MICROSTRUCTURE AND PROPERTIES OF ELECTRON BEAM MULTI-MATERIAL WELD OF INCONEL 718 AND INCONEL 625

DUDEK Agata, STRZELCZAK Katarzyna

Czestochowa University of Technology, Institute for Material Engineering, Faculty of Production Engineering and Materials Technology, Czestochowa, Poland, EU
dudek@wip.pcz.pl, strzelczak.katarzyna@wip.pcz.pl

Abstract

Inconel® is a group of nickel-based superalloys, which are featured by superior combination properties. Their good mechanical properties at high temperature, good oxidation and corrosion resistance cause them to become attractive choices for diverse applications in aerospace, marine, chemical, petrochemical and energy industries. Welding of Ni-based superalloys is difficult, because alloying elements such as Nb, Cr, Ti cause harmful precipitations of carbides. Another concern is segregation of Nb and formation of Nb-rich brittle intermetallic Laves phase in the interdendritic regions during weld metal solidifications. In some applications, especially in the aerospace, implementation of innovative design and technology for property, quality and performance are necessary. A favorable solution seems to be multi-material joining. However, problems, associated with the proper selection of materials and welding method, are given rise to. Therefore, any research on the microstructure and properties are justified. In this study, laser beam weldability of these superalloys was evaluated, and the microstructural characteristic and the mechanical properties of their weld joint were investigated. Optical microscopy, scanning electron microscopy and hardness test were utilized for the investigation.

Keywords: Inconel 718, Inconel 625, electron beam welding, microstructure, hardness

1. INTRODUCTION

Austenitic nickel based superalloys exhibit superior properties at high temperatures (150 - 1500 °C) in terms of mechanical properties such as higher strength, stress-rupture strength, toughness and resistance to thermal fatigue, and moreover high corrosion resistance [1]. Inconel® 718 is an age-hardenable, Ni-Cr-Fe-based superalloy, which was designed to minimize strain age cracking. The main weldability problems of this alloy are solidification cracking and microfissuring behavior in the heat-affected zone (HAZ) [2-3]. Inconel® 625 was developed as a solid solution strengthened superalloy. This Ni-Cr based alloy contains molybdenum and niobium which can be retained without precipitation heat treatment. Due to its high weldability properties Inconel 625 is mainly used in aerospace applications [2, 4].

Characteristic for Inconels® during solidification in welding process is Nb segregation that initiates the formation of Laves phase represented as $(Ni,Fe,Cr)_2(Nb,Ti,Mo,Si)$. The greater the segregation of niobium in the interdendritic regions, the higher Laves phase volume. The presence of the Laves phase in the microstructure of the fusion zone is undesirable, due to the depletion of the base material in the alloying elements, mainly Nb. Furthermore Laves phase is a fragile intermetallic structure, which creates favorable conditions for the formation and propagation of cracks. The long chains of interconnected thick Laves particles have a worse effect on the mechanical properties of the weld than the finer, unrelated particles [5-8]. It is well known that in order to minimize the segregation of niobium and the Laves phase in the fusion zone of welded Inconels® increasing of the cooling rate of welded alloys are necessary [9], and depends on the type of welding technique, which controls heat input and dictates liquid metal convection in the weld pool [10-11]. For this reason electron beam welding is the most favorite. Electron beam welding allows for a high depth to width ratio of the weld, which results in a minimal size of fusion zone and heat transfer zone [12-13].

In addition, the use of this technique reduces the distortion and residual stresses. The high vacuum, characteristic for electron beam welding, avoids material contamination and provides deep penetration [13 - 14].

Oscillated electron beam welding in comparison to unoscillated electron beam welding results in enhanced weld cooling rates that cause less segregation of Nb, and thus lower volume of Laves phase. Analysis of the dendritic morphology of the welds was made by oscillating and unoscillating techniques allows determine differences in the size and structure of the Laves phase. In the oscillated weld, the Laves phase consist of finer and discrete particles, and the interdendritic regions are characterized by a lower Nb concentration than the unoscillated weld [9, 15].

