The weak link in a fixed partial denture framework has been found to be the solder joint.1 Kriebel et al,2 using several different types of solder, found that 109 of 120 specimens failed through the solder joint, confirming that the solder joint is the weakest part of a fixed partial denture. Yet, soldering is an essential procedure to join sections of fixed, removable, and implant-supported prostheses. Furthermore, both fixed and removable partial denture frameworks that have been joined by soldering have been found to be more dimensionally accurate compared to those that have been cast in one piece.3-5 Both preceramic soldering (joint formation prior to porcelain application) and postceramic soldering (joint formation following porcelain application) are currently used to assemble fixed partial denture frameworks.

The literature to date has tested preceramic and postceramic solder joints in both tensile strength and fatigue. The research on tensile strength has mixed findings. Squire6 tested several different metal-ceramic alloys and found the ultimate tensile strength of preceramic solder joints to be stronger than the postceramic solder joints. Using Olympia alloy (JF Jelenko), Monday and Asgar7 found no significant difference in the ultimate tensile strengths of preceramic soldered versus postceramic soldered joints. The test variable was the number of stress cycles required to fail each specimen. Results: All specimens failed adhesively at the joint interface between the solder and parent metal. There were significant differences in the number of stress cycles to failure between groups 1 and 2, groups 1 and 4, and between groups 2 and 3. Conclusion: The load cycle to failure for postceramic soldered joints was affected by the metal surface treatment. Int J Prosthodont 2001;14:239–244.
postceramic soldered joints. Using a palladium-based alloy and a medium-gold alloy, Lorenzana et al8 found that for the gold alloy there was no significant difference in the ultimate tensile strength of the presoldered and postsoldered joints, but the palladium-based alloy was found to have a significantly higher ultimate strength for the postceramic soldered joints. The bulk of the literature, however, seems to suggest that the ultimate tensile strength for the postceramic soldered joints is consistently greater than preceramic solder joints.9–12

There are several ways in which fracture of a solder joint can occur, but given the type of functional and parafunctional loads that occur in vivo, load fatigue is likely the most common cause of ultimate joint failure. Therefore, it would be more clinically relevant to determine joint strength in load fatigue testing as opposed to ultimate tensile strength testing.13 For this reason, this study evaluated the fatigue life of postceramic soldering. One study on fatigue life of solder joints has suggested porcelain firing cycles used are given in Table 2. For this reason, this study considered only the fatigue life of postceramic soldered joints.13 This study therefore considered only the postceramic soldering technique.

The postceramic soldering technique has several advantages and disadvantages. The advantages include (1) permitting a union between dissimilar metals; (2) avoiding the distortion incurred during the oxidation and porcelain application cycles; (3) allowing better individualization of teeth during porcelain application; and (4) correcting for movement of the teeth that has occurred between final impressions and prosthesis cementation.16 The disadvantages include (1) ceramic color change because of investment contamination; (2) potential for porcelain cracking because of additional oven firings; and (3) metal brittleness because of precipitation of iron platinum with additional heat treatment.17

No study to date has considered the effect of the surface treatment of the joint prior to soldering on the strength of the joint. In fact, the bulk of the research on soldering has neglected to mention what type of surface treatment was rendered prior to soldering. In the remainder of the literature, there is absolutely no consensus as to what type of joint surface treatment prior to soldering is most appropriate. The purpose of this study was to determine the significance of the surface treatment of the metal prior to soldering on the fatigue life of postceramic soldered joints.

### Materials and Methods

The materials used in this study are listed in Table 1. Ten half specimens were fabricated for each of the four treatment groups, for a total of 40 half specimens. The four treatment groups were intended to represent coarse, medium, and smooth joint surface finishes prior to soldering. The soldering of two half specimens formed a complete test specimen, and a total of 20 postceramic soldered specimens were prepared. The manufacturers’ instructions were followed for all postceramic soldering procedures. The fabricated specimens were then tested to failure in fatigue loading. The fatigue stress applied to each specimen was 241.1 MPa. This fatigue stress applied was 40% of the predetermined value of the fracture load stress of the joint material (#650 solder).18

### Specimen Preparation

Twenty-mm-long cylindric Ready Made Wax Shapes (Kerr) of 3-mm diameter were sprued, invested in Deguvest investment (Degussa), then cast using new Olympia alloy in a broken-arm centrifugal casting machine (Degussa). The cast specimens were then cut into 10-mm lengths. Forty of these half specimens were fabricated.

All half specimens underwent a series of simulated porcelain firing cycles prior to being soldered. Although no porcelain was applied, the porcelain firing cycles provided the thermal history associated with porcelain application. The manufacturer’s suggested porcelain firing cycles used are given in Table 2. One end of each half specimen was then subjected to a designated surface treatment.

