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ABSTRACT

Context: Alloys have been considered to be of paramount importance in the field of prosthodontics. Long span prosthesis may often require joining of one or more individual castings to obtain better fit, occlusal harmony and esthetics in comparison to one-piece casting.
Aim: This study was undertaken to evaluate the mechanical properties of base metal alloys joined by two different techniques, namely, gas oxygen torch soldering and laser fusion, compared to a one-piece casting. Mechanical properties evaluated were tensile strength, percentage of elongation and hardness of the solder joint. In addition, corrosion properties and scanning electron microscopic appearance of the joints were also evaluated.
Materials and Methods: The samples were prepared according to American Society for Testing Materials specifications (ASTM, E8). Specimens were made with self-cure acrylic and then invested in phosphate-bonded investment material. Casting was done in induction casting machine. Thirty specimens were thus prepared for each group and compared with 30 specimens of the one-piece casting group.
Statistical Analysis Used: SPSS software (version 10.0, Chicago, IL, USA) was used for statistical analysis. ANOVA and Benferroni post hoc tests were done for multiple comparisons between the groups and within the groups for mean difference and standard error.
Results: Results showed that tensile strength of the one-piece casting was higher than laser fused and gas oxygen torch soldered joints. Laser fused joints exhibited higher hardness values compared to that of gas oxygen torch soldered joints. Scanning electron microscopic examination revealed greater porosity in the gas oxygen torch soldered joints. This contributed to the reduction in the strength of the joint. Gas oxygen torch soldered joints showed less corrosion resistance when compared to laser fused joints and one-piece casting.
Conclusion: Laser fusion, which is a recent introduction to the field of prosthodontics, produces joints which have properties between those of one-piece casting and the gas oxygen torch soldering.

Received : 01-10-09
Review completed : 06-01-10
Accepted : 01-09-10

Key words: Base metal alloys, gas oxygen torch soldering, laser fusion, microstructure, one-piece casting, properties, solder joints

Joining or fusion of a metal or an alloy is required for assembling bridges in prosthodontics, uniting component parts of bridges for establishing esthetics, to develop harmony and for uniting wrought clasp to a cast metal framework in removable prosthodontics.[1,2] This procedure was conventionally done using methods like soldering, brazing and welding. Newer techniques such as laser fusion, infrared fusion and electron beam fusion have been recently introduced.[1,3,4]

Laser fusion is a method in which a high-energy beam in the form of light is focused on the approximated alloy. It can be applied at a very small, pointed area as a focal spot.[5] The metal pieces to be joined together are held in close approximation for laser fusion. The most important advantage of this technique is that there is less distortion.[6] Laser welding has recently added a new dimension to the field of fixed prosthodontics.[5,7]

Factors to be considered in soldering to develop a joint with

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Access this article online	
Quick Response Code:	Website: www.ijdr.in
	DOI: 10.4103/0970-9290.90326

ideal properties are (1) the type of soldering, (2) composition of the solder, (3) composition of the parent metal to be soldered, (4) flow temperature of the filler metal or alloy, (5) ability of the filler metal to wet the parent alloy, (6) adequate fluidity at the temperature of soldering, (7) gap distance between the metals or alloys to be united, (8) heat source used to obtain the required temperature and (9) time. These factors determine the properties of the joint area, which determines the successful utility of the prosthesis in service.[1,3,8]

Few decades ago, only noble or high noble alloys were considered for fabrication of single piece fixed prosthesis.[9] Base metal alloys have become popular since 1930s for the fabrication of cast partial denture frameworks and also for fixed prostheses. They have been used in prosthodontics because of their high modulus of elasticity, resistance to tarnish and corrosion and light weight.[10] These base metal alloys have different metallurgical properties both in the cast and wrought conditions compared to those of noble metals. Hence, in order to proportionate the equivalent metallurgical properties, high temperature of fusion as well as high fusing filler alloys are required for obtaining a joint with optimal properties. Consequently, a change in the technique of soldering is necessary for joining base metal alloys.[11]

