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An experimental study on the deformation behavior of Aluminium armour plates impacted by two different non-deformable projectiles

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Abstract

The present study describes the experimental results pertinent to the penetration of AA-2024, AA-6061 and AA-7017 plates with two different non-deformable steel projectiles. The diameters of the projectiles used for ballistic impact testing are 7.62 and 12.7mm. The projectiles are impacted on the aluminium targets of 70 mm thickness with velocities in the range of 840±10 m/s. The results presented include variation in damage pattern in experimental alloys with respect to different projectiles. The microstructures and micro-hardness values along the projectile penetration path have been investigated to understand the material deformation behaviour. Some observations relating to the adiabatic shear band formation have also been presented. From the ballistic testing experiments, it is observed that AA-7017 plates display higher ballistic resistance among the tested aluminium alloys. The ballistic performance of the aluminium alloy plates have been correlated with their respective mechanical properties.

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Key words: Aluminium alloys; Mechanical Property; Ballistic Performance; Adiabatic Shear Band.

1. Introduction

Aluminium alloys are extensively used in applications where weight is an important design criterion. These alloys are very popular in automotive and aerospace applications owing to their high strength, low density, good fracture toughness, good formability, ease of weldability for manufacturing purposes and excellent corrosion resistance. Based on these properties, these alloys are also candidate materials for ballistic applications wherein steels are normally chosen. In addition, several investigations have shown that the aluminium alloys can reduce the

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weight of a protective structure by approximately 25% in comparison to those of steels against a similar level of threat [1-2].

Ballistic impact is an immensely localized process. Heat generated during such severe and rapid impact may induce local thermal softening and microstructural instability. The research activities in the field of ballistic impact have been mainly focused on experimental tests, understanding the behaviour of materials under high strain rate loading and creation of analytical models. However, majority of these investigations to a certain extent lack the inclusion of starting microstructure and its subsequent modifications during projectile impact. In addition, material failure at high strain rates is a complex process involving many material parameters like strength, hardness, ductility, toughness, strain hardening co-efficient etc. Materials with a balanced combination of strength and toughness may display better ballistic performance in comparison to those only having higher strength or toughness [3]. It is, therefore, of interest to study the deformation behaviour of different aluminium alloys based on microstructural modifications in post impact materials.

In the present study, the ballistic behaviour of three different series of heat treatable aluminium alloys namely AA 2024, AA 6061 and AA 7017 plates subjected to the impact of 7.62mm and 12.7mm projectiles has been investigated. The changes in the microstructure, hardness and damage pattern in post impact samples with respect to the two different projectiles have been studied.

2. Experiments

The analysed chemical composition of the three aluminium alloys is given in Table 1. The aluminium alloys were received in the peak aged condition in the form of 70 mm thick plates. Microstructure characterization of the plates were carried out following standard metallographic techniques used for aluminium and its alloys and etched using Keller’s reagent (5ml HNO_3, 3ml HCl, 2ml HF and 190 ml H_2O). Mechanical properties of the alloys were evaluated by hardness and tensile properties measurements. Hardness of the plates was measured according to ASTM E 140-02 by using a Vickers hardness tester. 10 kg load was employed to determine the hardness of the plates. Tensile samples are machined according to ASTM 8 and tensile properties were evaluated at an ambient temperature on round tensile specimens (20 mm gauge length) using INSTRON 8500 testing machine at a crosshead speed of 1.0 mm/min. In case of each alloy, three tensile tests were carried out and average values of the properties are reported.

Ballistic tests were conducted in a small arms range using a standard rifle. All the tests were carried out at normal impact angle i.e. at zero obliquity. The plates were impacted with two different non-deformable steel projectiles. The detailed description of the projectiles is illustrated in Table 2. The angle of attack was normal to the target plates. The striking velocity of the projectiles was measured using infrared light emitting diode photovoltaic cell by measuring the time interval between the interceptions caused by the projectile running across two transverse beams placed 2 m apart. The velocities of impacts were within range of 840± 10 m/s. The projectiles were fired from a distance of 15 m. The testing arrangement is described elsewhere [4]. At least three shots were fired on each plate and three sets of plates were fired in order to get the ballistic behavior statistically. After ballistic testing, plates were cut into half across the craters and then subjected to standard metallographic procedure to reveal the post ballistic microstructures. The microstructures along the path of the projectile were examined in optical microscope. Vickers micro hardness values were obtained adjacent to the crater wall along the path of the projectile by using a Leica micro hardness tester at 100 gm load.

Table 1. Chemical composition of aluminium alloys

Material	Chemical composition (Wt.%)
AA 2024	Cu – 4.05, Mg – 1.43, Si – 0.43, Mn - 0.38, Fe - 0.32, Ti - 0.017, Pb - 0.031, Al - Balance
AA 6061	Mg – 1.2, Si – 0.8, Fe – 0.7, Cu – 0.4, Mn - 0.15, Cr – 0.35, Zn – 0.25, Ti – 0.15, Al – Balance
AA 7017	Zn – 5.2, Mg – 2.3, Si – 0.35, Cr - 0.35, Fe – 0.45, Mn - 0.2, Zr – 0.1, Al – Balance

Table 2: Some parameters of the projectiles

Property	Projectile	
	7.62mm	12.7mm
Core material	High hardness steel	High hardness steel
Bullet length	26.53 mm	52.7 mm