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The Fatigue Life Of A Cobalt-Chromium Alloy After Laser Welding

Nabil Jalal Ahmad Al-Bayaa*, Robert K.F. Clark†, Andrzej S. Juszczyk‡ and David R. Radford§

Abstract - *The aim of this study was to investigate the fatigue life of laser welded joints in a commercially available cast cobalt-chromium alloy. Twenty rod shaped specimens (40 mm x 1.5 mm) were cast and sand blasted. Ten specimens were used as controls and the remaining ten were sectioned and repaired using a pulsed Nd:YAG laser welder. All specimens were subjected to fatigue testing (30N ~ 2Hz) in a controlled environment. A statistically significant difference in median fatigue life was found between as-cast and laser welded specimens (p<0.001). Consequently, the technique may not be appropriate for repairing cobalt chromium clasps on removable partial dentures. Scanning electron microscopy indicated the presence of cracks, pores and constriction of the outer surface in the welded specimens despite 70% penetration of the weld.*

KEY WORDS: Laser welding, Cobalt chromium alloy, Fatigue strength

INTRODUCTION

Cobalt-chromium (Co-Cr) alloy is the material of choice for the metal framework of removable partial dentures (RPD). Soldering and brazing are conventional methods used for joining Co-Cr alloy components[1], however, it is difficult to use these methods to repair the fractured parts of an existing prosthesis due to the need to heat a large area, which may lead to the acrylic resin components being affected[2,3]. Laser welding can be used to join parent metals using only localized heat. The tensile strength of welded joints in cast Co-Cr wires has been found to be considerably less than the tensile strength of unwelded wire[4]. However, tensile failure of a Co-Cr component in service is unlikely as fatigue fracture would be a more likely cause of failure. The clinical experience of loss of retention of an RPD after a period of service, suggests that repeated deflection of the clasps retaining the denture in function and during insertion and removal of the denture may cause metal fatigue in a clasp[5].

Laser welding offers a convenient method for joining cobalt-chromium components during construction and repair of RPDs[6]. However, little appears to have been reported in the literature of the fatigue life of Co-Cr alloys or the effect of laser welding on fatigue life. Thus, the aim of this study was to compare the fatigue life of Co-Cr alloy after laser welding with the fatigue strength of "as cast" specimens. The null hypothesis was that there was no difference in the fatigue life between the laser welded Co-Cr alloy and the "as cast" alloy.

* BDS MSc
† BDS PhD FDS
‡ LCGI, PhD
§ BDS PhD FDS MRD

MATERIALS AND METHODS

20 specimens (40mm +/-0.1mm x 1.5 mm +/-0.1mm diameter) were cast using round profile wax as a pattern. After casting the specimens were finished by sand blasting using extra course silica free blast grit (particle size, course; grade 60/80). Ten specimens formed a control group. Ten specimens were sectioned centrally and then rejoined by laser welding. A repositioning jig was used to locate the two ends to be welded using a pulsed Nd: YAG laser. The parameters for welding were frequency at 1 Hz, pulse duration at 10 ms, voltage 200A and spot diameter 0.5 mm[1]. Specimens were inserted into the welding machine on the repositioning jig. The first weld spots were undertaken opposite to each other so as to maintain the correct alignment. A double welding technique was used so as to increase the joint strength of the weld[7,8]. A previously advocated overlapping technique of 70% was used [9,10,11] to avoid distortion.

Specimens were subjected to fatigue testing using a universal SMAC machine (Fig 1). A computer controlled linear actuator with a stroke length of 15 mm was set to deliver a force of 30N at a speed of 2Hz. Each specimen was fixed between the 2 grips of the machine, and the fatigue test was undertaken, the software was programmed to stop at the time when the specimen fractured. The number of cycles was calculated and the fractured specimen was stored dry.

The microstructure of the fracture ends of the welded and the "as cast" specimens was investigated using SEM. Specimens were selected randomly, three per group, mounted on an aluminium stub using carbon cement. Specimens were sputter coated with gold to ensure optimal conductivity. Each specimen was viewed in a Hitachi S 3500N scanning electron microscope using an accelerating voltage of 12KV at magnifications of x45, x150 and x1000.

