Abstract

18% Ni maraging steel exhibit an excellent combination of ultra-high strength and good fracture toughness. The maraging steel grade MDN250 has been the workhorse material in the Indian context for construction of rocket motor casings in the propulsion system of launch vehicles. Starting from 1980’s, this grade is being produced and used in India in large quantities, the aerospace sector being the main user.

Joining by welding is importantly involved in fabricating various structures out of this alloy. This alloy can be welded with almost all welding processes ranging from electron beam to submerged arc welding. In common practice, gas tungsten arc welding (GTAW) is mainly employed in view of the consistency of the weld quality, amenability to automation of the process and the overall economy. However, ductility and toughness are the main concern of the weld fusion zone. Alloying element segregation, coarse dendritic structure, large cell size and massive austenite islands observed in the fusion zone, deteriorates mechanical properties of the welds. This is in spite of the filler wire with optimized chemical composition and process technique being used. These microstructural features are not conducive to the weld joint matching well with the base steel in terms of strength and toughness. Hence, a need was felt to develop welding technique or use of the welding process to avoid problems related to melting and solidification.

A solid state welding process can overcome most of the problems associated with fusion welding process mentioned above. Friction stir welding (FSW) is a localized solid-state thermo-mechanical welding process, which is free from solidification defects. FSW of soft alloys is well established and adopted by many industries in production line. However, FSW
of high strength/high melting temperature material has not progressed to that extent as that of soft materials.

The main obstacle in using a FSW process for welding high strength/high melting point materials is the development of tool materials capable of surviving the high temperatures, forces and flow stress generated during welding. Development of tool geometry and establishing a process parameter range also plays a critical role in developing FSW procedure of high strength material. No research paper or direct application of FSW process for welding of maraging steel is available in open literature.

Keeping the foregoing in the view an attempt is made to join 18 % Ni maraging steel of grade 250 using FSW process. Type of tool material, tool geometry and process parameters are evaluated in establishing welding of maraging steel. FS-weld and GTA-weld microstructures are studied in detail with respect to microstructural changes observed as a result of two different classes of welding process. Mechanical properties such as tensile strength, impact toughness, fracture toughness and stress corrosion cracking of weld and base metal are correlated with microstructure. Role of weld thermal cycle, thermo-mechanical working and microstructural variation on microhardness and residual stress is also studied.

The thesis of the research work is divided into seven chapters. The first chapter gives the introduction to the investigation carried out and the outline of the objective and scope of the work.

The second chapter focuses towards physical metallurgy of maraging steel used in the present investigation. A brief historical development of maraging steel is also discussed. Based on the finding of different researchers, the relationship between microstructure and mechanical properties of maraging steel is described. Weldability of maraging steel, influence of process parameter and welding process on microstructure and mechanical properties of the weld is
also highlighted. Challenges in welding of steel or other high strength/high hardness material by FSW and developments toward welding of high strength material also form a part of this chapter.

The third chapter presents details of material, welding process parameters and various equipments used for testing and analysis. A standard used for testing, test sample geometry and testing method is highlighted. It also describes briefly the fracture toughness evaluation procedure used for the present study.

The fourth chapter describes the development of FSW process for welding of maraging steel. Selection of right tool material, tool geometry and process parameters that can lead to defect-free weld is the main focus of chapter 4. Tungsten-molybdenum and polycrystalline cubic boron nitride are observed to be suitable tool material for welding of maraging steel. A narrow range of process parameters was found to exist for welding maraging steel for a given thickness of the base metal and tool geometry.

Microstructural changes as a result of two distinct welding processes applied to maraging steel is brought out in chapter 5. It is observed that the microstructure of the stir region of FS-weld is substantially refined and contains a high fraction of low angle grain boundary when compared to GTA-weld. Segregation of alloying elements which is un-avoidable in fusion welding of maraging steel was not observed in FS-weld. Both welding processes resulted in austenite reversion. However, size and distribution of this austenite was different. In FS-weld volume fraction of reverted austenite is dependent on welding temperature that can be controlled by tool rotation speed. Formation of Ti(CN) along the prior austenite grain/cell boundary in GTA-weld was also observed.

Effect of microstructural changes on mechanical property, namely tensile strength, Charpy V-notch impact toughness, fracture toughness and SCC is the main focus of the sixth chapter.
Emphasis is laid on the effect of reverted austenite morphology and distribution in base metal, GTA-weld and FS-weld on properties. Fine and uniformly distributed reverted austenite is observed to be highly beneficial for improvement in ductility and toughness, conversely coarse reverted austenite along the prior austenite severely impairs mechanical properties. Alignment of Ti(CN) along the prior austenite grain boundary is GTA-weld is found to provide an ease in crack propagation, thereby deteriorating the weld properties.

Chapter 7 outlines the general conclusions drawn from this research work. It focuses towards the development of FSW process and highlights the advantages associated with welding of maraging steel using FSW.