Performance

We evaluated the properties of the Sn-Pd plating, which is low in friction, in comparison with the conventional reflow Sn plating.

Figure 5 shows a schematic drawing of the cross section when the terminals are in the mated state. The female terminal has a spherical protrusion on the part in contact with the male terminal. When the terminal is inserted, the frictional force between the male terminal and the protruding part on the female terminal greatly affects the insertion force. For this reason, we prepared a flat test piece to model the male terminal and an embossed test piece*³ to model the protruding part of the female terminal, as shown in Fig. 6. Each test piece was made from a copper alloy plate with a thickness of 0.25 mm. The plating specifications were as shown in Table 2. On the embossed test piece, we performed reflow Sn plating, which is used widely for connectors. For the flat plate, we produced two different types: one with reflow Sn plating and one with Sn-Pd plating. Table 3 shows the combinations of plating used in the evaluations.

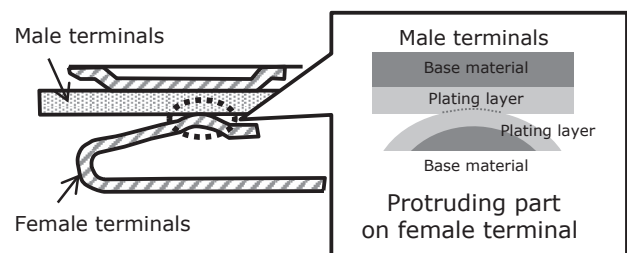


Fig. 5. Schematic drawing of terminal cross section in mated state

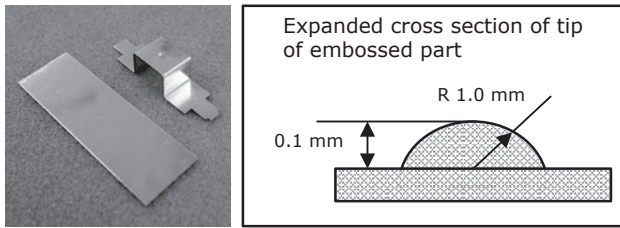


Fig. 6. Flat test piece and embossed test piece

Using these conditions, we evaluated the coefficient of friction (3-1), the resistance to abrasion (3-2), the contact resistance characteristics (3-3), and the resistance to whisker*4(3-4).

Table 2. Plating specifications for test piece

Sample	Type of plating	Plating conditions	Reflow treatment
Embossed test piece	Reflow Sn plating	Sn 1.0 μm	Applied
Flat test piece	Reflow Sn plating	Sn 1.0 μm	Applied
	Sn-Pd plating	Sn 1.0 μm Pd 0.02 μm	Applied

Table 3. Combination of plating conditions for performance evaluation (3-1~3)

Condition	Embossed test piece	Flat test piece
①	Reflow Sn plating	Reflow Sn plating
②	Reflow Sn plating	Sn-Pd plating

3-1 Coefficient of friction

The terminal insertion force depends on the coefficient of friction, and a smaller coefficient of friction results in a smaller insertion force. We verified the reduction in the coefficient of friction resulting from the replacement of Sn plating with Sn-Pd plating.

Figure 7 shows a schematic drawing of the method used to measure the coefficient of friction. The test load was set to 3 N to model the contact load on the small terminals used in multiway connectors. Also, the sliding distance was set to 2 mm in order to model the terminal insertion distance when connectors are mated.

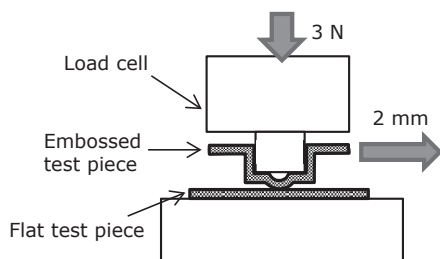


Fig. 7. Schematic drawing of method for friction coefficient measurement

Figure 8 shows the results of the measurement of the coefficient of friction under each of the test conditions. When the sliding distance is up to 2 mm, the peak value was 0.54 for reflow Sn plating and 0.36 for Sn-Pd plating, and therefore the coefficient of friction reduction effect is 33%.

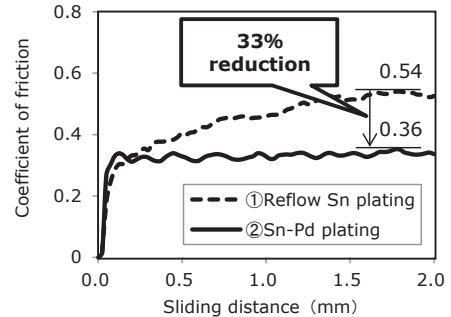


Fig. 8. Results of friction coefficient measurement

3-2 Resistance to abrasion

Figure 9 shows the results of the observation of abrasion marks during the measurement of the coefficient of friction in the preceding item. A scanning electron microscope (SEM) was used for the observation.

