Weld Characteristics of M250 Grade Maraging Steel in Aerospace Industry

S. Sundaresan[1*], Goutam Nayak[1], A.P. Beena[1], C.K. Krishnadasan[1] and B. Nageswara Rao[2]
[1]*Vikram Sarabhai Space Centre, Thiruvananthapuram, India*
[2]*Department of Mechanical Engineering, Vaddeswaram, India*
E-mail: [*]sundaresan.isro@hotmail.com

Abstract—*Welding is one of the important manufacturing processes employed for fabrication of many aerospace components ranging from rocket motor cases and propellant tanks to various structural systems. 18% nickel maraging steels having high strength–to-weight ratio provide good fracture toughness, easy weldability and simple heat treatment. This paper examines various welding characteristic of M250 grade maraging steel and its applicability to rocket motor cases. Motor cases are fabricated by roll bending and welding of plates and rings. The reasons for formation of cracks in motor cases stored for long time is examined. The mechanism responsible for the improvement in the mechanical properties is a key subject of investigation which is discussed briefly. Residual stresses in the weld zone are discussed. The mechanical properties achieved through filer–wiring welding is presented with the limited sample observations. The quality procedures to be followed during welding processes for achieving better results.*

Keywords: *M250 Grade Maraging Steel, Fracture Toughness, Welding, Weldability, Filer-Wiring, Residual Stresses*

INTRODUCTION

The maraging steels created tremendous interest in the aerospace industry all over the world since 1959. These low-carbon, high-nickel, iron-base alloys considered important because of their extraordinary combination of structural strength and fracture toughness along with the easy weldability. These alloys are termed as "maraging" because they possess a martensitic microstructure when annealed and attain their ultrahigh strength on being aged in the annealed condition. These maraging steels are widely used in numerous applications because of their ultrahigh strength. Many have studied the mechanical properties of the maraging steels, investigated the failures of maraging steels components under test and contributed to an improved understanding of the fracture toughness of the materials.

It has been pointed out that maraging steels can easily be machined, formed and welded. Preweld and postweld treatments are not required and full strength is obtained by ageing at 900°F against the conventional quench and heat treatment used for other high strength alloys which would find problems in handling and process the large motor cases.

This paper explains about the heat affected zone (HAZ) in the weldments, the effect of solution treatment after welding to remove austenite film present in the HAZ, and the presence of residual stresses. The mechanical properties obtained using filer–wiring welding is presented with the limited sample observations. The quality procedures are examined in the welding components for better performance of fabricated systems. The brief details of some of the important characteristics of M250 grade maraging steel are explained below as an opportunity to share our experiences in the process of fabricating rocket motor cases., Age hardening effect, Iron–Nickel transformation system, the requirement of solution treatment for the welded motor cases, Residual stresses effects and the quality requirements in the welding processes are explained.

ROCKET MOTOR CASE

M250 grade maraging steel is employed for fabrication of rocket motor cases because of its high strength and fracture toughness. A typical large diameter $(\approx 3m)$ maraging steel rocket motor casing (having 8 mm nominal thickness) shown in Fig. 1 consists of five individual welded segments, namely a head end (HE) segment, a nozzle end (NE) segment and three middle segments (MS). The number of segments is chosen based on the feasibility of propellant casting, hardware fabrication limits, and ease of transportation/ handling, etc. These segments are connected to each other through the tongue and groove type of joint [1].

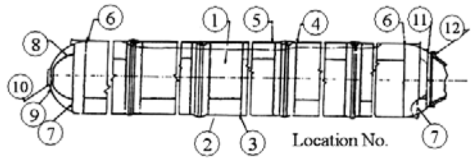

Fig. 1: Weld-Joints in a Typical Large Size Maraging Steel Motor Case

Locations: (1) Cylindrical shell; (2) Long seam joint; (3) Cirseam joint; (4) Weld between cylindrical shell and tongue ring; (5) Weld between cylindrical shell and grooved ring; (6) Weld between Y-ring and cylindrical shell; (7) Weld between Y-ring and spherical shell; (8) Weld between petals; (9) Weld between HE boss and HE dome; (10) HE boss and hub junction; (11) Weld between NE dome and the flanged ring; and (12) Nozzle convergent flange.

