

Penetration of Hemispherical Projectile Into the Three Layer Targets with Different Materials and Layouts

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Abstract. In this paper, the penetration of a hemispherical projectile into the targets with three adjacent layers (without air gap) with different arrangement and materials has been studied. To study the set parameters, some ballistic tests as well as FEM simulations had done and the numerical results compared with experimental ones. While defining ballistic limit for the projectile-target system, the effect of layers arrangement sequence and material in their ballistic operation was perused. The result of the experiments showed that if the aluminum plates (harder material) are placed in the two first layers and CU (softer material) is placed in the third layer, the resistance against penetration will have the maximum value. Experimental results show that by decreasing the initial velocity of projectiles, velocity downfall is increased while the amounts of absorbed energy do not change significantly. The projectile velocity has a significant effect on the fracture mode. Increasing the velocity make the fracture accomplish in the Plugging mode while decreasing the velocity get the fracture to take petaline mode.

1. Introduction

The penetration of projectile into the target is a complicated mechanical process. This subject has been under consideration by researchers due to its military and non-military applications. The most important applications of this subject include: military applications like the design of structures that are resistant against the penetration of projectile, anti-bullet armors, design of the light weight armor systems (personal armor) to protect police officers, governmental and military individuals, design of missiles and rockets, and non-military applications like manufacturing of machines for transporting dangerous materials, strengthening the body of helicopters and aircrafts, design of ships body, protecting spacecrafts, securing important centers and design of protective coverings for nuclear reactors. In the above mentioned applications the impact loads arising from the stroke of external objects such as missiles and rockets or internal reasons like increasing the applied pressure are of the major importance.

In 1973 Zaid et al. [1] studied multi-layer targets and concluded that single plate of equal thickness have more strength in comparison with laminated (multi-layer) shields when the thicknesses in both states are equal while by increasing the thickness of targets, the resistance of multi-layer targets would be larger than solid targets.

In 1978 Backman and Goldsmith [2] during a series of ballistic experiments showed that the resistance of multi-layer objects is less than monolithic targets. In 1979 Marom and Bodner [3] studied analytically and experimentally the resistance of adjacent multi-layer and monolithic targets with identical thickness against penetration for Al6061-T6 materials. They deduced that in comparison with



solid targets, multi-layer targets have more resistance. In 1983 Corran et al. [4] stated that in comparison with monolithic targets, adjacent multi-layer targets have more resistance if the arrangement of layers causes to change the response of targets from shear state to bending or membrane extension state. In 1990 Nurick and Walters [5] perused the resistance against penetration for multi-layer targets and they concluded that in comparison with solid targets, ballistic limit for multi-layer targets has greater value by 4% to 8% when the thickness in both states is identical.

In 1991 Woodward et al. [6] studied the penetration through adjacent multi-layer sheets. They demonstrated that near the ballistic limit, the amount of energy absorbed by thin steel targets is independent of three components of being laminated, bending and tension while the material properties have the main effect in this case. They also stated that in penetration process, layers with specific gap have more efficiency in comparison with laminated layers with no gap. In 1988 Radin and Goldsmith [7] during a series of ballistic experiments that was performed with ductile aluminum demonstrated that the resistance of multi-layer targets with gap is less than the resistance of multi-layer targets with no gap. In 1999 Ben-Dor et al. [8] studied the effect of arrangement of adjacent multi-layer targets with different materials in the penetration of a projectile with semi-spherical head. They introduced distortion pressure and stated that for increasing the resistance of a target, the layers should be arranged so that this ratio of distortion pressure is increased. In 2000 Chao et al. [9] perused two-layer targets during a numerical study. In 2002 Borvik et al. [10] studied penetration of projectiles with flat, semi-spherical and conical heads through steel sheets using ballistic experiments. In 2005 Elek et al. [11] perused multi-layer targets using a thorough analytical study. During this study they perused the effect of sequence of layers arrangement and number of layers. Using their analytical model they specified that the maximum resistance of a target is obtained when the thickness of first layer approaches to zero and this is equivalent to using a solid target. This study declared that increasing the number of layers results in the reduction of projectile penetration into the target. In 2007 Dey et al. [12] studied the resistance of multi-layer targets with different arrangement sequences against projectile penetration and they concluded that despite of the projectile geometry, the resistance against the penetration for two-layer targets in comparison with solid targets is significantly greater. In 2008 Gupta et al. [13] studied the behavior of laminated aluminum sheets with various thicknesses and solid sheets with equivalent thicknesses. They stated that by increasing the number of layers, the downfall in ballistic limit velocity is less in comparison with solid target. Referring to results printed by other researchers one can say that for determining whether multi-layer targets are more resistant or solid targets, different parameters should be assessed including impact velocity, target material and thickness, projectile head geometry, projectile stiffness, the number and arrangement of layers, the gap between layers and etc. Accordingly for achieving a precise result, all of the possible states should be studied. In the present study, the resistance against penetration for three layers targets with different materials under the impact of a cylindrical projectile with semi-spherical head is perused experimentally. The main object of this research is to compare the ballistic operation of multi-layer targets with different materials using eight different arrangements. The results of experiments and numerical simulations are compared and then the amount of error related to numerical simulation is calculated.

2. Experimental Work

The equipments used for experiment are: gas gun with caliber of 8.7 mm and length of 2 m, pressurized Helium gas used as the firing instrument in the tests and a chronograph that is placed after target to increase accuracy in measuring residual velocity of projectile. There is a fixture around all of the targets as depicted in Fig. 1.

To prevent deviation of projectile, targets are placed in front of the gun at a distance of 30 mm. To obtain the impact velocity, gun volleys three to six times before targets are placed within the fixtures. When the projectile crosses between two optical sensors, which are placed in front of the target, chronograph saves the time of the projectile stroke. According to the velocity formula, the velocity of impact is calculated.

