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Development of Spot Weldable Vibration Damping Steel Sheets for Room Temperature Use

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Development of Spot Weldable Vibration Damping Steel Sheets for Room Temperature Use*


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A thermosetting type of polyester resin with a three-dimensional molecular structure crosslinked by an isocyanate hardening agent having three functional groups was developed for use as a viscoelastic resin in vibration damping steel sheets for room temperature application. The vibration damping steel sheet, made by laminating two steel sheets with this new viscoelastic resin and Ni powder, has superior series-spot weldability with no defects such as sparking and ringed cut-off. Vibration damping steel sheets composed of cold-rolled steel sheet and galvanized steel sheet have wide applications with the optimum amount and hardness of Ni powder, and the optimum ratio of Ni powder average diameter to resin thickness. These newly developed vibration damping steel sheets have the same spot weldability, formability, baking durability and anti-corrosion properties as normal steel sheet for commercial use in the automobile, household electrical appliance and building material industries while providing superior vibration damping capability to satisfy the demand for greater quietness.

1 Introduction

The increasing urban concentration and accompanying traffic network that has been developed in recent years have brought the problems of noise and vibration[1] into the focus of attention. As a result of more stringent noise restriction laws and regulations for automobiles, the development and use of noise prevention materials have become increasingly important. One result has been the composite type of vibration damping steel sheet (hereinafter referred to as "vibration damping steel sheet"), which is made by sandwiching a viscoelastic resin between two steel sheets to achieve remarkable vibration damping capability. This material is being applied to various components of automobiles, household electrical appliances, buidling partitions, business machines, and audio equipment. Kawasaki Steel started the operation of coil-line facilities[2-4] for vibration damping steel sheet with a monthly production of 1 000 t in January 1990.

This report describes the product design and quality characteristics of vibration damping steel sheet for room temperature use, which has particular application in automobiles and household electrical appliances, and as a building material.

2 Development Parameters of Vibration Damping Steel Sheet for Room Temperature Use

2.1 Required Performance

Various components that apply vibration damping steel sheet vary in their vibration damping capability depending upon the applied temperature, and are most

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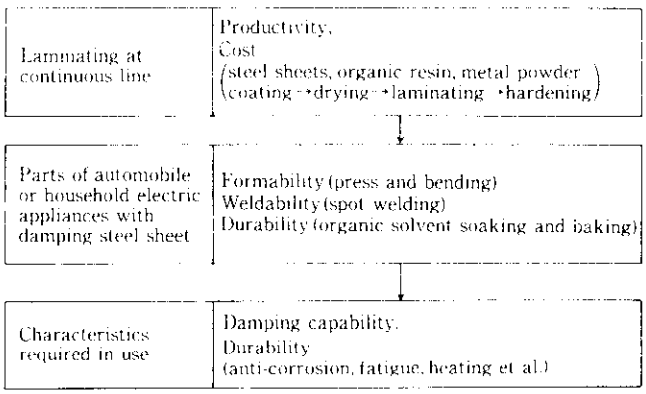

Fig. 1 Characteristics required for vibration damping steel sheets

frequently used under room temperature conditions (15 to 60°C). A vibration damping steel sheet used for such components must possess the characteristics shown in **Fig. 1**. When vibration damping steel sheets are used for automobile and household electrical appliance components, it is most important that their vibration damping capability is available under relevant operating conditions. In addition, the material must perform in various forming, welding, assembling, and painting processes at least as well as the currently used thin steel sheets. Conventional vibration damping steel sheet is, because it contains an intermediate resin layer, generally inferior to ordinary cold-rolled steel sheet in its press formability, bending workability and shearing. Furthermore, current conduction for spot welding is also inferior, because the resin layer is an insulator. Since shunt current preheated welding with a by-pass circuit has poor workability, it is necessary to apply a welding method by direct current conduction. Conventional vibration damping resin also requires improvement in its resistance against elution by the paint solvent during the coating process, as well as heat resistance and durability against peeling of the steel sheet due to softening and melting of the resin layer during baking.

