

Development of a Lead-Free Fuel Tank

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ABSTRACT

A hot dip Sn-Zn alloy (8% Zn) coated steel sheet having superior corrosion resistance, formability and processability was developed as a lead-free fuel tank. As soldering material, an Sn-Ag alloy (3.5% Ag) having low temperature soldering characteristics and superior galvanic corrosion characteristics with the coating was developed.

An issue in the production engineering area was that consecutive spot welding quantity declined to 1/2 the number of current welds. The cause was degradation of the electrode caused by an alloy reaction between the metallic electrode and the coated metal. The technical improvement measures to handle this were the surface contact resistance was controlled, the weld current was reduced, and the shape of the electrode tip was optimized.

This enabled attainment of processability equivalent to current levels using existing equipment, and development of a fuel tank having superior corrosive durability, formability and welding characteristics, and overall performance.

1. Background

Laws and regulations that call for reducing the use of substances such as lead that place a burden on the environment are becoming more common. Examples of which include the European waste regulations (ELV) and the Japanese Ministry of International Trade and Industry laws related to waste treatment and clean up. Control standards for products containing lead are scheduled to be tightened. An example is the announcement in May 1997 of Japanese government targets as a part of the end-of-life automobile recycling initiative.

The Voluntary Recycling Action Plan calls for a reduction in the amount of lead (chemical symbol Pb) used per automobile to less than 1/3 of the 1996 level by the end

of 2003. Fig. 1 shows the major parts that use lead and the amounts of lead used per automobile (source: Japan Automobile Manufacturers Association).

The amount of lead used in a fuel tank is typically 200 g, which is equivalent to roughly 11% of the total amount used per automobile. The use of lead-free fuel tanks will therefore be indispensable for reducing the amount of lead used to 1/3 of the 1996 level.

2. Present State and Important Issues

As shown in Fig. 2, the lead used in fuel tanks is in the form of steel sheet coating components, solder metal and coating components for pipes and other parts.

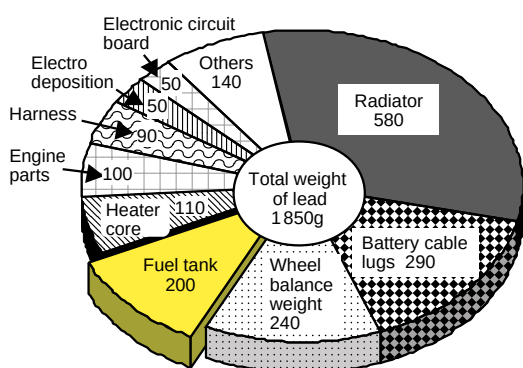


Fig.1 Automobile parts containing lead and amount they contain

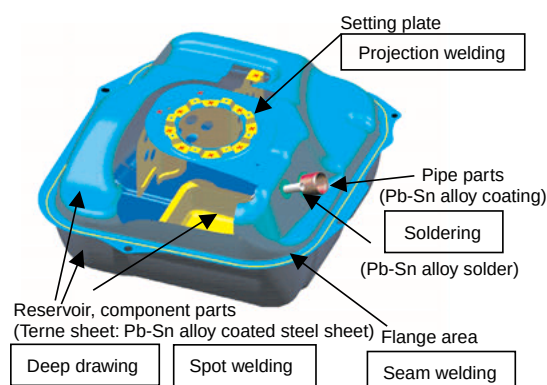


Fig.2 Areas where lead alloys are used, the alloy type is in parenthesis and the production technology is in the box

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Fuel tanks are required to have high corrosion resistance on both their inner and outer surfaces, and as shown in Fig. 2, deep drawing formability, as well as, for example, suitability for various types of welding and joining techniques. The terne sheet currently used as material for fuel tanks inherently possesses outstanding suitability with respect to all of these requirements.

(1) Internal Corrosion Resistance

Soured gasoline, which contains numerous olefin components and so forth, degrades due to the formation of organic acids resulting from oxidation. Moreover, the moisture that condenses in the tank results in a high acidic concentration. ⁽¹⁾⁽²⁾ Terne sheet is chemically stable against these organic acids.

(2) External Corrosion Resistance

A high level of corrosion resistance is required in environments where the vehicle is splashed by water containing rock salt and other salts that are sprinkled on roads to melt snow. The chemical stability and outstanding formability of terne sheet ensures little damage to the coating and a minimal decrease in its corrosion resistance.

(3) Formability

The physical properties of fuel tank materials are required to provide high levels of elongation, flexibility (deformation resistance) and solid lubricity. Terne sheet demonstrates outstanding characteristics with its high levels of elongation, rollability and flexibility for press forming and other plastic processing.

(4) Weldability

Stable weldability is required for seam, spot, projection and other types of resistance welding, and it is necessary for suppressing any deterioration of the welding electrodes. The lead contained in terne sheet has the characteristic of resisting the formation of an alloy with the copper (chemical symbol Cu) of the electrode, thereby demonstrating satisfactory weldability.

(5) Solderability

Fuel tank materials are also required to have such characteristics as high mutual reactivity with the solder metal and low coating surface energy that inhibits the formation of an oxide film and results in good wettability. In addition, the materials are also required to inhibit bimetallic corrosion with the solder. The solder used with terne sheet is the same type of Pb-Sn material as that of the coating, resulting in satisfactory solderability and resistance to bimetallic corrosion.

The objective of this present development was to obtain levels of corrosion resistance, weldability, formability and other workability equal to or better than the current levels, as well as a level of processability equal to or better than current with existing production equipment.