Even though the required properties of the resultant joint are mentioned in literature, which technique of soldering will produce a joint with all the ideal properties is not clear. When base metal alloys are used, they require solders which match the parent alloy in color properties and strength. Hence, in such cases, nickel chromium alloy solders are used to fabricate joints, especially in metal ceramic bridges.[1,12-15] Fixed partial dentures are subjected to various stresses and are also prone to corrosion within the oral environment. The internal structure of the joint thus plays an important role in obtaining optimal mechanical properties.[16-19]

Hence, this study was undertaken to evaluate properties of the joint area when two different techniques are used for soldering. The properties evaluated were tensile strength, hardness, percentage of elongation, corrosion properties, porosity of the joint and microstructure, when gas oxygen torch soldering and laser fusion techniques were used in comparison to a single-piece casting.

MATERIALS AND METHODS

This study was conducted to evaluate the properties of base metals alloy joints fabricated by gas oxygen torch soldering and by laser fusion. The base metal alloy and solder used in the study was nickel chromium alloy and nickel chromium solder, respectively. A die was prepared for fabrication of base metal alloy samples for joining [Figure 1]. The die was made with stainless steel. This die was used to prepare samples according to specifications recommended by American Standards for Testing Materials (ASTM, E8).

The patterns were prepared in cold cure acrylic resin (Dental products of India, Mumbai, India) to avoid distortion. The prepared samples had the dimensions of 40 mm length and 4 mm width at the joint area. Cross-sectional area in the gauge length portion was 3.2 mm^2, which simulated the clinical situation. The specimen was fabricated in two stages: the first stage consisted of preparing the base metal alloy specimen and the second stage consisted of joining the two primary base metal alloy specimens by gas oxygen torch soldering and laser fusion. These samples were subsequently used for evaluating the properties.

Thus, a total of 150 acrylic samples were initially fabricated. The specimens were invested in a casting ring and once the investment (Bellavest SH and Begosol, Bego Dental Products, Bremen, Germany) had set, the mold was placed in a burnout furnace. The burnout mold was placed in induction casting machine (Fornax T induction casting machine, Bego Dental Products) and casting was done according to manufacturer's instructions using nickel chromium alloy (Wiron 99, Bego Dental Products). Likewise, 15 castings were made in a phased manner to obtain a total of 150 samples for the study. All the specimens were sand blasted with 100 μm grit aluminum oxide (Perlablast, Bego Dental Products) for 20 seconds under 60 psi of compressed air. All test samples were made according to ASTM, E8 [Figure 2].

For soldering, the cast alloy specimens were cleaned, dried and aligned with a gap distance of 0.3 mm between them.[4] Flux was applied with a brush and graphite was used as the antiflux.[1,11,12] Gas oxygen torch (Multiplex, Bego Dental Products) was used for soldering and care was taken to see that the outer oxide zone was avoided to prevent oxide formation on the joint area. The specimens were then bench cooled to room temperature and finished.[20,21] Thus, 30 specimens were obtained which were subsequently subjected to testing.

Nd:YAG (Neodymium:Yttrium, Aluminum, Garnet) laser welding apparatus in an argon atmosphere was used for laser fusion[14] (Model 2220A, Miyachi Technos, Tokyo, Japan). The laser welding apparatus had the following parameters: irradiation power of 30 J/pulse, pulse range of (0.3–9.9 ms, optical fiber SI-600-SY5M, focal length of 70 mm, voltage range of DC 250–499 V. A specially designed holding device was used to keep the two halves of the specimen in close contact during the welding process. A single pulse from laser beam was used for laser fusion.[14] The specimens were finished and polished before evaluating the properties. Thus, a total of 30 specimens were obtained.

For obtaining a one-piece casting, the fabricated acrylic specimens were united to form a single piece. Spruing was done and the specimens were invested and casting was done