2.2 Resin Design

2.2.1 Resin for room temperature use

It is vital that a resin for vibration damping steel sheets for room temperature use has a large loss factor in the temperature range of 15 to 60°C. A resin which satisfies this condition is one which is in the rubber state in the room temperature range, and whose tan δ(δ is the phase difference between stress σ and strain ε) is a maximum in the audible range of 20 Hz to 20 kHz.

Normally, a vibration damping resin has, as shown in **Fig. 2**, a greater vibration damping capability of the resin as its adhesion decreases, and conversely the greater its adhesion, the lower the vibration damping capability. Furthermore, formability is improved by an increase in adhesion.[5-8] Consequently, in designing a suitable vibration

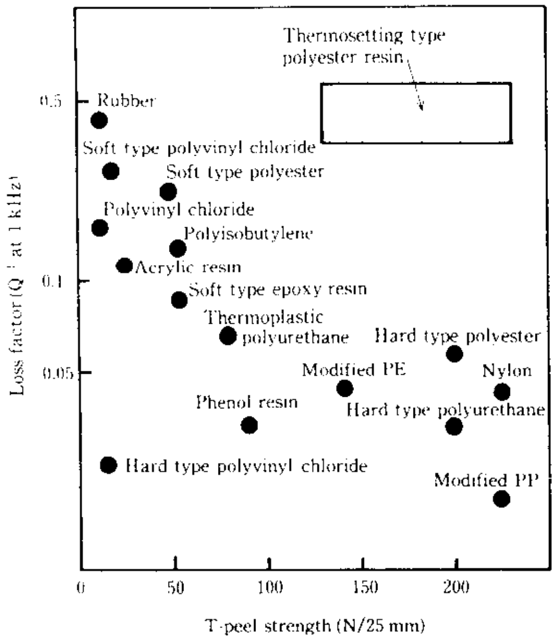

Fig. 2 Relation between T-peel strength and loss factor of vibration damping steel sheet

damping resin, it is necessary to optimize these above-mentioned contradicting characteristics. The vibration damping resin must also possess solvent and heat resistance for the post-forming processes of coating and baking, and durability in the actual use environment.

In the present study, the molecular structure of the resin regarding its molecular weight and crosslinkage density were optimized by combining a polyester resin and isocyanate hardening agent having three functional groups with a thermosetting polyester-based resin (the upper zone of Fig. 2). The result is a three-dimensional crosslinkage structure with the required vibration damping capacity, adhesion, solvent resistance, heat resistance, and durability.[9,10] The development of the resin first involved selecting a polyester resin with a molecular weight of 30 000 and high vibration damping capability and durability as the base polymer. This resin by itself is thermoplastic and has little adhesion in the vibration damping temperature range (near room temperature), but a three-dimensional structure was formed by the isocyanate hardening agent, and adhesion was simultaneously improved by introducing a polar group. Adequate solvent resistance and heat resistance during coating and baking were ensured by adjusting the quantity of the isocyanate hardening agent. In addition, by subjecting the base polymer and the hardening agent to a chemical reaction and by controlling the viscosity suitable production characteristics for coating, drying, laminating, and hardening were provided.