With respect to corrosion resistance in particular, there is growing need for a relative increase in the corrosion life of the fuel tank to accompany the general increase in service life of automobiles in recent years due to the improved corrosion resistance of automobile bodies. Not only is this need growing in North America and other regions having a severe corrosion environment, but a similar need has recently become conspicuous in Japan due to the significant increase in the amount of road salt sprinkled on expressways and

major trunk roads in snowbound regions since the use of studded tires was prohibited.

In addition, there is increasing attention being focused on the inside of the fuel tank due to the problem of soured gasoline accompanying the expanding automobile demand in developing countries, and the use of this gasoline resulting in the need for a higher level of corrosion resistance.

3. Design of Metallic Coatings

3.1. Selection of Coating Metal

Two important elements of a highly corrosion-resistant coating are as follows:

- high chemical stability against soured gasoline on the inner surface of the fuel tank and against salt damage to the outer surface
- an anodic corrosion potential of the coating relative to iron (chemical symbol Fe); namely, demonstration of sacrificial corrosion prevention by the coating

The relationship between the corrosion potential relative to iron and the eluted volume in soured gasoline (containing 10% water) for the typical metals used for coating is shown in Fig. 3. Moreover, the relationship between the corrosion potential and eluted volume in sea water (as an estimate of the external corrosion resistance) is shown in Fig. 4.

Aluminum (chemical symbol Al) demonstrates the best performance among metals, this being followed by tin

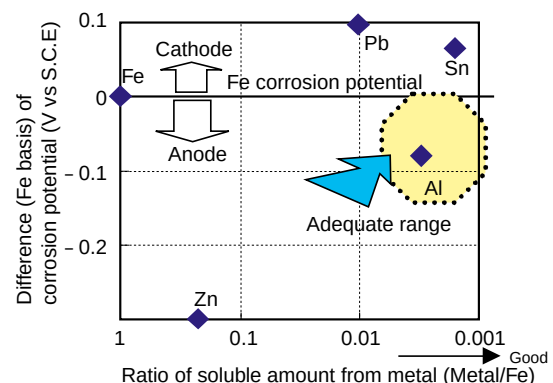


Fig.3 Comparison of the corrosion potential and dissolution in soured gasoline solution of various metals

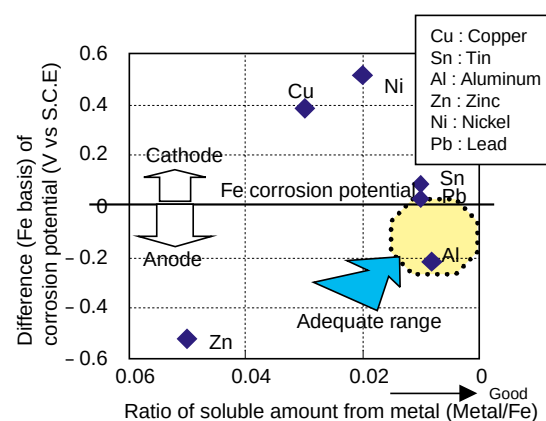


Fig.4 Comparison of the corrosion potential and dissolution in sea water of various metals

(chemical symbol Sn). However, aluminum was discounted because soldering is difficult due to the formation of a hard oxide film on the surface. Since the potential of tin is cathodic, it is necessary to make the potential more anodic in order to improve the corrosion resistance. Tin inherently has excellent soldering properties, and is likely to be highly suitable for fuel tank use due to its formability based on its outstanding flexibility and elongation.

Thus, in this study, we attempted to optimize the potential by using an anodic metal alloy based on tin.

Although examples of anodic metals that can be used for coating include magnesium (Mg), aluminum and zinc (Zn), it is difficult to obtain satisfactory coating processability with magnesium, and a high content is required to adjust the corrosion potential in the case of aluminum. Since problems with solderability also exist, zinc was selected and its anodization examined. In addition, hot dip coating was selected for the coating method due to its high processability and the potential use of existing coating equipment.

3.2. Alloy Design ⁽³⁾⁽⁴⁾

Fig. 5 shows the change in corrosion potential and metal eluted volume in soured gasoline versus the zinc content of the zinc-tin alloy.

The potential moves toward the anodic side as the amount of zinc is increased, becoming anodic at 4%. Since the potential stabilizes when the amount of zinc exceeds 6%, a zinc content of 7% or more was considered to provide the optimum potential.

On the other hand, although the eluted volume was low and remained stable until a zinc content of 10% was reached, it tended to increase rapidly with a zinc content of around 11%. This phenomenon can be interpreted from the two-element equilibrium diagram for Sn-Zn shown in Fig. 6 and from the eutectic states shown in Fig. 7.

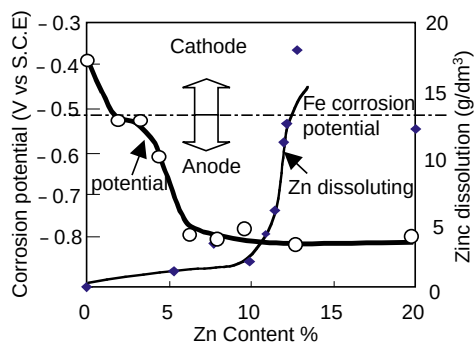


Fig.5 Relationship between Zn content and corrosion potential and Zn dissolution

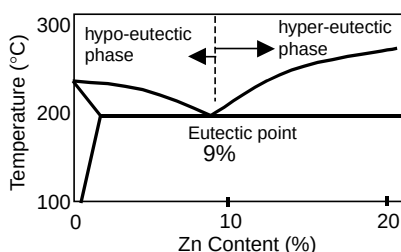


Fig.6 Equilibrium diagram of Sn-Zn alloy

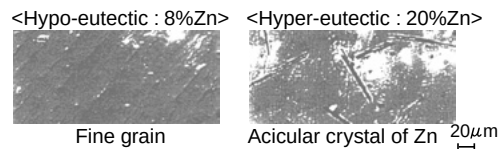


Fig.7 Appearance of Sn-Zn alloy crystal

The eutectic point for alloys of tin and zinc is at a zinc content of 9%. Coarse zinc crystals are formed in the hyper-eutectic range in excess of this zinc content, and it is assumed that the excess zinc dissolves to result in an increase in the eluted volume.

