A Review on Contact Ballistic Impact Studies on Monolithic Plate and Welded Joints

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ABSTRACT

In recent years, the ongoing threat of ammunition and explosively-formed projectiles to civil and military structures has increased the need of improvement against ballistic impact loading. In the present work an attempt has been made to study the influence of parameters such as, bullet shape, bullet size and failure mechanisms on ballistic behavior of monolithic plates and welded joints. Since the ballistic experiments are often time consuming and expensive, many researchers have investigated the ballistic behavior of targets using numerical method. The present paper provides the comprehensive summary of the art of experimental ballistic studies of monolithic, composite plates and welded joints which are commonly used in bullet proof jackets, combat vehicles and aircraft structures. The present work also explores the future scope available to improve the ballistic behavior of targets.

KEY WORDS: Ballistic impact loading, Ballistic behavior, Bullet shape, Welded joints, Bullet proof jackets.

1. INTRODUCTION

Due to the increase in violent incidents around the world, such as, terrorist attacks on the world trade Centre in New York, trains in Madrid and the metro system in London, awareness of the public safety raises in the private sectors, government and semi–government organization. In general, “Ballistics” is defined as the science which deals with a phenomena that occurs when a projectile is fired until its effects are observed in a target. In contact ballistics, the projectile directly comes in contact with the target. In non-contact ballistics, shock waves are generated due to bombs and nuclear effects. Fig.1.illustrates the general threats occurring to the army and civil structures. For many decades, researchers have been focusing on utilizing high strength metallic alloys to struggle the ballistic threats by increasing the strength of the materials (DamithMohotti, 2015).

Nowadays, many researchers investigate the ballistic behavior of lightweight materials, which can be used to blast and ballistic protective structures (Abdullah, 2015). The major cause of failure is due to impact loading caused by the bullet which penetrates through the tank sheet and frames of ground vehicles. At present ground vehicles and trailer bed frames and aircraft cockpits are replaced by lightweight materials. It was observed that, the shape of the tank and trailed bed frame is joined by welding. Automobile manufacturers, dedicatedly work towards achieving in ballistic and armor protection in four wheelers. The armored passenger cars are being developed by the specialized automotive companies. This review paper focusses on the various terminal ballistics studies which are carried out by experiment. The study of terminal ballistics helps to develop more effective weapons and to invent new methodologies to protect against enemy weapons.

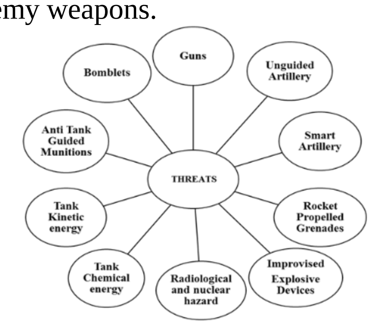

Figure.1. Platform of Threats

Studies on Influencing Parameters on Ballistic Performance of Targets: In this section, the influence of various ballistic parameters such as, target material, projectile geometry and material, failure mechanism and microstructure, on ballistic behavior of targets and welded joints have been reported.

Effect of Material Property on Ballistic Behavior: Materials such as, Rolled Homogeneous Armor (RHA) steel, aluminium alloys of various series and magnesium alloys are generally used to manufacture the structures of aerospace, marine, automobile and defense combat vehicles sectors. It has been reported that, the most significant factors affecting the ballistic resistance of the huge target plates are its size, shape, density, hardness, ductility, microstructure and thickness. Commonly, ground vehicles and aircraft cock pit are subjected to low to moderate impact loading. Jones (2007) investigated the ballistic performance of the AZ31B magnesium alloy plate and compared with aluminium 5083 plate. It was noted that, AZ31B saves 20mm Friction Stir Processing (FSP) performance. Demir (2008) compared the ballistic behavior of aluminium alloys of AA7075 and AA5083 with High strength low alloy steel (HSLA) against 7.62 mm Armor piercing projectile (AP) and observed improved performance of aluminium alloy 7075. The author also suggested that magnesium alloy is suitable material for ballistic and military applications. Dey (2007), compared the ballistic behavior of Weldox 700E steel target plate with double layered target. The authors used the numerical and experimental methods to determine the ballistic resistance. Improved ballistic resistance was observed for double layered targets compared to monolithic targets. In recent years, armor plates of RHA steel are replaced by the aluminium and magnesium alloys for weight reduction and less fuel consumption of armor vehicle without compromising penetration resistance. The projectile penetration resistance still can be increased by increasing the properties of target materials. It was also noted that lack of work has been done to study the ballistic behavior of magnesium alloy targets.