The present study is designed to examine the effect of oscillated electron beam welding technique on formation of fusion zone of multi-material weld of Inconel® 718 and Inconel® 625. The analysis is based on the microstructure and selected properties of the obtained weld.

2. MATERIALS AND METHODS

The research was carried out for specimens of welded Ni-based superalloys. Compositional specification of both superalloys Inconel 625 and Inconel 718 is included in **Table 1**.

Table 1 Chemical composition of Inconel® 718 and Inconel® 625 (in wt.%)

	Ni	Cr	Fe	Nb	Mo	Ti	Al	C
Inconel® 718	51.34	19.41	16.88	3.96	2.72	1.02	0.56	4.13
Inconel® 625	57.91	21.88	4.64	3.82	8.33	0.16	0.41	3.42

The samples were welded by oscillated electron beam welding technique. Etching of Inconel 718 was carried out with the mixture of two parts of aqua regia and one part of aqua, while Inconel 625 was etched in Kalling's reagent. The structure and shape of the resulting weld was determined by a microscope OLYMPUS SZ31. Analysis of microstructure of weld after electron beam welding of Inconels 625 and 718 was carried out using microscope AXIOVERT 25 with stereo digital image recording and electron scanning microscope JOEL JSM 5400. The same electron scanning microscope with an EDS device was used for analysis of chemical composition. To determine phase composition in the obtained samples X-ray diffractometer Seifert 3003 TT with a cobalt lamp with characteristic radiation wavelength of $\lambda_{CoK\alpha}$ = 0.17902 nm was employed. The measurements were carried out for angle range of 2θ = 20÷100°. The Vickers microhardness tester Shimadzu HMV-G -21DT with load of 0.98 N was used for specimens.

3. RESULTS AND DISCUSSION

The macrostructure of multi-material weld obtained by oscillated electron beam welding is presented in **Figure 1**. **Figure 2a** shows the microstructure of the weld of Inconel 718 and Inconel 625 etched by Kalling's reagent (optical microscope Axiovert 25). The microstructure of heat-affected zone and fusion zone are shown on **Figure 2b** and **2c**. **Figure 3** presents the microstructure of fusion zone obtained by the scanning microscope JOEL JSM 5400. Microstructural examination revealed a homogeneous cellular-dendritic structure of the fusion zone with the Laves phase which consists of fine particles of small volume. The examination also showed no microcracks and defects in the heat-affected zone. In addition to the Laves phase, the presence of the γ phase, β phase, δ phase and carbides are revealed. The occurrence of these phases is characteristic for welds generated by Inconel welding. The presence of the above phases was confirmed by X-ray examinations to which X-ray diffractometer Seifert 3003 TT was employed (**Figure 4**). The **Table 2** lists the lattice details for each phase.

Figure 1 Macrostructure of multi-material weld obtained by oscillated electron beam welding

