Chapter 7

Conclusions and future work

Chapter 1: In this chapter authors offer a concise overview of 7075 Al alloy, elucidating its precipitation, compositions, properties, and application along with fatigue and fracture behavior with a brief literature survey on Al-Mg-Zn alloy and the effect of corrosion on this alloy is also illustrated. Based on the literature survey, the objective of the thesis is outlined and accordingly, the results with discussions and important findings followed by conclusions are presented in subsequent chapters. Following conclusion is drawn from this chapter

- Difficulty in cold rolling of 7075 Al alloy
- Very limited studies are available regarding elastic plastic J_{1c} fracture toughness and fatigue crack growth behavior of 7075 Al alloy in normal condition and in corrosive environment

Chapter 2: In this chapter authors present the methodology utilized for thermomechanical processing (solution heat treatment +artificial aging + cold rolling). The chapter also addresses characterization techniques that are used for data collection and analysis. X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and electron backscattered diffraction (EBSD) was employed to assess the microstructure and phase constituents. An electrochemical workstation (Gamry Interface 1010 E) was used for electrochemical testing. Fatigue crack growth rate and elastic plastic (J_{1c}) fracture toughness was studied well on SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and

SHT+PA+90% CR samples. Additionally, Vickers hardness and tensile test and corrosion testing in 3.5% NaCl solution were performed.

Chapter 3: The primary goal of this study was to obtain 90% cold rolling in 7075 Al alloy, and thoroughly study elastic plastic (J1c) Fracture toughness of SHT, peak aged and 90% cold rolling in 7075 Al alloy. For this detail Optical, SEM, XRD, and TEM investigation was performed, and correlated with the investigated mechanical properties. From the investigated results following conclusions can be made:

- SHT and aging process is successfully optimized, SHT was performed at 470°C for 8 hours followed by aging at 140°C for 21 hrs.
- Fine precipitate of η'' (Mg_2Zn_3) was formed at peak aged condition, confirmed by XRD, TEM and SAED pattern analysis. The Split diffraction spots with satellite pattern in long range ordering is observe in SAED pattern of η''. It indicates the formation of stacking faults and periodic arrangement of precipitates, respectively, which helped to achieved 90% deformation of 7075 Al alloy.
- Tensile test result is supporting the hardness test result. Aging and Cold rolling treatment effectively enhanced the hardness and tensile strength due to formation of fine cylindrical shape precipitates of η''(Mg_2Zn_3) and grain refinement, respectively.
- Strength of 90% rolled sample is highest in comparison of as received, SHT and peak aged samples. The maximum Vickers hardness and Tensile strength achieved after 90% cold rolling are 226 HV and 526±5MPa, respectively. Fractography of tensile samples are showing that SHT sample has ductile fracture, and aged sample

has mixture of ductile and brittle fracture while rolled sample is showing completely brittle fracture.

- (J1c) Fracture toughness of SHT, peak aged (SHT+PA) and 90% cold rolled (SHT+PA+90%CR) samples are determined with the help of load vs displacement diagram in all three conditions. (J_{1c}) fracture toughness value achieved after 90% cold rolling is 344.54±10 kJ/m^2. SHT sample is showing ductile fracture due to the presence of large dimples and voids, peak aged sample is showing combination of ductile and brittle fracture ascribed to having micro voids, small dimples and cleavage facet, respectively. while rolled sample is showing brittle fracture caused by cleavage facet, river like pattern and beach mark perceived on fracture surface.

Chapter 4: In this work, FCGR study correlating with microstructure analysis of SHT, SHT+PA, SHT+45% CR, SHT+60% WR and SHT+PA+90% CR 7075 Al alloy were employed. The mechanical properties were assessed using measures of hardness and tensile strength, and the fracture behavior was observed using fractography analysis and a Conditional Elastic-Plastic (J_Q) fracture toughness was calculated using load point displacement method. Based on the investigation, the following conclusions were drawn:

- EBSD and fatigue crack growth study of SHT+45% CR, SHT+60% WR and SHT+PA+90% CR sample is accomplished very well. From IPF image it is clear that SHT+PA+90% CR sample is heavily deformed than SHT+60% WR and SHT+45% CR sample. From IQ image it is found that area fraction of more than 10 µm grains are maximum in SHT+45% CR sample and minimum in SHT+60% WR sample while moderate in SHT+PA+90% CR sample because in cold rolling, grains resist fragmentation to some extent due to strain hardening whereas in warm rolling, due to elevated temperature the thermal energy allows for easier movement of dislocations within the crystal lattice.

- From ODF study it is observed that SHT+45% CR is showing strong brass ({110}<112>) texture whereas SHT+60% WR sample is showing strong rotated cube({001}<110>) texture, while SHT+PA+ 90% CR sample is showing strong brass({110}<112>), strong Cu({112}<111>) and strong S({123}<634>) texture.
- From the TEM images of the SHT + PA sample, it is evident that the precipitates (Mg_2Zn_3) have a rod-like shape, with an average length of 1.8 nm and a width of 1 nm and critical diameter of 1.95 nm. Since size of precipitate is less than the critical diameter therefore, in the present study precipitation strengthening is governed by Shearing mechanism.
- Tensile, hardness and load point displacement curve are correlated with each other and maximum strength (526±5 MPa), maximum average hardness (226 HV) and maximum conditional J_Q fracture toughness (344.54 kJ/m²) was observed in SHT+PA+90% CR sample due to strain hardening and grain boundary strengthening.
- Crack initiation taking place fast in SHT because formation of persistent slip bands (PSBs) is easier in this sample due to easy movement of dislocations while in SHT+PA+90% CR sample crack initiation is difficult as well as crack growth rate is slow because of work hardening effect and grain boundary strengthening which create obstruction in movement of dislocation and formation of PSBs.
- From the fractography of the stable crack growth (region 2) it was observed that crack propagation is faster in SHT and SHT+60% WR sample (Longer striation

length), while crack propagation is delayed in SHT+PA, SHT+45% CR and SHT+PA+90% CR sample (shorter striation length).