2.2.2 Resin film thickness

The effect of this polyester resin film thickness on

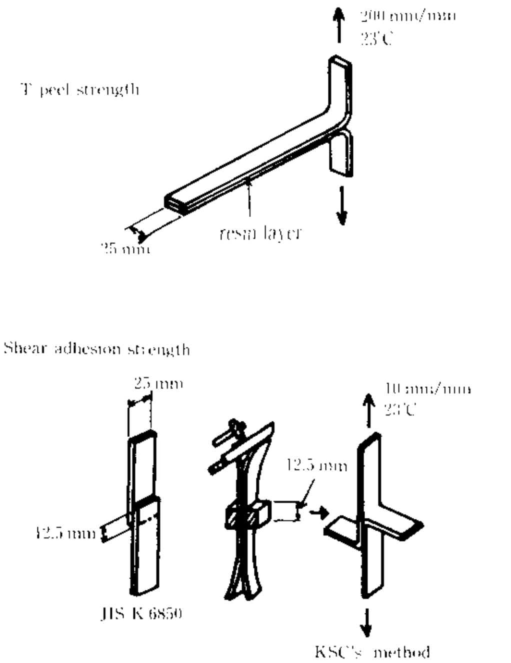

Fig. 3 Adhesion test methods of vibration damping steel sheet

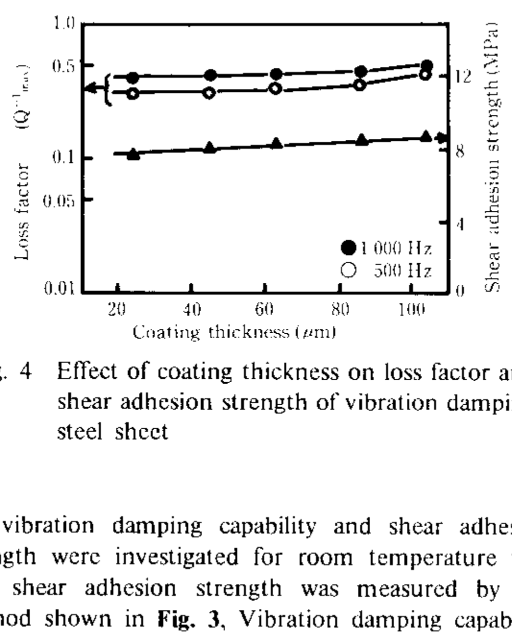

Fig. 4 Effect of coating thickness on loss factor and shear adhesion strength of vibration damping steel sheet

the vibration damping capability and shear adhesion strength were investigated for room temperature use. The shear adhesion strength was measured by the method shown in **Fig. 3**, Vibration damping capability was obtained by Eq. (1), using the mechanical impedance method at the resonance point for resonant frequency (f_0), and two points (f_1 and f_2) 3-dB lower than the resonant frequency.

$$Q^{-1} = (f_2 - f_1)/f_0 \cdots\cdots\cdots\cdots (1)$$

Between 20 and 100 μm film thickness, little variation in the vibration damping capability and shear adhesion strength was apparent as shown in **Fig. 4**. However, with less than 20 μm, variation occurred due to the uneven thickness of the resin film.

2.3 Ensuring Spot Weldability

Spot welding vibration damping steel sheet is difficult due to low current conduction during welding, because the resin acts as an insulator between the two steel sheets. Therefore, a conductive material was added to the resin layer to improve its conductivity. Kawasaki Steel had previously developed a conductive vibration damping steel sheet by adding a graphite filler with good conductivity and comparatively small grains. This filler, however, required a large amount of graphite[11] which reduced the adhesive strength between the steel sheet and the resin, and still created difficutly in welding workability. On the other hand, a large grain-diameter metallic powder filler can provide adequate conductivity by relatively small addition, with little effect on the adhesive strength. This gives spot weldability by creating an internal short circuit between the upper and lower steel sheets via the metallic powder filler.[12-19] In the present vibration damping steel sheet, a small quantity of large-grain diameter metallic powder was added instead of the earlier graphite grains to provide good spot weldability.

2.3.1 Spot weldability design

Figure 5 shows the basic concept of the welding process for vibration damping steel sheet to which conductivity has been given by adding large-grain metallic powder. At the initial stage of welding, a minute electric current flows through the current-conducting powder,