Thus, it is necessary for the zinc content to be less than the eutectic point of 9% in order to inhibit the formation of coarse zinc crystals.

Summary:

The optimum range for the zinc content is thus 7-9% based on the corrosion potential and the elution properties (to inhibit the formation of coarse zinc crystals). Coating was performed in molten Sn-Zn alloy containing a median value of 8% zinc, this being subsequently referred to as the Sn-Zn coating.

The Sn-Zn coating was enhanced by chemical conversion coating to further improve the corrosion resistance and adhesion of the coating.⁽⁵⁾

Fig. 8 shows a cross-section of this newly developed coated steel sheet.

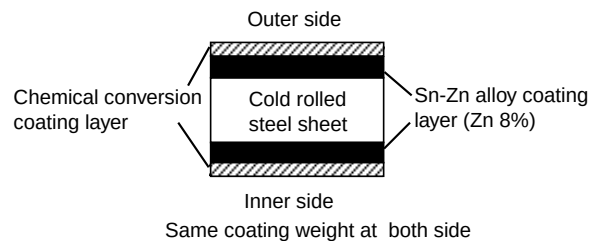


Fig.8 Schematic illustration of the Sn-Zn coated steel sheets for fuel tank applications

4. Major Technical Elements and Test Results

The following section describes the results of examining the major fuel tank technical elements of corrosion resistance, spot weldability, seam weldability and solderability.

4.1. Corrosion Resistance

4.1.1. External Corrosion Resistance

Photographs taken after a corrosion test on a test piece incorporating the variation in sheet thickness equivalent to that of a fuel tank formed by press working a coated steel sheet are shown in Fig. 9.

The Sn-Zn coating provided particularly good corrosion resistance at the drawn portions. This is the result of the good elongation of the coating and its having suitable sacrificial corrosion prevention properties. In the case of the current material, rust started to form where the coating was damaged due to the absence of any sacrificial corrosion prevention effect.

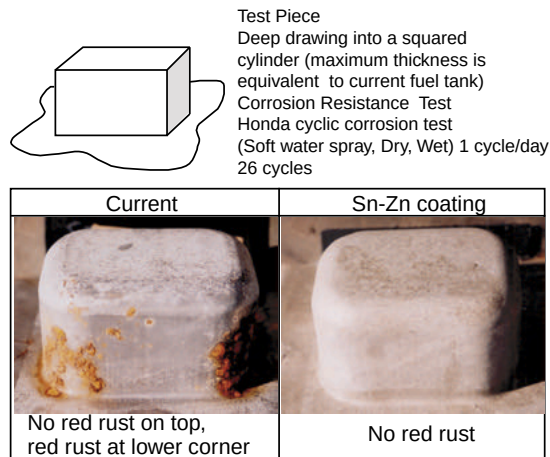


Fig.9 Appearance after corrosion test

4.1.2. Internal Corrosion Resistance

The results for corrosion resistance against soured gasoline are shown in Fig. 10 for a test piece worked in the same manner as that described in section 4.1.1 above.

In comparison with the current material, the Sn-Zn coating provided superior corrosion resistance.

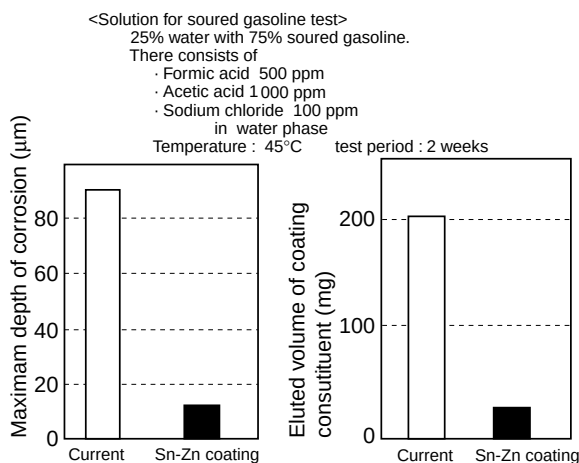


Fig.10 Result of corrosion resistance by soured gasoline test

4.2. Spot Welding

Fig. 11 shows the results of a electrode tip life test on the spot weldability of the current material and the Sn-Zn coated material, while Fig. 12 shows the states of the weld at the start and completion of an electrode tip life test of the Sn-Zn coated material.

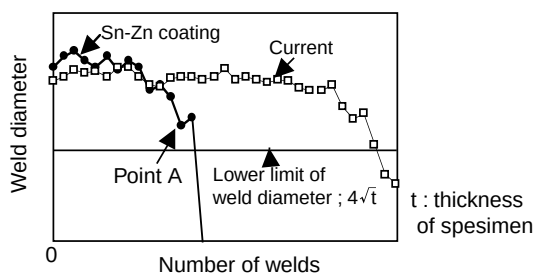


Fig.11 Changes of weld diameter during electrode tip life test

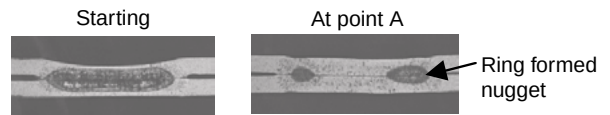


Fig.12 Cross-sectional view of nugget (Sn-Zn)

The Sn-Zn coated material demonstrated roughly half the electrode tip life of the current material, and at the end of the electrode tip life test (point A), the nugget exhibited an unstable ring shape.

