Journal of Manufacturing Processes 30 (2017) 51–62

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Full Length Article

The effect of electrospark nickel interlayer thickness on the characteristics of Niobium to 410 stainless steel dissimilar laser welding

Seyed Hamzeh Baghjari [a], Farshid Malek Ghaini [a,*], Barbara Previtali [b], Ali Gokhan Demir [b], Hamid Reza Shahverdi [a], Carlo Mapelli [b], Silvia Barella [b]

[a] Department of Materials Engineering, Tarbiat Modares University, Tehran, Iran
[b] Dipartimento di Meccanica, Politecnico di Milano, Via La Massa 34, 20156 Milan, Italy

ARTICLE INFO

Article history:
Received 31 January 2017
Received in revised form 1 September 2017
Accepted 5 September 2017

Keywords:
Dissimilar laser welding
Electrospark deposition
Niobium
AISI 410 stainless steel
Interlayer
Intermetallic

ABSTRACT

Dissimilar welding of Niobium to 410 stainless steel has important engineering applications. An interlayer should be used for avoiding or reducing formation of brittle intermetallic phases in weld. In this research the effect of gradual addition of ESD interlayer on the chemical composition, microstructure and mechanical properties of Nb to 410 stainless steel dissimilar laser welding is investigated. The Nb plate with the ESD interlayer thickness equivalent to about 25%, 50%, and 100% of base plate thicknesses on its edge (produced by novel electrospark deposition process) was laser welded to 410 stainless steel by pulsed Nd:YAG laser. The welds were then subjected to metallographic, X-ray diffraction and mechanical tests. Results showed that with an increase in ESD interlayer thickness, the weldability increased due to reduction of brittle μ and ε-Laves intermetallic phases in the fusion zone. Tensile test results of dissimilar Nb to 410 stainless steel weld, showed that the chemical composition of the dissimilar weld zone determines the mechanical strength of the joint. Furthermore, in order to reach high mechanical strengths, contact of the weld pool and its solidification on the Nb also has to be avoided due to formation of brittle ε-Laves phase.

Introduction

The high quality dissimilar junction between Niobium alloys and stainless steel have some applications in aerospace industries like turbojet engines which are subjected to high temperature and stress [1]. The main difficulty in joining Niobium to stainless steel using fusion is their large differences in thermo-physical properties and the formation of brittle intermetallic compounds (like ε-Fe_2Nb and μ-Fe_7Nb_6 with hardness of about 1000 HV) which degrade the mechanical properties of the dissimilar weld [2,3]. To obtain an acceptable mechanical strength for Nb to stainless steel joint, an interlayer should be used. However, using an interlayer in the form of a strip has its own technical limitations [4].

Electrospark deposition (ESD) is a low heat input deposition process that uses short-duration, high-current electrical pulses to weld a consumable electrode material to a metallic substrate [5]. Vishwakarma et al. [6] and Ebrahimnia et al. [7,8] used ESD for repairing IN718 and IN738LC gas turbine blade materials, Which are both considered as alloys generally difficult to be welded. The formation of brittle intermetallic compounds would be the main problem in Niobium to 410 steel welding. However, Baghjari et al. [3] incorporated electrospark interlayer for dissimilar laser welding of Nb to 410 steel and reported that, very low heat input and also dilution with the respective substrate, make ESD desirable for welding incompatible dissimilar joints Also Gould [9] used electrospark deposition for dissimilar welding of refractory metals to cast Ni-based superalloy, with a Hastelloy X filler metal. He reported formation of no brittle intermetallic compounds at the interface.

The Laves phase is an intermetallic compound with a hexagonal crystal structure and A_2B stoichiometry. In laves phase "A" indicates elements such as Ni, Fe and Cr, and "B" indicates elements such as Nb, Ti and Mo [10]. Laves phase exists in the simple Fe-Nb binary phase diagram over a composition range of 38–50 wt.% Nb. The formation of the Laves phase is because of the micro segregation of alloying elements in non-equilibrium solidification conditions, mostly for high atomic diameter elements like Nb, Mo

* Corresponding author.
E-mail address: fmalek@modares.ac.ir (F. Malek Ghaini).

http://dx.doi.org/10.1016/j.jmapro.2017.09.007

Table 1
Chemical composition of base metals and filler metal.

Nb wt%	Ti wt%	S wt%	P wt%	Ni wt%	Cr wt%	Mn wt%	Fe wt%	C wt%	Alloy
0.0	0.0	0.02	0.02	0.20	12.30	1.00	Balance	0.08	AISI 410
2.74	0.4	0.01	0.03	Balance	21.87	3.14	0.36	0.05	Alloy 82
99.99	0	0	0	0	0	0	0	0	Niobium

and Ti [11]. Rather than increasing Ni, the addition of Fe to Ni-Nb alloys increases Fe content of the austenite matrix and hence promotes the formation of more γ/Laves. Also Fe, Cr, and Si increase the segregation tendency of Nb and promote Laves at the expense of δ-Ni_3Nb [12,13,15].

In our previous research [3], we focused on the characterization of electrospark nickel interlayer and showed that using this interlayer is useful in improving the dissimilar Nb to 410 steel weldability. However, in the present work the main goal is to study the effect of gradual addition of ESD interlayer on Nb to 410 steel dissimilar laser welding, which is deposited by the electrospark deposition process (ESD). The complex microstructure evolution across the dissimilar laser welds as well as the mechanical properties of the joints are investigated. With the addition of ESD interlayer in weld, dilution of Nb base metal is reduced, which has effects on the amount of intermetallic compounds formation.