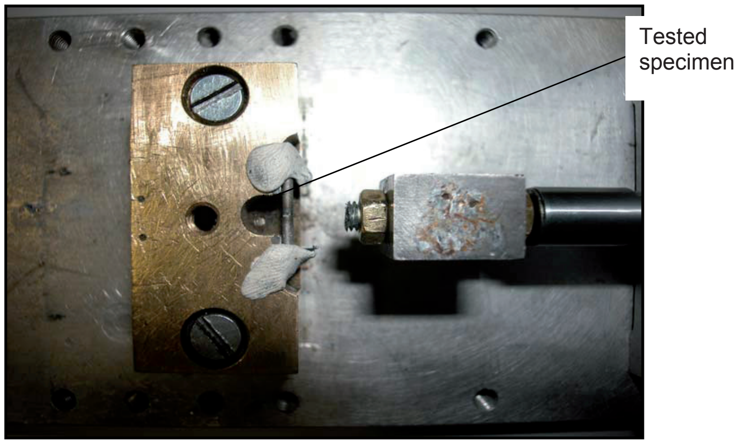

Figure 1. *The specimen is secured on a block.The computer controlled actuator has a stroke length of 15mm at which it delivers a force of 30N at 2Hz*

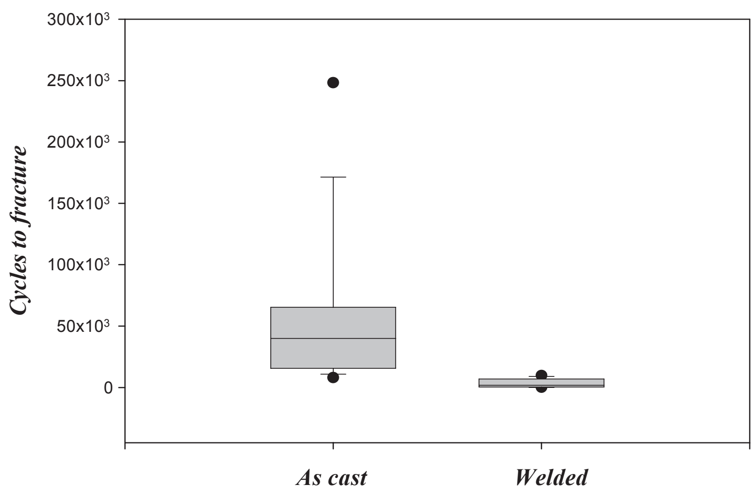

Figure 2. *Box plot of number of cycles required to fracture for both control and welded specimens.*

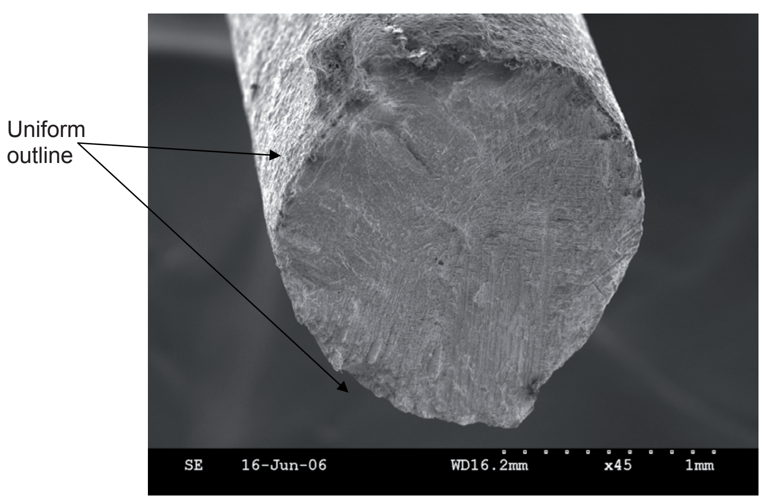

Figure 3. *Fractured control specimen. (Mag. of x45) N.B. the uniform outline of the specimen and fracture planes of the dendrites.*

