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Studies on welding of maraging steels

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Abstract

This work involves with investigations on Maraging steel weldments done by GTA welding technique. Similar welding of maraging steel plates of 5mm thick using ErNiCrMo-3 filler wire was done in order to evaluate the weldability and performance characteristics. Micro structural and X- Ray diffraction analysis were done to analyze the structure and phases developed post – weld. Block martensite was formed in the heat affected zones of the parent metal. Tension testing using different strain rates and hardness profile measurements were done to investigate the mechanical properties and the study concludes that the strain rate has considerable influence on the nature of ductility whereas it has very less influence on the Ultimate Strength of Maraging steel.

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Keywords: Maraging steel (250); GTAW; ErNiCrMo-3; Strain rate.

Nomenclature	
MDN 250	Maraging steel (250)

1. Introduction

Several critical applications in defence, especially aviation industry, requires materials with high strength whilst possessing several other important characteristics such as high strength to weight ratio and good impact toughness and moreover good joining capabilities. Maraging steels are a family of high alloyed steels which possess ultra high strength and other necessary characteristics which makes these materials suitable for use in critical aviation applications [1, 2]. Some of the applications of these materials include aircraft landing gears, shaft drives of helicopters and most importantly in the making of rocket motor cases [3].The high strength and toughness of the maraging steels are mainly due to two solid state reactions, martensitic transformation followed by aging [4]. In addition, maraging steels derives their strength not from either the carbon content or from its major substitutes but from precipitation of its inter metallic constituents of type Fe-Ni, Ni-Mo and Fe-Mo [5].

In aviation industries, ease of weldability of the materials is an important consideration as there are huge amount of joining possible throughout the structure. Therefore the selected material is to possess excellent weldability with superior metallurgical and mechanical properties. The unique property of maraging steels being readily weldable without any preheat

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procedures in as aged condition makes these steels a best choice in fabrication huge structures. Amidst several welding techniques available, gas tungsten arc welding GTAW is the most widely employed welding technique due to its high weld quality and ease of fabrication. However, the detailed analysis need to done for developing the defect free weld by optimizing the weld process parameters [6]. From the available literature, it is evident that only very few works have been reported on weldability of maraging steel. The metallurgical and mechanical properties have direct relevance and correlation of these properties becomes important in critical applications and needs further study. In this research, multi layer (3 layers) and multi pass(5 passes) Gas Tungsten Arc (GTA) welding with Inconel filler wire was done and the results examined.

1.1. Experimentation

The maraging steel weld has been produced by conventional DCEN GTA welding technique using ErNiCrMo-3 filler wire and their chemical compositions and parameters are shown in Table 1 and Table 2 respectively. Single - V butt joint configuration with a V- groove angle of 60 deg for welding a plate size of 5 mm thickness was used in this study.

In order to observe the microstructure under the optical microscope, specimens were cut from the welds, and then prepared according to the standard procedures. The cross – sectional weld specimens were hot mounted and were polished with emery sheets from 220 grit emery to 2000 and then disc polished using alumina powder followed by water polishing. Modified Fry's reagent was used to etch the HAZ and parent metal of MDN 250 and the etchant (20 ml of Hcl + 1ml of HNo3 + 5ml of glycerol + 0.25gm of CuSo4) was used to etch the weld region. Micro-hardness tests were carried out using a Vickers digital micro-hardness tester across the weld joint. A load of 500 gf (gram force) was applied for duration of 10 seconds (dwell time). Tensile samples were machined using EDM wire cut to the required dimensions of the sub size specimen of ASTM standards [7]. In addition, the tensile specimens were tested under different strain rates 2, 3, 4 and 5mm/min, pertaining to the limitations of strain rates using hydraulic testing machines [8]. The heat affected zones were analyzed by X-ray diffraction analyzer (XRD) for studying the phase composition.