These weld joints should be made efficiently to ensure the expected performance of rocket motor case. In order to ensure the quality of weld joints, all quality checks are made at weld joints and if any defect observed, repair work is carried out at the weld point to improve its strength. The characteristics of welding in M250 grade maraging steel play an important role in the determination of parameters relating to the performance of rocket motor case.

The Specified Mechanical Properties of M250 Grade Maraging Steel are

Ultimate tensile strength, σ_{ult}

Parent: 1765 MPa

Weldment: 1589 MPa

Yield strength, σ_{ys}

Parent: 1725 MPa

Weldment: 1549 MPa

Plane-strain fracture toughness, K_{IC}

Parent: 90 MPa $\sqrt{m}$

Weldment: 81 MPa $\sqrt{m}$

Heat Affected Zone (HAZ)

The heat affected zone in maraging steel consists of three zones, viz., the zone nearest to the weld (A), the narrow weld region of weld (B) and the weld zone (C) that experiences temperatures approximately 900°F or just above that.

The weld zone A is heated into austenitic region by the heat of welding and transformed to martensite on cooling. If the weld joint in the zone A is aged after welding, the strength of zone A increases almost to the strength of the parent plate/ material. The zone B is the region of weld which experiences heat of 1350°F to 1100°F known as eyebrow region or dark band because it etches black. It is martensitic with a fine dispersion of stable.

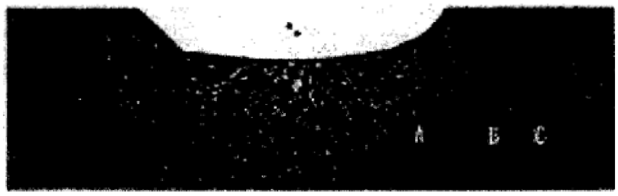

Fig. 2: Weld Regions of Heat Affected Zone

Reverted austenite Fig. 2 the dark band remains weaker than the rest of the heat-affected zone area. This was studied in details by Peterssen [4] using the Gleeble equipment. In actual welds the width of the dark band is an important factor because the thinner the band the more effectively it is supported by surrounding stronger material. Therefore low heat inputs would be expected to be beneficial. Heat–affected zone failures at strengths corresponding to joint efficiencies of 80 to 85 %. Hence one should be careful to control the heat input in order to minimize the dark zone is recommended as good practice. The zone (C) is not affected much by the heat of welding. This can be considered as the unwelded plate/ material.

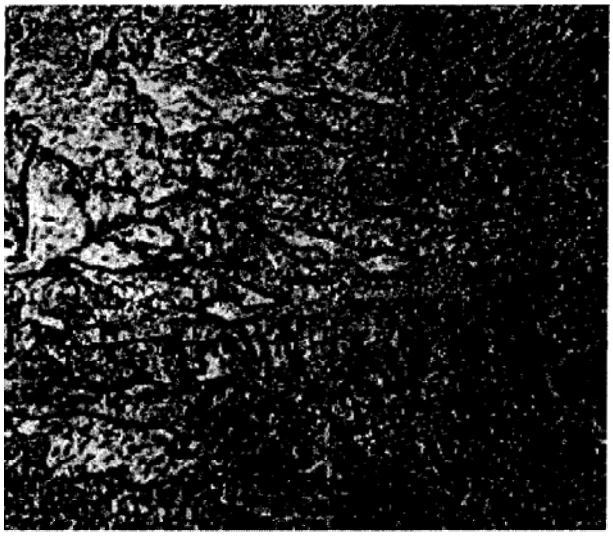

Fig. 3: Dispersion of Austenite in Martensite in the Heat Affected Zone of Dark Band

Weldments are therefore a composite of materials containing base metal, heat–affected zone, and weld metal regions, each having different properties. Each region could require a separate test to understand the characteristics [2, 5].

