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Laser welding of niobium to 410 steel with a nickel interlayer produced by electro spark deposition

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Some combination of metals such as niobium to stainless steel cannot be joined directly by laser welding due to formation of deleterious phases. On the other hand placement of a narrow strip of a third alloy between the two metals can introduce many technical and availability limitations. In this work, a more versatile method is developed using electrospark deposition (ESD) for facilitation of subsequent Nb to 410 stainless steel dissimilar laser with minimum heat input successfully. The 1 mm Nb plate edge was clad by Alloy 82 using a 4 mm round electrode by ESD process. The layer has minimum dilution with Nb while having a metallurgical bond. It exhibited a fine cellular structure with Laves phase particles with 30–50 nm in diameter. The Nb plate with edge built up was then laser welded to 410 stainless steel using a 1 KW fiber laser machine. The presence of the interlayer material suppressed the formation of Nb—Fe intermetallic in the laser fusion zone and increases weldability. Tensile test of dissimilar laser weld with the nickel base ESD interlayer exhibited an ultimate strength of 285 MPa with the failure located at the Nb side and not in laser weld metal or at the ESD interface.

1. Introduction

Welding of dissimilar materials is continuously attracting attention by the industry because of its potential benefits on saving material cost, reducing weight, increasing design flexibility and complexity as well as enhancing product functionality. The creation of a junction between two incompatible dissimilar materials by fusion can be associated with undesirable phenomena such as the formation of brittle intermetallic compounds which degrade the mechanical properties of weld. Niobium is a refractory metal which has many desirable properties which makes it suitable for a number of demanding engineering applications [1,2]. Niobium to stainless steel joints are used in fabrication of superconducting niobium cavities cooled by superfluid Helium contained in stainless steel cryostats, which are widely used for particle accelerators in many physics laboratories around the world [3]. But niobium forms brittle intermetallic phases when alloyed with iron as suggested by the binary Fe—Nb phase diagram (Fe_2Nb and FeNb intermetallic form) (Fig. 1). Thus, in fusion dissimilar welding of Nb to stainless steel an interlayer compatible with both materials should be placed in between [1,4].

To the best of our knowledge the only reported attempt to weld-brazing of Nb to steel has been made by Budkin et al. [10]. They used electron beam for weld-brazing of 2 mm niobium sheets with 12Cr80Ni10Ti steel. A continuous layer of Fe_2Nb intermetallic compound formed at the contact boundary between niobium and remelted steel. Zaho [5] used Niobium as interlayer in hot-roll bonding of Ti—6Al—4V and 0Cr18Ni10Ti stainless steel. Fe—Nb intermetallic layer formed at the interface of Nb and cracking occurred between stainless steel and intermetallic layer. Vacuum brazing of niobium-316 L stainless steel transition joints has been reported by Abhay Kumar [3]. The brazed specimens displayed no brittle intermetallic layers on any of their interfaces, but transition joints displayed low tensile strength (about 120 MPa). So direct joining of Nb to steel has encountered severe problems because of differences in their physical and chemical properties and formation of very brittle Fe—Nb intermetallic forms in weld [5]. The mechanical strength of such welds can be enhanced by insertion of interlayer that modifies final phase composition [6]. Laser welding can be one of the choices for joining Nb to stainless steel. However, especially for thin sheets and foils placement of an interlayer in the form of a strip has technical challenges regarding availability of the interlayer in the thickness required and also fitting the interlayer. In this work, a more versatile method is developed using electrospark deposition (ESD) for producing a miniature in situ interlayer with minimum heat input on the edge of one of the dissimilar materials to be laser welded.

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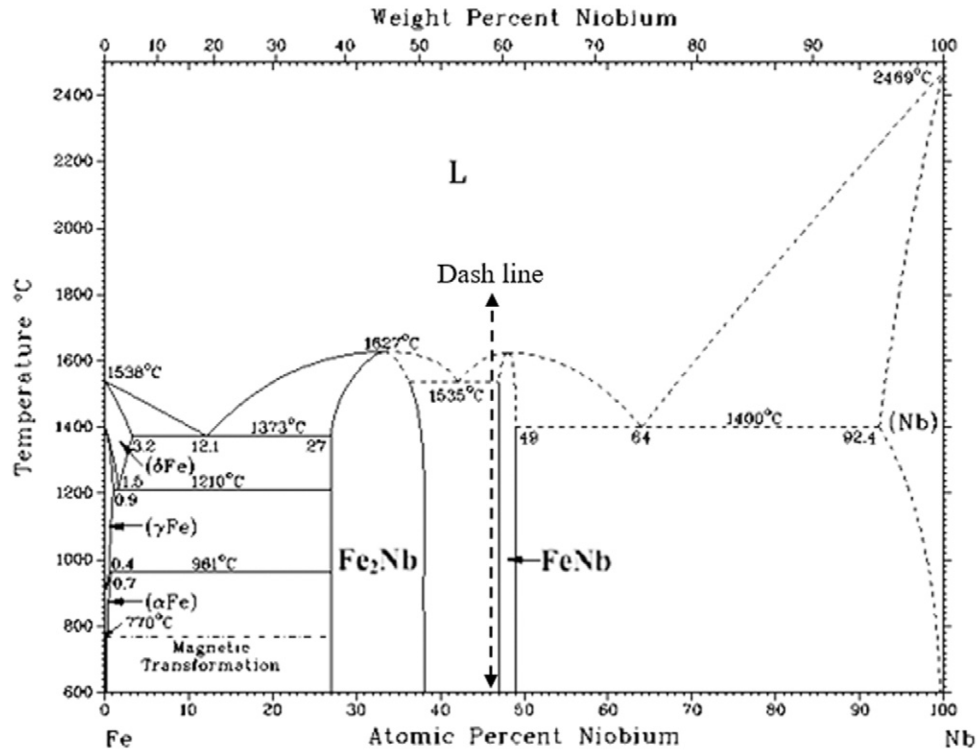