Studies on Ballistic Behavior of Composite and Non-Ferrous Materials: Many researchers have studied the ballistic behavior of targets made up of composite materials. Borvik (2009), has compared the ballistic resistance of five different armor grade monolithic metallic targets (Weldox 500E, Weldox 700E, Hardox 400, Domex protect 500 and Armox 560 T) with metal matrix and surface composites. It was observed that, for both protection classes, only steels that meet the requirement for used thickness are the armor steels (Domex protect 500 and Armox 560T) .Sullivan (2011), observed that, aluminium alloy of 7010 has shown less ballistic limit due to loss hardness due to over ageing. Sudhakar (2016), investigated the effect of addition of boron carbide powder during friction stir processing of AA7075 aluminium alloy. It was noticed that addition of boron carbide powder increases the surface hardness of aluminium and thus improved ballistic resistance. It was also noticed that, addition of molybdenum di-sulphide to boron carbide on the surface decreases the depth of penetration of projectile resulting in the stopping of projectile in the thick target plate .Karamis (2003), tried to improve the ballistic resistance of aluminum alloy AA5083 and AA6063 by reinforcing silicon carbide powder. Reduced penetration depth of the projectile was noticed. Generally ballistic test has to be performed to determine the ballistic limit for any applications with the help of residual velocity. Reported that polyurea layers contributes positively towards the reduction of residual velocity of the projectile in composite plate systems of AA5083 Aluminum alloy. The effect of adding lead along with magnesium alloy was found that increase in the ballistics impact compare with monolithic plate of magnesium AZ31B.

Studies on Ballistic Resistance of Welded Joints: Many researchers have studied the ballistic resistance of welded joints using numerical and experimental methods. Generally three different welding process are commonly used for fabrication of combat vehicle's namely, Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW) and Flux Coated Arc Welding (FCAW) (Balakrishnan, 2013). It was observed that, SMAW process offer highest ballistic limit and lower Heat Affected Zone (HAZ) soft zone width .Found that HAZ as greater ballistic limit when compared with the harder T7651 tempered condition. It was also understood that, improved ballistic performance occurs with conditions of lower heat input, narrow HAZ and free of deformation. In addition, the welded armor steel joints shows poor ballistic performance compared with base metal (Balakrishnan, 2013). It was noticed that, ballistic failure mode can be controlled by the weld factors like weld quality, relative and absolute sizes of the Fusion Zone (FZ) and HAZ (Grujicic, 2015). In the welding process, the heat input plays an important role resulting in a lower yield strength, which has an undesirable impact on the ballistic limit (Borvik, 2008). The increased heat input results in wide soft zone leading to poor ballistic performance. The ballistic shock performance of the friction stir welds improves the performance over welds made with GMAW was demonstrated. It was examined that aluminium alloy weld by friction stir welding process would yield better resist cracking under ballistic shock (Sudhakar, 2016). The effect of the post weld residual stress with associated plastic damage on the ballistic performance of AA6061 similar and dissimilar welded combination was numerically investigated .In the HAZ and FZ, increase in material hardness, decrease in ductility, formation of the back face petaling becomes less pronounced and progressively replaced by spalling.

In recent years, three different types of hard facing technique is adopted. Among them plasma transferred arc hard facing technique has more advantage as it causes lower dilution and narrow HAZ over conventional technique. Hard facing weld consisting of uniformly distributed hexagonal chromium carbides in an austenitic matrix possessing of high hardness can be beneficial to improve the immunity of ballistic resistance .Tungsten carbide and chromium carbide hard faced inter layers successfully stops the projectiles penetration due to the higher hardness and tough Stainless Steel (SS) root layer .The sandwiching of plasma transferred arc (PTA) hard faced interlayer in between the soft austenitic stainless steel and normal sandwiching showed better ballistic performance than the normal welded joints. The hardness level of the steel armor target is as high possible which enhances ballistic resistance. The property of hardness plays an important role in increasing the ballistic resistance of welded plate was investigated by several papers.