### Table 1 Treatment Products Used

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olympia alloy</td>
<td>JF Jelenko</td>
<td>51.5% Au, 38.5% Pd, 8.5% In, 1.5% Ga</td>
</tr>
<tr>
<td>#650 soldering alloy</td>
<td>JF Jelenko</td>
<td>65.0% Au, 14.0% Ag, 15.0% Cu, also Sn and Zn</td>
</tr>
<tr>
<td>Aluminum oxide</td>
<td>Kavo</td>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, Na&lt;sub&gt;2&lt;/sub&gt;O, FeO&lt;sub&gt;3&lt;/sub&gt;, CaO + MgO, TiO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Aluminum oxide stone</td>
<td>Brasseler</td>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, Al&lt;sub&gt;2&lt;/sub&gt;SiO&lt;sub&gt;5&lt;/sub&gt;, binder = ceramic</td>
</tr>
<tr>
<td>Brown rubber point</td>
<td>Shofu Dental</td>
<td>Silicone carbide, binder = synthetic rubber</td>
</tr>
<tr>
<td>Gray silicone wheel</td>
<td>Pacific Abrasives</td>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, F&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, S, T&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, ZnO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Pink silicone wheel</td>
<td>Pacific Abrasives</td>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, F&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, S, T&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;, ZnO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

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Press et al

**Volume 14, Number 3, 2001**
Surface Treatment of the Joint

The four treatment groups differed in the type of surface treatment performed on the end of each half specimen that was to be soldered. The 40 half specimens were randomly assigned to one of the four treatment groups. All surface treatments were performed using a slow-speed handpiece (Titan, Star Dental) mounted in an engineering lathe (Unimat, Emco). The specimens were clamped in the chuck of the lathe and rotated during this surface treatment. Each surface treatment was performed for 30 seconds, and upon completion all treated surfaces were steam cleaned (Belle de St Claire) for 30 seconds. The four treatment groups were:

- **Group 1**: Finished with an aluminous oxide pink stone (AOS) and steam cleaned. This was the coarse-finish surface treatment group.
- **Group 2**: Sandblasted (SB) at 30 psi with 50-µm aluminum oxide and steam cleaned. This was one of the medium-finish surface treatment groups.
- **Group 3**: Polished with a brown rubber point (BRP) and steam cleaned. This was one of the medium-finish surface treatment groups.
- **Group 4**: Polished with a gray silicone wheel (GPW), then with a pink silicone wheel, and steam cleaned. This was the smooth-finish surface treatment group.

Following steam cleaning, the surfaces to be soldered were inspected under 20× magnification to verify surface cleanliness. The half specimens were then aligned for the solder indexing procedures. The alignment of the half specimens prior to soldering was accomplished using a specially designed jig described by Nicholls and Lemm. Following indexing, the specimens were removed from the alignment jig, invested in Red Hot High Heat Soldering Investment (Pacific Rim Dental), then oven soldered.

The postceramic soldering sequence was:

1. The invested half specimens were placed into a room-temperature burnout oven, and the temperature was raised to 600°C at a rate of 38°C per minute. This was done to dry the investment patty, as well as burn off the resin index.
2. The invested half specimens were removed from the oven and allowed to bench cool. They were then steam cleaned, and the surfaces to be soldered were examined under 20× magnification to verify surface cleanliness.
3. T-flux (Degussa/Ney) was applied with a brush to the solder gap. A strip of #650 solder was beveled, steam cleaned, dipped into T-flux, then placed in the gap.
4. The invested and fluxed half specimens were placed in the porcelain furnace. The initial temperature was 600°C. The temperature was raised at 38°C per minute under vacuum. The specimens were monitored during the soldering procedure for verification of solder flow. The platform of the oven was then lowered, and the soldered specimen was removed and allowed to bench cool to room temperature.
5. The investment was then removed using a brush and running water, and the joint was inspected using 20× magnification to verify that excess solder had flowed beyond all boundaries of the joint. Specimens that did not meet these criteria were discarded, and new ones were fabricated.