An analysis of the cause was made, and the change in the shape of the electrode tip faces occurring in the test was impressed on a piece of pressure-sensitive paper. The results are shown in Fig. 13, while the appearance of the electrode after the test is shown in Fig. 14.

Number of welds	1	100	point A
Before modifying			
After modifying			

Fig.13 Change of electrode tip face shape during electrode tip life test

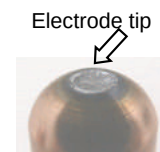


Fig.14 Appearance of electrode after welding

The electrode tip was worn down during the electrode tip life test, and the area of the contact surface can be seen to have become larger.

The results of an EPMA analysis of the electrode cross-section after the electrode tip life test are shown in Fig. 15.

An indentation had formed in the center of the electrode tip, and Cu-Sn or Cu-Sn-Fe alloy was deposited progressively deeper toward the center. The top of this deposit consisted of a coated metal or heterogeneous alloy layer, and is believed to have been easily peeled. It is thought that the electrode deteriorated in this manner, inhibiting the formation stability of the nugget and reducing the electrode tip life.

In contrast, the current material deposited a thin, uniform layer of alloy on the electrode and there was only slight deterioration as shown in Fig. 16. This is because a lead and copper alloy is difficult to form.

Summary: Causes of Decreased Electrode Tip Life

The cause of the deterioration in electrode tip life of the Sn-Zn coated material relative to the current material is that, during the course of the electrode tip life test, an alloy formation reaction occurred between the electrode and coating, causing a deterioration in the form of an indentation at the center of the electrode which expanded the tip and

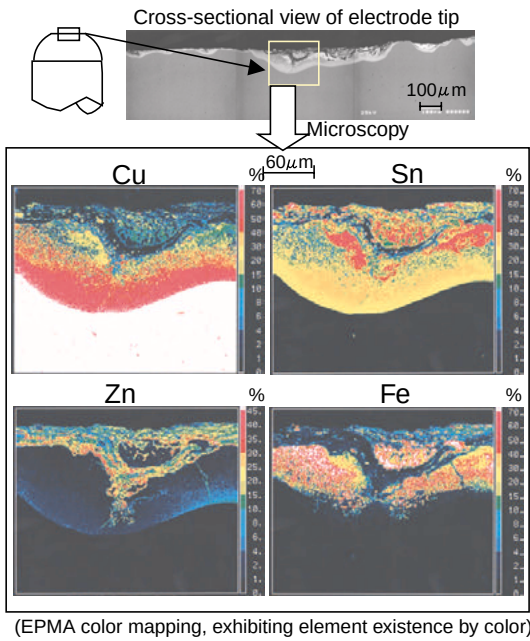


Fig.15 Metal distribution at cross-section of deposition electrode tip



Fig.16 Cross-sectional view of electrode tip used for welding the current material

resulted in an increase in the contact surface area of the electrode tip. This decreased the current density, which is thought to have caused insufficient nugget formation. A schematic diagram of this is shown in Fig. 17.

Thus, the corrective action required to improve the electrode tip life involves the three factors listed below.

- (1) Reducing the amount of wear (rate of progression) caused by alloy formation on the electrode by using a lower current, etc.
- (2) Reducing the coating weight to reduce the absolute amount of alloy formed.
- (3) Inhibiting the increase in contact surface area of the tip caused by wear through optimization of the electrode tip shape.

The results of our studies conducted based on the above viewpoint are described in section 4.2.1.

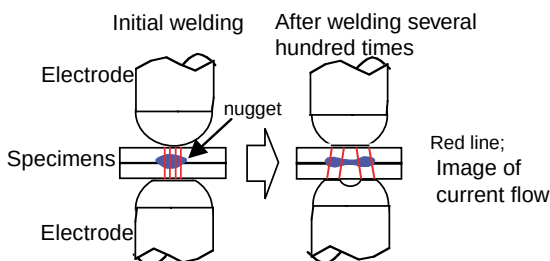


Fig.17 Model of degenerated electrode

4.2.1. Results of a Study to Improve the Spot Weldability

(1) Use of a Lower Current

One way of allowing a lower current to be used while still producing an acceptable nugget is to increase the value of resistance (R) shown in equation 1. This can be achieved by increasing the contact resistance between the steel sheets.

$$\text{Heat quantity equation: } Q (\text{cal}) = 0.24 \cdot I^2 \cdot R \cdot t \quad (1)$$

where I is the current (A), R is the resistance (Ω) and t is the time (s).

Two factors that govern the contact resistance are the coating weight (thickness) of the chemical conversion coating and the condition of that coated surface.

More specifically, increasing the coating weight and decreasing the surface roughness are presumed to contribute to increasing the resistance value. (Inhibiting the alloy formation reaction between the electrode and coating is also expected to contribute to this effect.)

An image of the condition of the surface is shown in Fig. 18, and the change in contact resistance when the amount of the chemical conversion coating and surface roughness were changed is shown in Fig. 19. In addition, the relationship with the contact resistance is shown in Fig. 20 by expressing the two variables of coating weight and surface roughness as the shield ratio (coating weight/surface roughness).

Although the contact resistance increases as the coating weight increases, if the surface roughness increases, this contribution is considerably decreased. Thus, it is effective to reduce the surface roughness. In addition, it was found that the contact resistance could be controlled by adjusting the shield ratio.

