International Poster Journal IPJ of Dentistry and Oral Medicine

Int Poster J Dent Oral Med 2009, Vol 11 No 3, Poster 453

Heat treatments effect on microplasma welded joints of Ni-Cr dental alloys

Language: English

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Date/Event/Venue:
24-27 September 2008
FDI Annual World Dental Congress
Stockholm, Sweden

Introduction

A distinguishing feature of Ni-Cr alloys is that their properties are developed by heat treatments.
Postweld heat treatment (PWHT) is any heat treatment after welding used to improve the properties of a weldment. The aim is to increase the resistance to brittle fracture and to relax residual stresses. Other desired results from PWHT may include hardness reduction and material strength enhancements (1,2).
Stress relief heat treatment is used to reduce the stress that remain locked in a structure as a consequence of manufacturing process. There are many sources of residual stress and those due to welding are of the magnitude equal to the Yield strength of the base material.
Uniformly heating a structure to a sufficiently high temperature but below the transformation temperature range, holding at this temperature for a predetermined amount of time and uniform cooling can relax those residual stresses.

Objectives

The aim of the study was to evaluate the effect of pre- and post-weld heat treatments on Ni-Cr dental alloys.

Material and Methods

Plates of different Ni-Cr alloys were cast conventionally using an induction melting centrifugal casting machine Orcacast (Π dental, Budapest, Hungary). The casting alloys used in this study were: Wirolloy (Ni 63.2, Cr 23.0, Fe 9.0, Mo 3.0, Si 1.8, C < 1.0, Bego, Bremen, Germany), Wirolloy NB (Ni 67.0, Cr 25.0, Si 15.0, Mo 5.0, Mn, Nb, B, C < 1.0, Bego, Bremen, Germany), Wirocer plus (Ni 65.2, Cr 22.5, Mo 9.5, Nb Si Fe Mn, Bego, Bremen, Germany), Heraenium NA (Ni 59.3, Cr 24.0, Mo 10.0, Fe, Mn, Si, Nb < 2%, Heraeus Kulzer GmbH, Hanau, Germany), V alloy (Ni 72.0, Cr 20.0, Fe 6.0, Si 1,5%, Mn 0,5%, Vaskut Kohászati KFT, Budapest, Hungary) (Fig. 1, 2).

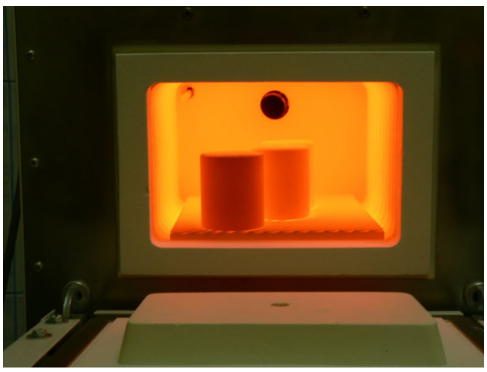


Fig. 1: Molds in the heating furnace

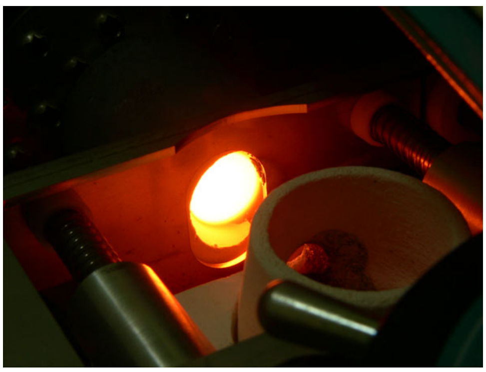


Fig. 2: Centrifugal casting of the plates

After casting, the plates were divested, air abraded with 250µm Al_2O_3 particles, grinded and prepared for welding by polishing and degreasing.
The plates were matched and welded using microplasma Welder (Schütz-Dental, Rosbach, Germany). Each specimen was bilaterally welded in a butt joint configuration, with a spot overlapping of more than 60%, using 1 mm in diameter wolfram electrode, varying the parameters of the device: power step (4 and 5). The pulse delay was maintained at 40 ms and the argon quantity at 5-6 l/min in all cases. 20 samples resulted, 4 for each tested alloy.
Half of the welded specimens were heat treated 60 min at 800°C and then cooled uniformly to room temperature. They were analyzed macroscopically, radiographic, and metallographic, the microhardness was determined in the base metal (BM), weld metal (WM) and heat affected zone (HAZ).