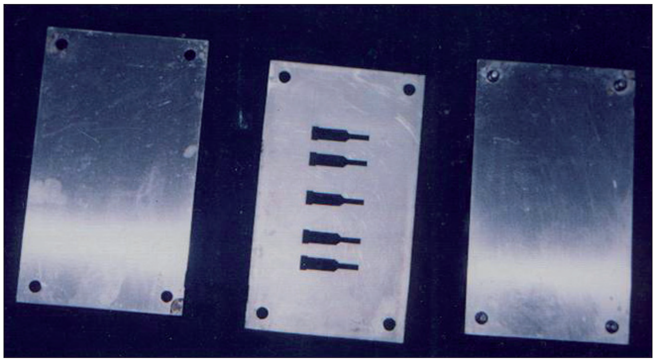

Figure 1: Die preparation

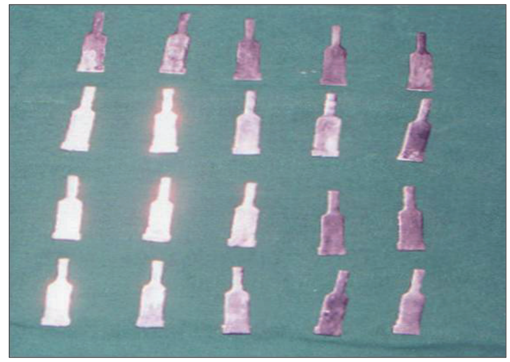

Figure 2: Samples

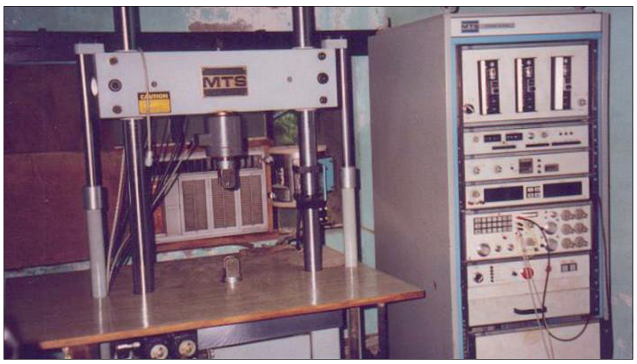

Figure 3: Instron testing machine

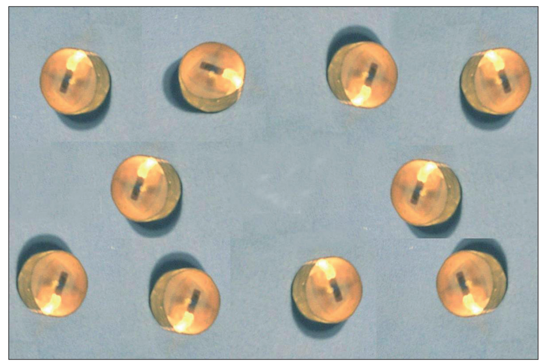

Figure 4: Samples prepared for SEM

in an induction casting machine. Thus, a total of 60 acrylic samples were fused together to produce 30 specimens.

The specimens thus obtained by gas oxygen soldering, laser fusion and as one-piece casting were cleaned and dried before being subjected to mechanical testing. Each specimen was placed in a custom made securing device that can be engaged in the universal testing machine [Figure 3]. An incremental tensile load was applied with a cross-head speed of 0.1 kN/minute to evaluate the tensile strength.[3,6,16,22] Load was applied until the specimens were fractured. The strength values were calculated and the results were tabulated.

Permanent deformation was determined after tensile strength test was completed when complete fracture occurred. It was measured with an extensometer. The percentage of elongation was calculated using the formula:

Percentage of elongation = Increase in length/Original length × 100.[1]

To evaluate microhardness of joint specimen, Vickers hardness tests were used. The specimens were sectioned longitudinally through the joint with diamond disk. The sectioned specimen was mounted on a resin base for evaluating microhardness. The specimens were cleaned and polished at the entire surface including the joint area. It was then placed on the flat table of the Vickers microhardness testing machine. After selecting the site to evaluate hardness, load was applied on the selected site. The prepared specimen in their molds was positioned centrally beneath the indenter of microhardness tester by applying 50 g of load for 30 seconds.[8] Hardness was tested on the specimen from base metal to the joint area.