Age Hardening

In M250 grade maraging steel, a wide range of aging condition used, temperatures have ranged from 700°F to as high as 1200°F with time of upto 1000 hours. However, in our welding processes, the aging temperature employed is 900°F and the time considered is 3 hours. The 3 hour treatment at 900°F is economical and it results in the increase of strength, ductility and toughness [2, 3].

Iron–Nickel Transformation System in M250 Maraging System

The important characteristic in maraging steels is the specific feature of iron–nickel binary system. The diagram developed by Owen and Liu is shown in Fig. 4. The diagram tells us that when an alloy containing 18 % nickel is held at temperature of about 1100°F and above, under equilibrium condition, its structure consists of entirely of gamma (austernite), whereas at temperature below 1100°F, the equilibrium structure is duplex consisting of a mixture of alpha (ferrite) and gamma [4].

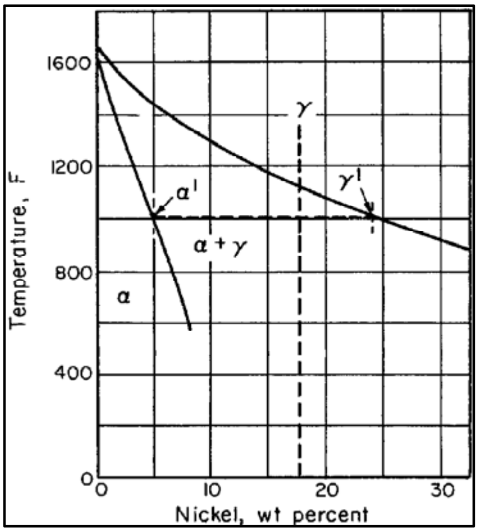

Fig. 4: Iron–Nickel Equilibrium Diagram

The work of Jones and Pumphrey has been shown graphically in Fig. 5. When this diagram is compared with the equilibrium diagram, one can see that on cooling, the start of the gamma–to–alpha transformation is depressed. This refers to the situation that favours the transformation of gamma (austenite) on cooling and discourages the development of two-phased ferrite–austerite structures. The single phased alloys generally increase toughness and ductility over wider temperature ranges.

It is seen from the Nickel–binary system Figure, 18 percent nickel maraging steel must be heated to a minimum temperature of about 1350°F to ensure complete transformation to austenite. In practice, annealing at a temperature of 1400-1500°F dissolves precipitates and promotes relief of internal residual stresses developed during hot working and cold working or joining.

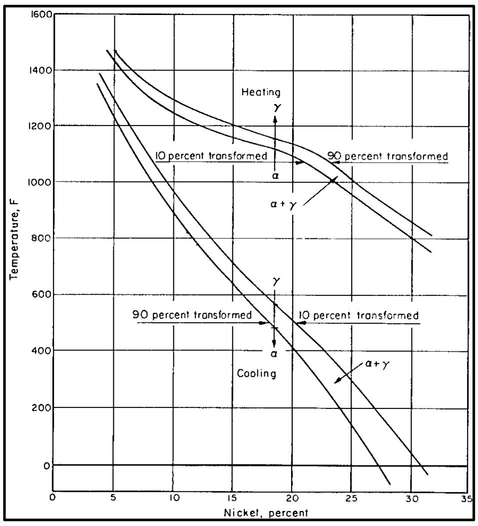

Fig. 5: Iron–Nickel Transformation Diagram

EFFECT OF SOLUTION TREATMENT

Solution treatment on the weld segment plays an important role in fabrication of motor cases. After welding, an ageing treatment at 480°F for three and a half hours is done. Cracks are formed in maraging steel rocket motor cases which are stored for a long time. The probable reason for this would be the presence of austenite film present in the Heat affected zone (HAZ) of the weld coupled with high residual stresses.