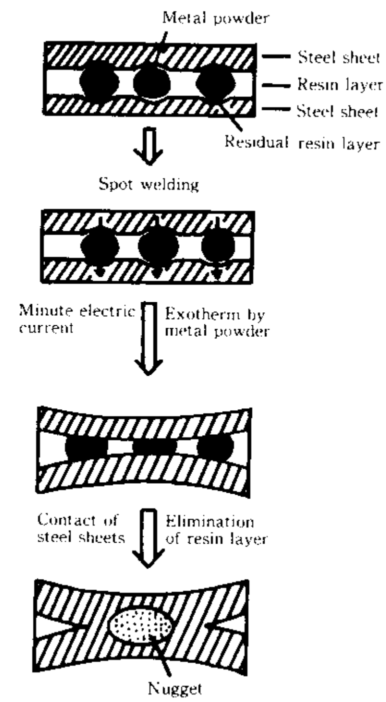

Fig. 5 Schematic of spot welding process of vibration damping steel sheet

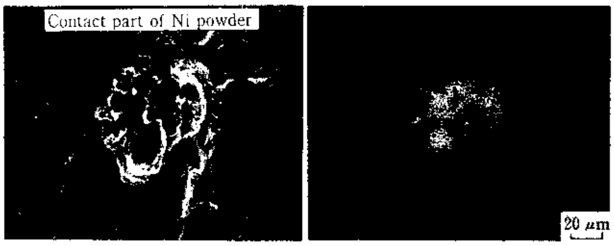

Photo 1 EPMA of contact part of Ni powder and steel sheet surface

and the resin is softened by an exothermic reaction and discharged from beneath the electrode chip by compressive force; consequently, an electric current flows as in the case of an ordinary steel sheet, and the welding nugget is formed. Thus, the fact that a minute electric current flows in the initial stage of welding through the conducting powder constitutes the most important aspect for providing spot weldability. **Photo 1** shows EPMA of the carbon content in the residual resin between the metallic powder and the outer-skin steel sheet. To achieve spot weldability, the following three points are important: (1) suppressing to the minimum the quantity of this residual resin between the metallic powder and the outer-skin steel sheet; (2) increasing the area where metallic powder comes into contact with the outer-skin steel sheet; and (3) controlling the exothermic reaction to an appropriate degree.

2.3.2 Optimization of the metallic powder filler

(1) Selecting an Appropriate Conductive Metallic Powder
The various kinds of conductive metallic powder shown in **Table 1** were examined. A 0.4 mm thick extra-deep drawing quality cold rolled steel sheet (**Table 2**) was used for the outer-skin, the sides coming into contact with the resin core material being given a non-rinse type of chromate treatment. It was found that nickel powder and stainless steel powder were advantageous from the viewpoints of weldability and corrosion resistance, but the moderately priced globular Ni powder was selected, which had a comparatively greater electrical resistance and which allowed a variation in hardness. The hardness of the Ni powder was HV 212, and the optimum addition to the resin was 1.0 vol%.

(2) Ratio of Average Ni Powder Grain Diameter to Resin Thickness
With the addition of Ni powder, whose hardness was HV 212, of 1.0 vol%, and a resin film thickness of 20 to 100 μm, the effect of the ratio of the average grain diameter of the Ni powder to the resin thickness on the electrical resistance in the first stage of spot welding was investigated. A spot-welded joint between two vibration damping steel sheets was made under the following welding conditions: a tip shape of 8R, a semi-globular Cu-Cr alloy electrode tip, an electrode force of 1 961 N, a welding current of 8 kA, a welding time of 8 cycles, a compression time of 10 cycles, and a holding time of 30 cycles. The electrical resistance in the first stage of welding was sufficiently low, and a good quality weld was obtained, as shown in **Fig. 6**, with an average Ni powder grain diameter/resin thickness ratio of 1.8 and above.

(3) Effect of the Outer-Skin Steel Sheet Handness
The effect of hardness of the outer-skin steel sheets on spot weldability is shown in **Fig. 7**. When the surface hardness of the outer-skin steel sheet exceeded the hardness of the Ni powder, the electrical resistance in the first stage of spot welding increased

Table 1 Comparison of metal powders for spot welding of vibration damping steel sheet

Metal powder	Electric resistance ($\mu\Omega$·cm)	Melting point (°C)	Micro Vickers hardness (Hv)	Spot weldability	Anti-corrosion	Cost
Nickel	6.58	1 455	80~212	○	○	△
Stainless steel	56.3	1 427	203	○	○	×
Iron	9.71	1 539	86	△	×	○
Copper	1.55	1 083	68	×	×	○
Zinc	5.92	420	47	×	○	○

○: Excellent, △: Good, ×: Poor

Table 2 Mechanical properties of materials used

Thickness (mm)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	n-value	r-value
0.40	298	162	49.4	0.21	2.12

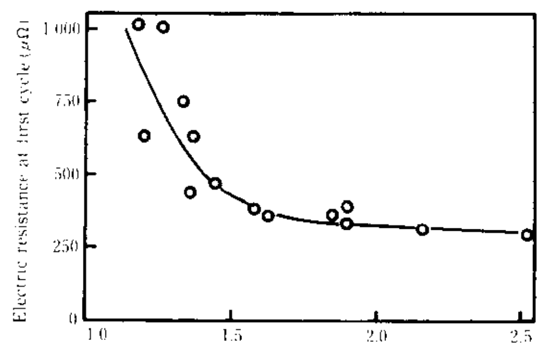

Fig. 6 Effect of ratio of Ni powder average diameter to coating thickness on the electric resistance at first cycle of vibration damping steel sheets

