Eur. J. Prosthodont. Rest. Dent., Vol.18, No. 2, pp 60-65
Printed in Great Britain

doi:10.1922/EJPRD_84606

Tensile Strength of Laser Welded Cobalt-Chromium Alloy With and Without an Argon Atmosphere

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Abstract - *The tensile strength and depth of weld of two cobalt chromium alloys before and after laser welding with and without an argon gas atmosphere were investigated. Using two cobalt chromium alloys, rod shaped specimens (5cm x 1.5 mm) were cast. Specimens were sand blasted, sectioned and welded with a pulsed Nd: YAG laser welding machine and tested in tension using an Instron universal testing machine. A statistically significant difference in tensile strength was observed between the two alloys. The tensile strength of specimens following laser welding was significantly less than the unwelded controls. Scanning electron microscopy showed that the micro-structure of the cast alloy was altered in the region of the weld. No statistically significant difference was found between specimens welded with or without an argon atmosphere.*

KEY WORDS: Laser welding, Cobalt chromium alloy, Tensile testing

INTRODUCTION

Cobalt chromium (Co-Cr) alloys are the material of choice for the construction of removable partial dentures[1]. Despite this, some mechanical properties of Co-Cr alloys such as high hardness, low ductility and high modulus of elasticity are incompatible with the properties required for clasps. Clinical and laboratory experience have shown many failures of clasps are due to fatigue.

Commercial dental Co-Cr alloys are not identical[2]. Small differences in minor constituents can affect the mechanical properties for example the addition of nickel in the basic alloy makes the alloy softer[3]. Clinical experience has also shown that the commercial Co-Cr alloys for use in dentistry could vary in ductility and hardness depending on the exact composition. A small change in the chemical composition of nickel-chromium alloys caused a significant difference in the weldability of the alloys, with alloys containing higher levels of carbon and boron reducing the weldability of the alloy[2].

Laser welding is a technique recently introduced in the dental laboratory, which can be used to repair fractured clasps or make additions to a metal framework to support additional teeth on a removable partial denture[4]. Although the majority of research on laser welding has been conducted on titanium and its alloys some studies[2,5,6,7] have investigated Co-Cr alloys. Regardless of the metal welded, most studies concluded that the alloy welded played a significant part in the quality of the laser weld and that in order to achieve maximum penetration of the laser beam and thus the best possible mechanical properties of the welded area, the welded parameters should be optimized. Attempts to optimize the parameters of the welding unit for the welding of Titanium[8], Fe-Ni-Cr alloy[6] and Co-Cr alloys[9] have used the same standard pulse duration and spot diameter and only varied the energy settings.

The use of an argon atmosphere while laser welding titanium and its alloys is crucial since it prevents oxidation and therefore embrittlement of these highly reactive alloys. None of the studies conducted on gold alloys discussed the use of argon gas atmosphere as it is not considered as highly reactive when melted[10].

Consequently, in order to introduce the laser welding technique for the repair or the addition of clasps and components to a framework, a high quality of joint with the best possible mechanical properties and least possible gas entrapment should be obtained. There has been little research on the parameters for laser welding Co-Cr alloys, no research reported on the effect of the minor differences in the chemical consistency of Co-Cr alloys on their weldability and no reports on whether the use of an argon atmosphere is necessary or a useful adjunct when laser welding Co-Cr alloys.

The purpose of this study was to determine whether minor changes in the composition of Co-Cr alloys could affect their weldability and whether the use of argon atmosphere while welding Co-Cr alloys is as essential as it is when welding Titanuim[10]. A second aim was to determine any difference in the microstructure between the parent and laser welded metal, as well as the depth of the weld.

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MATERIALS AND METHODS

Two readily available Co-Cr alloys used within King's College Dental Institute were chosen (Table 1). Eighty specimens were produced using round profile wax adapted onto individually prepared refractory casts. The specimen patterns were attached with wax to sprues, invested and cast using an induction centrifugal casting machine. All castings were allowed to bench cool to room temperature before divesting. Castings were divested, finished by sand-blasting and separated with a cut-off disc. Specimens were reduced to 5 cm in length and re-sandblasted. Dimensions (5 cm long and 1.5 mm ± 0.1 mm diameter) were verified using a Vernier Calliper and ultrasonically cleaned for 10 minutes with acetone prior to testing.