Table 1. Parent material and filler wire compositions

Parent/ Filler Wire	C	Ni	Mo	Co	Ti	Al	Mn	Si	Cr	Cu	Fe
MDN 250	0.012	18.06	5.19	8.34	0.47	0.14	0.018	0.049	0.043	0.019	67.1
ErNiCrMo3	0.10	58	9	-	0.40	0.40	0.5	0.5	22	0.5	5

Table 2. Weld process parameters

Process	Voltage (V)	Current I (A)	Argon Flow (Lit/min)	Filler Dia (mm)
GTAW	13 – 14.5	150-153	14.4	2.5

2. Results and discussions

2.1. Macro and Microstructure

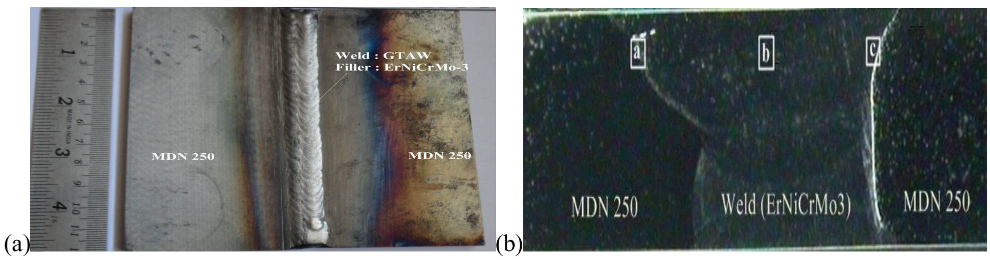


Fig. 1. Images of (a) As-welded sample. (b)Macrostructure of weld cross section.

The cross- section of the GTA welded sample shows a defect free macro structure and complete penetration (Fig 1). The micrographs for different zones of the weldment is represented in Fig.1 (b) is shown in Fig (2). As the carbon content in the maraging steel is very low (0.012% C), lath martensite structure with unique habit planes along with internal structure of parallel twins is seen in the parent metal microstructure, Fig 1 (d).

The micrographs taken at the interface of parent and weld metal on both the sides of the weld, Fig.2 (a) and Fig.2(c) shows the presence of martensite blocks, which is another form of martensitic structure [9]. It is obvious that during the time of weld as the interface is subjected to very high temperatures, as a result of which the orientation of the lath martensite which was in plate form in parent metal is transformed to martensite in block form after the weld in Fig.2 (a) and Fig.2(c). Even though this change in the grain boundary size has taken place, it has not affected the mechanical property of the weldment as it is evident from the tensile results that the fracture has not occurred in the weld interface but exactly at the weld region. This narrows down to the fact that effective fusion has occurred and the filler ErNiCrMo-3 has shown excellent weldability with the Maraging steel. The microstructure of the weld region has dendrites as its predominant structure as seen from Fig.2 (b).

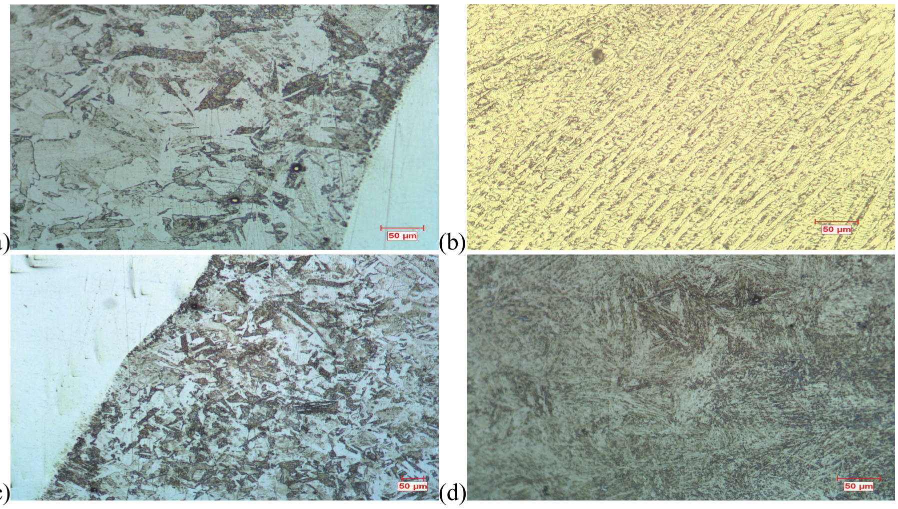


Fig. 2.Micrographs of (a) Interface on the left hand side (b) Weld region(c) Interface on the left hand side (d) Parent Metal of Maraging steel 250.

