Preface

Armour is a means of protection against different kinds of projectile during combat. Armour materials perform a significant role in ballistic protection applications. Armour is needed to provide protection for soldiers against small arms and fragments. In case of combat vehicles protection is required against different lethal weapons. An understanding of the penetration mechanism of projectiles in to the target plate during the ballistic impact plays a crucial role in the design and development of any armour. Ballistic impact and penetration is a very complex phenomenon because it depends on several parameters like velocity, spin, geometry, density, strength of the projectile and thickness, strength, hardness and impact toughness of the target material. This calls for exploration of different materials and novel processing methods.

Ballistic impact research has been focused on developing lighter materials which can resist the threat successfully. Light weight armour materials are important for saving energy and increasing mobility. Therefore, materials with the lowest possible areal density that can resist the threat successfully are required in armour design studies. Aluminum alloys are of particular interest in this regard because of their high strength to weight ratio and energy absorption capability. In addition these alloys are less sensitive to adiabatic shear banding and thermoplastic instabilities due to good thermal conductivity than most of the steels. These materials can also be easily shaped or extruded into panels with integrated construction details. High strength aluminum alloys can give equally good or even better ballistic protection per unit weight compared with those of the traditional steel. Aluminum armor plates are being used mainly for protection of military vehicles against rifle ammunitions and parts of artillery projectiles. For armour application, aluminium alloys are produced in the form of rolled plates.

Age-hardenable 7xxx series aluminium alloys are widely used for ballistic resistance applications because of their superior properties like higher strength, toughness, good machinability and formability. Among these, the aluminium 7017 alloy is a Mg–Zn precipitation-hardened alloy and is one of the commonly used armour material at present. This doctoral work pertains to studies related to this alloy for armour applications.

The thesis has been divided into nine Chapters. Chapter 1 gives brief account of literature relevant to present work. This involves the historical development of armour, different materials used in ballistic resistance applications and application of aluminum alloys for ballistic applications. The scope of the present investigation has been spelt out at the end of this Chapter. Chapter 2 deals with the experimental procedures and techniques utilized for this work.

The AA 7017 alloy used in the present study was obtained from Alcan International, U.K. in hot rolled and peak aged condition. The other aluminum alloys like AA 2024, AA 2519, AA 5059, AA 5083, AA 6061 used for comparison of AA 7017 alloy were received from Aleris International, (USA).

Chapter 3 describes microstructure, texture, mechanical and ballistic properties correlation of the as received 70 mm thick AA 7017 alloy plate at surface and centre. The microstructure and texture are studied extensively at surface and centre of the plate. Tensile properties, hardness and impact toughness are evaluated at surface and centre of the plate. Ballistic properties of the plate at centre and surface are measured by impacting with two different 7.62 mm deformable projectiles (lead and soft steel). Ballistic performance of the plate at surface and centre has been correlated with the microstructure, texture and mechanical properties. Related damage and deformation microstructural patterns of the material after ballistic impact have also been analyzed. In addition, a comparative study of the mechanical properties has been carried out to explain the ballistic behavior.

Chapter 4 deals with correlation among microstructure, texture, mechanical and ballistic properties of the as received 70 mm thick AA 7017 alloy plate along three sample directions namely longitudinal (L), long transverse (LT) and short transverse (ST). The difference in microstructure and texture in L, LT and ST direction are investigated. Tensile properties, hardness and impact toughness are determined along L, LT and ST direction of the plate. Fractographic studies of the Charpy impact tested samples are carried out to reveal the difference in fracture behavior. Ballistic properties of the plate in three directions are evaluated by impacting with 7.62 mm high hardness steel projectiles. The post ballistic microstructural observations and micro-hardness measurements adjacent to the impacted crater walls have also been carried out. An attempt has been made to correlate the ballistic behavior of the material with corresponding microstructure, texture and static mechanical properties along three directions.

Chapter 5 and 6 describe the effect of heat treatment on ballistic resistance of AA 7017 aluminium alloy plates. The as-received material is further hot rolled to 40 mm thick plates. The samples are solution treated (ST) at 470 °C, water quenched (WQ) at ambient temperature followed by artificial aging. The samples are aged at three different ageing conditions namely under-aged (UA), peak-aged (PA) and over-aged (OA). Tensile properties, hardness and impact toughness of the different heat treated plates are evaluated. After heat treatment some plates from each heat treated condition are machined to 25 mm thickness to evaluate their ballistic behaviour against 7.62 mm deformable projectiles. The ballistic evaluation of 40 mm plates are carried out against high hardness steel projectiles. Chapter 5 elucidates the effect of heat-treatment on the mechanical properties and ballistic performance of 40 mm thick AA 7017 alloy plates. The variation in microstructure and micro-hardness of the heat treated plates after ballistic evaluation against deformable projectile has been analysed in Chapter 6.

Chapter 7 illustrates a comparative study of the mechanical and ballistic behaviour of AA 7017 alloy with other commercially available aluminium alloys used for armour application like AA 2024, AA 2519, AA 5059, AA 5083 and AA 6061. Microstructure, tensile properties, hardness and impact toughness of all the aluminium alloys are evaluated. The ballistic behaviors of all the aluminium alloys are obtained by impacting 20 mm thickness plates with 7.62 mm deformable projectiles. The ballistic behavior of the different aluminium alloy plates have been interpreted in terms of their mechanical properties. The changes in the microstructure, hardness and damage pattern in post impact samples have also been studied to understand their deformation behavior at high strain rate.

Chapter 8 elucidates the comparison of the ballistic behaviour of AA 7017 alloy with AA 2024 and AA 6061 against two different caliber high hardness projectiles. The 70 mm thick plates of the aluminium alloys are impacted with 7.62 mm and 12.7 mm high hardness steel projectiles. The variations in the microstructure, hardness and damage pattern in the aluminium alloys have been equated to understand their deformation behavior during ballistic impact.

Chapter 9 gives summary of the results as well as scope for future investigations. The important conclusions drawn in this Chapter are enumerated below:

1. Microstructure and texture of the AA 7017 plate are inhomogeneous at surface and centre. The different microstructures and textures at surface and centre of the plate give rise to anisotropy of the mechanical properties. This has resulted in a difference in ballistic behaviour of the material at the centre as well as on the surface of the plate.

2. There is a variation in morphology and orientation of the grains along three directions of the AA 7017 plate. As a consequence of such a variation, anisotropy in mechanical properties and fracture behaviors along three directions is observed. This causes a difference in ballistic behaviour of the material when impacted along different directions.

3. Mechanical properties of AA 7017 alloy vary significantly with heat-treatment and ballistic penetration resistance of AA 7017 alloy increases with increase in strength and hardness of the plates.

4. Strength and hardness values are dominant parameters in comparison to ductility and toughness in determining the ballistic performance of aluminium alloys against small caliber ammunitions. Among the studied aluminum alloys AA 7017 alloy demonstrates the best ballistic resistance owing to its superior strength and hardness values.