Metals and alloys are generally more susceptible to corrosive attack because of electrochemical reactions. In the present study, the electrochemical corrosive resistance test method (potentio-dynamic polarization test) was followed. A saline solution (Ringer's solution) was used as test medium to test the corrosion resistance of the joints in the study. The 0.9% NaCl was used as corrosive solution after being adjusted to a pH of 7.[23,24] After immersing the specimen for about 15–20 minutes under equilibrium conditions, potential scan was done from open circuit potential toward the noble direction at a scan rate of 0.2 mV/second. Corresponding current between the specimen and platinum counter electrode was recorded. The potentials were measured with respect to a reference saturated calomel electrode. Corrosion resistance was then calculated.[23,24]

Randomly selected specimens from each group were sectioned with diamond disk longitudinally to evaluate the appearance of the gas oxygen torch solder joint and the laser fused joint [Figure 4]. These specimens were prepared for scanning electron microscope (SEM) examination by the application of gold coating and photographed with SEM to characterize the microstructure and porosity.

Analysis of variance (ANOVA) and Bonferroni post hoc tests were used for statistical evaluation. Post hoc tests were done for multiple comparisons between the groups and within the groups for mean difference and standard error.

RESULTS

The data obtained after testing for various properties were tabulated and were subjected to statistical evaluation. The results are tabulated in Tables 1–5. Statistical analysis was carried out with the SPSS software (SPSS, Chicago, IL, USA). An alpha level of less than 0.05 was considered to be statistically significant.

The mean tensile strength values obtained in this study for one-piece casting, laser fused and for gas oxygen torch soldered techniques were found to be 668.5, 562.5 and 456 MPa, respectively [Table 1]. Thus, the one-piece casting group was found to have a higher tensile strength when compared to the laser fusion and the gas oxygen torch soldered group.

Another mechanical property that is important for successful utility of the prosthesis is percentage of elongation. In this study, one-piece casting exhibited greater percentage of elongation than the laser fused and the gas oxygen torch soldered specimens. The mean percentage of elongation of one piece casting was 2.69%, and it was 2.56% for the laser fused specimen and 1.31% for the gas oxygen torch soldered specimen [Table 2].

Laser fused joints were found to have greater hardness at the joint area when compared to that of gas oxygen torch soldering [Table 3]. The interdendrite arm spacing of laser fused joint is low compared to that of cast specimen. The hardness values in the joint were more or less same as that of base metal. But the heat affected zones on both sides showed a dip in the hardness values.

Table 4 revealed that cast base metal, laser fused joint and soldered joint had similar equilibrium potential in Ringers solution.[23,24] Table 5 shows that the gas oxygen soldered joint started pitting early at about 175 mV. Laser fused specimen started pitting after crossing 300 mV, almost at the same value as that of the base metal. This difference can be attributed to the porosities and defects in the soldered joint.[23]

SEM examination of gas oxygen torch soldered joints [Figure 5] revealed greater amount of porosities as compared to laser fused joints. SEM examination of laser fused

Table 1: Tensile strength values for gas oxygen soldering, laser fusion and one-piece casting group

	N	Mean	Std. deviation	Std. error	95% confidence mean		Min	Max
					Lower bound	Upper bound		
One-piece	10	668.5	17.8	5.629	655.76	681.23	640	690
Laser fused	10	562.5	24.97	7.896	544.63	580.36	520	590
Gas oxygen torch soldering	10	456	24.24	7.666	438.65	473.34	420	500

Table 2: Percentage of elongation - Gas oxygen soldering, laser fusion and one-piece casting group

	N	Mean	Std. deviation	Std. error	95% confidence mean		Min	Max
					Lower bound	Upper bound		
One-piece	10	2.69	0.137	4.333E-	2.592	2.788	2.5	2.9
Laser fused	10	2.56	0.302	9.568E-	2.343	2.766	2.1	3
Gas oxygen torch soldering	10	1.31	0.196	6.227E-	1.169	1.45	1	1.7

Table 3: Hardness (Vickers Hardness Number) values for gas oxygen soldering, laser fusion and one-piece casting group

	N	Mean	Std. deviation	Std. error	95% confidence mean		Min	Max
					Lower bound	Upper bound		
One-piece	10	572	21.94	6.94	556.2	587.7	532	590
Laser fused	10	591.8	13.74	4.34	571.2	590.9	560	610
Gas oxygen torch soldering	10	581.1	33.75	3.85	567.6	615.9	560	666

Table 4: Equilibrium potential values - Gas oxygen soldering, laser fusion and one piece casting group