2.2. Tensile Test

The tensile samples tested after the test is represented in Fig 3 (a, b). It is very clear that both elongation and failures of all the samples have occurred in the weld zone and the results is represented in Table 3.

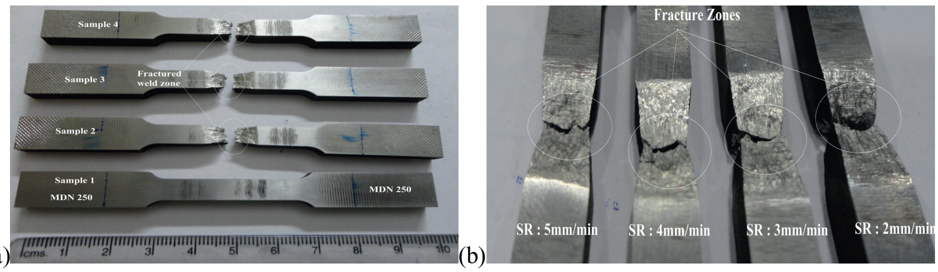


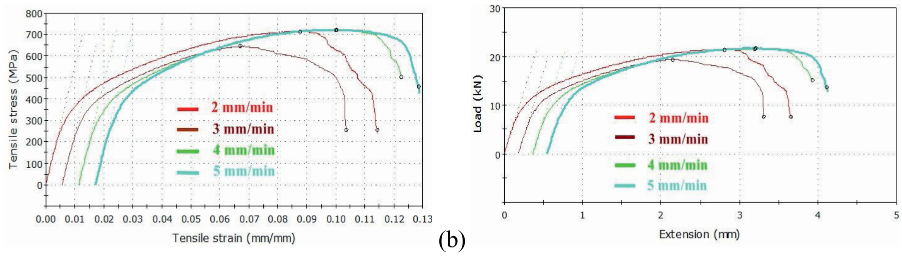
Fig. 3(a) Tensile Specimens tested at different strain rates (b) Fracture zones enlarged depicting nature of fracture

Table 3. Tensile test results

Parameters/ Strain Rate	Maximum Load (N)	UTS (MPa)	Tensile strain at Break (%)	Tensile stress at break (MPa)	Load at Break (kN)	Elongation at Break (%)	Reduction of area (%)	Tensile stress at Yield (MPa)
2mm/min	21422.15	714	11.421	255.02	7.65	10.85902	73.33333	714.07
3mm/min	19373.63	646	9.786	253.95	7.62	9.21975	73.33333	645.78
4mm/min	21614.88	720	11.127	501.58	15.05	10.02147	73.33333	720.49
5mm/min	21682.77	723	11.146	457.39	13.72	10.09091	73.33333	722.75

From the results it can be inferred that the strain rate has not much influenced on UTS of all the tensile specimens. Further it is also observed that the specimen tested at 3mm/min shows slightly lesser UTS which may be due to loading and gripping conditions of the sample at the time of tensile test. It can be observed that failure has happened in the weld region in all the samples. It is evident that the filler wire selection is judicious and the process parameters used in this study are optimum. It is evident from the micrographs, where the formation of martensite grain boundary in blocks which acts as a barrier to the dislocation and influence the strain hardening as reported by [9]. This is the reason why the failure has not occurred in the interface but at the middle of weld region.

As observed from Fig.3 (b), the fractured area of the samples moving from right to left, the samples tested under strain rate of 2mm/min and 3 mm/min has cup and cone shape fracture undergoing void coalescence which is a clear identification of a ductile failure. Moreover as the strain rate increased, proper void coalescence has not taken place in the samples tested at strain rate 4 and 5mm/min and the shearing has taken place in a zig-zag manner, the direction of shear traveling in an upward direction growing towards outer cross section initiating from the middle of the cross section of the sample but yet, the fracture being ductile. Also the values "load at break" for the samples with 4 and 5mm/min strain rate is double as that of the first two samples and so as the "tensile stress at break", which also reinforces that the latter two samples shows slightly less magnitude of ductility. It can be ascertained that the tendency or inclination from ductile to brittle transformation is visible as the strain rate increased. The stress versus strain graph shown in Fig 4(a) stands as one another proof for ductility exerted by the specimens and the Load Vs Extension is also shown which can be considered as engineering stress – strain graph for design purposes as the denominators (Ao and Lo) of both factors (Engineering Stress and Engineering Strain) are constant values, shown in Fig4 (b).



