The purpose of this study was to evaluate the bonding interface and bonding strength of electroformed coping when cast joining was used with a multi-purpose alloy. The multi-purpose alloy was cast at a mold temperature of 700, 750 or 800 °C. A high noble alloy tab was also soldered onto an electroformed coping as a control. Sectioned surfaces of cast joining and soldered specimens were observed using a scanning electron microscope and analyzed using an electron probe micro analyzer. Shear bonding strength of specimens cast at 750°C and that of soldered specimens were determined. The edge of the cast joining alloy was round, but this improved as temperature increased. Diffusion of elements from the cast joining alloy and electroformed coping was detected at the interface, which contributed to a significantly higher bonding strength in the cast joining specimen than in the soldered specimen. These results suggested that the cast joining could be potentially employed for electroformed copings.

Key words : Cast joining, Electroformed coping, Multi-purpose alloy

INTRODUCTION

Recently, several materials have been used for dental prostheses, such as titanium\(^1\), ceramic\(^2\), and composite resin\(^3\). However, gold remains the most reliable and popular material for dental prostheses because of its high corrosion resistance\(^4\) and superior biocompatibility. Electroforming or galvaniforming method, which is dependent on the principle of electro-deposition, was introduced to the field of dentistry for inlay fabrication in 1960\(^5\). Nowadays, several electroforming systems for dental application are available. Electroformed coping can be directly deposited on the model die, thereby boasting of two advantages. It can be applied easily without any need of special skill, and it shows superior adaptation to the field of dentistry for inlay fabrication. Electroformed coping consists of 99.9 wt% gold. It is therefore applicable not only for single crown restorations and fixed partial dentures, but also as a superstructure for implant prostheses\(^6\). However, the space for ceramic veneering is very thick when using electroformed coping for prosthetic superstructures, because the implant abutment is smaller than a natural tooth abutment. In this case, a cast frame is optionally used to compensate for the space and improve the shape of the implant abutment. Moreover, electroformed coping should be joined to a pontic frame when implant abutments are splinted. There are several joining methods for metal — soldering\(^7\), laser welding\(^8\), and cast joining\(^9\). Manufacturers of electroforming system generally recommend soldering for joining method, and usage of conventional alloys for pontic or cast frames for metal ceramic restorations. However, the soldering process is relatively complicated and the resultant bonding efficiency has not been clearly investigated. The cast joining or cast-on method is a long-established technique employed for Buddha statues, and has been used to develop posts and cores as well as attachments. Using the cast joining it is possible to connect several points simultaneously. One of the oldest reports on the use of cast joining in dentistry is concerned with the repair of casting defects on a copper alloy\(^10\). In this previous study, a gap was observed and the metallic bond was not detectable due to oxidation of the metal surface. As a result, bonding between the two components was mainly that of mechanical interlocking\(^10\). However, diffusion of metal elements was observed when the two components were covered with sputtered gold\(^15\), or cast simultaneously and then separated by platinum foil\(^20\).

With regard to the ideal material for pontic or cast frames, the casting temperature of conventional alloys for the metal ceramic restoration is usually higher than that of electroformed coping, which will result in melting and distortion of the electroformed coping if cast joining is used. Therefore, an alloy with a relatively low casting temperature is desirable. Multi-purpose alloys have been suggested as a suitable option for metal ceramic restorations at a low casting temperature. Moreover, the thermal expansion coefficient of multi-purpose alloys is more similar to that of gold compared to conventional alloys.
alloys for metal ceramic restorations. Therefore, this type of alloy might also be suitable when using cast joining for electroformed copings. The purpose of this study was to evaluate the bonding interface and bonding strength of electroformed coping when cast joining was used with a multi-purpose alloy.

MATERIALS AND METHODS

Electroformed coping

The alloys used in the present study are listed in Table 1. Twenty-one cast square plates, 10.0 x 10.0 x 1.0 mm, of a noble alloy (E-E2, Cendres & Métaux, Biel-Bienne, Switzerland) were prepared for the matrix plate of the electroformed coping according to the manufacturer's instructions. Casting surface was polished flat with a sheet of #600 SiC paper, and an approximately 0.2-mm-thick electroformed coping was directly deposited on the casting using an electroforming system (AGC Micro, Wieland, Pforzheim, Germany). The output level was 3, the amount of electrolyte was 28 ml, 4 ml of brightener additive was added, and the duration of deposition was 300 minutes.