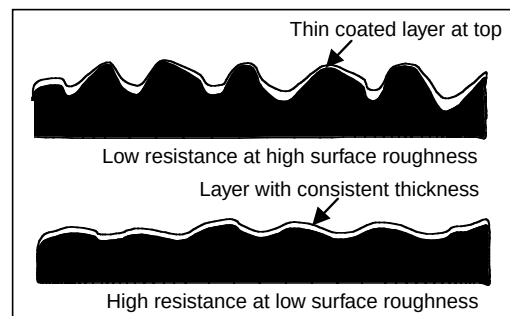


Fig.18 Image of cross-sectional view of coating

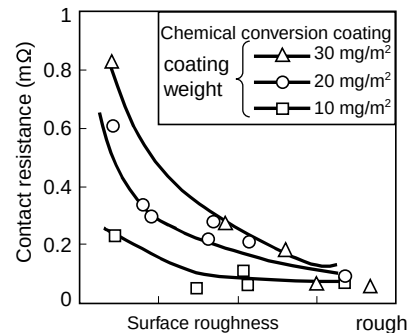


Fig.19 Relationship between surface roughness and coating weight and contact resistance

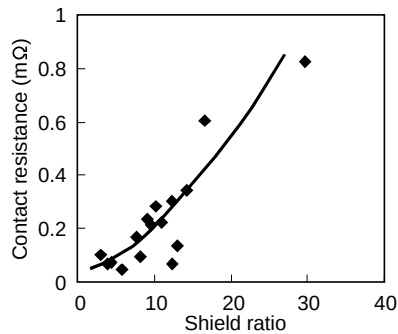


Fig.20 Relationship between shield ratio (coating weight/surface roughness) and contact resistance

The effect of contact resistance on the lower limit of the welding current over the weldable range was confirmed on the basis of the foregoing results. Fig. 21 shows the relationship between the contact resistance and the lower limit of the welding current, while the effect on improving electrode tip life is illustrated in Fig. 22.

Summary: Use of Lower Current

The contact surface condition can thus be optimized by controlling the surface roughness, while the electrode tip life can be improved by reducing the welding current.

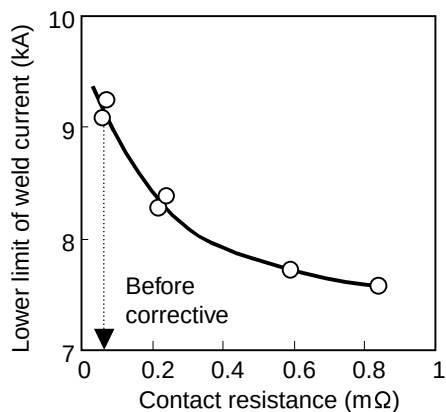


Fig.21 Relationship between contact resistance and lower limit weld current

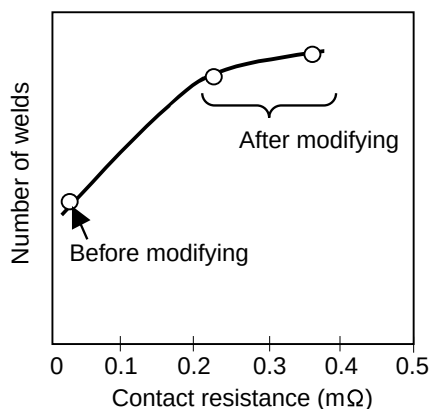


Fig.22 Relationship between contact resistance and electrode tip life

(2) Coating Weight

It is necessary to consider the effect on corrosion resistance when reducing the coating weight. The relationship between electrode tip life and corrosion resistance (the area over which red rust had formed after 72 hours of the salt spray test) according to the coating weight is shown in Fig. 23.

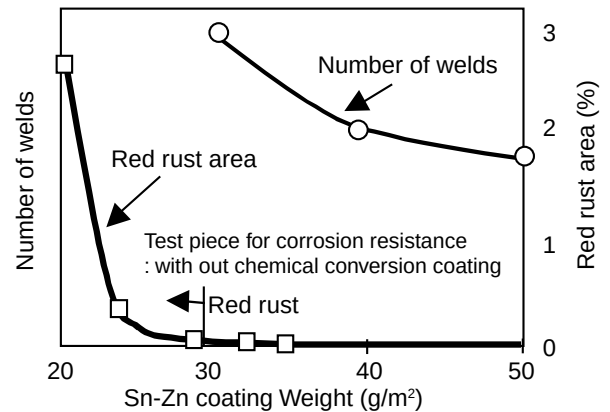


Fig.23 Relationship between Sn-Zn coating weight and electrode tip life and corrosion resistance

The thinner the coating, the better the electrode tip life. However, the lower limit was set at 30 g/m² to achieve a suitable balance with the corrosion resistance.

(3) Optimization of the Electrode Shape

Reducing the diameter of the electrode tip was most effective for suppressing the increase in contact surface area. Fig. 24 shows the relationships between the electrode tip diameter and the electrode tip life and lower limit of the welding current, while Fig. 25 shows on the change in contact surface area of the electrode tip.

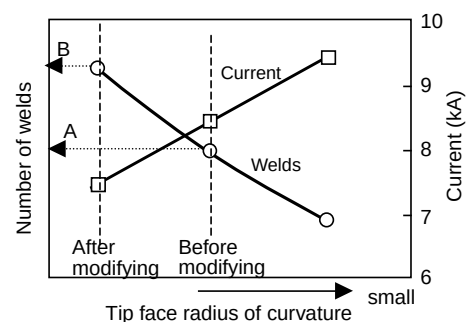


Fig.24 Relationship between shape of electrode and electrode tip life and lower limit of welding current

Number of weld	1	100	A	B
Before modifying				—
After modifying				

Fig.25 Change of electrode face shape during electrode tip life test

Together with inhibiting the increase in contact surface area over the span of the electrode tip life, reducing the diameter of the electrode tip also improved the electrode tip life due to the synergistic effects resulting from a decrease in the initial contact surface area (see the first weld in Fig. 25), the lower welding current, and the reduced electrode deterioration. However, since reducing the diameter of the electrode tip also results in such a problem as small nugget diameters, the tip diameter was ultimately set to maintain the optimum balance.