Following soldering, all joints were machined with a Diamond Separating Disc (JF Jelenko), then with a gray silicone wheel on a slow-speed handpiece (Titan) mounted in an engineering lathe (Unimat) while the specimens were rotating. This was done to remove the excess solder and obtain a smooth

### Table 2: Firing Cycles Recommended for Olympia by Jelenko

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Initial temperature (°C)</th>
<th>Final temperature (°C)</th>
<th>Rate (°C/min)</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation</td>
<td>600</td>
<td>1038</td>
<td>38</td>
<td>No</td>
</tr>
<tr>
<td>First opaque</td>
<td>600</td>
<td>980</td>
<td>38</td>
<td>Yes</td>
</tr>
<tr>
<td>Second opaque</td>
<td>600</td>
<td>960</td>
<td>38</td>
<td>Yes</td>
</tr>
<tr>
<td>First body bake</td>
<td>600</td>
<td>920</td>
<td>38</td>
<td>Yes</td>
</tr>
<tr>
<td>Second body bake</td>
<td>600</td>
<td>900</td>
<td>38</td>
<td>Yes</td>
</tr>
<tr>
<td>Glaze bake</td>
<td>600</td>
<td>920</td>
<td>38</td>
<td>No</td>
</tr>
</tbody>
</table>
surface machined between parent metal and solder. This machining operation included the removal of an area of parent metal of approximately 2 mm on each side of the joint. This area was then examined under 20X magnification to check for flaws in the joint. Specimens that were found to be flawed, ie, that had a porosity in the joint, were discarded, and new ones were fabricated.

The diameter of each joint was measured using a Vernier Caliper (Mitutoyo) having an accuracy of 0.005 mm. Three measurements were made on each joint, then the specimen was rotated 90 degrees and another three measurements of joint diameter were made. The average of these six measurements was used in the determination of the load required to create the given stress level for fatigue testing. One investigator performed all measurements, and the measurement error was calculated to be ± 0.02 mm. This measurement error was determined by making ten measurements of one joint. The reading error was then calculated as:

\[ \text{Reading error} = \pm \frac{\text{measurement range}}{2} \]

The moment arm between the applied load and the distal solder interface (Fig 1) was measured with a Nikon Measurescope 20, which had an accuracy of 0.001 mm. All measurements were performed by one investigator, and the reading error was calculated to be ± 0.012 mm. This measurement error was calculated using the same formula as that for the joint diameter.

To hold the test specimen in the fatigue machine, each end of the soldered specimen was inserted into a predrilled brass rod (Fig 2). The specimens were secured in these rods using autopolymerizing GC Pattern Resin. The brass rods were aligned using an alignment jig (Fig 2). This alignment jig allowed the two brass holders to be colinear, with the soldered specimen connecting them. In this way, no eccentric forces were produced while the test specimens were rotating in the fatigue machine. One brass rod was held in the fatigue machine using a three-jaw chuck, while the other had a roller bearing from which the test load was suspended.

**Fatigue Loading**

A specially designed machine used specifically for testing the specimens in load fatigue at 30 cycles per second has been described previously.\textsuperscript{13} That article also describes the method used to calculate the applied load and specimen preparation for fatigue loading.

**Statistical Analysis**

The null hypothesis tested was that there was no difference between the four treatment groups in the number of load cycles required to create failure of the postceramic soldered joints. The nonparametric Kruskal-Wallis test was used to determine significant differences, with the 95% level or higher being considered significant.

**Results**

All 20 specimens failed adhesively at the joint interface between the solder and parent metal. This indicated that all four joint surface treatments performed prior to soldering affected the fatigue life of the postceramic solder joints.

**Fatigue Data**

The number of cycles to failure for each of the test specimens is given in Table 3. It is clear from this table that two groups (AOS and BRP) survived a mean cycle count greater than 1,000,000, whereas two groups (SB and GPW) had a mean cycle count of less than half this value. As a percent of the mean, the standard deviations ranged from 40% to 82%, with AOS having the smallest value.
Statistical Analysis

The data in Table 3 were subjected to the homogeneity test for variances, and this test failed. Thus, a Kruskal-Wallis nonparametric test was used to evaluate significant differences between surface treatments. The test indicated three definitive subsets ([AOS, BRP], [SB, GPW] and [BRP, GPW]) at significance ($P < .009$). The AOS group, while not significantly different from the BRP group, had a significantly higher number of cycles to failure than the other two groups (SB and GPW).

Discussion

Joint Contamination

Differences in number of cycles to failure between the four groups suggests (1) surface contamination from the treatment, or (2) a joint surface following surface treatment that is conducive or detrimental to solder flow. After all testing had been completed, a feasibility study was conducted to determine if contamination had been induced by the surface treatment. Specifically, this study was done to determine if a contaminant was left on the parent alloy surface. Each parent alloy specimen was checked under 20× magnification following (1) surface treatment, (2) steam cleaning, and (3) simulated oven soldering in which the specimen was subjected to the soldering temperature but no solder was applied. If contamination was not visible after a given step, the specimen was not subjected to further testing.

With AOS, there was no contamination following surface treatment. With SB, particle contamination remained after simulated soldering. (The melting temperature of the sand particles is 2,040°C.) With BRP, there was no contamination following steam cleaning. With GPS, contamination remained after simulated soldering.

