Dimensional Change of Laser-Welded Gold Alloy Induced by Heat Treatment

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<u>Purpose:</u> This study examined the effects of laser welding and heat treatment on the dimensional change of cast gold alloy frameworks.

<u>Materials and Methods:</u> Pairs of cast gold alloy plates were matched, fixed in a jig, and welded in a laser-welding machine at constant welding parameters. The specimens were welded unilaterally (on one surface) or bilaterally (on two surfaces) with five spots as follows: two ends fixed/unilaterally welded (A); two ends fixed/bilaterally welded (AA); one end fixed/unilaterally welded (B); two ends fixed/welded on one surface and then one end fixed/welded on the opposite surface (AB); or one end fixed/bilaterally welded (BB). The dimensional change was determined by measuring the gap between the jig base and one end of the specimen after each welding application. Dimensional change was also measured after two different heat treatments (softening and hardening). The results were analyzed using a two-way ANOVA and Duncan's test ($p < 0.05$).

<u>Results:</u> The dimensional change of the specimens fixed at only one end on either surface (AB, B, and BB) was higher compared with the two ends-fixed specimens (A and AA) after laser welding. The heat treatments also increased the dimensional change in all groups except for the B group. The dimensional change was similar for each fixing method between the two types of heat treatment.

<u>Conclusions:</u> The method of fixing the specimens in the jig significantly affected the amount of dimensional change of the gold alloys. The heat treatments of the laser-welded specimens increased the dimensional change by releasing the residual stress.

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INDEX WORDS: laser, dimensional change, gold alloy, heat treatment

LASER WELDING has increasingly been applied for dental and maxillofacial prostheses because of the ease of joining metal frameworks without any effects of heating or the need for additional materials, as in conventional soldering. Numerous studies have been conducted to investigate the mechanical strength of laser-welded dental alloys.[1-9] Some of these studies indicated that laser welding produced mechanical joint strength equivalent to the non-welded parent alloys when the optimal parameters (power, pulse, and spot diameter) were selected for laser welding.[7-9]

One of the clinical concerns of joining metal frameworks by means of laser welding is distortion (dimensional change) of prostheses directly affecting the dimensional integrity of the prostheses. Conventional soldering is known to create distortion due to the heating-cooling process that causes the expansion and contraction of the investment materials and metal frameworks;[10-13] however, there is little information about the distortion induced by laser welding, which produces less heat and a different heating/cooling effect during the welding procedure.[14,15] Huling and Clark[14] evaluated the distortion of three joining procedures (laser welding, soldering, and one-piece casting) and reported that there was significantly less post-joining distortion for laser-welded and one-piece castings than for soldering, and significantly greater reliability (the least error variance) for joining with the laser compared with either one-piece casting or soldering. Iwasaki et al[15] investigated the distortion of laser-welded titanium and reported less distortion for two-sided

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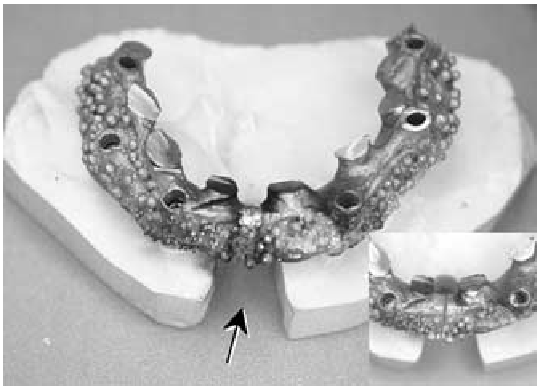

Figure 1. Laser-welded gold alloy metal framework for implant-supported superstructure screwed onto abutment replicas of the master and the metal framework before laser welding (right bottom corner). Arrow indicates an access hole through which the bottom of the framework can be welded.

welding compared with one-sided welding and that pre-welding significantly reduced the distortion by stabilizing the welding assembly. In clinical practice, laser welding is always performed on a master cast (Fig 1). Note that the metal framework is tightly screwed onto the abutment replicas on the master cast. After the top of the framework is welded, the metal framework sometimes distorts when the bottom is welded after the framework is unscrewed and removed from the abutment replicas.

This study investigated the dimensional change caused by the laser welding of gold alloy frameworks when the welding pattern and the method of fixing the ends of the specimens in the jig were varied during the welding process. The effect of heat treatment on the dimensional change was also investigated.

Materials and Methods

The alloy used in this study was a Type IV gold alloy (Ney-Oro 60; Au: 56%, Ag: 19.9%, Cu: 17%, Pd: 4%, Zn: 3%; Degussa-Ney Inc., Bloomfield, CT). To prepare the cast plates, wax plate patterns ($0.5 \times 3.0 \times 10$ mm) were invested in mold rings using a cristobalite investment (Cristobalite, Whip Mix Corp., Louisville, KY). The gold alloy ingots were then cast using a broken-arm centrifugal casting machine (Kerr Centrifico, Kerr Manufacturing Corp., Romulus, MI). After the cast surfaces were air-abraded with 50 μm Al_2O_3 particles, the welded surfaces (3.0×0.5 mm) were polished with No. 600 SiC paper, and the two plates were matched and butted together.