Ten specimens were randomly chosen for each of six groups, three groups for each material, consisting of a control group, a group for welding in argon and a group for welding without argon. The specimens to be welded were sectioned and welded on a locating jig prior to seam welding with an overlap of approximately 70% around the diameter of the specimen using a pulsed Nd: Yag laser set at an energy level of 187V, spot diameter 0.9 mm, pulse duration 11m sec at 1Hz.

Specimens were tested in tension to failure in an Instron universal testing machine at a crosshead speed of 5 mm/sec. Loads at fracture were taken from an integrated chart recorder with a full scale deflection of 2000N.

Fractured halves of specimens were subsequently mounted on EM stubs using Leit C, conductive carbon cement. Specimens were viewed in a scanning electron microscope with an accelerating voltage of either 12 and 15kV with a 40°tilt at magnifications between x50 and 4k.

Statistical analysis

Factorial analysis of variance (ANOVA) was performed to investigate differences between different materials and different welding conditions using Stata 8 statistical program. The data obtained from the tensile tests exhibited a Normal distribution therefore, means and standard deviations were used to plot representative graphs (Fig 1). The data indicated an imbalance and interaction in the model and subsequent analysis was performed separately for each factor ($p<0.05$).

RESULTS

Maximum, minimum, mean and standard deviations of load at fracture for the controls and the welded groups, with and without argon and the means and standard deviations are presented (Table 2 and Fig 1). Croform Excel control specimens exhibited a lower mean of load to fracture and a wider standard deviation compared to Heraenium EH control specimens. Croform Excel specimens exhibited higher values of load at fracture-compared to Heraenium EH - when welded with or without argon gas atmosphere. Although there was no statistical significance in the effects of welding condition between the different metals *($p=0.5421$)*, the difference in the mean values of the loads at fracture between the two metals was considered to be statistically significant *($p=0.026$)*. The laser welded specimens required a statistically significant lower load to cause fracture when compared to their respective controls *($p=0.01$)*.

Croform specimens welded with an argon gas atmosphere exhibited higher mean values at fracture load, compared to the specimens welded without argon gas. In contrast with this, Heraenium specimens when welded under ar-

Table 1. Composition and melting range of alloys

	Co	*Cr*	*Mo*	*Si*	*Mn*	*C*	*N*	*Range of melting temperature*
CXL	61%	30%	5%	1%	Not defined			1390ºC
HEH	63.5%	28%	6.5%	1%	0.6%	0.15%	0.25%	1330-1380ºC

CXL= Croform Excel HEH= Heraenium EH

Table 2. Maximum, minimum load at fracture in Newtons (N), mean values, and standard deviations for group specimens

	Control CXL	*Control HEH*	*Welded without argon CXL*	*Welded without argon HEH*	*Welded with argon CXL*	*Welded with argon HEH*
Maximum	1635	1565	995	1050	1265	905
Minimum	970	1165	645	400	450	365
Mean	1243.5	1378	841.5	730	877.5	690
Standard deviation	185.7	144.8	125.2	205.7	250.9	177.6