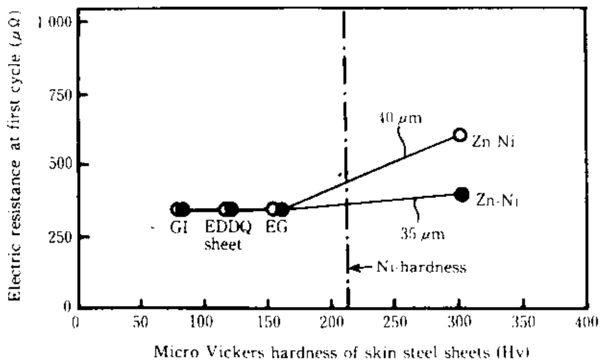

Fig. 7 Relation between micro Vickers hardness of skin steel sheets and spot weldability of damping steel sheets (Ni powder content, 1.0 vol%; average diameter, 65 μm)

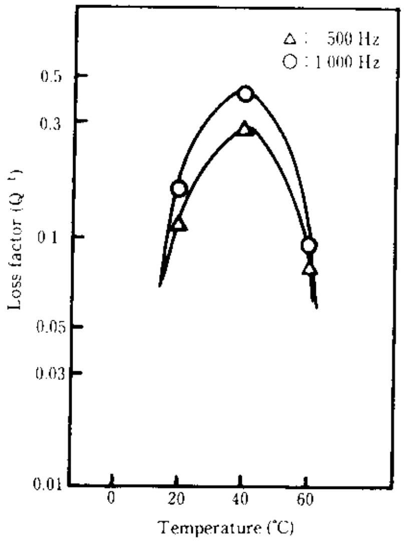

Fig. 8 Loss factor of vibration damping steel sheet (Coating thickness: 35 μn)

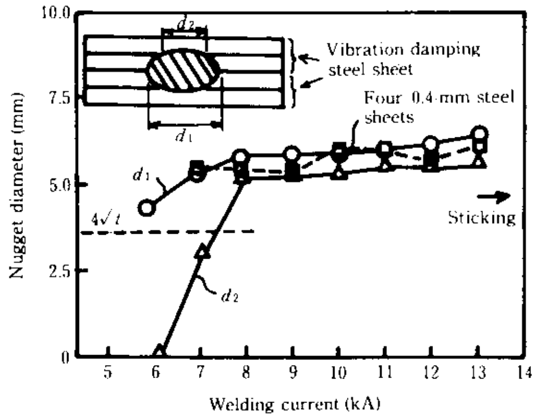

Fig. 9 Effect of welding current on nugget diameter (Coating thickness, 35 μm; Ni powder content, 1.0 vol%; average diameter, 65 μm)

at a resin thickness of 40 μm, but when the resin thickness was decreased to 35 μm, the electrical resistance in the first stage of the hardest Zn-Ni electroplated steel sheet was greatly reduced. This fact indicates that, in the case of an average 65 μm grain diameter of Ni powder and a resin thickness of 35 μm (average again diameter/resin thickness = 1.86), it is possible to manufacture a vibration damping steel sheet with surface-treated steel sheet that has good weldability that is not affected by the hardness of the outer-skin steel sheet. After a non-rinse type of chromate treatment, the adhesion between the outer-skin steel sheet and the vibration damping resin was increased and resin peeling from the edge due to corrosion was suppressed.

3 Characteristics of Vibration Damping Steel Sheet for Room Temperature Use

The characteristics are described for a vibration damping steel sheet in which a thermosetting polyester resin was used, Ni powder with an average grain diameter of 65 μm at 1.0 vol% was blended into 35-μm-thick resin, and 0.4-mm-thick extra-deep drawing cold rolled steel sheets were used for the outer-skin.

3.1 Vibration Damping Capability

The loss factor for this newly developed vibration damping steel sheet was, as shown in **Fig. 8**, 0.1 or more at a frequency of 500 Hz and 1 000 Hz, and within a temperature range of 20 to 55°C. At a temperature of 40°C, and the loss factor reaches its maximum value of 0.42.