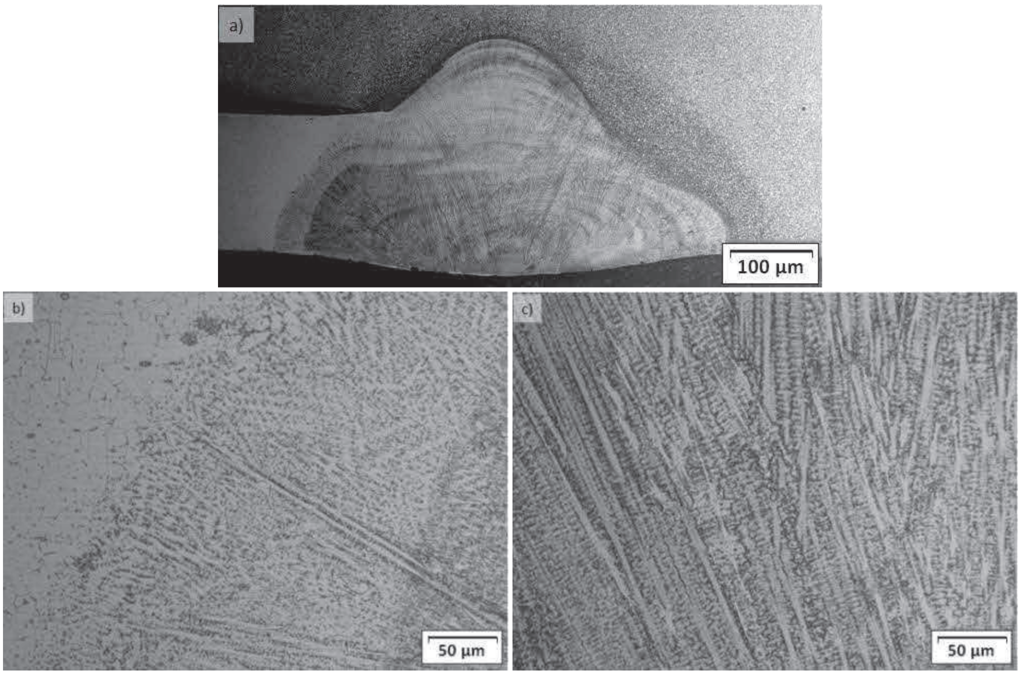

Figure 2 Microstructure of multi-material weld of Inconel® 718 and Inconel 625:
a) structure of entire weld, b) heat-affected zone, c) fusion zone

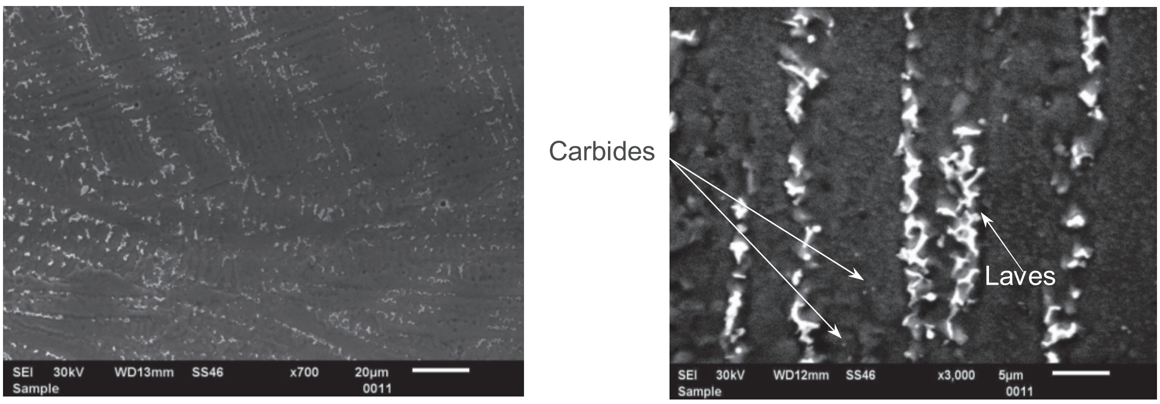

Figure 3 Microstructure of cellular dendritic fusion zone of Inconel 625 and Inconel 718 weld