CXL= Croform Excel HEH= Heraenium EH

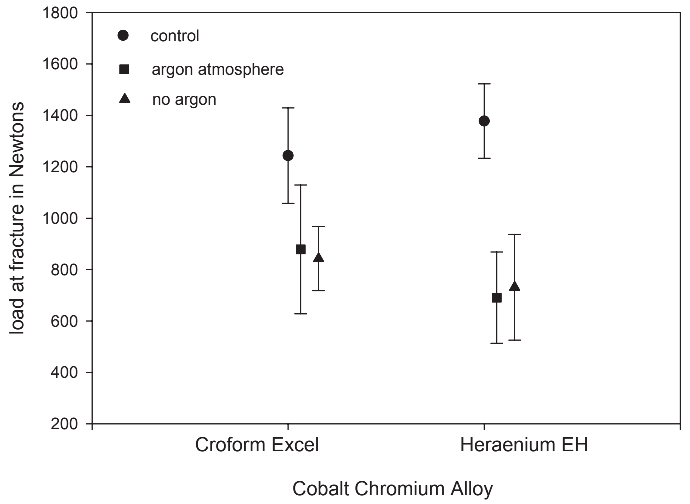

Figure 1. *Graph of fracture strength (Newtons) of welded specimens and controls of Croform Excel and Heraenium EH*

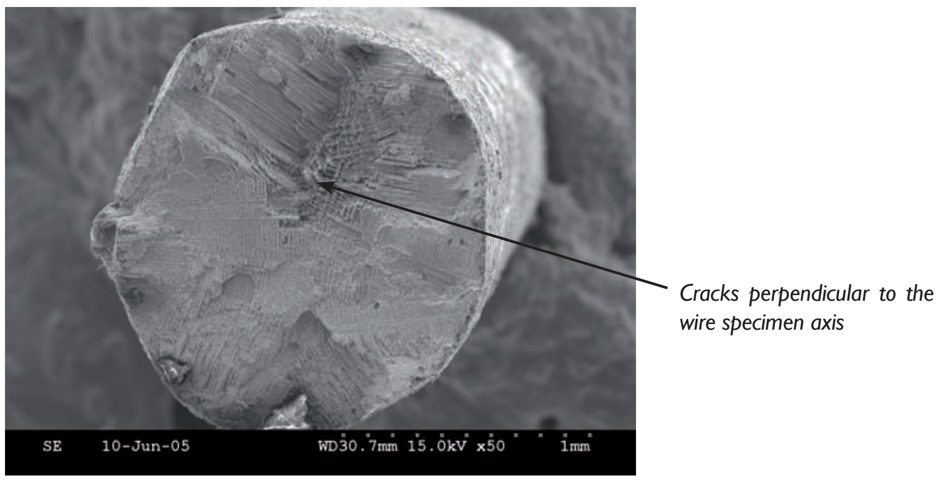

Figure 2. *Croform Excel control specimen: magnification x50. Specimen shows fracture between planes of dendrites and vertical fractures to the axis of the specimen.*

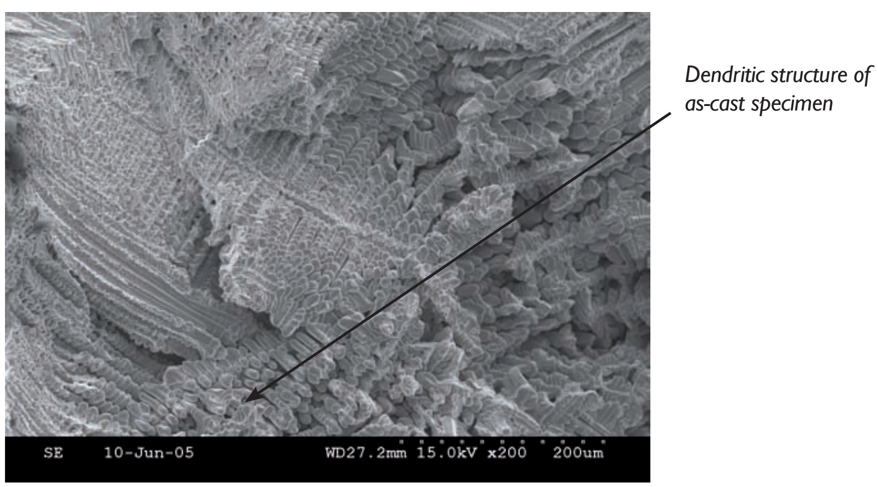

Figure 3. *Heraenium EH Control specimen: magnification x200. Dendrite structure of the as cast specimens. Similar appearance of both the Excel and Heraeium alloys specimens.*