Specimens preparation

Cast joining and soldered specimens were fabricated according to the following procedures. With the cast joining specimen, a teflon-coated mold — 6.0 mm in diameter and 2.0 mm thick — was placed on the electroformed coping. An inlay wax (Inlay wax soft, GC, Tokyo, Japan) was then built up over it. A gypsum-bonded investment (Cristobalite P, Shofu, Kyoto, Japan) was used for the pre-heating mold at 700°C, and a phosphate-bonded investment (Ceravest G, GC) at 750 and 800°C. The wax tab on the electroformed coping was placed in the center of a casting ring lined with one layer of casting liner and attached using a 2.0-mm diameter wax sprue. It was then invested and heated according to the manufacturer's instructions. The multi-purpose alloy (DGVO8, Cendres & Métaux) was cast using an electro-resistant, melting centrifugal casting machine (TS3, Degussa, Hanau, Germany) at a casting temperature of 1,150°C for 60 seconds, and then cooled on a bench until room temperature. Three, eight, and two specimens were prepared at preheating temperatures of 700, 750, and 800°C, respectively.

With the soldered specimen, a cast tab of high noble alloy (Bio Ethic, Cendres & Métaux), 6.0 mm in diameter and 2.0 mm long, was prepared according to the manufacturer's instructions. A 0.2-mm thick piece of adhesive tape with a 6.0-mm diameter hole was placed on the electroformed coping, and soldering paste (AGC Keradec, Wieland) was applied to the hole before removing the tape. The cast tab was then carefully placed on the area coated with soldering paste. Soldering was performed in a porcelain furnace (Astromat 3001, Dekema, Freilassing, Germany) at a maximum temperature of 940°C under a vacuum of 74 cmHg for four minutes in accordance with the manufacturer's instructions. Eight soldered specimens were prepared.

Observation of the bonding interface

Both cast joining and soldered specimens were embedded in an autopolymerized resin, then sectioned at the center using a low-speed cutter (Isomet, Buehler, IL, USA). The sectioned surfaces were polished with diamond paper and alumina slurry, and coated using a carbon evaporating machine (VED, Akashi, Tokyo, Japan). The surfaces were observed using a scanning electron microscope (SEM; S4500, Hitachi, Tokyo, Japan) and analyzed using an electron probe micro analyzer (EPMA; Emax, Horiba, Kyoto, Japan). The number of cast joining specimens at 700, 750, and 800°C and that of soldered specimens examined were 3, 2, 2, and 1, respectively.

Measurement of shear bonding strength

Six specimens cast at 750°C and six soldered specimens were mounted in an acrylic tube with an autopolymerized resin for shear bond strength measurement. The assigned bonding interface corresponded to the upper surface of the acrylic tube. Shear bonding test was conducted at a cross-head speed of 1 mm/min by means of a universal test machine (1123, Instron, MA, USA). Maximum load before the removal of cast gold tab was recorded and converted to bonding strength based on the original cast joining or soldered area of 6-mm diameter. Shear bond strengths were statistically analyzed using the t-test at a significance level of 5%.

Table 1 Materials used in the present study

<table>
<thead>
<tr>
<th>Material</th>
<th>Product (wt%)</th>
<th>Composition (wt%)</th>
<th>Melting temperature (°C)</th>
<th>Casting temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix plate</td>
<td>E-E2</td>
<td>Cendres &amp; Métaux</td>
<td>Au: 32.5, Pd: 41.9, Ag: 18.0, Sn: 5.0, Others: 2.6</td>
<td>1,240–1,350</td>
</tr>
<tr>
<td>Cast joining alloy</td>
<td>DGVO8</td>
<td>Cendres &amp; Métaux</td>
<td>Au: 70.0, Ag: 13.2, Pt: 9.4, Cu: 3.0, Others: 4.4</td>
<td>900–990</td>
</tr>
<tr>
<td>Soldered alloy</td>
<td>Bio Ethic</td>
<td>Cendres &amp; Métaux</td>
<td>Au: 86.70, Pt: 10.75, Ag: 0.03, Others: 2.52</td>
<td>1,000–1,150</td>
</tr>
<tr>
<td>Soldering paste</td>
<td>Keradec</td>
<td>Wieland</td>
<td>Au: 98.3</td>
<td>940*</td>
</tr>
</tbody>
</table>

