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A comparative evaluation of microstructural and mechanical behavior of fiber laser beam and tungsten inert gas dissimilar ultra high strength steel welds

Jaiteerth R. JOSHI [a], Mastanaiah POTTA [a,*], Kumar ADEPU [b], Ramesh Kumar KATTA [a], Madhusudhan Reddy GANKIDI [c]

[a] *Defence Research and Development Laboratory, Kanchanbagh, Hyderabad, Telangana 500058, India*
[b] *National Institute of Technology, Warangal, Telangana 502205, India*
[c] *Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad, Telangana 500058, India*

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Abstract

The influence of different welding processes on the mechanical properties and the corresponding variation in the microstructural features have been investigated for the dissimilar weldments of 18% Ni maraging steel 250 and AISI 4130 steel. The weld joints are realized through two different fusion welding processes, tungsten inert arc welding (TIG) and laser beam welding (LBW), in this study. The dissimilar steel welds were characterized through optical microstructures, microhardness survey across the weldment and evaluation of tensile properties. The fiber laser beam welds have demonstrated superior mechanical properties and reduced heat affected zone as compared to the TIG weldments.

Keywords: TIG welding; Fiber laser; AISI 4130 steel; Laser beam welding; Maraging steel

1. Introduction

18% Ni maraging steels are extensively used in aerospace and defense applications because of their incomparable fracture toughness coupled with high tensile strength. The steels achieve superior mechanical properties through a simple low temperature precipitation hardening heat treatment and they are easily weldable as well [1]. Whereas one of the chromium-molybdenum steels, AISI 4130 steel, possesses moderate strength and reasonable ductility in hardened and tempered condition. This feature of AISI 4130 steel makes it highly suitable for various critical applications in air craft and automobile industries [2]. In many cases combination of steels in structures is necessary for technical and economical reasons. Therefore dissimilar joints are inevitable for connecting the components/systems made of different materials. Welding is a major route adopted for fabrication of such components. Though enough number of articles are noticed in open literature about fusion welding of either of these steels in their similar combinations, very few articles are published about dissimilar welding of these two ultra high strength steels. The high strength low alloys (like AISI 4130 steel) are found to be very sensitive to the heat affected zone softening behavior as compared to that of maraging steels [3,4]. So performance of weld joint majorly depends on this softer HAZ region (which is a weak link in the entire weldment) and thus controlling the extent of softening is highly essential in real time applications in order to realize better performing structures or pressure vessels.

Nascimento and Voorwald [5] have studied the repair welding effects on the fatigue strength of aerospace structure made of AISI 4130 steel. They reported that during cyclic loading, the failure of AISI 4130 steel weld joint has occurred in the HAZ region due to the presence of tempered martensite that was formed during repair welding process. There exist several ways to control the HAZ softening behavior during welding of high strength low alloy steels. One way of controlling the degree of softening is by means of applying external cooling methods during and after welding process so that the excess welding heat input can be extracted effectively from the HAZ region. Yan et al. [6] have imposed faster cooling rates in HAZ region of high strength offshore steel by employing

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* Corresponding author. Tel.: +914024583528.
E-mail address: mastanaiah_p@rediffmail.com (M. POTTA).

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compressed air immediately after submerged arc welding process. They found that the fast cooling has improved the efficiency and low temperature impact toughness of the off-shore steel weld joints by reducing the width of HAZ. Dong et al. [7] have reported that reducing the welding heat input during gas tungsten arc welding of HSLA steel has substantially increased the hardness and thus the strength of HAZ region by limiting the formation of martensite.

Joshi et al. [8] have reported effect of different welding techniques and external heat extraction methods on heat affected zone softening in dissimilar metal weld joints of maraging steel and AISI 4130 steel. They used continuous current and pulsed current modes in TIG and applied an external water re-circulating copper jacket to extract the excess welding heat input from HAZ region. In their study, Joshi et al. [8] have reported that use of pulsed TIG welding process along with external cooling method has drastically reduced HAZ softening and has resulted in dissimilar steel welds with superior mechanical properties.