Results

The welded plates were analyzed macroscopically, microscopically (Fig. 3) and radiographic (Fig. 4). The welding imperfections, like a nonuniform width of the welding rib, craters on the welding surface, lack of melting between the components could be detected during these nondestructive analyses.
Micrographic analyses perpendicular to the weld axis were conducted in order to analyze the quality of the microstructure of all samples. The microhardness was measured both in the welded and the heat affected zones and than compared to the non welded cast alloys without and with heat treatment.
The areas with increased microhardness values, located in the heat affected zone are fragile structures. Associated with welding defects, like voids and cracks, these can lead to an early degradation of the welded structure.

Fig. 3a: Craters on the welding surface associated with cracks along the welding rib: a. macroscopically aspect

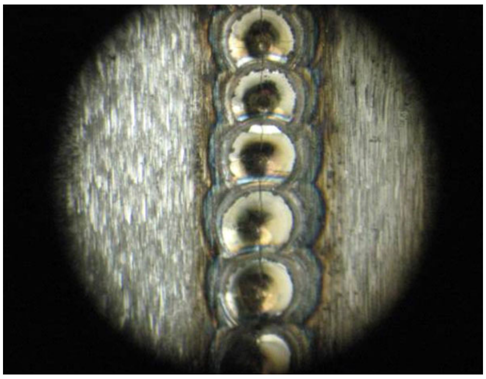


Fig. 3b: Craters on the welding surface associated with cracks along the welding rib: b. microscopically aspect

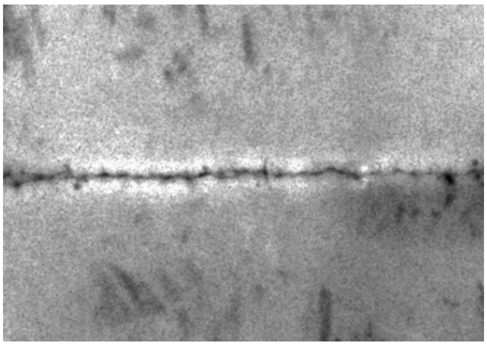


Fig. 4a: Radiographic aspects of the welded joints: a. cracks and craters along the entire welding rib

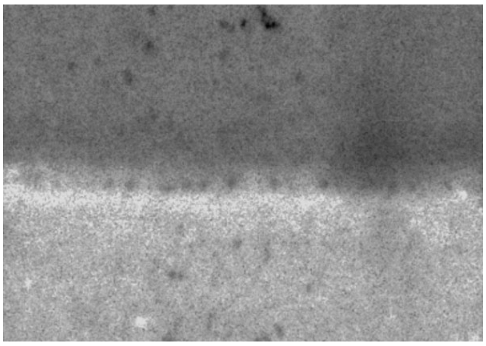


Fig. 4b: Radiographic aspects of the welded joints: b. welding without imperfections

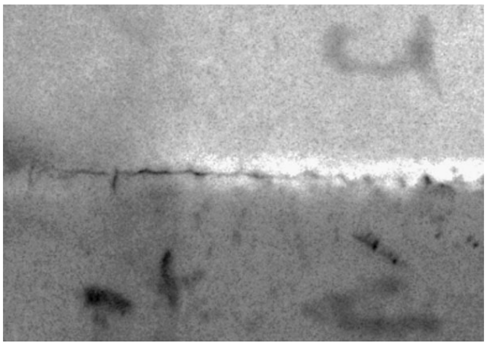
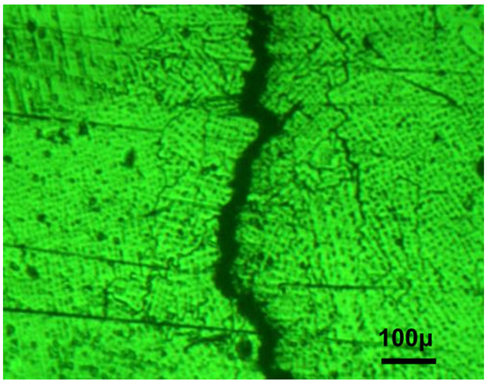