3.2 Spot Weldability

3.2.1 Welding conditions

Figure 9 shows the effect of welding current on the spot weldability of two laminated vibration damping steel sheets. The current for a nugget diameter (d_1) between the two outer-skin steel sheets with direct contact exceeding $4\sqrt{t}$, which was obtained by the U-bend peeling method, was 6 kA, while the current for a nugget diameter (d_2) between two steel sheets with an insulated resin and metallic powder was 7 to 8 kA, the nugget being shown in **Photo 2**. With a welding current exceeding 13 kA, sparks were generated. The relationship between the welding current and the nugget diameter formed is hardly any different between the laminate of four single cold-rolled steel sheets (□ symbol in fig. 9) and the laminate of two vibration damping steel sheets (○ and △ symbols in Fig. 9). Thus, spot welding of the vibration damping steel sheets can be done under the same conditions as those for ordinary steel sheets.

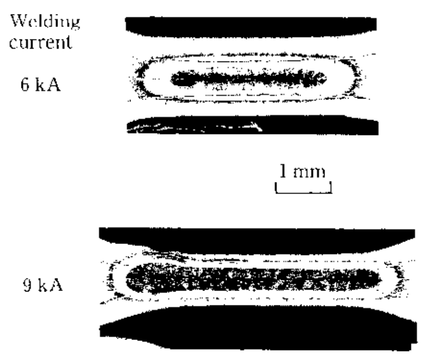

Photo 2 Cross section of weld nugget

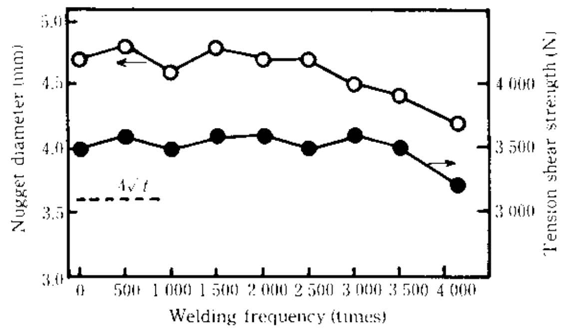

Fig. 10 Relation between welding frequency, nugget diameter and tension shear strength (coating thickness, 35 μm; Ni powder content, 1.0 vol%; average diameter, 65 μm)

3.2.2 Continuous frequency weldability

Figure 10 shows the result of continuous-frequency spot welding of two laminated vibration damping steel sheets. Even at a welding frequency of 4 000, the nugget diameter formed was $4\sqrt{t}$ or more, the shear adhesion strength (conforming to JIS Z 3136) was 2 942 N/spot or more, and the joint fractured in the base material, thereby indicating that the newly developed vibration damping steel sheet is suitable for series spot welding.

3.2.3 Welding defects

Welding defects of the vibration damping steel sheet include the sparking phenomenon, in which a small hole is opened at a position slightly away from the outer circumference of the electrode chip, and ringed cut-off, in which the surface-skin steel sheet surrounding the electrode chip melts.

Sparking is caused by a non-uniform welding current, and is thought to be related to the dispersion of Ni powder and the electrical conductivity.[13,15] **Figure 11** shows the relationship between the spark generation rate and electrical resistance in the first cycle of spot-welding two vibration damping steel sheets. The spark generation rate was zero when the electrical resistance in the first cycle was 500 $\mu\Omega$ or less.

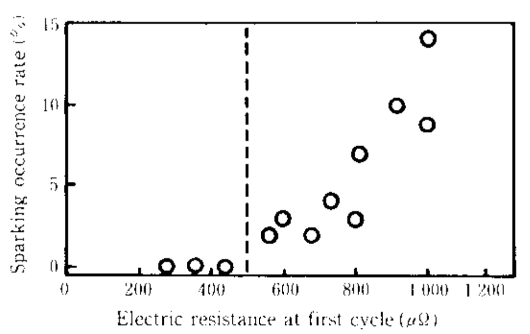

Fig. 11 Effect of electric resistance at first cycle on sparking occurrence rate

3.3 Workability

3.3.1 Maximum drawing ratio

An Erichsen test was performed with various additions of hardening agent to the polyester resin, and the effect on the extreme drawing ratio was measured for various values of shear adhesion strength of the vibration damping steel sheet. The result is shown in **Fig. 12.** This vibration damping steel sheet had a shear adhesion strength of 5.88 MPa or more (arrow mark in Fig. 12), and could be deep drawn to the same degree as ordinary steel sheet.