* Soldering temperature (°C)
RESULTS

Bonding interface

After each joining method, the electroformed coping appeared as a shiny golden surface. Typical SEM images after each joining method are shown in Fig. 1. The edge of the multi-purpose gold alloy of the specimen cast at 700°C was round in shape. Further, a thin gap — approximately 0.5 μm wide — was observed between the electroformed coping and multi-purpose gold alloy. The gap is not clear under a low-magnification image such as Fig. 1. The radius

![SEM images of the bonding interface with casting at (a) 700; (b) 750; (c) 800°C; and (d) with soldering. CA: Cast joining alloy, EF: Electroforming, MP: Matrix plate, SA: Soldered alloy, SP: Soldering paste.](image1)

![EPMA analysis of a specimen (a) cast at 750°C; and (b) by soldering. CA: Cast joining alloy, EF: Electroforming, SA: Soldered alloy, SP: Soldering paste.](image2)
of the rounded edge and the length of the gap averaged across three specimens were approximately 180 and 160 μm, respectively. However, as investment temperature increased, the shape of the edge of the multi-purpose gold alloy of cast joining specimens improved. The radius of the edge of specimens cast at 750 and 800 °C were approximately 60 and 30 μm, respectively. For the specimen cast at 800 °C, there were no gaps between the two materials. In particular, the central layer of the electroformed coping almost disappeared in one specimen cast at 800 °C. Typical elemental line analysis of the specimen cast at 750 °C is illustrated in Fig. 2. Elements of the multi-purpose alloy (Ag) and electroformed coping (Au) diffused for about 30 μm at the interface between the two materials.

The interface between the soldered alloy and solder, and between the solder and electroformed coping showed smooth bonding because of higher noble element contents of these alloys. Thickness of the solder layer was not clear, and numerous voids were observed as expected in the solder layer. Moreover, elemental line analysis did not reveal an obvious interface between solder, soldered alloy and electroformed coping.

**Bonding strength**
For the cast joining specimen, the bonding strength and standard deviation were 71.9 and 11.5 MPa, respectively. For the soldered specimen, the bonding strength and standard deviation were 20.9 and 6.0 MPa, respectively. These results were significantly different (Fig. 3). The surfaces of the cast joining specimens showed interfacial fracturing between the electroformed coping and matrix metal; however, the surfaces of the soldered specimens exhibited cohesive failure in the solder layer.

![Fig. 3 The bonding strengths and standard deviations of the cast joining and soldered specimens.](image)

**DISCUSSION**
Performance of the cast joining is influenced by several mold-related factors — such as size, shape, and content of the mold, mold temperature, casting method, and type and size of alloy used for casting. In particular, mold temperature has been indicated as the most important factor, because an oxidized film is easily created at a high temperature and will interfere with the bonding between two materials. However, a high temperature is useful for rapid diffusion of the elements to achieve good bonding. Against this background, the effect of mold temperature on bonding behavior with cast joining was investigated.

