Application of semisolid joining—Part 4 glass/metal, plastic/metal, or wood/metal joining

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ABSTRACT
A new process of joining nonmetals and metals such as glass and metal, plastic and metal, and wood and metal is proposed; the process shows excellent formability and joining ability of semisolid metals, and differs from the process of joining using adhesive or mechanical joining with screws or nails. In the process, a semisolid metal is inserted into the channel of the material to be joined such as glass, plastic, or wood and is rapidly solidified under pressure. The applications of the process to the fabrication of different components such as knobs, shafts, buttons, hinges, frames, and electronic substrate are considered. The application range of the process is wide, i.e., from the electronic industry to arts. The advantages of this new joining process are (1) ease of joining, (2) good joining strength, and (3) ease of carrying out mass production.

1. Introduction

The concept of eliminating the use of useless materials and using only necessary materials in a suitable place is important, considering the future depletion of resources. Thus, the development of a joining technique for different materials is strongly required.

The morphology of joined materials varies. The joining of metal to metal, ceramic to metal, and glass to metal is well known, which is made possible by various processes such as the use of mechanical joints, diffusion bonding, and adhesive bonding. Goods manufactured using joined glass: metal have been used since ancient times: for example, kitchen wares like frying pans, pots, kettles, and washbowls, bathroom fixtures such as those used in bathtubs, and everyday accessories such as brooches, pendants, and rings. In general, products made of joined glass: metals are made by cloisonnè and enamel processes which are mainly utilized for joining solid metal with liquid glass.

Semisolid joining is quite different from the above cloisonnè and enamel processes or other processes types of joining. Briefly, it consists of pushing a solid material into a semisolid metal or pushing a semisolid metal into a solid material. Thus, various solid materials such as glass, stone, wood, or plastic can be used to join the metal in such a process.

Semisolid metals have some useful properties for joining them to each other, such as (1) moderate softness, (2) excellent workability, (3) good flowability, (4) flexible geometrical adaptability, and (5) high chemical and metallurgical joining abilities.

In this paper, we show different combinations of semisolid joining, and discuss some of its expected applications.

2. Previous semisolid joining studies

2.1. Semisolid metal properties

Metal in semisolid state has excellent characteristics, in terms of formability and joining ability, which cannot be found in
metal in completely solid state or molten state. Here, the temperature and microstructure of semisolid metal are observed and discussed. The relationships among the temperature, solid fraction, and microstructure of A2011 aluminum alloy are shown in Fig. 1. From the figure, the semisolid temperature range of the A2011 alloy is 540–644 °C. The solid fraction changes from about 60% at 630 °C to about 80% at 610 °C. However, it is clear from the microstructure and temperature that the solid phase becomes globular and the liquid phase becomes distributed around the solid phase. In such semisolid state, the solid phase is easily transformed by the action of the liquid phase, and becomes as soft as clay or butter. Semisolid joining process utilizes only this property.

### 2.2. Semisolid joining studies

In previous studies [1-4], we reported some results of semisolid joining. Table 1 shows the previous semisolid joining.

In case 1, the joining between aluminum alloy, cast iron, or stainless steel of a base blank and particles, balls, short fibers of metallic or nonmetallic materials, such as ceramic, glass, tile, or stone, was explained. The base blank is in semisolid state, and the particles and short fibers are inserted into the base blank under pressure. The products are expected to be applied as a surface hardening material, an abrasion-resistant material, a heat-resistant material, or a decorative material.

<table>
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<tr>
<th>Table 1 – Previous semisolid joining</th>
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<td>Joined form</td>
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<td>Case 1</td>
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<td>Case 2</td>
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<td>Case 3</td>
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In case 2, the joining between aluminum alloy of a base blank and wire pins or sheet fins of aluminum alloy, copper alloy, or stainless steel was presented. The base blank is in semisolid state, and wire pins or sheet fins are inserted into the base blank. The products are expected to be applied mainly as a heat exchange device.

In case 3, bosses or flanges made of aluminum alloy were joined to a base blank of aluminum alloy. In this case, the base blank is in solid state and the boss or flange is in semisolid state and is joined to the base blank under pressure. The joining process used allows surface-to-surface joining rather than line-to-line joining achieved by conventional welding. Therefore, it prevents corrosion at the interface of the components as well as confers better shape than welding.