The other way of reducing the heat affected zone softening is by employing low heat input welding processes such as electron beam welding or laser beam welding processes in place of conventional arc based fusion welding processes. Huang et al. [9] have studied the influence of post weld heat treatments on the strength and resulting residual stresses in electron beam welded joints of AISI 4130 steel. Their work has shown that subjecting weld joints to heat treatment results in reduced residual stresses and improved the percentage elongation. The work by Chang and Wang [10] has demonstrated that by applying electron beam and furnace post weld treatments on AISI 4130 steel EB welds, it is possible to change the nature of tensile residual stresses into compressive stresses. This reversal of mode of residual stresses has drastically improved the resistance offered by EB welds to fatigue crack growth. Souza Neto et al. [11] have compared the mechanical properties of TIG and laser beam weld joints of AISI 4130 steel. Their study revealed that HAZ width of laser beam welds of AISI 4130 steel are ten times lesser than that of gas tungsten arc welds.

In the recent past, fiber lasers are invented and introduced into manufacturing sector. The fiber lasers score better than conventional CO_2 type lasers in terms of high energy density, deeper, narrower and possible high welding speeds especially in thin walled cross sections [12]. These high aspect ratio welds are produced with a relatively low heat input. As a consequence fiber laser welding can be used to a particular advantage where it is desirable to minimize HAZ softening, distortion and shrinkage stresses. Though the work by Joshi et al. [8] has revealed the possible improvement of the mechanical properties of dissimilar steel TIG weld joints of maraging steel and AISI 4130 steel, still the joint efficiency in terms of yield strength was reported as 72%. There exists further scope to improve the joint efficiency beyond 72%. In a quest to perceive the maximum possible joint efficiency for this dissimilar steel welds, advanced fiber laser beam welding process was employed and studied in this work. Though it is a well established fact that the laser beam welds impose less heat input compared to those of TIG welds, interaction of laser beam particularly on joining of dissimilar steels cited above is not reported.

However, very few articles are reported on the application of laser beam welding process in joining the high strength steels. The studies on dissimilar fusion welding of maraging steel and AISI 4130 steel are very scarcely available in open literature. The goal of current work is to bring out a comprehensive understanding about the mechanical and microstructural characteristics of dissimilar steel welds of maraging steel and AISI 4130 steel produced by tungsten inert welding and laser beam welding processes. This investigation assumes to be important as there exists a scarce literature on the subject, in particular, on dissimilar welding of the two ultra high strength steels under consideration.

2. Experimental procedure

2.1. Parent materials

The parent materials considered for investigation are AISI 4130 steel and 18% Ni maraging steel of MDN-250 variety. The maraging steel was taken in the form of a thin walled flow formed test ring with an external diameter of 225 mm, thickness of 2 mm and 125 mm of length. The test ring was subjected to a low temperature aging heat treatment: 485 °C/soaking for 3.5 hours and followed by air cool. A test ring of similar dimensions made of AISI 4130 steel was machined from a forging which undergone a heat treatment of hardening (870 °C/1 hour/oil quench) followed by tempering (260 °C/1 hour/air cool). The chemical composition and tensile properties of both the parent materials are mentioned in Table 1.

2.2. Welding trials

The test rings of maraging steel and AISI 4130 steel were TIG welded in a single pass by both in continuous current and pulsed welding modes using a W_2 grade maraging steel filler wire of diameter 1.6 mm. The filler wire of maraging steel was primarily employed because of its superior as-deposited strength and weldability as compared to that of AISI 4130 steel [1]. The chemical composition of W_2 grade maraging steel filler wire is mentioned in Table 2 and the TIG welding parameters are given in Table 3.

Another set of test rings were welded using a CNC solid state laser beam welding machine built by M/s. Arnold, Germany. Laser beam welding trial was conducted without

Table 1
Chemical composition(wt%) and tensile properties of parent materials.

	C	Ni	Cr	Co	Mo	Ti	Al	Mn	Si	Fe	UTS/MPa	0.2%YS MPa	%El./
Maraging steel	0.02	18.9	–	8.1	4.9	0.4	0.15	0.04	–	Bal.	1839	1810	2.9
AISI 4130 steel	0.3	–	0.86	–	0.25	–	–	0.48	0.26	Bal.	1530	1215	8.5