3.3.2 Bending work

When the vibration damping steel sheet was subjected to V-bending, the so-called "seagull" phenomenon was observed (**Fig. 13**). This phenomenon was caused by slippage of the external steel sheet from the internal steel sheet because of the existence of the resin core. This "seagull" phenomenon was affected by the sheet thickness differential, material strength (**Fig. 14**), resin core thickness, and die width (**Fig. 15**). Prevention of this phenomenon is possible by increasing the steel sheet thickness, increasing the material strength and

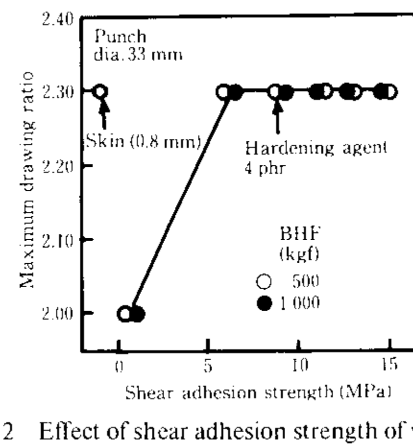

Fig. 12 Effect of shear adhesion strength of vibration damping steel sheets on maximum drawing ratio

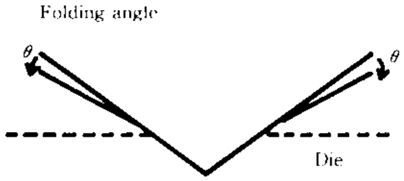

Fig. 13 Folding angle of vibration damping steel sheet in V-bending

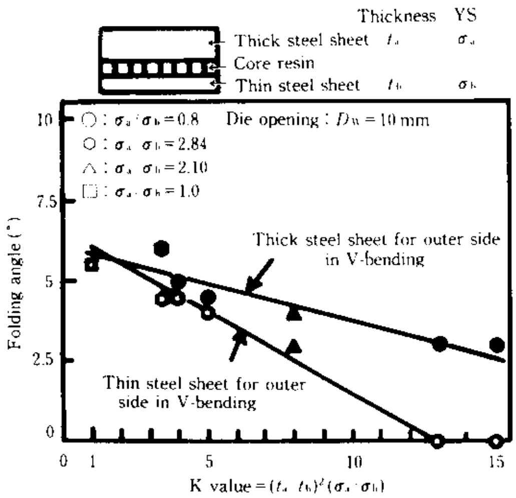

Fig. 14 Effect of skin steel sheets on folding angle in conventional V-bending of vibration damping steel sheets (Core resin thickness: 35 μm)

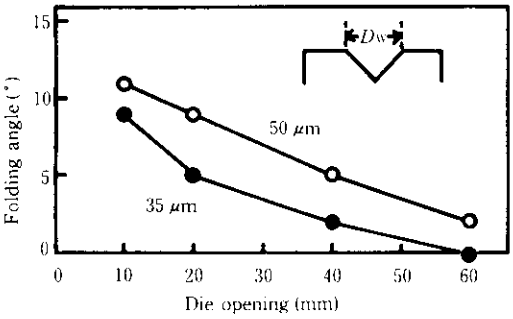

Fig. 15 Relation between folding angle and die opening and core thickness

enhancing the adhesive strength.

3.3.3 Bead drawing

For a vibration damping steel sheet which has been press-worked for passing through beads, the adhesive strength of the bead-passing section decreases as the bead height increases as shown in **Fig. 16**. This can be prevented by increasing the resin core thickness.