Studies on Effect of Projectile Geometry on Ballistic Resistance: Many researchers have made an attempt to determine the effect of projectile geometry on ballistic resistance of targets. Ball projectile has a soft core of alloyed lead, while the armor piercing projectile AP has hardened steel core as shown in Fig.2. The AP bullet is composed of brass jacket, hardened steel core, sabot, and lead antimony cap. Fragment simulating projectile (FSPs) is the standard for developing armor. The AP projectile absorbs the impact energy due to the enlargement of ductile hole.

Different types of geometry and materials will be used for manufacturing the bullets. Various geometry of projectile behaves differently during the penetration of target considering the shape, size, material of the bullets during the conduct of test. The ball projectile consist of soft lead core is cast into 87 % of copper and 10% of zinc whereas armor piercing projectile consists hardened core of 1007 tool steel inserted in brass (Borvik, 2009). Generally, the nose shapes are designated such as conical, hemispherical, hemispherical + conical are made up of maraging steel with a heat treated one. The projectile with hardened steel core of 7.62 mm × 63 AP M2 projectile has been found as the toughest to defeat for high strength steel plates. The FSPs consists of a cylindrical shape and a flat front face with two chamfered edges.

It was found that, conical projectile penetrates the target in a less efficient way than blunt projectiles when the target thickness was moderate. The projectile with blunt nose shape shows higher ballistic resistance. The different nose shape projectile (blunt, hemispherical and conical) made up of arne tool steel used to penetrate 12 mm thick, weldox 460 E steel plate and it was found that hemispherical and conical projectile gives a ballistic limit velocity close to 300 m/s, while the blunt projectile has the ballistic limit of 85 m/s. It was found that hollow bullet was able to achieve greater penetration depth and maintain higher exit velocities than the corresponding traditional bullets. If the bullet velocity increases, the internal energy of the target plate also increases. During the penetration process the projectile head under goes high strain. The maximum amount of the kinetic energy absorbed by a hemispherical nosed projectile has been reported. The ballistic behavior of aluminium alloy of 7075, 5083 and HSLA steel, AISI 4140 against 7.62 mm armor piercing projectile was compared. They observed that AZ31B + 1% Pb gives minimum energy which is 874 J for 9 mm × 19 mm parabellium projectile. But NATO projectile of 5.56 mm × 45 mm has higher energy of 1584 J. Impact angle also plays the vital role .The oblique impact revealed that the residual velocity of projectile decreased by 8 % and 7% for 15° and 30° impact angle respectively (Balakrishnan,2013).

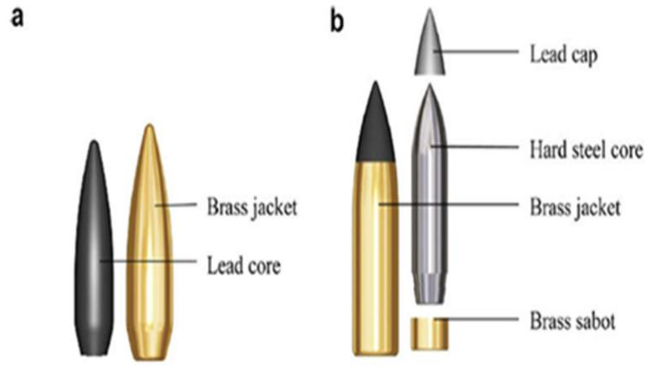

Figure.2. (a).Ball projectile (b). Armor piercing projectile (Borvik, 2008).

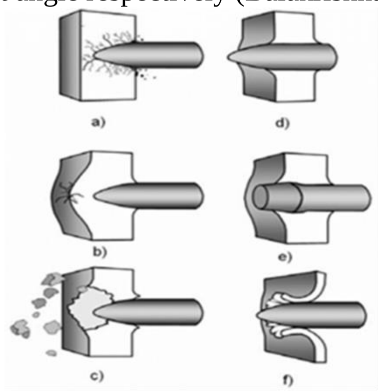

Figure.3. Failure mechanisms, (a) Brittle cracking, (b) Radial cracks initiating at the projectile exit side, (c) Fragmentation, (d) Ductile hole growth, (e) Plugging, and (f) Back plate petaling (Sullivan, 2011).

In summary, bullet shape, size and material affects significantly the ballistic resistance of monolithic plate and weld joints. Different types of bullet exhibit different penetration mechanism, which consequently bring above diverse damage shapes. There is general trend that can be related to bullet parameters for all the materials and weld joint, therefore each material need its own study to achieve its ballistic limit for the ballistics test.