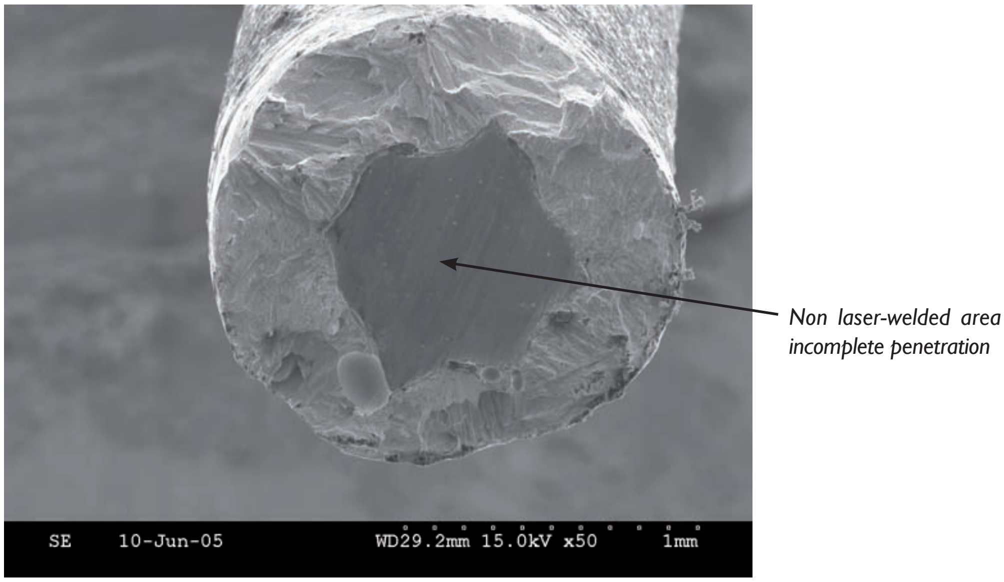

Figure 4. *Croform XL test specimen: magnification x50. Specimen has been laser-welded under argon atmosphere. Note the central area showing striations of where the specimen had been sectioned and the peripheral area of the weld.*

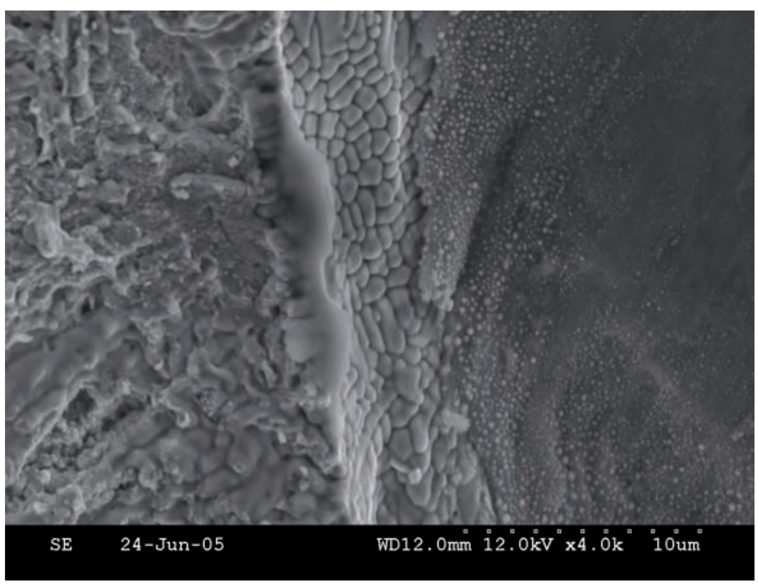

Figure 5. *Croform XL test specimen: magnification x4k. Specimen has been laser-welded. Photomicrograph illustrating Heat affected zone (HAZ) between the laser welded zone (left) and the non laser-welded area to the right of the Figure.*

gon exhibited smaller mean load at fracture compared to the specimens welded without argon gas. The difference between the mean values of the load at fracture amongst different welding conditions (argon and non-argon atmosphere) was not statistically significant *($p=0.97$)*.