	N	Mean	Std. deviation	Std. error	95% confidence mean		Min	Max
					Lower bound	Upper bound		
One-piece	10	−169.5	5.835	1.845	−173.67	−165.32	−179	−162
Laser fused	10	−189.7	3.784	1.196	−194.6	−189.19	−197	−187
Gas oxygen torch soldering	10	−183.7	3.622	1.145	−192.29	−187.1	−195	−183

Table 5: Pitting potential - Gas oxygen soldering, laser fusion and one piece casting group

	N	Mean	Std. deviation	Std. error	95% confidence mean		Min	Max
					Lower bound	Upper bound		
One-piece	10	290.1	4.557	1.441	286.84	293.35	285	299
Laser fused	10	312.1	3.281	1.037	309.75	314.44	307	317
Gas oxygen torch soldering	10	178.6	3.687	1.166	175.96	181.23	173	184

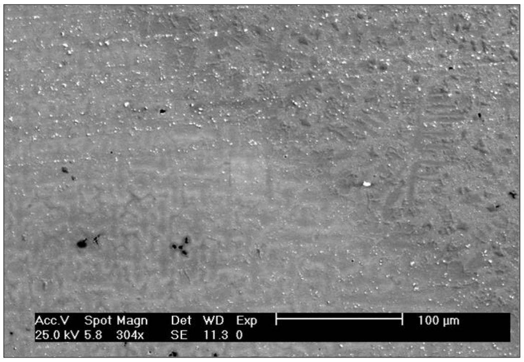

Figure 5: SEM of gas oxygen torch soldered joints

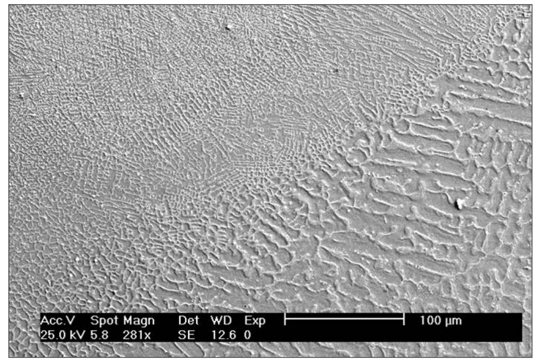

Figure 6: SEM of laser fused joints

samples [Figure 6] displayed large grains located in the heat affected zone.

DISCUSSION

Alloys have been considered to be of paramount importance in the field of fixed and removable prosthodontics. This is because alloys have been proved to have accurate fit and excellent mechanical properties which are the essential requirements for successful service of these prostheses.[25,26] Long span prosthesis, of which alloys are an integral part, may often require joining of one or more individual castings to obtain better fit, occlusal harmony, accuracy and esthetics in comparison to one-piece casting.[10] Although noble and high noble metal alloys were considered for prosthodontic use till a few decades ago, base metal alloys have evolved as an alternative due to various reasons such as lower cost of the alloy, hardness, high elastic modulus and high melting range compatible with ceramic application, etc.[9]

Component parts of fixed partial denture can be joined by several techniques such as soldering and welding, laser fusion, infrared fusion, electron beam fusion, etc. According to the literature, marked variations are observed in the mechanical properties of the joints produced by any of the above techniques and this can be clinically significant.[26] This fact was an important basis for selecting this study. This study aimed at testing the soldered joint developed with two techniques, namely gas oxygen torch soldering and laser fusion, when compared to a one piece casting. The alloy specimen for the study was standardized as per ASTM specification number E8. This standardization provided equal thickness at the critical joint area for both gas oxygen soldering and laser fusion.

Tensile strength is necessary for the prosthesis to withstand occlusal forces within the oral cavity.[3,6] Among the two test groups, the gas oxygen torch soldered joint was found to be the weakest [Table 1]. It exhibited lower values due to the interphase material (solder) that was used.[16] During deformation, adhesion generated by the penetrations of solder into surface irregularities of the parent metal tends to hold the soldered interface. Thus, the strength of the joint is affected when the applied force produces an axial stress in outward radial direction at the solder parent metal interface. Lautenschlager *et al*, have described these as orthogonal or triaxial stresses.[16] Ten specimens from each group were subjected to tensile stress testing. The specimens were then subjected to ultimate tensile strength testing using universal testing machine with a cross-head speed of 0.1 kN/minute to evaluate the tensile strength of solder joint.[5,8]

Hardness is a property that is used to predict the wear resistance of a material and its ability to abrade opposing dental structures. The hardness profiles of solder fused joints and laser fused joints are different from the hardness of one-piece casting. This is due to the microstructural difference in that region due to rapid cooling and rapid heating.[1] It could be due to grain growth, which would have taken place while heating the edges to 950°C for soldering.