3.4 Baking Strength and Durability

The effect of backing temperature on the shear adhesion strength of the newly developed vibration damping steel sheet is shown in **Fig. 17**. During high temperature baking at 200 to 220°C, no peeling deformation occurred,

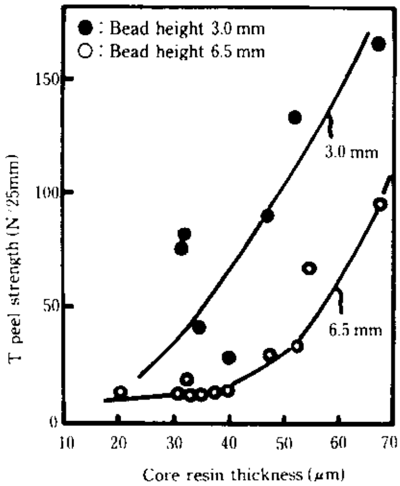

Fig. 16 Effect of core resin thickness on T-peel strength after drawing bead test of vibration damping steel sheets

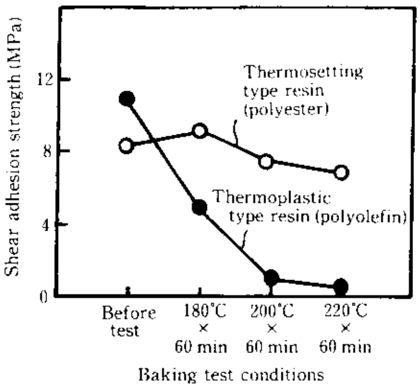

Fig. 17 Change in adhesion strength of vibration damping steel sheets at baking test

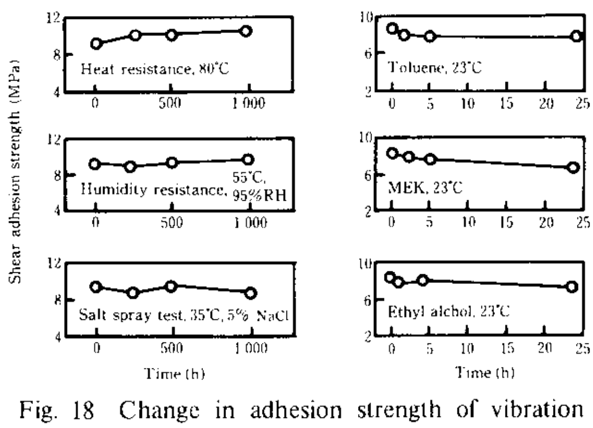

Fig. 18 Change in adhesion strength of vibration damping steel sheets at various environmental durability tests

and no reduction in the adhesive strength at room temperature after heating and cooling was observed. Furthermore, in various environmental deterioration tests with such coating solvents as toluene and methylethylketone, and in heat-resistance, moisture-resistance and salt-spray tests, no reduction in adhesive strength occurred as shown in **Fig. 18**.

4 Application Examples

(1) Business Equipment
Photo 3 shows a business desk manufactured by using a vibration damping steel sheet for the front panel. In order to suppress the seagull phenomenon in bending and to ensure spot weldability of the outer-skin steel sheet, the optimum ratio of resin and metallic powder was used.

Photo 3 An example of application of vibration damping steel sheet (desk)

(2) Household Electrical Appliance Components
The new material has been used for a washing machine body and motor fan cover. To prevent resin peeling and wrinkling during press working, the most appropriate outer-skin steel sheet and resin core material were selected.

(3) Automobile Components
The new material has been used for parts which require strong vibration damping capacity such as the floor panel, dashboard panel, and inner wheel housing.

5 Conclusions

A new range of vibration damping steel sheets for room temperature use was developed employing a thermosetting resin as the core material. The result are summarized as follows:

(1) This thermosetting type of polyester is a new resin for room temperature use, which has a three-dimensional crosslinkage to maximize its vibration damping capability, adhesion, and heat and solvent resistance.

(2) By setting the ratio of the Ni powder average grain diameter/resin thickness at 1.8 or above and by adding Ni powder to 1.0 vol%, the vibration damping steel sheet is free from such welding defects as sparking and ringed cut-off, and is suitable for series spot welding.

(3) The vibration damping steel sheet for room temperature use has wide applications by selecting and controlling EG, GI, and Zn-Ni electroplated steel sheets, resin thickness, and the ratio of the Ni powder average grain diameter/resin thickness.

(4) This newly developed vibration damping steel sheet has outstandingly balanced characteristics of weldability, workability, heat resistance, and environmental resistance.

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