Scanning electron microscopy of the control specimens showed a well defined dendritic structure that occurs with slow cooling after casting (Fig 2). At higher magnification there was evidence that the dendrites were elongated that would have occurred during testing to failure in tension. (Fig 3). Both alloys showed a similar pattern of dendrites at the fracture surface (Fig 3). However, a very different pattern was observed in the welded specimens at the fracture surface. At low magnification at the centre of specimens, linear striations were seen that had been caused during sectioning of the specimens prior to welding (Fig 4). The outer third to half of each specimen showed fracture through the welded joint. (Fig 4). The laser welded areas did not show a characteristic dendritic structure, however, in the zone between weld and no weld closely packed dendrites were observed at high magnification (Fig 5). All specimens examined exhibited these three defined zones, an area affected by the laser energy the circumferential area or fusion zone, an interface or the heat affect zone and the central area of the specimen which had not been fused. The depth of welds observed varied between 0.3-0.5mm.

DISCUSSION

The results of the tensile testing showed that there was a statistically significant difference between the tensile strength of the two alloys tested. This difference may be the result of slight differences in their chemical composition particularly of the minor elements for example Heraenium EH contains a higher percentage of molydibium and the figure for carbon content of Croform has not published.

Specimens, which had been laser welded showed statistically significant reductions in tensile strength at the laser welded area possibly as the result of incomplete penetration of the weld and reduction of the specimen cross section. However, there were no statistically significant differences between the specimens laser welded in air and in an atmosphere of Argon. Cobalt chromium alloy is not as reactive even when molten as metals such as titanium and this may be the reason that the atmosphere during welding did not affect the tensile strength of the welded alloy.

The null hypothesis, that there would be no difference between the tensile strengths of the two alloys used therefore was not proven, but a second null hypothesis, that there would be no difference between those specimens welded in an air atmosphere and those welded in argon gas atmosphere, was proven.

The fusion zone exhibited a very fine microstructure, which was different to the dendritic pattern of the as-cast specimens. This could have resulted from of the rapid increase of the temperature during welding, which can melt the dendritic structures, and the formation of equiaxed grains during the rapid solidification of the molten metal. Dental castings usually exhibit an equiaxed structure. Normally the nuclei are equally spaced with reference to each other at the time of the solidification. The grains meet and they are flattened along various surfaces. Still, the grains have the tendency to remain spherical, therefore they are likely to have the same diameter in all directions. Such a grain is said to be equiaxed.

The interface between the welded and the non-welded area exhibited a non-dendritic microstructure with Figure 5 being highly representative, the welded area is on the left, the interface in the middle and the non-welded area on the right.

The results of this investigation have shown that the structure of cobalt-chromium alloys is changed by laser welding. The effect of varying parameters, such as spot diameter and pulse duration, on depth of the weld, need to be investigated further. Clinically, tensile failure in function is unlikely, but other relevant causes of failure of a weld such as fatigue failure need to be investigated.

CONCLUSIONS

Within the limitations of the study welded specimens of a diameter of 1.5mm of cast cobalt chromium alloy had a lower tensile strength than as-cast specimens. There was a statistically significant difference in tensile strength observed between the two alloys tested. The use of an argon gas atmosphere did not affect the eventual tensile strength of the welded joint of either of the cobalt chromium alloys tested. The microstructure of the cast alloy was altered in the region of the laser weld.

MANUFACTURERS DETAILS

- Neolaser ALC 30/35, Alphalaser, Puchheim, Germany.
- Instron Ltd High Wycombe, UK.
- Emitech Ltd, Ashford, UK.
- Hitachi High Technologies Corporation, Wokingham, UK.
- Davis Schotlander and Davis, Lechworth, UK.
- Gallony, Milan, Italy.
- Stata Co, USA.
- Chaperlin and Jacobs, Sutton, UK.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Ron Wilson for his assistance with statistics.

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