Welding was performed with a Nd:YAG laser (Neolaser L, Girrbach Dental Systems, Pforzheim, Germany) at a constant voltage of 200 V, pulse duration of 10 ms, and spot diameter of 1 mm. The specimens were welded using a jig apparatus (Fig 2). Five spots were applied unilaterally (on one surface) or bilaterally (on two surfaces). First, three laser spots (1 mm spot diameter) were linearly applied to cover the 3 mm width on one side, and two laser spots were added to overlap with 50% of the three previously applied spots. Specimens were prepared with two ends fixed in the jig and welded either unilaterally (A) or bilaterally (AA) (Fig 3). The other specimens were fixed on one end and welded unilaterally (B), fixed on two ends and welded on one surface and then fixed on one end and welded on the opposite surface (AB), or fixed on one end and welded bilaterally (BB). This experimental setup (Fig 3) resembles the clinical case shown in Figure 1 as follows:

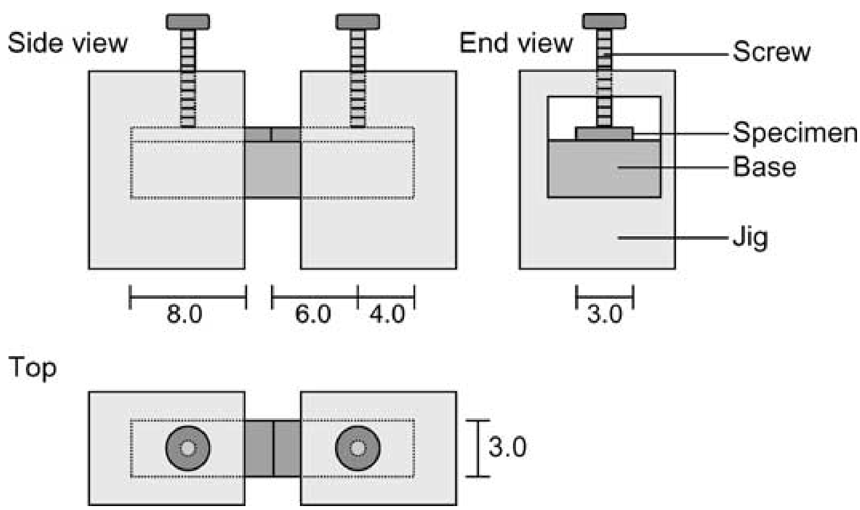

Figure 2. Illustration of jig setup (unit: mm).

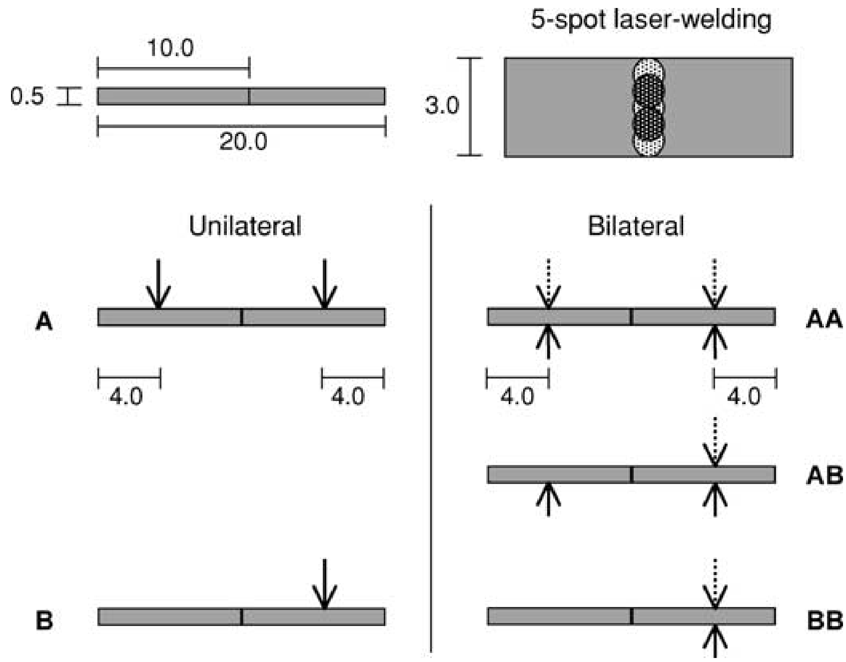

Figure 3. Experimental patterns for laser welding and fixing the ends of specimens (unit: mm). Solid arrows: fixing location for first welding; dotted arrows: fixing location for second welding; A: fixed at two ends; and B: fixed at one end.

(1) A: the top of the framework is welded after both right and left screws are tightened.
(2) B: the top of the framework is welded after only the right or left screw is tightened.
(3) AA: the bottom is then welded through the access hole without unloosening the screws of both sides for top welding (A).
(4) AB: the bottom is welded through the access hole after the screw on one side is unscrewed for top welding (A).
(5) BB: the bottom is welded through the access hole without unscrewing the screw on one side for top welding (B).

