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Polyurea coated composite aluminium plates subjected to high velocity projectile impact

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ABSTRACT

High velocity projectile penetration through polyurea coated AA5083-H116 aluminium alloy plates has been studied. The effect of different polyurea thickness on the residual velocity of full metal jacket (FMJ) projectiles is examined and presented. Steel-tipped 5.56 calibre (5.56 × 45 mm) projectiles were fired at coated aluminium plates from a distance of 10.0 m at a fixed velocity of 945 m/s. Seven configurations of plate arrangements with different total thicknesses were used. Each configuration consisted of combinations of 5 mm and 8 mm base plates (AA5083-H116) with 6 mm and 12 mm polyurea layers. A 5.56 calibre gun was used to shoot at close range, where the targets were placed perpendicular to the flying direction of the projectile. The input and output velocities were measured using two laser velocity screens. The effectiveness of the polyurea coating in terms of reduction of the residual velocity, damage mechanism, kinetic energy absorption of the plates, and the effect of different layer configurations on residual velocity are presented and discussed. By comparing the different thicknesses of polyurea coatings, it indicated a good ability in absorbing energy, and subsequently, in a reduction of the residual velocity of the projectiles. Also, the ability of the polyurea coating to act as a protective shield against flying particles and fragments was established.

1. Introduction

Over the last few decades, many researchers have investigated the use of polyurea as a protective coating material due to its ability to absorb a considerably high amount of energy compared to most other similar coating materials. In recent years, researchers have drawn their attention towards the application of polyurea to enhance the resistance of structures and systems against extreme impulsive loadings. With adequate surface preparation, polyurea bonds well with most structural materials (such as concrete, steel and aluminium), thereby forming composite behaviour. It can be used either as the outer face of a structure, or as an interlayer material, by utilising its compressive or tensile properties depending upon the nature of the load transmitted. However, most previous research work on polyurea coated plates has been focussed only on distributed dynamic loadings induced from an event such as a blast. Very limited attention has been paid to investigate its behaviour under localised loadings which can be generated from an event of ballistic impact. Xue et al. [1], Sayed et al. [2] and Roland et al. [3] are a few instances where the polyurea coated materials were investigated under ballistic loadings. These investigations were studied on considerably larger diameter projectiles in comparison to handgun ammunitions where the impact object's diameter is in the range of 3–10 mm. This study attempts to address this gap in knowledge by examining and quantifying the velocity reduction ability of different thicknesses of coatings and the possibility of using polyurea as a protective coating against ballistic threat scenarios.

Ballistic impacts generally induce localised failure in their targets. The working mechanism of real ammunition starts by creating a ductile crater and enlarging it till the ammunition reaches complete penetration or loses its momentum completely. This whole process depends on the behaviour of materials during the deformation process, as well as the structural dynamics effect involved during the impact and penetration process. In order to understand this complex mechanism comprehensively, one must study the real ammunition penetration at the recommended velocities rather than simplifying the process with rigid non-deformable projectiles.

As highlighted above, several investigations have been performed over the last decade to study the ability of polyurea in reducing the destructive effects from projectile impact. A detailed numerical and experimental program of rigid projectile penetration through polyurea coated DH-36 steel plates was performed by Xue et al. [1]. They observed a positive contribution from the polyurea coating in terms of improving resistance against ballistic

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impact when applied at the back face of the plates. A computational and experimental assessment of ballistic effects on polyurea retrofitted high strength structural steel plates was carried out by Sayed et al. [2]. Roland et al. [3] reported on the ability of polyurea coatings to enhance the resistance of High Hardness Steel (HHS) plates under high velocity impact, where they observed the effect of different layer configurations on the residual velocity. The glassy phase transition of polyurea during the impact was highlighted in this study [3]. A study on the ballistic resistance of nano-enhanced polyurea coated plates subjected to ballistic impact was reported by Fowler [4]. Meanwhile, Amini et al. [5] and Nemat-Nasser [6] investigated the effects of polyurea coatings on steel plates when used as monolithic and bilayer steel–polyurea plates subjected to impulsive and direct pressure pulse. Their investigation revealed that polyurea applied on the back face of the plate played a significant role in reducing the critical effective plastic strain, and highlighted the significance of interface bond strength between the plate and the polymer layer on the performance of the bilayer plates [5,6]. A comprehensive study on high velocity impact mitigation of nano-enhanced polyurea composites has been reported by Al-Ostaz et al. [7].

In addition to these researches, a number of numerical investigations have been undertaken on polyurea coated plates subjected to ballistic impacts. Amini et al. [8] extended their investigation reported in [5] to numerically analyse the response of monolithic and bilayer plates under impulsive loads. Grujicic et al. [9] investigated the impact energy absorption capacity of polyurea coatings via deformation induced glass transition in the material. An enhanced computational model has been used to incorporate the effect of fracture into the simulation of polyurea.