3. Outline of process

A2011 aluminum alloy was used as a main joining material. The other joining materials used were as follows: glass, plastic, or wood. The glass used was borosilicate glass, the plastic used was phenolic resin, and the wood used was ebony wood, which were all cylindrical specimens of 20–25 mm in diameter and about 15 mm in height. The joining temperature range was 620–635 °C; at these temperatures, the solid fraction of A2011 varied from 74 to 50%. The punch pressure was 20 MPa maximum. All the experiments were carried out under normal environmental conditions. Table 2 shows the experimental conditions.

Fig. 2 shows an outline of the semisolid joining of glass/metal, plastic/metal, or wood/metal. The experimental procedure is as follows:

1. Fill the flow channels made of a joining material, such as glass, plastic, or wood, with semisolid metal.
2. Set the joining material for the punch.
3. Pour molten metal or semisolid metal into the mould, and wait until the metal reaches an adequate semisolid state.
4. Insert the punch with the joining material to the mould under pressure.
5. Quickly cool while maintaining pressure.

Fig. 3 shows the punch, cylindrical glass for joining and metal mould. The cylindrical glass is temporarily installed in the punch.

Fig. 4 shows the appearance and shape of the glass, wood, and plastic joining materials. For each joining material, the flow channel is filled with a semisolid metal. Each channel is through a hole of 5 mm diameter, and the upper part of the channel is a spot of 10 mm diameter and 3 mm depth. Naturally, the channel size, form, or number differ depending on the intended purpose.

A ceramic coating material is applied to the osculating plane with the metal, when the joining material is heat-sensitive. Fig. 5 shows a sample in which wood is coated.

<table>
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<th>Table 2 – General chart of experimental conditions</th>
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<td>Material Combination</td>
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<td>Size of nonmetal (mm)</td>
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<tr>
<td>Joining temperature (°C)</td>
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<tr>
<td>Solid fraction (%)</td>
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<td>Joining pressure (MPa)</td>
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Fig. 2 – Schematic illustration of semisolid joining.

Fig. 3 – Punch, cylindrical glass for joining and metal mould.
with the ceramic coating material. In case of joining glass and metal, the glass need not be coated with the ceramic coating material.

4. Some applications of the semisolid joining process

Fig. 6 shows an example of joining glass and metal. Borosilicate glass is used for the glass. It is resistant to thermal shock and has a low thermal expansion coefficient. The metal used is A2011 aluminum alloy. It perfectly filled the channel in the glass, and no voids are observed. The conditions for joining such materials are good.

Fig. 7 shows an example of joining plastic and metal. In this case, phenolic resin is used for the plastic. Among plastic materials, phenolic resin has excellent mechanical property and is noncombustible and comparatively cheap. By using the new joining process, which does not require adhesive or screws, a good joining of plastic and metal was achieved.

Fig. 8 shows an example of joining between wood and metal. In this case, ebony wood was used for the wood. It is categorized as hard wood, making it a difficult material to process. Ebony wood is used in furniture, musical instruments, inlay marquetry, and sports goods such as heads of the golf clubs. Examples of three joining patterns are shown in the figure. In each pattern, the metal was used to fill the channel, and good joining was achieved.
5. Expected application

Various applications are considered in this new joining process, ranging from the arts to the electronic industry. The application is classified into the clad type, frame type, and column type. Expected products are shown in Table 3.

6. Conclusion

The joining of metal and nonmetal materials has been carried out until now using adhesive, nails, and screws. The authors proposed a new joining process that is not based on the above method. A semisolid metal is inserted into the flow channel of the joining material and is rapidly solidified under pressure. Semisolid joining has the following advantages over joining by adhesive or mechanical joining:

(1) The joining strength is high; the joining strength can be freely determined by adjusting the form and the number of flow channels generated in the joining material. It is mechanical joining of anchor style, which does not require screws or nails.

(2) The productivity is high compared with mechanical joining using screws or nails; it can easily be automated.

(3) The durability is good. The secular change is smaller than that in the case of joining using adhesive. The degree of degradation at high temperature is also minimal.

(4) The aesthetic property is good. Comparison with the joining using screws and nails, it is possible to conceal the part that may deface the beauty of the products by designing the flow channels generated in the joining material.

REFERENCES