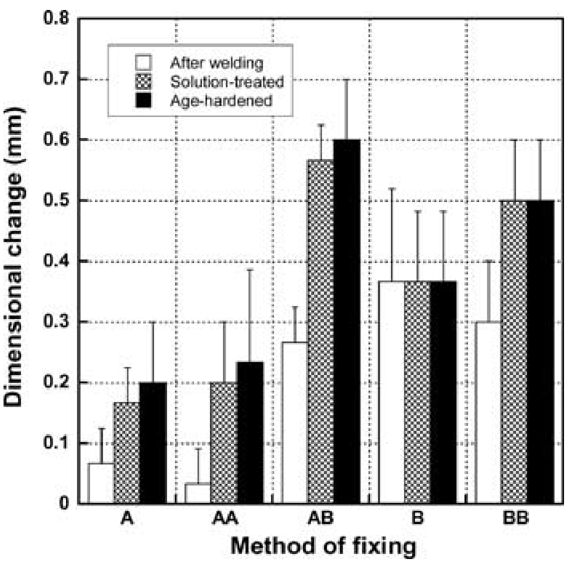

Figure 4. Dimensional change induced by laser welding and heat treatments. A: two ends fixed/unilaterally welded; AA: two ends fixed/bilaterally welded; B: one end fixed/unilaterally welded; AB: two ends fixed/welded on one surface, and then one end fixed/welded on the opposite surface; and BB: one end fixed/ bilaterally welded

The dimensional change was determined by measuring the gap between the epoxy jig base and the end of the specimen after each welding application. After the measurement of dimensional change, all specimens removed from the jig underwent two heat treatments: (1) solution treatment at 700°C for 5 minutes and then quenching in ice water, followed by (2) age-hardening at 315°C for 30 minutes, then quenching in ice water. These heat treatments are recommended by the manufacturer. Each specimen was replaced at the same position on the jig base, and the dimensional change was again measured after each heat treatment. Three specimens were evaluated for each experimental condition. The results were analyzed using an ANOVA and Duncan's test ($p < 0.05$).

Results

The dimensional change induced by laser welding and the heat treatments is presented in Figure 4. Statistical significance was found in the fixed condition ($F = 15.952$, $p = 0.001$) and the heat treatment ($F = 9.790$, $p = 0.007$) factors. Compared with the two ends fixed specimens (A and AA), the specimens fixed at only one end on either surface (AB, B, and BB) had higher dimensional change, particularly immediately after welding (significant at $p < 0.05$). The heat treatments also increased the dimensional change in all groups (although only the results for the AB group were significant), except for the one end-fixed welded unilaterally group (B). The dimensional change of the heat-treated groups was similar for each fixing method between the solution treatment and age-hardening treatment.

Discussion

More dimensional change was found for those experimental groups with only one end fixed (AB, B, and BB) (Fig 4), simply because the other end of these specimens was free to distort. The solution heat treatment significantly affected the dimensional change of all of the groups, except for the one end-fixed unilaterally group (B). This finding probably occurred because the heat generated by the solution treatment released the residual stress produced at the laser-welded region. The fixing of both ends during laser welding increased the residual stress at the region to be welded. The subsequent age-hardening treatments did not further affect the specimens, since the residual stress had already been released during solution treatment. Therefore, there was no difference in the dimensional change between the solution and the age-hardening treatments.

When the conditions for A (unilaterally welded) and AA (bilaterally welded) were compared, increasing the number of laser-welding spots (bilateral AA > unilateral A) based on the fixing conditions decreased the dimensional change due to the larger welded area and higher strength. However, increasing the number of laser-welding spots increased the residual stress and resulted in an increase in the dimensional change. Before heat treating, the dimensional change for AA was less than for A; however, after heat treating, it was higher for AA than for A. The heat treatment had no effect on the dimensional change of one end fixed/unilaterally welded specimens (B), since one end was free to distort by releasing the residual stress that built up during the melting/solidification process. Although the one end fixed/bilaterally welded specimens (BB) also had one end free to distort, the dimensional change of this group increased after heat treating. This result may have occurred because, after these specimens were welded on one surface, the bent specimens with a certain amount of dimensional change were forced down on the flat base of the jig when the screw was tightened on one end for second welding, which increased the residual stress. As for the AB group, the specimens had residual stress and a slight amount of dimensional change from the first welding (A). The second welding on the opposite side increased the residual stress due to the constraint of the first welding and being tightened during the second welding, even though the specimens were fixed on only one end (B) for the second welding. Thus, this group had the highest dimensional change after solution treatment.

The results of this study indicate that the metal framework should be tightly fixed at a certain position to prevent distortion during laser welding. In the clinical case shown in Figure 1, making an access hole in the casting beneath the framework enabled us to weld the bottom of the framework without removing it from the abutment replicas on the cast and to minimize the occurrence of distortion of the welded framework. After laser welding, metal frameworks should not be heated by any source in order to prevent the release of residual stress, which causes distortion.

Conclusion

The method of fixing the ends of the specimens in the jig significantly affected the amount of dimensional change of the laser-welded gold alloy. Heat treating the laser-welded specimens increased the dimensional change by releasing the residual stress.

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