Fig. 1. Binary phase diagram of Fe/Nb [19].

Electrospark deposition (ESD) is a process that has recently attracted a great deal of interest due to its potential to process advanced materials. It is a low heat input micro welding/deposition process that uses short-duration, high-current electrical pulses to weld a consumable electrode (rotating or vibrating) material to a metallic substrate [7,8,15]. The short-duration current pulses combined with the intermittent contact result in extremely rapid thermal cycle. Small droplets (called "splat") of the melted electrode are accelerated through the arc, impact against the cold substrate and solidify rapidly to create a deposited layer. Several passes are made to create a multi-layer coating [8]. Electrospark deposition has been used for repair and buildup of Ni-based superalloys [9,10,11]. Gould [7] used electrospark deposition for joining refractory metal (Mo—Re and Ta—W alloys) to cast Ni-based superalloy (MarM-247) successfully. ESD welding with a Hastelloy X filler was found readily feasible with minimum dilution of or reaction with the respective substrates and no brittle intermetallic was observed at the interface. The T-111 to MarM 247 joints showed tensile strengths near 700 MPa, and elongations ranging from roughly 5 to 9%.

The objective of this research is to study the possibility of laser welding of Nb to 410 stainless steel by employing an interlayer of nickel base alloy produced by electrospark deposition process. In this method at the first Nb plate edge built up with a nickel base alloy by ESD process and then act as an interlayer in subsequent Nb to 410 stainless steel dissimilar laser welding which suppresses the formation of brittle Fe—Nb intermetallic in weld metal and increases weldability. This technique if proved successful, can in certain conditions facilitate laser welding of dissimilar alloys which have low weldability in direct combination. In the present work microstructure and mechanical properties of ESD interlayer and weld metal will be characterized.

2. Experimental procedure

Alloy 82 in the form of a round bar with 2 mm diameter was used in this study to deposit on a pure Nb sheet with dimensions of 1 mm × 100 mm × 10 mm. 410 stainless steel plate with 1 mm × 100 mm × 10 mm dimension was the another counterpart. The chemical composition of base metals and filler metal are shown in Table. 1.

2.1. First stage: production of the interlayer on Nb

At first ESD interlayer was deposited on Nb plate to diminish the contribution of Nb in the subsequent dissimilar laser weld to 410 stainless steel. For this goal a groove was made on one side of the Nb plate by grinding, and then this groove was filled with Alloy 82 using ESD process. Then with grinding on the back of the first side, another groove was made on the second side to obtain a full penetration interlayer. Then plate was cut out from the middle to form two plates which had built up of an Alloy 82 over their edges, (Fig. 2a and b). ESD interlayer was deposited with voltage of 120 V, duty cycle of 3% and frequency of 204 Hz using an ESD machine developed at Tarbiat Modares University. During deposition, the electrode was oriented preferentially at an angle of 30–45° to the work-piece and rotated at speed of 2500 RPM, the shielding argon gas was delivered through applicator at a flow rate of 20 ml/min.

2.2. Second stage: laser welding

The Nb plate with ESD interlayer was laser welded to 410 stainless steel. Schematics of the configuration is shown in Fig. 2.c. The set up is composed of IPG YLR-1000 Fiber Laser Beam Welding machine with a maximum power of 1000 W, frequency of 5 kHz , 1070 nm wavelength combined with a HIGHYAG BIMO welding head with 200 mm focus lens diameter and 100 mm collector and with ABB IRB 2400 6-axis anthropomorphic robot as a positioning machine. The actual laser power of 600 W and welding velocity of 50 mm/s were used to obtain a full penetration weld. It needs to be mentioned that for the purpose of comparison, laser welds between Nb and 410 stainless steel (without interlayer) was also investigated.