Several researches have also been reported in recent years examining the usability of polyurea to mitigate blast-induced damage of both steel and concrete structures. Ackland et al. [10] investigated the ability of polyurea to mitigate damage on steel armour plates under blast loading. Meanwhile, Raman et al. [11] used polyurea coatings as a protective measure for reinforced concrete panels and concluded that the coating contributed positively in reducing damage to the panels. Composite sandwich plates with polyurea interlayers were used by Bahei-El-Din et al. [12] and Bahei-El-Din and Dvorak [13] to examine the blast mitigation capability of the composite panels. Tekalur et al. [14] observed that the enhancement of blast resistance of composites was more pronounced when the soft material faced the blast pressure. Polyurea has also been investigated for application as a suspension pad material in combat helmets by Grujicic et al. [15]. Experiments have revealed that the polyurea pads have a substantial ability to lower the peak loading experienced by the brain during a blast event.

The main objective of the present study is to assess the ability of polyurea (when used as a coating material) to reduce residual velocity under high velocity ballistic impacts. An attempt has been made to analytically quantify the velocity reduction with reference to the thickness increment of the polyurea layers. In addition, failure mechanisms of the layered plate systems, effect of different configurations towards the reduction of residual velocity, and the energy absorption capacity of polyurea were analysed and presented.

2. Characteristics of target plates and projectiles

2.1. Composite plate configurations

Table 1 presents schematic views of the composite plate arrangements used in this study. The base plates were made from a combination of 5 mm and 8 mm aluminium alloy AA5083-H116 plates. In configuration C_1, three 5 mm thick plates were bundled to form a 15 mm thick layered plate system. Configurations C_2 and C_3 are polyurea coated versions of configuration C_1, and all three consist of a total aluminium thickness of 15 mm. Similarly, configurations C_4–C_7 are formed from the combination of two 8 mm aluminium plates. Different configurations have been formed by applying 6 mm and 12 mm thick polyurea coatings to the base plates, as shown in Table 1.

2.2. Projectiles

The projectile mass, area of contact, and material properties of the target and the impactor have a high influence on the penetration mechanism. Most of the previous researches on polyurea coated plates have been conducted using rigid projectiles with considerably larger diameters compared with normal handgun ammunitions [1,9]. Assumption of rigidity of the projectile material can under-predict the restraining capacity of the target, as most of the commercially available handgun ammunitions are made out of deformable materials. Use of larger diameter projectiles over-predicts the restraining capacities of the targets, since a larger contact area of the projectile facilitates in the resistance provided by the targets. Therefore, such assumptions can result in considerable misrepresentations in an actual ballistic event.

Full metal jacket (FMJ) 55 grain (3.56 g) 5.56 × 45 mm projectiles were used in this study. Fig. 1a shows a general view of the projectile and Fig. 1b shows a close-up view of the projectile. A schematic view of the projectile cross-section obtained along the symmetrical axis is given in Fig. 2. The projectile consists of a brass cover, steel tip, and lead core.

2.3. Target plate material

Aluminium alloys have been studied as possible candidate materials for personal protection armour applications due to their low densities and their comparatively high ductilities and strengths. As such, aluminium alloy AA5083-H116 was selected as the base material in the layered plate systems throughout this study. Aluminium AA5083-H116 belongs to the aluminium 5000 series and is alloyed with magnesium as the major component. Aluminium 5083 is mainly used for cryogenic applications, which are done at very low temperatures, thereby using its brittle-ductile non-transition property. The main reason for selecting aluminium for structural systems (such as armour, naval and marine structures) is its tendency to resist corrosion and its comparatively high ductility compared with most other aluminium alloys [16]. The chemical composition of the aluminium alloy is presented in Table 2.

2.4. Polyurea coating

Polyurea is a type of elastomeric material formed by the rapid chemical reaction between an isocyanate and an amine. A detailed description about the formation of polyurea is reported in Grujicic et al. [17]. Due to the complex nature of its microstructure, polyurea shows a high level of stress–strain non-linearity, rate sensitivity, and a high degree of pressure dependency compared to other elastomeric materials. In addition, polyurea has a higher energy density than most other elastomeric materials. In recent years, a spray-in-place methodology has been introduced for polyurea coating, which has increased its usage in many industrial applications such as tank liners, manhole and tunnel coatings, and secondary coatings on bridges, roofs and parking decks. It also possesses the desired characteristics for effective protective coating application against blast and ballistic loadings in both vehicles and ground structures.