Mechanical and Corrosion Behaviour of Maraging Steel Processed by Powder Bed Fusion using Laser Beam

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Doctor of Philosophy

By

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7.1 INTRODUCTION

A detailed study was carried out to investigate the effect of build orientations (0^o, 45^o and 90^o) and heat treatment (solution treatment plus aging treatment) on microstructure, tensile, fatigue, wear, erosion and corrosion behaviour of maraging steel processed by Powder Bed Fusion using Laser Beam (PBF-LB) and compared with the behaviour of conventionally manufactured (cast and hot rolled) maraging steel. The major findings are concluded in the subsequent section.

7.2 MAJOR CONCLUSIONS

7.2.1 Initial Characterization

This section gives details of processing of M300 grade maraging steel in different orientations by selective laser melting (SLM) and attempts to characterize the resulting microstructures and physical properties of the as-built and heat-treated specimens. Important observations are summarized below.

1. The process parameters utilized in SLM gave 99% dense maraging steel plates in 0^o, 45^o and 90^o build orientations. 45^o oriented plates showed maximum surface roughness due to the stair step effect.

2. As built AM samples revealed two types of structures in microscopy. At lower magnification, meso-structure, which showed process parameters characteristics, interlayer regions and laser track overlapping (44%) was seen while at higher magnification, very fine microstructure (<1µm) mainly consisting of cellular and columnar grains were observed. The conventional samples showed equiaxed coarse grained microstructure in as received condition.

3. Both the additive manufacturing (AM) and conventional manufacturing (CM) samples exhibited a small amount of retained austenite in the martensitic matrix prior to heat treatment. Subsequent heat treatment (solution treatment at 815° C for 1hour and aging at 520° C for 5 hours) led to the reversion of austenite and resulted in the increased presence of austenite (*fcc* phase) along with the martensitic matrix.

4. Aging also resulted in the formation of needle-shaped nanosized precipitates of Ni_3Ti in the martensitic matrix, which were distributed uniformly. Additionally, globular precipitates of Fe_2Mo were also observed in the matrix.

7.2.2 Tensile and Low Cycle Fatigue Behaviour

The study aimed to investigate the tensile and fatigue behaviour of additively manufactured maraging steel in their as-built and heat-treated conditions and compare them with conventional manufactured maraging steel. It also examined the effect of build orientations anisotropy on the tensile and fatigue results. The following findings can be summarized in this section.

1. All As-built samples compressive residual stresses irrespective of build orientation. The stresses generated in 90° AB samples dos not easily transfer to the base plate, so it had maximum residual stresses. 0° AB plate had more surface contact with the base plate, so it retained less residual stresses. After heat treatment due to thermal recovery, the stresses were found to be relieved.

2. Residual stresses, precipitation and austenite reversion due to heat treatment also significantly affected the hardness and tensile properties of as-built as well as heat-treated AM maraging steel.

3. As built AM samples showed anisotropy in tensile properties. 0^o AB samples showed maximum degree of work hardening with maximum ductility followed by the values for 45^o AB and 90^o AB samples. After heat treatment, 45^o HT sample showed better strength without loss of ductility than on AM heat treated samples. Before heat treatment, conventional samples showed inferior strength parameters than those of AM samples because AM samples had fine microstructure. After heat treatment, conventional samples showed better strength properties than parameters for AM samples due to excessive precipitation and less percentage of reverted austenite. Fractography revealed ductile fracture for both as-built and heat-treated tensile tested samples.

4. The anisotropy present in microstructure and tensile properties of AB AM samples was due to layer-wise processing and was reduced after heat treatment because of homogenized microstructure after heat treatment in AM samples.

5. The fatigue characteristics of the samples were influenced by the orientation of defects relative to the loading axis. In both the as-built (AB) and heat-treated (HT) conditions, Samples with 90^o orientation exhibited the shortest fatigue life.

6. On the fracture surfaces of both the as-built (AB) and heat-treated (HT) samples, multiple crack initiation sites can be seen. In the case of 90^o as-built (AB) samples, noticeable defects of large and irregular shape were observed, attributed to insufficient fusion during SLM processing.

7. The application of post-heat treatment (HT) proved to be highly effective in enhancing the fatigue life of the samples. Remarkable improvement in fatigue life was observed in all orientations as a result of the formation of precipitates and the reduction in the size and quantity of defects.

7.2.3 Wear and Erosion Behaviour

In this chapter, a comprehensive investigation of wear and erosion properties of additively manufactured maraging steel built-in 0^o, 45^o, and 90^o orientations was done and compared with those of conventional samples. Salient features can be summarized below.

1. Wear rate was affected by the applied load and wear resistance was found to be dependent on combined effect of microstructure, residual stress and hardness in the as-built additive samples, whereas after heat treatment, it was mainly governed by precipitation hardening and reverted austenite formed during aging.

2. Maximum wear rate was observed for the as received conventional samples followed by 0^o AB, 45^o AB and 90^o AB samples. The best wear resistance was observed for 90^o AB samples because 90^o AB samples showed maximum hardness among all the specimens.

3. Coarser microstructure of the as-received conventional materials resulted in lower wear resistance as compared to the additive samples, while the formation of a lesser percentage of austenite during heat treatment resulted in better wear resistance.

4. After heat treatment, the 90^o HT samples showed better wear resistance followed by 0^o HT and 45^o HT samples. Conventional samples after heat treatment showed better wear resistance than additive samples because of less percentage of austenite in the martensite matrix and higher hardness.

5. The coefficient of friction (COF) decreased with increase in load due to strain hardening and smoothening of the wear surface.

6. Before heat treatment the wear mechanism was found to be abrasive and after heat treatment the wear mechanism was adhesive in nature.

7. Erosion resistance was found to be governed by the meso- and microstructures. Conventional samples depicted maximum erosion rate. The erosion surface of the as-received and heat-treated samples showed ductile erosion consisting of lips, deformed lips, and craters on the eroded surface.

7.2.4 Corrosion Behaviour

The chapter discusses the results of corrosion behaviour of PBF-LB maraging steel and also compared the behaviour with the results of conventional maraging steel before and after heat treatment. Important points can be summarized as follows.

1. It was found that the corrosion rates of AB samples increased with increase in built orientation. The best corrosion resistance was observed in 0^o orientation among all the orientations. AB samples exhibited better corrosion resistance than conventional AR samples.

2. Aging caused deterioration in the corrosion resistance of both PBF-LB and conventional maraging steel. Precipitation and reverted austenite played a significant role in the corrosion behaviour of heat treated PBF-LB maraging steel.

3. As built additive and conventional samples showed better corrosion resistance than heat-treated conditions. This is because of the protective oxide layer of TiO_2 and MoO before heat treatment while after heat treatment, corrosion resistance decreased due to precipitation of intermetallic precipitates and the reduction of protective oxide layers.

4. Pitting corrosion was observed in both AB and HT specimens. Pitting was found to initiate from the interlayer region in AB samples and homogenous deep blunt pitting with subsurface corrosion was observed in HT AM samples.

7.3 SUGGESTIONS FOR FUTURE WORK

Following suggestions can be proposed for future work:

1. Study the tensile and fatigue behaviour of maraging steel processed by PBF-LB at elevated temperatures.
2. Effect of surface treatments and coatings to improve fatigue life of additive manufactured alloys.
3. Influence of surface coatings to improve wear and erosion behaviour of additive manufactured maraging steel.
4. Assess the corrosion behaviour of additive manufactured maraging steel in different corrosive media.
5. Study of multi-axial fatigue behaviour of additive manufactured alloys.