Solution treatment of the welded segment is suggested as the best solutions for eliminating both the austenite film as well as residual stresses. Studies were carried out to understand the effect of solution treatment on mechanical properties and ultrasonic noise level. During welding, segregation of elements like Ni, Mo, and Ti occurs in the weld zone leading to lower mechanical properties. Solution treatment, being a high temperature treatment, is expected to reduce this segregation and improve mechanical properties, especially, fracture toughness. Residual stresses will be reduced and become uniform throughout the motor case. Samples for evaluation of mechanical properties and for metallographic analysis were prepared from welded plates in the two conditions, viz., 1. Welded and aged 2 welded solution treated and aged. To confirm the absence of austenite firm, the material after solution treatment, X-ray diffraction was done on samples cut from rolled plates. Three samples were considered for two conditions, namely: 1. Welded and aged 2. Welded solution treated and aged.

Table 1: Mechanical Properties of Samples under Two Conditions

Condition	Sample No.	UTS (MPa)	YS (MPa)	% Elong.	Fracture Toughness MPa$\sqrt{m}$
Welded, and Aged	1	1680	1650	8.0	85.8
	2	1695	1665	2.9	80.3
	3	1710	1680	3.1	81.9
	Average	**1695**	**1665**	**4.6**	**82.6**
Welded, Solution Treated & Aged	1	1710	1695	8.2	100.2*
	2	1720	1700	6.0	93.4
	3	1750	1720	7.2	96.0*
	Average	**1727**	**1705**	**7.1**	**>93.0**

RESIDUAL STRESSES IN MARAGING STEEL WELDMENTS

The residual stresses measured in maraging steel weldments is very essential. The conventional pattern of residual stresses shows stresses to be maximum along the weld centerline extending into the heat-affected zone. During cooling, residual tensile stresses are set up in the usual way because of contraction. But, when the austenite to martensite transformation takes place, there is resulting increase in volume that sets up opposing compressive stresses that are large enough to neutralize and overcome the tensile stresses. It is because the transformation occurs at comparatively low temperature that these compressive stresses are so dominant [4, 7].

It has been noted that the fracture toughness of high strength steels at specific yield strength are determined primarily by the cleanliness of the materials. If the materials contain the low levels of impurity elements, then the toughness increases.

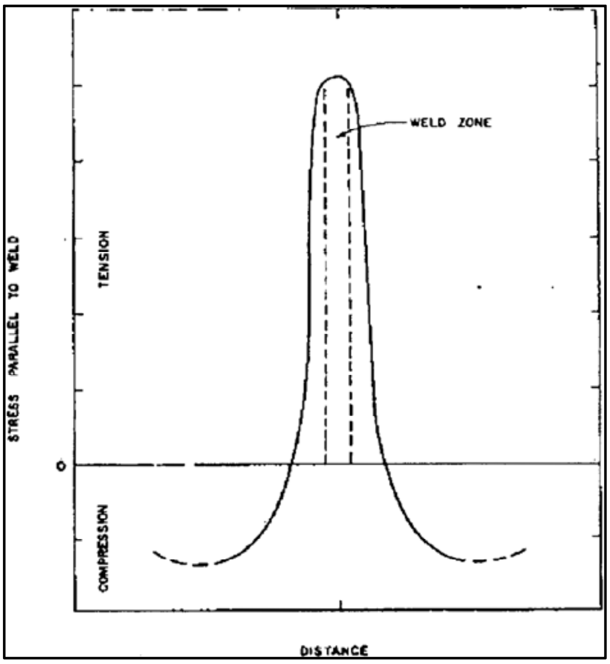

Fig. 6: The Conventional Residual Stress Pattern in the Near Vicinity of a Weld

Filler Wire Method of Welding

This method is most commonly used in welding hardware subsystems for aero applications. The composition of filler wires used to weld maraging steels is usually very similar to those of the base plates. Both the weld and plate have the same basic structure in that both consist of a low carbon martensite matrix which on ageing hardens through the precipitations of inter mettalic compounds.

Table 2: Mechanical Properties of M250 Grading Weld Properties Using Filler Wire Method

Sample No.	UTS (kg/mm^2)	YS kg/mm^2)	Fracture Toughness K_{1C} MPa $\sqrt{m}$
1	172.65	169.5	82.79
2	172.21	169.51	89.31
3	172.07	168.29	88.93
4	170.91	168.85	91.16
5	174.07	171.63	80.03

- Limited sample only provided. All the sample results can be obtained from the author.