This contamination associated with SB and GPW treatments is likely because of the abrasives’ material chemical composition and physical properties. The surface contamination provides areas in which solder will not be in contact with the parent metal. This would behave like an existing crack to the fatigue loading, and would thus reduce the fatigue life.

Discarded Specimens

The object of this study was to determine the fatigue lives of postsoldered joints, with the primary variable being the surface treatment of the joint. For a fair comparison, each of these soldered joints had to be free of visible voids. Thus, following soldering and joint truing, the actual solder periphery was evaluated at 20× magnification to determine if voids existed. If a void in the solder was detected, the sample was discarded. In addition, following testing and joint failure, each specimen was evaluated at 20× magnification for obvious voids. If a void was seen, the sample was discarded. In all, three specimens were discarded, two prior to testing and a third following testing. This latter specimen was in the AOS group and failed at 125,264 cycles. Visual inspection at 20× magnification revealed a major void close to the outer edge of the solder. This void location is the most damaging because it is in the region of high stress under specimen bending and causes fatigue failure at a lower number of cycles. The closer the porosity to the outer edge of the joint, the more detrimental will be the effect on the fatigue life. This variability in void size and location lends to the large variation seen in the fatigue lives of the individual specimens within a given group. All of the data provided in Table 3 were derived from specimens that had no visible voids under 20× magnification. Although there were no visible voids at this magnification, there may have been undetectable voids that caused variation in the fatigue lives of the specimens and inconsistencies in the soldering procedure.

Table 3  No. of Load Cycles to Failure for the Four Treatment Groups

<table>
<thead>
<tr>
<th>Sample</th>
<th>Group 1 (AOS)</th>
<th>Group 2 (SB)</th>
<th>Group 3 (BRP)</th>
<th>Group 4 (GPW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,463,871</td>
<td>536,281</td>
<td>1,183,528</td>
<td>160,016</td>
</tr>
<tr>
<td>2</td>
<td>1,011,639</td>
<td>152,455</td>
<td>774,696</td>
<td>598,854</td>
</tr>
<tr>
<td>3</td>
<td>2,380,522</td>
<td>425,866</td>
<td>832,189</td>
<td>352,644</td>
</tr>
<tr>
<td>4</td>
<td>989,397</td>
<td>487,726</td>
<td>2,872,554</td>
<td>259,126</td>
</tr>
<tr>
<td>5</td>
<td>1,275,344</td>
<td>210,119</td>
<td>537,821</td>
<td>1,230,421</td>
</tr>
<tr>
<td>Mean</td>
<td>1,424,154</td>
<td>362,889</td>
<td>1,240,157</td>
<td>520,212</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>569,548</td>
<td>171,566</td>
<td>941,314</td>
<td>429,117</td>
</tr>
</tbody>
</table>


Conclusions

This study compared the effect of four surface treatments applied to a metal-ceramic alloy on the fatigue life of postceramic solder joints. Under the conditions of this study and with the specific materials used, the following conclusions may be made:

1. All 20 specimens failed adhesively at the interface between the solder and the parent metal. Thus, the significant differences between the number of cycles to failure can be attributed to contamination caused by joint surface treatment prior to soldering.

2. The AOS group, while not significantly different from the BRP group, had a significantly higher number of cycles to failure than the other two groups (SB and GPW).

Acknowledgments

The authors would like to thank Mr Ron Lemm and Mr Al Pinch for their technical support in the soldering procedures, as well as the JF Jelenko Company for their generous donation of the alloys used in this study.

References


Literature Abstract

Smoking in adolescence as a predictor of early loss of periodontal attachment.

The aim of this study was to examine the role of chronic exposure to cigarette smoking as a risk factor for greater prevalence and extent of periodontal loss of attachment among 26-year-old participants in a long-standing prospective cohort study (n = 914). Loss of attachment was measured at three sites per tooth in two randomly selected contralateral quadrants. Cigarette smoking history was obtained at ages 15, 18, 21, and 26 and was used to categorize participants as “never-smokers,” “ever-smokers,” “long-term smokers,” or “very long-term smokers.” In the total sample, the prevalence of loss of attachment of 4 mm or more was 19%. In the group of ever-smokers, the prevalence was 33.6%. After controlling for gender, self-care, and dental visits, this group was nearly three times as likely to have one or more sites with loss of attachment of 4 mm or more compared to the others. It was concluded that exposure to smoking is a strong predictor of periodontal disease prevalence in young adults.

Hashim R, Thomson WM, Pack ARC. Community Dent Oral Epidemiol 2001;29:130–135. References: 13. Reprints: Dr W. M. Thomson, School of Dentistry, PO Box 647, Dunedin, New Zealand. e-mail: mthomson@gandalf.otago.ac.nz—SP

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