Summary: Improvement of Spot Weldability

Spot weldability could therefore be significantly improved by optimizing the surface contact resistance, coating weight and shape of the electrode, to attain a performance equivalent to the current level.

4.3. Seam Welding

Although there was expected to be a decrease in weldability due to alloy formation, since copper was used for the electrode in the same manner as that for spot welding, weldability equal to the current level was obtained. Fig. 26 shows a photograph of the test, while Fig. 27 shows the state of the nugget during the electrode tip life test.

The quality of the nugget was favorable even after 2000 m of welding, indicating long electrode tip life.

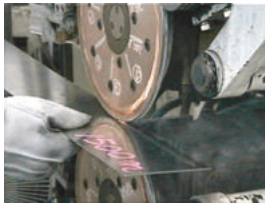


Fig.26 Seam welding test

Distance of consecutive welding		Cross direction	Longitudinal direction
Sn-Zn coating	100 m		
	500 m		
	2000 m		
Current Over 1000 m (mass production)			

Fig.27 Cross-sectional view of nugget during electrode tip life test

Fig. 28 shows the appearance of the electrode after 10 m of welding, while Fig. 29 shows the state of metal distribution at the electrode tip as determined by an EPMA analysis during electrode tip life tests.

An alloy consisting mainly of tin was formed as blisters on the surface (arrow “a” in Fig. 29) and an alloy consisting mainly of iron was formed near the electrode interface. Both

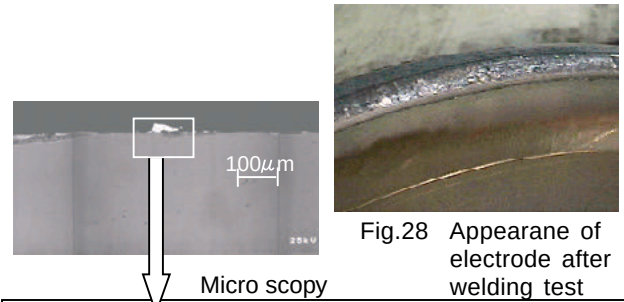


Fig.28 Appearance of electrode after welding test

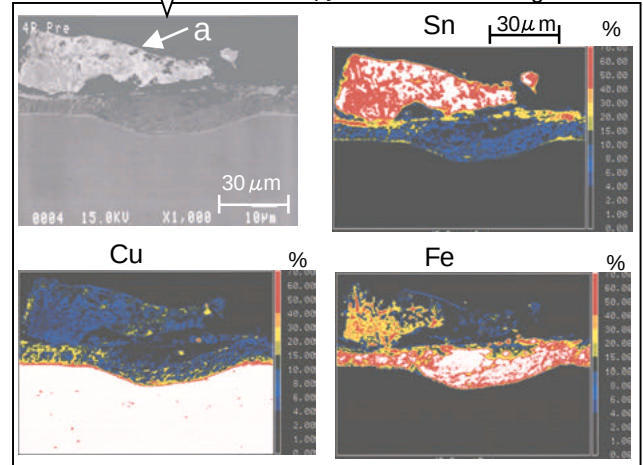


Fig.29 Metal distribution in cross-sectional view of electrode tip (EPMA color mapping, exhibiting element existence by color)

of these are components of the coated steel sheet material, and the phenomenon of alloy formation with copper, as occurred on the spot welding electrode, was only observed to an extremely small degree. In addition, intermittent peeling and separation of adhered substances from the electrode were apparent in the electrode tip life test. The appearance and components of the substances that peeled off are shown in Fig. 30.

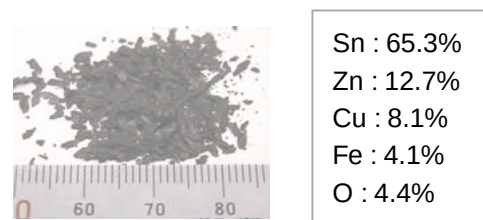


Fig.30 Appearance of peeled sample and its composition

The substances that peeled off consisted primarily of coating components and a small amount of copper (electrode material), indicating that the coating repeatedly accumulated and then separated from the electrode.

On the basis of these findings, it is believed that electrode deterioration was inhibited as a result of self-dressing by which the coating components peeled off the electrode before an alloy could be formed between the electrode and coating, thereby resulting in satisfactory electrode tip life.

The mechanism by which coating components peeled off the electrode is illustrated in Fig. 32.

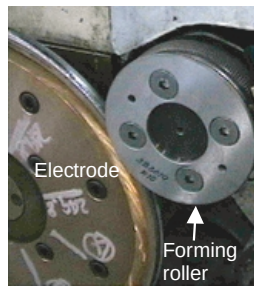


Fig.31 Layout of forming roller

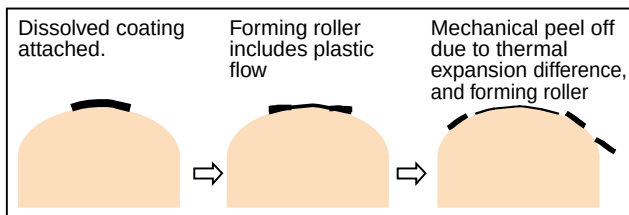


Fig.32 Behaviour of by-products on electrode tip

- (1) Effects appear in which the forming roller, a component part of the welding machine (the position is shown in Fig. 31), physically forms the tip of the electrode while ejecting the adhered coating.
- (2) The adhered coating is induced to plastic flow by the forming roller due to its low melting point and low deformation resistance.