Table 1. *A summary of the number of cycles required to fracture "as cast" and welded specimens.*

	Control	*Welded*
Highest	248272	9721
Lowest	8062	65
Median	39926	1732.5
Inter quarter range 25% - 75%	15640-65355	362-6863

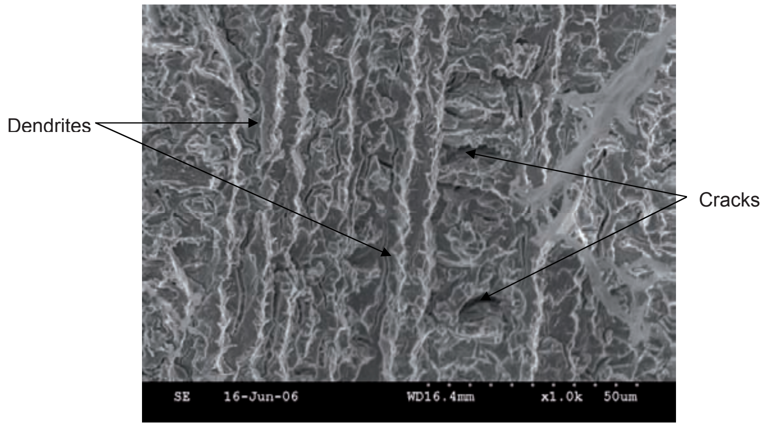

Figure 4. *Fractured control specimen (Mag. x1000) N.B. the long dendritic structure and cracks between the dendrites.*

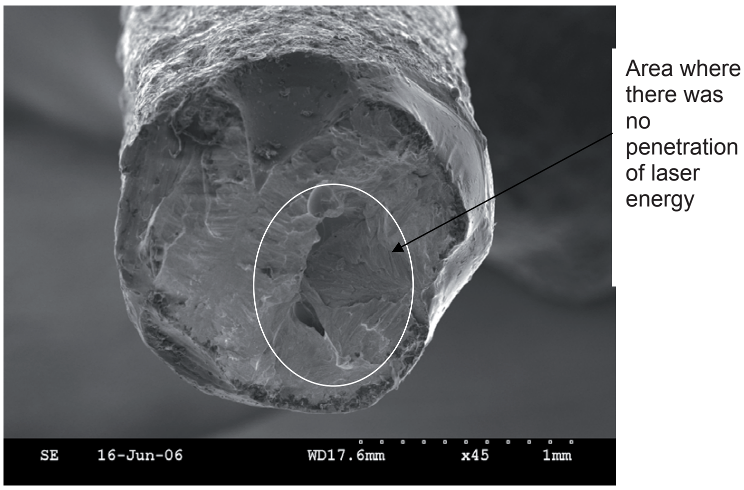

***Figure 5.** Welded specimen at fracture side (Mag. x45) N.B. the non uniform outline due to deformation of the welding process. Areas of fracture site where welding was incomplete.*

Statistical analysis

Using SigmaStat software, the data failed the normality test. Mann Whitney Rank Sum test were used to investigate differences between groups and a p-value of 0.05 was accepted as a statistically significant.

RESULTS

Summary data are presented in Table 1 and Fig 2. A statistically significant difference in median fatigue life was found between as-cast and laser welded specimens ($p<0.001$). All the welded specimens fractured at the weld.

Fig 3 presents a low power image (x45) of the fracture surface of the "as cast" specimen, separate grains can be seen due to different orientation of dendrites. A uniform round circumference was observed. Fig 4 demonstrated clearly the cracks that were evident in the fractured surface. Fig 5 shows that more than 70% of the total cross sectional area was penetrated by laser energy. Fig 6 shows that the microstructure of the welded zone demonstrated very fine grains. The Heat Affected Zone (HAZ), which represents the interface between the welded and non-welded area exhibited a non dendritic microstructure but not as fine as the welded area, which indicated microstructure changes in the HAZ of Co-Cr alloy. The non-welded region did not show the classical appearance of dendrites that was shown at the same magnification of the "as cast" specimens.