It has been suggested that multi-purpose alloys are applicable not only for fixing prostheses with ceramic veneering but also as a denture base. Several multi-purpose alloys are commercially available, where the melting range is between 890°C to 1,070°C; the melting range decreases with increasing copper content. Copper content causes discoloration of veneered ceramics and produces a black oxide film. To create sufficient bonding with the cast joining, the melting temperature of the cast joining alloy should be similar to that of electroformed coping, but the casting temperature should be slightly higher than that of electroformed coping to prevent complete melting. DGVO8 was selected for the present study because of its intermediate melting range of 930-990 °C, a casting temperature which is higher than the melting temperature of gold, and because of its relatively low copper content. Generally, gypsum-bonded investments are recommended by manufacturers for casting of multi-purpose alloys. However, gypsum-bonded investments should not be heated to more than 700 °C. Therefore, in this study, phosphate-bonded investment was used at mold temperatures of 750 and 800 °C. Temperature of the cast joining alloy at casting is another factor critical to successful bonding. For the multi-purpose alloy used in the present study, the manufacturer suggested that the casting temperature be from 1,100 to 1,150 °C. The cast joining performance in our pilot study was very poor when the casting temperature was 1,100 °C. Therefore, a casting temperature of 1,150 °C was applied in the present study.

Performance of cast joining has been evaluated mainly by observations of the joining area, and by determining the bonding strength using tensile, shear and pull-out loadings. Due to its poor mechanical properties, the electroformed coping was unable to endure the bonding strength test, especially after heating. Moreover, the thickness of the coping was too thin for gripping or clamping. Thus, the electroformed coping was directly deposited on the matrix plate during the shear bond test. Observations using EPMA were also performed to show diffusion of the elements at the interface. Good bonding performance was observed at the central interface of the specimen cast at 700 °C. However, insufficient bonding was observed at the edge of the cast joining alloy. At high temperatures, metal surfaces generally become covered with an oxidized
film—which reduces wetting by the molten alloy and which interferes with the diffusion of elements. However, the surface of the electroformed coping was visually devoid of oxidization because of the high purity of the gold (99.9%). Therefore, imperfection of the casting edge might have been caused by a decrease in temperature at the molten cast joining alloy when heat was absorbed through the electroformed coping to the matrix plate. Consequently, insufficient bonding at the edge of the cast joining alloy was improved with a higher mold temperature. Nevertheless, a mold temperature as high as 800°C might not be desirable because the electroformed coping could melt in the cast joining alloy. For this reason, a temperature of 750°C was considered most favorable with regard to bonding strength.

Numerous voids were observed at the interface of the soldered specimen. A soldering paste which included a kind of organic solvent and particles of a few μm in diameter was used (Fig. 4). Weight loss of the solder was found to be 11% when heated up to 940°C by means of differential thermal analysis. Sintering of the solder and evaporation of the organic solvent during heating might have caused the voids in the solder layer.

Bonding strength of the cast joining specimen was significantly higher than that of the soldered specimen. This is the first data presented regarding the shear bonding strengths of cast joining and soldered joints. Interfacial fracturing was shown on the cast joining specimen between the electroformed coping and matrix metal, while the soldered specimen showed cohesive fracturing in the solder layer. These results indicated that the cast joining alloy was sufficiently bonded with the electroformed coping. The soldered metal and solder, and the electroformed coping and solder might also have bonded well. However, the measured bonding strength between the soldered metal and electroformed coping was low because of a lack of mechanical strength in the solder due to the numerous internal voids.

It has been reported that the application of gold sputtering increases the soldering strength of cobalt-chromium alloys. The reason suggested for this was that gold is normally oxidization-free even at high temperatures. The multi-purpose alloy used in this study contained a 79.4% sum of gold and platinum, and 13.2% silver. Therefore, the oxidization layer of the cast joining alloy might be very thin. Moreover, multi-purpose alloys which contain silver are thought to create a solid solution with gold easily. For all the above-mentioned reasons, the electroformed coping and cast joining alloy thus exhibited good bonding in the present study.

The edge of the cast joining alloy exhibited a round shape, which is undesirable for ceramic veneering because thin and sharp ceramic edges are easily fractured. Therefore, a round edge should be trimmed and reshaped. This problem can be solved if the edge of the wax is sharp. Thus, even if the edge of the cast joining alloy is round, it can be easily trimmed and reshaped.

The findings of this study suggested that cast joining using a multi-purpose alloy is a promising technique for improving the shape and splinting of electroformed copings. However, with this method, the hardness of the electroformed coping is reduced due to heating, and dimensional change and deformation might occur during the casting process. Further investigations with respect to these issues are therefore mandatory before cast joining can be applied for electroforming copings.

REFERENCES