Quality Requirements in Welding Materials

If the materials contain the low levels of impurity elements, then the toughness increases.

It has been fully understood the importance of purity in high strength steel welds and fabricators are very clear about the cleanliness in materials and in the welding process is essential for the production of weld segments with good mechanical properties [7].

It is also recommended that preweld preparations should include cleaning the joint surfaces and surrounding areas with a ketone or alcohol solvent.

Wire quality is an important factor in improving weld soundness and properties. The wire should be made from very clean material and must be processed so that surface quality is good and there is no entrapped oxide or lubricant. Vacuum annealing of the wire is recommended and ultrasonic cleaning also proved very useful. To avoid contamination, the spooled wire is packaged and stored in dry, argon-purged containers. The gas analysis of the wire is an indication of its suitability. Oxygen and nitrogen levels below about 50 ppm and hydrogen below 5 ppm are desirable [2, 4, 6].

The shielding gas used for the welding should be maintained pure and dry, and the cleanliness and equipment through which it travels should be clean and free of possible leakage. Many researchers proved that auxiliary shields such as trailing shields can minimize porosity and improve the properties of the joints [7]

Delayed cracking can be prevented by improving storage conditions. Thermal stresses generated during welding could be controlled. Regular UT scanning is necessary after fabrication of weld segments for detecting cracks. Post weld solution treatment in maraging steel is expected to minimize residual stresses, improve tensile strength and toughness of weld. It has been observed that due to solution treatment, significant improvement in the mechanical properties of weld and the weld fracture toughness very near to fracture toughness of parent metal [6].

Conclusion

This paper describes some of the important characteristic features of M250 grade Maraging Steel, widely used for fabricating rocket motor cases. The composition of heat affected zone (HAZ) is described. The effect of solution treatment at higher temperature not only improves mechanical properties but also control thermal stresses and residual stresses. Delayed cracking can be avoided by better environmental conditions and by regular UT scans on the hardware. Because of the special characteristic behavior of M250 grade maraging steels providing higher strength and toughness, it finds wider applications in aero space industries. The presence of such material is a boon for industry.

ACKNOWLEDGEMENT

The authors would like to thank shri. P. Balachandran, Group Director, Structural Analysis and Testing Group (SATG) and Dr. Annamala Pillai S, Deputy Director, Structural Engineering Entity (STR) of Vikram Sarabhai Space Centre (VSSC), for their encouragement; Dr. Ramakrishnan S, Director, VSSC for giving permission to publish this paper. Thanks to Editorial Board for making arrangements for reviewing this paper.

REFERENCES

[1] Sundaresan, S., Manirajan, M. and Nagrswara Rao, B., (2010), On the Fracture Toughness Evaluation in the Weldments of a Maraging Steel Rocket Motor Cases, Vol. 31, pp. 4921–4926.

[2] Decker, R.F. (1963), “Maraging Steels Structure Property Relationships”, *NPL Symposium*, pp. 648–671.

[3] Baker, A.J. and Swann, P.R., (1964), “The hardening mechanism in Maraging steels”, *Trans. ASM*, Vol. 57, pp. 1008–1011.

[4] Reisdorf, B.G. (1963), “Identification of Precipitates in 18, 20, and 25 % Ni Maraging Steels”, *Trans. ASM*, Vol. 56, pp. 783–786.

[5] Petersen, W.A. (1964), “Weld Heat-Affected Zone of 18% Nickel Maraging steel”, *Welding Journal*, Vol. 43 (9), pp. 428–432.

[6] Welding Hand Book (1966), *Metals and their Weldability*, Fifth Edition, American Welding Society.

[7] Saperstein, Z.P. (1964), “Evaluation of Maraging Steel for Application to Space Launch Vehicles”, Report No.43105, Douglas Aircraft Co., Santa Monica, Calif., NASA Contract NAS7-214.