4.4. Soldering

4.4.1. Selection of the Solder Material

When selecting a solder, in addition to its spreadability, wettability and physical properties, the solder should satisfy the following requirements for adequate corrosion resistance:

- (1) A low degree of potential difference corrosion caused by bimetallic contact between the solder material and coating (steel sheet and soldered tube)
- (2) A low soldering temperature, namely a low melting point for the solder material, and a resulting resistance to deterioration of the Sn-Zn coating of the steel sheet and tube coating caused by heat (melting and oxide formation).

The corrosion potential series of typical metals used for soldering and brazing along with their melting points are shown in Table 1.

An Sn-Zn alloy also consisting primarily of the Sn was the most favorable solder material based on its low melting point and position in the corrosion potential series. This

Table 1 Typical solder, metal and corrosion potential series and melting point

Corrosion potential series in sea water		Melting point (°C)
Zn-Al	Anode ↑ ↓ Cathode	390
Sn-Zn		200
Pb-Sn (current)		191-215
Sn-Ag (Ag3.5%)		221
Cu-Zn		850-900
Cu	Cathode	1 100
Ag-Cu		650-750

was followed by Sn-Ag (containing 3.5% Ag), the potential candidates being limited to these two types.

In addition, an Sn-Zn coating of the same type as that used for the steel sheets (electroplated, with a Zn content of 30-45%) was used for the tube coating.

The wettability performance was next evaluated by a soldering simulation test with the high frequency induction heating method as shown in Fig. 33. A photograph of the resulting cross-sections is shown in Fig. 34.

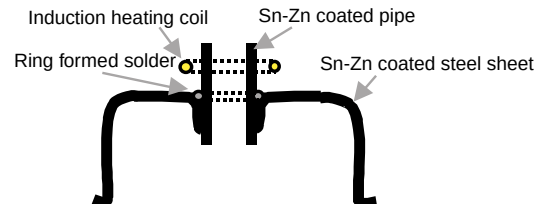


Fig.33 Solderability evaluation model (Induction heating method)

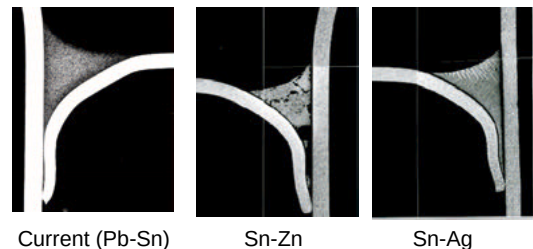


Fig.34 Cross-sectional microstructure of soldering

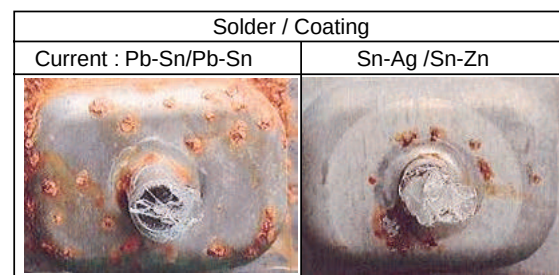
Although Sn-Ag exhibited favorable wettability comparable to the current level, adequate wettability could not be obtained with Sn-Zn, even though it was heated to 150°C above its melting point.

This is presumed to have been due to oxidation of the Zn component, resulting in entrapment of oxide and increased viscosity, which in turn increased the surface tension and decreased the wettability.

A corrosion resistance test was next performed after soldering, a photograph of the results obtained after the test being shown in Fig. 35.

The combination of Sn-Ag solder and Sn-Zn coating was favorable in that it reduced corrosion around the solder to a greater extent than the current soldering method.

Tests were also conducted on other parameters including



Corrosion test : CCT 15 cycles

Fig.35 Appearance after corrosion test on soldered area

the adhesion strength and creep characteristics. As a result, the Sn-Ag solder was confirmed to be equal to or better than current solder materials.

On the basis of these results, it was decided to use an Sn-Ag alloy (containing 3.5% Ag) as the solder material.

5. Evaluation of Suitability as a Fuel Tank Material

A prototype fuel tank was produced using a mass-production line and equipment, and the quality and performance of this prototype tank were evaluated in order to identify its suitability for use as a fuel tank. The results of the technical evaluation consisting of formability, spot weldability and corrosion resistance are indicated.

5.1. Formability

The sheet thickness at individual points was measured and a comparison was made with current materials. Sheet thickness data are shown in Fig. 36 as standard deviations.

Since the sheet thickness distribution of the Sn-Zn coating is equivalent to that of current materials, it was determined to provide satisfactory formability.

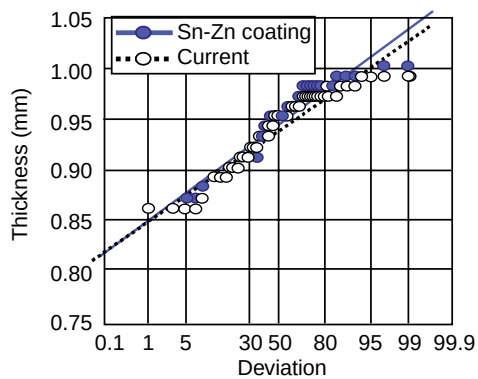


Fig.36 Sheet thickness distribution on formed work

5.2. Weldability

Both the welding quality and welding properties were favorable. Fig. 37 shows the change in the number of welds and the mean value of the weld diameter at spot-welded positions in the electrode tip life test. A photograph of the cross-section of the weld nugget is shown in Fig. 38.