In the laser fusion process, there is no filler or solder involved. Laser melts the two edges that are kept closely and the melt pool solidifies. The microstructure developed in that region is dependent on the cooling rate. The heat affected zone also is very narrow in the process. As the melt pool solidifies, dendrites would form during the crystallization process. In this study, SEM pictures revealed a clear pattern of dendritic structure in the cast specimen and also in the laser fused zone. However, the interdendritic arm spacing was very small in the laser fused zone due to fast cooling rate. The higher hardness values obtained in the laser fused zone could be attributed to this low arm spacing.[27]

Metallic restorations in contact with saliva release components into the oral environment because of the formation of an electrogalvanic cell. The release of nickel, chromium and other elements might cause reactions in some patients. The electrical potential formed by coupling nickel chromium alloy with solder can differ among the alloys, resulting from the polarization caused by creation of galvanic cells with two electrodes.[23,24]

Electrochemical reaction revealed that the cast base metal, laser fused joint and soldered joint had similar equilibrium potential in Ringers solution[23,24] [Table 4]. However, as the potential was varied, they followed different traces of current densities. In the passive region, laser fused specimen displayed higher current density as compared to that of base metal. This could be due to the galvanic coupling between the laser fused zone and the metal zone. The soldered joint interestingly showed somewhat better passivity due to coarsened grain structure. However, it started pitting early at about 175 mV. Laser fused specimen started pitting after crossing 300 mV, almost at the same value as that of the base metal. This difference can be attributed to the porosities and defects in the soldered joint[23] [Table 5].

For SEM examination, the specimens in the current study were molded into araldite to prepare uniform surfaces. Since araldite is nonconducting, a very thin coating of gold was applied to the total surface of the specimen as well as the araldite mold. Since the passive film coating is very thin, it just follows the surface corrugations and thus does not affect the image of the specimen under study.[1,12] SEM examination of gas oxygen torch soldered joints [Figure 5] revealed a greater amount of porosities as compared to laser fused joints. SEM examination of laser fused samples [Figure 6] displayed large grains located in the heat affected zone. These factors play an important role in the hardness of the joint.[22]

Metal possesses greater affinity for dissolving gases when they are in molten state than in the solid state. With decreased solubility at lower temperatures, these gases come out of solution and are entrapped in the solidification metal as voids known as gas porosities or pin holes. By proper degasification technique, prior to pouring, this condition may be eliminated. Larger voids known as blow holes may also result from the presence of moisture, volatile matter or poor venting in sand molds.[27] This could explain the lower strength values for gas oxygen torch soldering group. Entrapped gas pinholes present within the solder area can significantly contribute toward strength reduction and hence overheating should be avoided during the soldering operation. Overheating leads to recrystallization that affects the mechanical properties of the joint.[12]

CONCLUSION

Tensile strength and percentage of elongation were higher in the one-piece casting group followed by laser fusion and gas oxygen soldered joint, when nickel chromium alloy and solder were tested. The laser fused joints exhibited better hardness, possessed better microstructure and had a high corrosion resistance. Gas oxygen soldered group showed joints with greater porosity and exhibited least corrosion resistance. Consequently, laser fusion, which is a recent introduction to the field of prosthodontics, produces joints which have properties between the one-piece casting and the gas oxygen torch soldering. The technique produces joints which possesses superior mechanical properties compared to those fabricated by conventional methods.

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How to cite this article: Machha S, Kumar MV, A, Rangarajan V. Microstructure, mechanical performance and corrosion properties of base metal solder joints. Indian J Dent Res 2011;22:614.

Source of Support: Nil, **Conflict of Interest:** None declared.