Studies on Ballistic Failure Mechanism: There is different failure modes associated during bullet penetration on the target due to the projectile motion. The types of failure shown in Fig.3.

Plugging Failure: This type of failure mechanism is connected with the formation and ejection of a cylindrical slug of the projectile which was shown in Fig. 4 (a). For hemispherical projectile, the Plug ejection failure mode was observed it was observed in case HAZ and FZweld zones being impacted with blunt projectile the result of shear cracking produced the formation of the adiabatic plastic shear band.

Spalling Failure: Spalling failure mechanism involves the separation of target material at the rear face. This type of failure is dominated by the normal through the thickness direction and shown in Fig. 4 (b). The loss of ballistic performance at high hardness within the weld joint related to spalling. The fragment simulation projectile to cause the spalling failure. This failure can be controlled by strengthening of the grain boundary.

Petalling: Front face and rear face petaling was observed for low hardness conditions. Blunt projectile failed the target by plug ejection due to process of high speed shearing, conical projectile causes failure due to process of piercing. Therefore, the findings of this study gave clear indication of the different failure mechanism associated during penetration each projectile behaves different failure mechanism. From most of experiments it is clear that FSPs caused by spalling failure, ductile hole enlargement caused by hemispherical and front face projectile due to sharpness of tip. Blunt and conical projectile causes petalling failure.

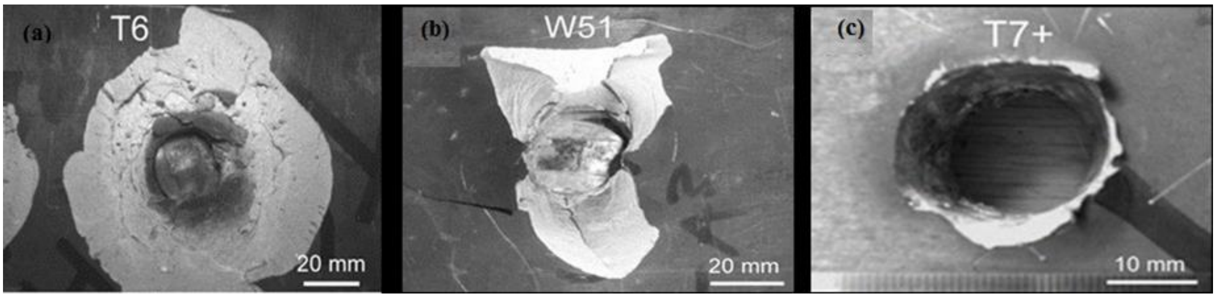

Figure.4. Rear face damage after ballistic test by FSPs projectile of friction stir welded aluminium alloy of AA7010-T6 condition (a) Plugging failure, (b) Spalling failure, (c)Ductile hole enlargement failure (Sullivan,2011)

Ductile Hole Enlargement: Ductile hole enlargement is the combination of petalling and spalling failure mechanism which was shown in Fig.4 (c). The HAZ generated in welding results in a lower material yield strength, which has negative impact on ballistic limit when failure is dominated by ductile hole enlargement .Hemispherical shape projectile and conical projectile lead to radial expansion inducting necking and radial cracks. In AA5083 which had resistance to adiabatic shear band formation was found to fail by ductile hole growth mechanism (Karamis, 2003). The higher level of hardness of target stop the ductile hole enlargement. This failure mechanism can be controlled by the increased the hardness and fracture toughness of the target material.

4. CONCLUSIONS

The present paper reviewed the research activities and progress in the development of experimental studies in concern with contact ballistic impact behavior on monolithic plate and welded joints. The effect of bullet shape size, failure mechanism and failure mode has been highlighted. In contrast to the reported observations, improved ballistic resistance has been attained by adding the ceramic powder to the aluminium, magnesium alloys. Thus there is significant scope to determine the influence of ceramic powder addition on projectile penetration. Each material needs its own welding process and parameters for identifying the various aspects of improving the ballistic strength of the welded joint. Friction stir welding are efficient with much reduced porosity, cracking distortion, minimized heat affected zone. Better ballistic performance is exhibited by friction stir welds. The discussion of the results takes into account recent information obtained from the experiment ballistic standards and effects.

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