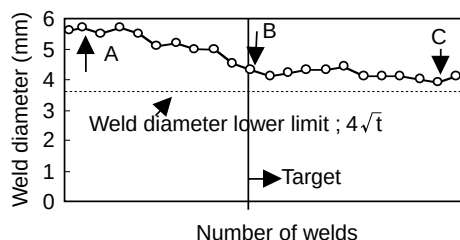


Fig.37 Changes of weld diameter during electrode tip life test

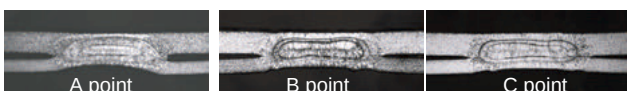


Fig.38 Cross sectional view of nugget

Electrode tip life was determined to be more than twice the target value with the developed material and welding specifications, while the quality of the nugget and so forth was also favorable.

5.3. External Corrosion Resistance

Fig. 39 shows the appearance of a painted fuel tank after the corrosion resistance test.

The Sn-Zn coating demonstrated good coatability, and provided outstanding corrosion resistance in comparison with that of current materials. More than twice the number of test cycles as that of current materials could be performed before red rust was formed in the deep-drawn portions.

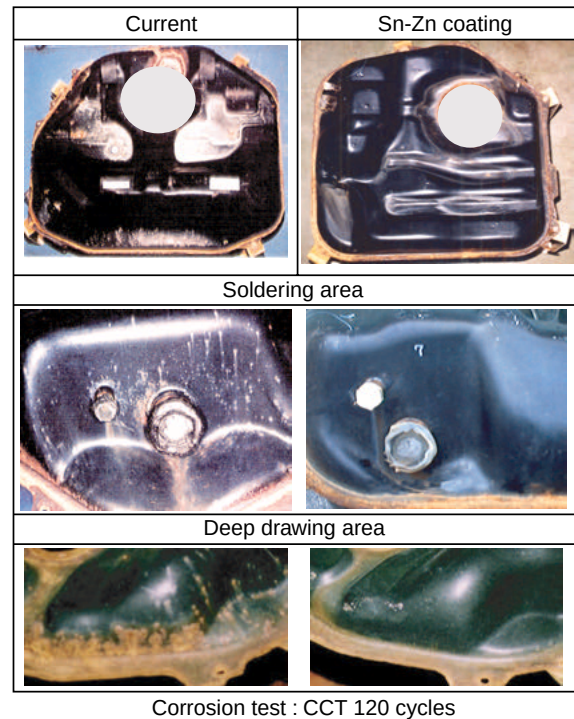


Fig.39 Appearance of fuel tank after corrosion test

5.4. Internal Corrosion Resistance

A circulation test was conducted on an Sn-Zn coated fuel tank with a soured gasoline test solution containing organic acids and salt water. The appearance of the fuel tank after the test is shown in Fig. 40, while the volume of metal eluted into the solution, the total weight of precipitated products and the maximum corrosion depth at each site are shown in Fig. 41.

In comparison with the current material, the Sn-Zn coating demonstrated lower levels of corrosion weight and

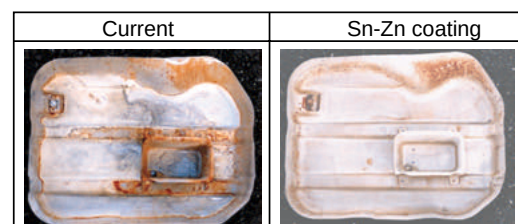


Fig.40 Appearance of fuel tank after soured gasoline test

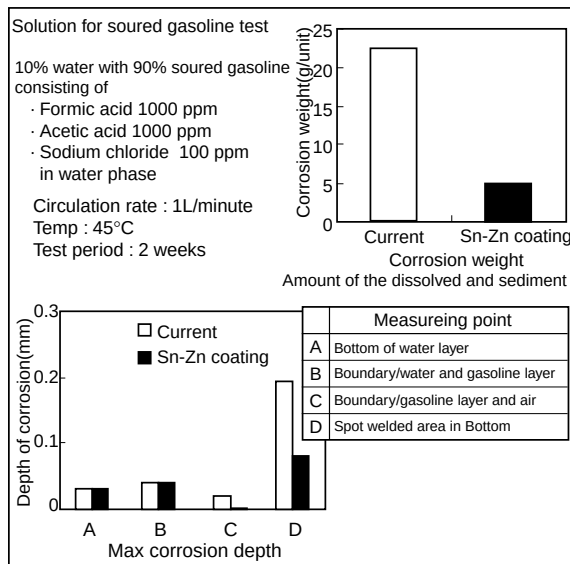


Fig.41 Result of soured gasoline test

corrosion depth, and thus was confirmed to have outstanding corrosion resistance.

6. Conclusions

This paper has presented conclusions of material and production technology development for a lead-free fuel tank, along with the results of evaluating its suitability. A summary of the findings obtained through this research is provided below.

- (1) A hot-dip Sn-Zn alloy coating was developed for coated steel sheet containing 8% Zn which demonstrated superior corrosion resistance, workability, processability and so forth. In addition, an Sn-Ag alloy containing 3.5% Ag was developed for use as solder material on the basis of the melting point, corrosion potential difference with the coating and so on.
- (2) With respect to the issue of spot weldability caused by the formation of an alloy between the copper electrode and the Sn-Zn coating, processability equal to or better than the current level could be obtained by controlling the surface contact resistance. This was done by improving the surface roughness of the coated steel sheet and by optimizing the shape of the electrode tip.
- (3) An Sn-Zn coating was confirmed to be equal to or better than current coatings in various suitability tests for use as a fuel tank, including tests of formability, welding quality, corrosion resistance and processability. The coating was determined to exhibit particularly excellent corrosion resistance.

This lead-free fuel tank is scheduled to be sequentially applied in automobiles beginning in 2001 models, with the goal that all fuel tanks be lead-free by the end of 2003.

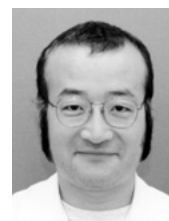
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