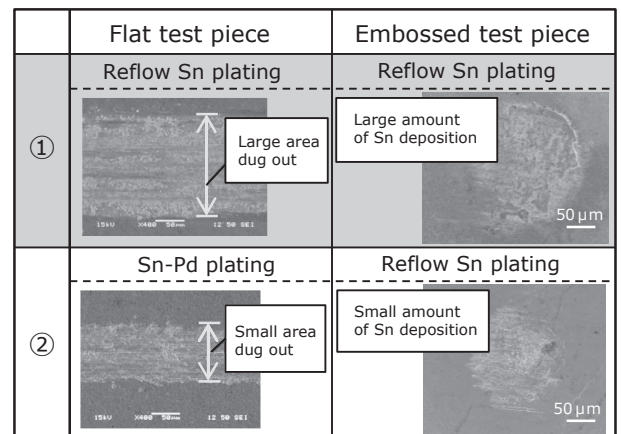


Fig. 9. Results of comparative observation of abrasion marks

With the reflow Sn plating, the coefficient of friction increases as the sliding distance proceeds. This is because a large area was dug with the reflow Sn plating and repeatedly adhered to the Sn on the embossed side as the movement progressed. This resulted in a large accumulation of Sn on the embossed test piece.

In comparison, with the Sn-Pd plating, even after sliding the test pieces, the coefficient of friction remains unchanged. With Sn-Pd plating, the hard alloy supports the load and prevents the embossed part from being pushed in,

which suppressed the digging and abrasion. Furthermore, it is also thought that the coefficient of friction was reduced because the adhesive force between the Sn and the Sn-Pd alloy parts exposed on the surface is weak and this has the effect of suppressing the adhesive wear.

3-3 Contact resistance characteristics

We measured the load-contact resistance to evaluate the connection reliability, which is an important characteristic for connector plating.

The method used for the evaluation was to press the embossed test piece on to the flat test piece as shown in Fig. 10. We slowly raised the load applied in the vertical direction from 0 N to 40 N while passing a current of 10 mA through and measuring the contact resistance using the four-terminal method.

Figure 11 shows the measurement results of the load-contact resistance. The contact resistance decreases when the load increases. This occurs because the real contact area increases as the load increases.⁽³⁾ Regarding this property, there were no big difference seen between reflow Sn plating and Sn-Pd plating, both showing good results.

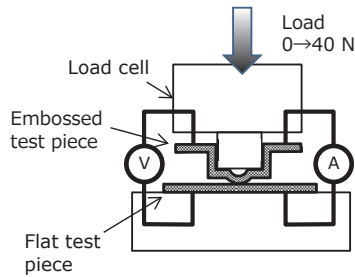


Fig. 10. Schematic drawing of load-contact resistance characteristics measurement

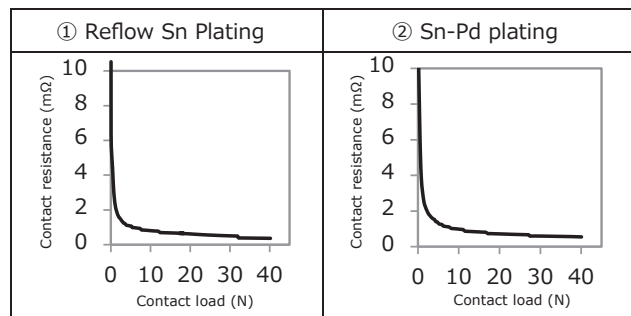


Fig. 11. Comparison of load-contact resistance characteristics

3-4 Resistance to Whisker

External stress is applied to the plating on the male terminal at the points in contact with the female terminal or the parts press-mated into the housing. When external stress is exerted on Sn plating, for which reflow treatment has not been applied, there is a possibility that whiskers may occur from the plating surface.

In general, the internal stress on Sn plating is relaxed

by melting the Sn and then recrystallizing it in a reflow treatment, and this suppresses the occurrence of whiskers. With Sn-Pd plating, it is thought that the resistance to whiskers is greater than with reflow Sn plating because, in addition to the performing of a reflow treatment, the hard Sn-Pd alloy supports the external stress and alleviates the load on the pure Sn parts, and also there is little of the pure Sn that is the source for the occurrence of whiskers. Therefore, in order to evaluate the superiority of the Sn-Pd plating, we implemented a sphere indentation test (Japan Electronics and Information Technology Industries Association JEITA RC-5241), which uses harsh conditions that generate whiskers on reflow Sn plating. Figure 12 shows the method used for the sphere indentation test. The test conditions used were a test load of 3 N left for 72 hours.