Fig. 4c: Radiographic aspects of the welded joints: c. cracks in a part of the welded area

Cracks appear along the joining line and propagated along the grain boundaries (Fig. 5). The cracks and the modification of the microstructure due to the rapid heating and solidification process can be a real problem and affect the quality of the weld.
The microstructure of the welded zone appears very fine as a result of the very rapid solidification (Fig. 6).
The base metal showed a dendrite microstructure due to a slow cooling process after casting (Fig. 7). After heat treatment the microstructure became finer (Fig. 8). The determination of the microhardness showed that the HAZ and WM had a higher hardness than the BM, due to the refining of the grain size during solidification. PWHT increased visible the microhardness in the HAZ for Heraenium NA and V alloy.
Even the chemical composition of the alloys is similar, the weldability and their behavior at heat treatment is different.



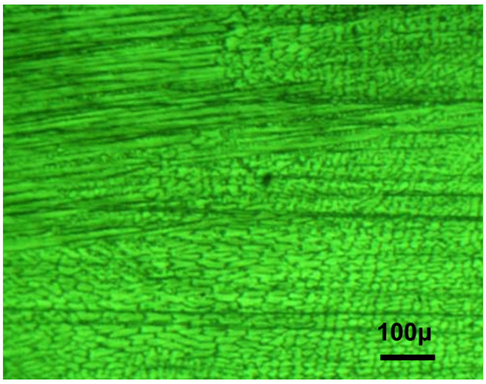
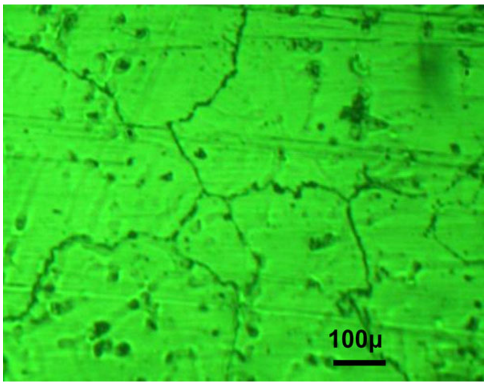


Fig. 5: Metallographic aspect of a crack in the WM

Fig. 6: Metallographic aspect of the WM with a fine microstructure, without imperfections



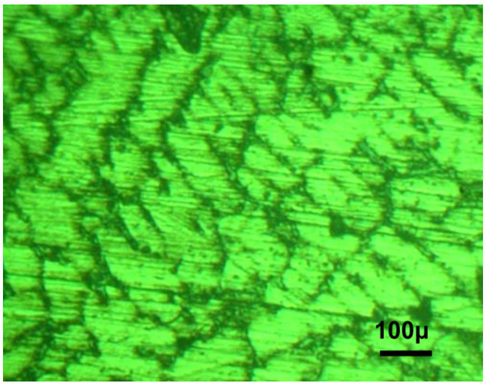


Fig. 7: Dendrite microstructure of the BM

Fig. 8: Fine dendrite microstructure of the BM after PWHT

Conclusions

Even the chemical composition of all the alloys was similar, the weldability and their behavior at heat treatment was different (3,4).
The influence of the PWHT of the WM, HAZ, and BM properties was assessed by metallographic analyses and microhardness measurements.
The most affected by heat treatment were Heraenium NA and V alloy, where the microhardness was increased especially in the HAZ.
At Wirocer and Wirolloy alloys the changes were little and Wirolloy NB appeared not to be affected by heat treatment.
By PWHT a fine distribution of particles in a nickel-rich matrix can be produced.
The metallurgical structure and the microhardness can be improved through stress relieving. It offers several benefits, because the potential for stress cracking is reduced (5,6).
Different alloys with similar composition may react differently to the welding process and PWHT. Therefore it is important that the new welding procedures be particularized for each alloy type.

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