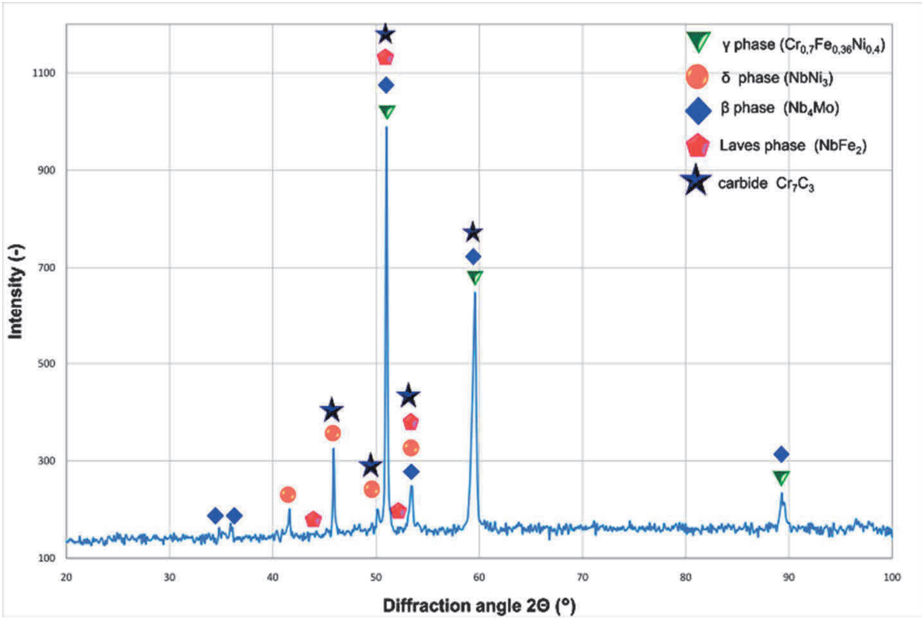

Figure 4 Diffractogram of fusion zone of Inconel 625 and Inconel 718 weld

Table 2 Details of X-ray diffraction peaks

Phase	Lattice details
Laves ($NbFe_2$)	HCP, $P6_3/mmc$, a = b = 0.4831 nm, c = 0.7881 nm
γ ($Cr_{0,7}Fe_{0,36}$ $Ni_{0,4}$)	FCC a = 0.3553 nm
β (Ni_4Mo)	BCT, I4/m, a = b = 0.572 nm, c = 0.3564 nm
δ ($NbNi_3$)	BCT, I4/m a = b = 0.3624 nm, c = 0.7406 nm
Cr_7C_3 carbide	Orthorombic, Pmcm, a = 0.7015 nm b = 0.4532 nm c = 1.2153 nm

Hardness was measured by the Vickers method at three different distances from the face: 0.13 mm, 0.83 mm, 1.43 mm and shown on **Figure 5**.