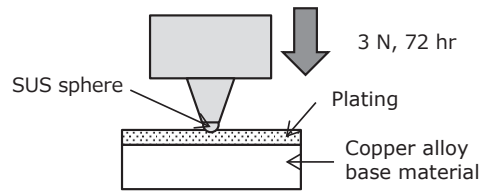


Fig. 12. Schematic drawing of sphere indentation testing

Figure 13 shows the SEM images taken after the test. On the reflow Sn plating, Sn is deformed around the indentation and whiskers were observed. On the other hand, on the Sn-Pd plating, the indentation was seen, but there was no whisker.

These results suggest that Sn-Pd plating has a higher resistance to whiskers than reflow Sn plating.

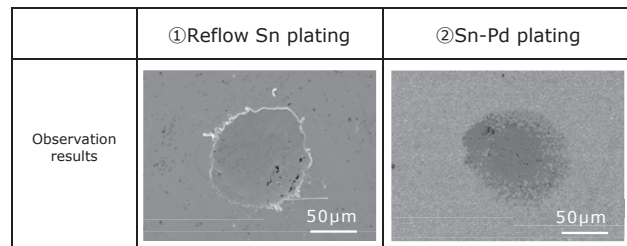


Fig. 13. Condition of plating surface after sphere indentation testing

4. Example Application to Products

4-1 Connector mating force

Figure 14 shows an example of the results of mating force evaluations on multiway male connectors with Sn-Pd plating. The female connectors were reflow Sn-plated and only the plating on the male connector was changed. If the mating force for conventional reflow Sn plating is taken to be 100%, the use of Sn-Pd plating obtained a 33% reduction in the connector mating force.

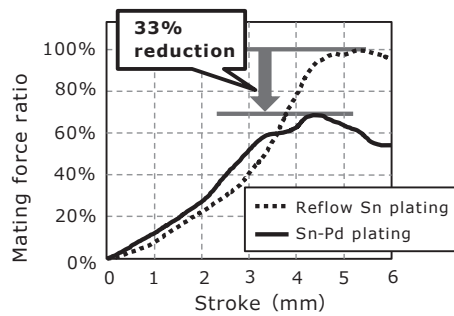


Fig. 14. Example reduction effect for connector durability evaluations

4-2 Connector durability performance

We performed connector durability evaluations assuming in-vehicle environments. Normally, the connectors are mated once during the vehicle assembly. However, the connectors need to be inserted or removed multiple times if a failure or problem occurs. Assuming these conditions, we examined whether the contact resistance could be kept low even after inserting and removing a connector ten times. For Sn related plating, with which the intermetallic compound grows over time, we tested the long-term stability. The samples were stored in an air atmosphere at 160°C for 200 hours, which is an extremely harsh condition where the contact resistance of the conventional reflow Sn plating increases.

Figure 15 shows the results of this series of durability tests. The contact resistance remained unchanged even after mating the connector ten times. A rise in the resistance was seen in the high temperature storage test conducted after inserting and removing the connector ten times, but the value was lower than that on reflow Sn plating.

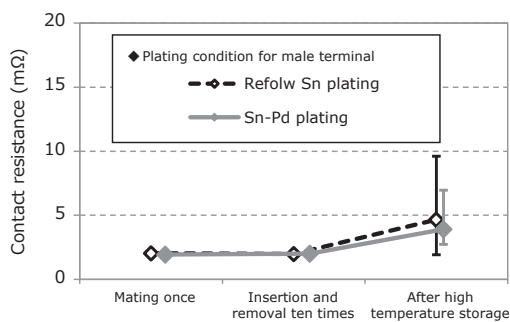


Fig. 15. Results of connector durability evaluations

5. Conclusion

In order to respond to the increase in the number of pins on automotive connectors, we have developed Sn-Pd plating with a low friction coefficient. The results are:

- (1) A 33% reduction of the coefficient of friction compared with conventional reflow Sn plating for small terminals
- (2) A 33% reduction of the connector mating force

when Sn-Pd plating is applied to the male connector

- (3) Connection reliability equivalent to or greater than that of conventional reflow Sn plating
- (4) Whisker resistance equivalent to or greater than that of conventional reflow Sn plating

This plating technology has been adopted for our male connectors, which have been mass produced since 2016.

Technical Terms

- *1 Reflow treatment: A treatment which involves heating after plating in order to melt and recrystallize the metal to relax internal stress in the plating and form an intermetallic compound through thermal diffusion with the underlying metal, so as to secure plating stability.
- *2 IMC: InterMetallic Compound: A compound composed of two or more types of metal.
- *3 Embossed test piece: A test piece produced by using a mold to form hemispherical protrusions on a metal plate.
- *4 Whiskers: Whisker is a metal single crystal that forms on the surface of the plating. Mainly seen in Sn plating.

References

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