DISCUSSION

Although the main purpose of the present investigation was not to study the effect of welding on the structure of the alloy, it can be clearly observed that laser welding had induced microstructural changes of Co-Cr alloy that may influence the fatigue strength. As Co-Cr alloy is a complex alloy, the smaller the grains, the better the physical properties[16]. With welding and soldering procedures, if the molten metal cools slowly, larger grain size will be anticipated, however, if molten metal solidified rapidly, a smaller grain size would be anticipated[12]. Despite the fact that the microstructure of the welded zone appeared very fine as a result of the rapid process of solidification, all the welded specimens showed lower fatigue strength than the controls. On the other hand, it was noticed that the dendritic microstructure of the control specimens could be seen very clearly (Fig 3), whereas with the welded specimens it is only just evident at the same magnification of x1000 (Fig 6).

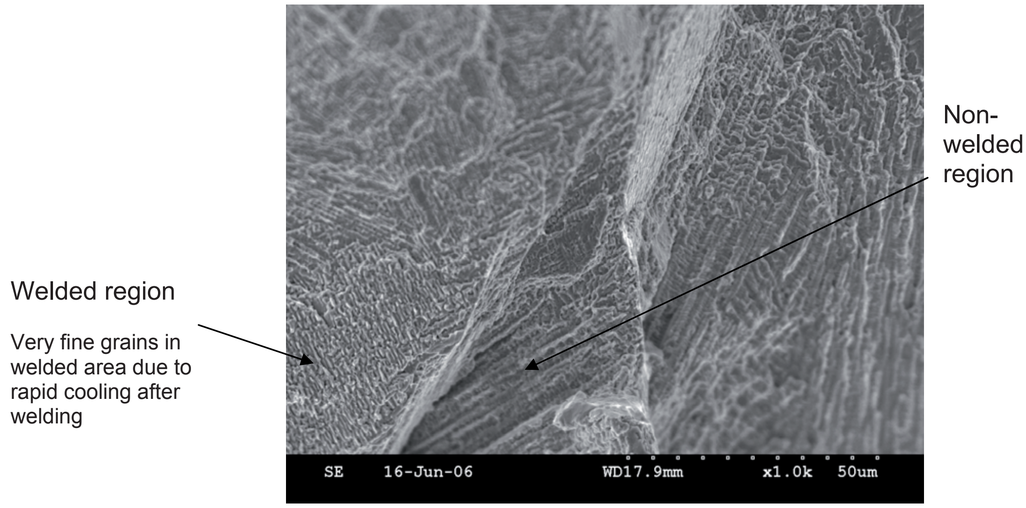

Figure 6. *Welded specimen at fracture side (Mag. x1000) Photomicrograph showing very fine dendritic structure of area of weld compared to non welded area.*

CLINICAL IMPLICATIONS

Laser welding produces a joint which features a significantly different median fatigue life than as-cast metal. It is not, therefore, a method, which can be recommended for repairing clasps on failed cobalt-chromium denture frameworks and by extension, adding clasps to previously cast frameworks.

CONCLUSION

Within the limitations of this study, the null hypothesis was rejected and it was concluded that laser welding results in a reduction in median fatigue life of a Co-Cr alloy compared to the “as cast” material.

ACKNOWLEDGEMENT

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MANUFACTURERS DETAILS

- Neolaser ALC 30/35, Alphalaser, Puchheim, Germany
- Chaperlin and Jacobs, Sutton, UK
- SMAC Europe Ltd, Horsham, UK
- Carbon Emitech Ltd, Ashford, UK
- Hitachi High Technologies Corperation, Workingham, UK
- SigmaStat 3, SPSS Science, Edgbaston, UK
- Davis Schottlander and Davis, Letchworth, UK
- Yeti Dental GmBH, 78234 Engen, Germany

ADDRESS FOR CORRSPONDENCE

Dr David R Radford, Department of Restorative Dentistry, Floor 25, Guys Tower, Guys Hospital. London SE1 9RT, United Kingdom. E-Mail: david.radford@kcl.ac.uk

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