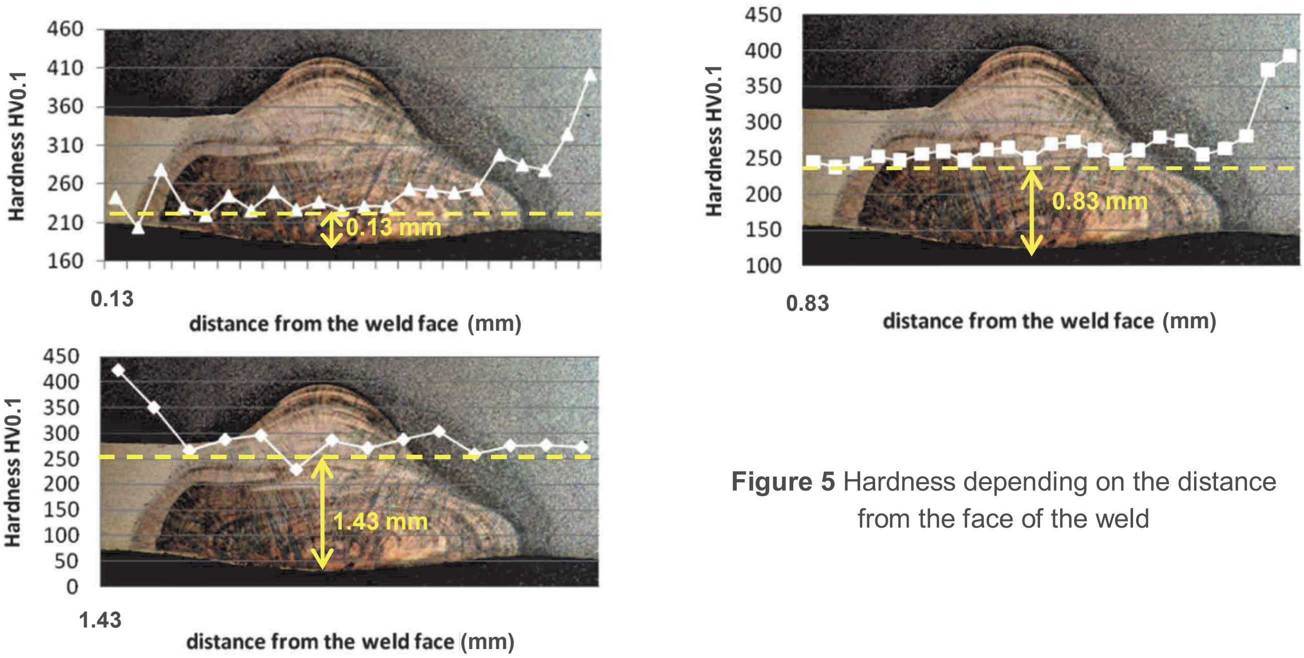

Figure 5 Hardness depending on the distance from the face of the weld

Depending on the distance from the weld face in the fusion zone, the hardness values are varied due to the internal stresses and differences in cellular-dendritic structure size and distribution.

The average hardness of the individual zones is summarized graphically and presented on **Figure 6**. Inconel 718 has the 349 HV0.1 hardness value, Inconel 625 has 245 HV0.1 hardness value and the value of the hardness of the weld region is 260.8 HV0.1.

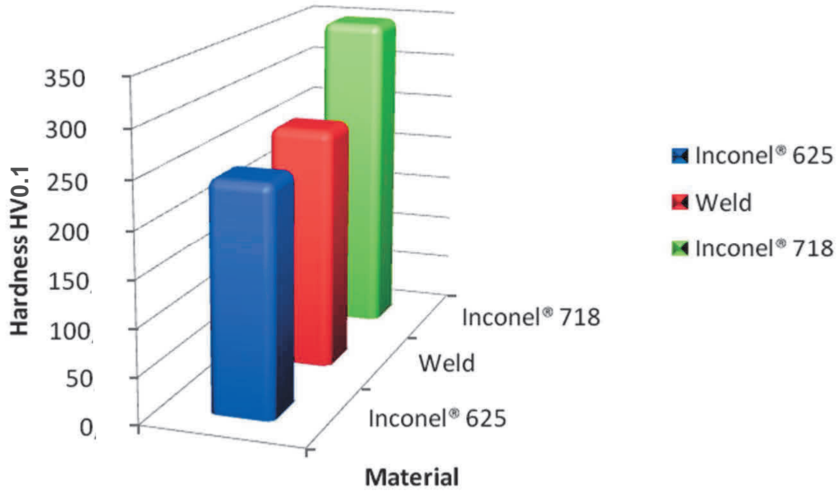

Figure 6 Average values of hardness HV0.1 in individual zones

4. CONCLUSION

Oscillated electron beam welding of Inconel 625 and Inconel 718 allows to obtain homogeneous cellular-dendritic fusion zone and heat-affected zone without micro-cracks. Segregation of niobium occurring during welding leads to the formation of the intermetallic fragile Laves phase. The electron beam oscillation promotes a faster cooling rate and hence the formation of finer, non-cumulative particles forming Laves phase. Hardness tests have shown that the highest hardness value - 349 HV0.1 - has Inconel 718, the lowest value - 245 HV0.1 - has Inconel 625, and the value of the hardness of the weld region is 260.8 HV0.1. However, the varied hardness results obtained for the fusion zone depending on the distance from the face of the weld are both due to differences in the microstructure of the layer (size and distribution of the cellular-dendritic structure), but also to the internal stresses in the areas of the fusion zone.

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