Overall, in the present study, the amount of acceptable dilution of the Nb and ESD interlayer alloying elements in the final laser weld metal to achieve the weld with appropriate mechanical properties, are determined. It is envisaged that the output of this research would confer intriguing potential in technological advancement of the very field.

Experimental procedure

The pure Nb and 410 stainless steel plates with 1 mm × 100 mm × 10 mm dimension were prepared by wire cut. A Ni based interlayer, Alloy 82, in the shape of a rod with 2 mm diameter used as filler metal in ESD process. The chemical composition of base metals and filler metal are shown in Table 1.

In the first stage, a groove was made on one side of the Nb plate by grinding, and then this groove was filled with ESD process using an Alloy 82 filler with 2 mm thickness. Then with grinding on the back of the first side, another similar groove was made on the second side to obtain a thicker interlayer. The schematic of preparing ESD interlayer on Nb plate edge, can be seen in Fig. 1. Electrospark interlayer deposited with ESD machine was developed in Tarbiat Modares University and with the following parameters: voltage of 120 V, duty cycle of 3%, frequency of 204 Hz and capacitance of 480 microfarad. The electrode was oriented at angle of 30–45° to the substrate and was rotating at the speed of 2000 RPM during deposition. The shielding argon gas was delivered to the work piece at 20 ml/min flow rate. After the Alloy 82 interlayer was deposited on both sides of the Nb plate, it was wire cut from the middle to form two Nb plates which were built up of an ESD interlayer over their edges. With this method, interlayer thicknesses of about 25%, 50%, and 100% of base plate thickness were obtained; see Fig. 2 stage 1, (a) through (d).

Then the Nb plates with different thicknesses of Alloy 82 ESD interlayer, were laser welded to 410 stainless steel. Fig. 2 shows schematics of the configuration (stage 2). A pulsed Nd:YAG laser welding machine with a maximum mean laser power of 120 W was used for welding. Pure argon gas with 20 ml/min flow rate was used for shielding. Full penetration welds were obtained using a laser spot diameter of 0.3 mm, pulse frequency of 13 Hz, pulse duration of 7 ms, energy per pulse of 7 J and welding speed of 200 mm/min, which were found to be an optimum set of process parameters through trials. In this article the 0.25, 0.5 and 1 mm thickness samples mean dissimilar welds with 0.25, 0.5 and 1 mm interlayer thickness.

Samples were cut in cross sections for metallographic study. Glyceregia (30 ml H_2O–60 ml HCl–20 ml HNO_3) was used for etching the dissimilar laser weld samples. Microstructural investigations were performed by Hitachi SU-70 TFEG scanning electron microscope equipped with Thermo Scientific EDS detector. Secondary and backscattered electron imagining micrographs and EDS analyses were taken with an acceleration voltage of 15 kV. X-ray diffraction (XRD) analysis was performed on weld zone for identification of phases in the fusion zone. For this purpose, two base metals of the weld were cut out and the bulk weld metal with approximately 0.5 mm × 1 mm × 10 mm dimensions was analyzed by X'Pert Pro MPD machine. This XRD equipment due to high sensitivity and resolution can identify the phases in such narrow sample. The microhardness of weld metal was measured using a Vickers micro indentation device at 100 g load and 15 s loading time. Tensile tests which were prepared according to ASTM: E8/8 M were performed on weld samples. This test was performed using a CMT6305-300 KN electro-mechanical universal testing machine at room temperature. The strain rate was set at 10^{-3} S^{-1}. Each tension test was repeated two times.

Results and discussion

Fig. 2 shows the cross sections of Nb to 410 stainless steel dissimilar laser welds made with various nominal thicknesses of ESD interlayer. In dissimilar laser weld without interlayer, the weld was completely broken from 410 steel side, while in samples with 0.25 mm interlayer thickness, transverse cracks were observed in the weld zone (Fig. 3a and b). Furthermore, no cracks were observed with the 0.5 and 1 mm interlayer thickness welds. It is necessary to point out that the formation of brittle ε-Laves and μ phases causes brittleness in the weld zone. Moreover, thermal stresses which originate from solidification, are one of the main reasons of track in the weld zone. That is to say, the combination of these two phenomena in the weld zone, leads to cracking in the dissimilar weld metal and further illustrates different results obtained with different interlayer thicknesses. However, increasing Ni content of the weld metal leads to suppression of μ-Fe_7Nb_6 phase formation and decreasing the brittle ε-Laves phases content in weld zone.

The average (bulk) chemical composition and elemental distribution profile of welds as measured by EDS are shown in Table 2 and Fig. 4. As expected, an increase in the thickness of ESD interlayer, the content of Ni element is also increased and Nb concentration is decreased. The presence of base metals and interlayer dilution in Table 3 confirm increasing the thickness of ESD interlayer, reduce the Nb dilution from 70% to 5%.

By using the ternary phase diagram of Fe-Nb-Ni isothermal section at 1200 °C which is shown in Fig. 5, and locating the chemical compositions of welds on the ternary phase diagram, a prediction can be made about the possible phases comprising the weld microstructure. Due to the fast cooling during laser welding, immediately after solidification of weld pool, the temperature falls down to room temperature and there is not enough time for diffusion. Therefore microstructure of laser weld will be very similar and can be predicted by the isothermal section of Fe-Nb-Ni diagram at high temperature (1200 °C).