(a) (b)

Fig.4. Graphs plotted between (a) Tensile Stress versus Tensile Strain (b) Load versus Extension

2.3. Hardness Measurements

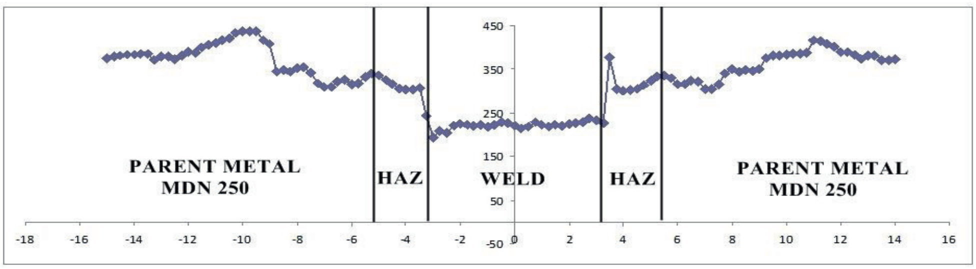
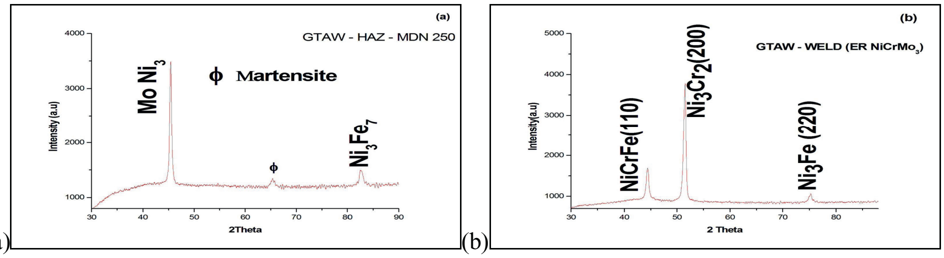


Fig.5. Hardness profile across the weld cross – section.

The sample was prepared according to ASTM E384-11e-1[10] standards and hardness traverse was made for one sample which was extracted from the centre of the weldment. The hardness values in the weld region has shown a constant trend whereas at the interface on both sides of the weldment the value has shown an uptrend and decreased subsequently. This could be due to formation of inter metallic precipitates as the weld interface is exposed to melting temperatures. Similar trend of hardness values has been observed in the HAZ of MDN 250 by Madhusudhan Reddy, G et al, 2012[1].

2.4. XRD Analysis

It is well known that during welding, the material is elevated to high temperatures and that the molten pool is again taken to austenitic phase and upon cooling it is brought to the room temperature where it ends up forming a phase according to type of cooling procedures adopted. It is also noteworthy to observe that the strength of the Maraging steel is due to the formation of inter metallic precipitates which are nothing but the different inter metallic phases formed during the solidification such as Mo+Ni and Ni+Fe. The 2θ values of the peaks from the XRD results obtained, matched exactly pertaining to above discussed phases. In addition, the martensite peaks were also noticed in the same, which exactly correlates with the micro structure. In weld region, different phases are formed in combination with nickel, being the major constituent in the filler material. The different phases and the corresponding Miller Indices are depicted in the Fig.6 (b).

(a)


(b)

Fig. 6. XRD pattern of (a) HAZ of the Maraging steel (b) Weld Region.

3. Conclusions

- The ErNiCrMo-3 filler wire has exhibited excellent weldability with Maraging steel (250).
- The different strain rate conditions have not influenced the Ultimate Strength of Maraging steel but have greatly influenced the magnitude of ductility.
- Within the tested strain rate limits, the welded sample shows tendency of slow transformation from ductile failure.
- Correlation of microstructures with tensile property results has shown good agreement and gives better understanding.
- The X-ray diffraction result has perfect relevance with respect to the physics and nature of welding of Maraging steels.

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