In the case of SHT+PA, SHT+45% CR and SHT+PA+90% CR sample due to presence of precipitates, dislocation strengthening, and precipitation, dislocation and grain boundary strengthening, respectively, were the possible reason for stable crack growth.

- Fractography of final fractured sample (After P_{max}) after J_Q reveals that the SHT sample has large ductile dimples whereas SHT+60% WR have small ductile dimples and both are following intergranular failure. SHT+PA sample has small dimples with facets and SHT+45% CR has large dimples with facets, following trans granular failure. SHT+PA+90% CR sample is showing facets and river like pattern on fractured surface. This correlate about the SHT+PA+90% CR sample has attained the Maximum P_{max} value compared to all other investigated samples.

Chapter 5: In this study, the conditional J_Q fracture behavior of Al-Mg-Zn alloy under 3.5 % NaCl environment and normal condition was investigated in relation to its microstructural evolution under various processing conditions, including SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR. Mechanical properties were evaluated through hardness, tensile strength and conditional J_Q fracture toughness measurements, while fracture characteristics were examined using fractography. Additionally, Conditional Elastic-Plastic (J_Q) fracture toughness was determined via the load point displacement method. Based on the findings, the following conclusions were drawn:

- Corrosion resistance of SHT+45% CR sample is highest (highest polarization resistance with highest corrosion life (9.869e-08 mmpy) and lowest Ecorr (0.4 V) and Icorr (8.16 µA)) due to absence of precipitates and passivation through dislocation.

- Corrosion resistance of SHT+PA sample is worst (lowest polarization resistance with lowest corrosion life (2.904e-01mmpy) and lowest Ecorr (0.7 V) and Icorr (26.27 µA)) due to presence of precipitates on grain boundary as well as on matrix.

- Corrosion resistance of SHT+PA+90% CR sample is moderate (more than SHT+PA and SHT+60% sample and less than SHT+45% CR sample and SHT sample) due to passivation through dislocations and presence of redistributed very fine precipitates

- Less no. of pits with small size is observed in SHT+45% CR sample while large no. of pits with big size is found in SHT +PA sample and SHT+60% WE sample. SHT sample has small no. of big size pits whereas SHT+PA+90% CR sample has moderate no. of pits with small size.

- Conditional fracture toughness for all five conditions sample is decreasing in 3.5% NaCl solution due to formation of pits.

- Fractography image of all five conditions sample in 3.5% NaCl solution showing more features of brittle fracture with reduced ductile dimples and more shiny cleavage facets.

- SHT+PA+90% CR condition is optimum condition with maximum hardness (226 HV in normal condition, 180±5 in 3.5% NaCl solution), maximum tensile strength (526±5 in normal condition,400±5 in 3.5% NaCl solution) and maximum conditional fracture toughness J_Q (344.54±10 in normal condition, 225±7 in 3.5%

NaCl condition) along with that moderate corrosion life(5.827e-5 mmpy) and moderate Ecorr (0.58 V) and Icorr (10.15 μA) due to formation of uniform sub grain boundary, dislocations, grain boundary strengthening and very small size uniformly distributed precipitates.

Chapter 6: In this chapter, the authors examined the fatigue crack growth rate (FCGR) of an Al-Mg-Zn alloy under five distinct conditions: solution heat treated (SHT), SHT followed by peak aging (PA), SHT followed by 45% cold rolling (CR), SHT followed by 60% warm rolling (WR), and SHT combined with PA and 90% CR. The FCGR behavior was evaluated in a 3.5% NaCl solution and compared to that of the alloy in its normal condition. Conclusion drawn from the present work is as follow

Environmental Impact on FCGR: The presence of a 3.5% NaCl environment significantly accelerates fatigue crack growth in Al-Mg-Zn alloys due to corrosion-assisted mechanisms such as hydrogen embrittlement, anodic dissolution, and pitting-induced crack initiation.

- The fatigue crack growth rate (da/dN) versus stress intensity factor range (ΔK) curve exhibits a steeper slope under corrosive conditions compared to air, indicating a reduction in fatigue resistance. The Paris law constants (C and m) are notably higher in the NaCl environment, confirming the detrimental influence of chloride ions.
- The formation of corrosion pits serves as stress concentrators, which significantly reduce the threshold stress intensity factor (ΔK) and promote early transition from pit formation to stable crack growth.

- In corrosive environments such as NaCl solutions, crack propagation accelerates due to chemical attack at the crack tip, leading to increased material loss per fatigue cycle and, consequently, longer striations. Additionally, corrosion generates hydrogen atoms that diffuse into the metal, decreasing its ductility. This promotes easier crack initiation and growth, further increasing the spacing between striations.
- The combined action of mechanical loading and electrochemical corrosion leads to a synergistic degradation mechanism, where cyclic stress opens up corrosion paths and corrosion, in turn, weakens the crack tip, accelerating fatigue failure.

Future scope: In this study, the calculated fracture toughness represents conditional elastic-plastic fracture toughness (J_Q) rather than elastic-plastic (J_{1c}) fracture toughness, as preparing a 17.394 mm thick sample after SHT+PA+90% CR proved to be a challenge. However, with advancements in techniques, it may be possible in the future to prepare such thick samples after rolling and accurately determine the elastic-plastic (J_{1c}) fracture toughness for this type of sample. Exploring this possibility could be a valuable direction for future research.