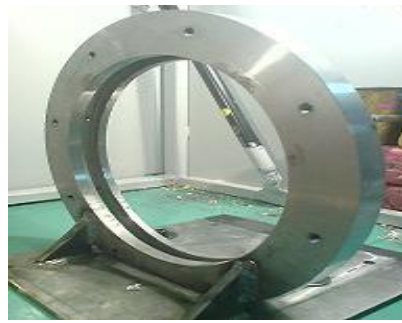


Figure 1. Targets support.

2.1. Preparation of projectile and samples

The targets are circular sheets with diameter of 240 mm, thickness 1 mm and the materials chosen are unalloyed copper (cu) and aluminum 1100 (al). Due to using three-layer targets, eight possible modes of layers arrangement are considered.

The material of projectiles used in the experiments is silver steel which are hardened to 54 Rockwell to prevent them from sustaining plastic deformation while impacting with targets. The dimension and geometry of all projectiles is depicted in Fig. 2. It should be noted that all projectile have a mass of 11.30 g.

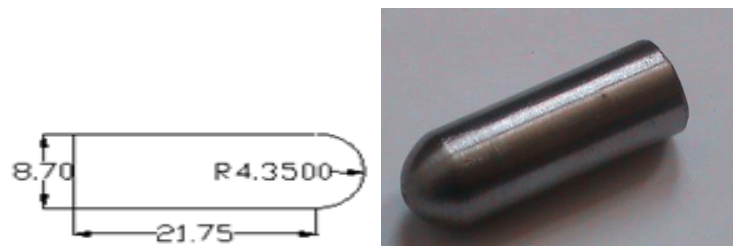


Figure 2. Projectile dimension and geometry

2.2. Tensile test and material analysis

To obtain the properties of projectiles and targets, tensile tests and material analysis are implemented. According to the ASTM-E8 standard [14] that is used for non-ferrous sheets, three samples are formed for each target using a milling machine. After tensile test, the yield stresses for aluminum and copper are specified as 108.54 Mpa and 81.92 Mpa respectively. On the other hand for specifying the material analysis for aluminum and copper targets, a sample is prepared and analyzed with material analysis machine and the percentage of each constitutive material is obtained.

3. Experimental Results

Ballistic limit velocity is the minimum velocity need to create complete penetration in the target so that the projectile can cross the target and also the residual velocity after crossing reaches zero. Thus to compute the ballistic limit velocity, projectile is shot with a velocity greater than ballistic limit and then shooting velocity is decreased so that the projectile could not penetrate the target thoroughly. Then the velocities between these two limits are tested and by averaging the minimum velocity of complete penetration and maximum velocity that projectile could not cross the target, the ballistic limit velocity of the projectile-target system is obtained.

The results show that by decreasing the initial velocity of projectiles, velocity downfall is increased while the amounts of absorbed energy do not change significantly. The fracture mechanism varies between Plugging and petaline. Usually the fracture mechanism occurs between these two modes. While a projectile impacts the target, the back face of the target bulges near the impact zone. If the fracture mode occurs in form of Plugging, the cut zone that is called plug can be removed from the target wholly with no crack (Figs. 3.6 and 3.7). If the fracture mode occurs in form of petaline, the

bulged zone is divided into the zones like petals and there are cracks around the hole (Figs. 3.1, 3.3, 3.5 and 3.8).

These experiments declared that in high velocity, the dominant fracture mechanism is plugging and by decreasing the velocity, the fracture mechanism tends to petaline. It should be noted that in the petaline mode there are small plug removed from the target but their size is smaller relative to plugging mode (Fig. 4).

In fact by decreasing the impact velocity, developed cracks are enlarged, the number of petals is decreased and their sizes are enlarged while the size of the removed plugs is shrunk. When the fracture mechanism is between petaline and plugging, the cracks are fine and the number of petals is generous while the size of petals is too small and their shape is like a rectangle. For example in sixth target (Fig. 3.6), the last layer has sustained petaline mode with 4 petals near the ballistic limit and by increasing the velocity, the number of petals is increased and their size is shrunk so that in velocities far from the ballistic limit, the fracture mode tends to Plugging mode and the diameter of plugs is enlarged and tends to diameter of cylindrical part of the projectile. The diagrams of the residual velocities versus initial velocities of projectile are plotted in Fig. 5 to Fig. 12.

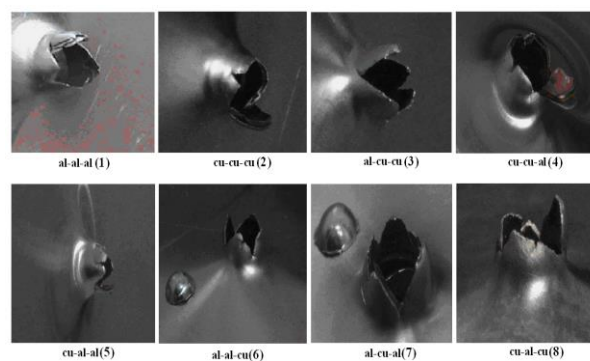


Figure 3. Fracture mechanism of targets; (3.1): $V_i = 169.17$ m/s, (3.2): $V_i = 165.46$ m/s, (3.3): $V_i = 180.91$ m/s, (3.4): $V_i = 159.94$ m/s, (3.5): $V_i = 174.48$ m/s, (3.6): $V_i = 169.17$ m/s, (3.7): $V_i = 180.91$ m/s, (3.8): $V_i = 165.46$ m/s



Figure 4. Plugs created due to different firing velocity.

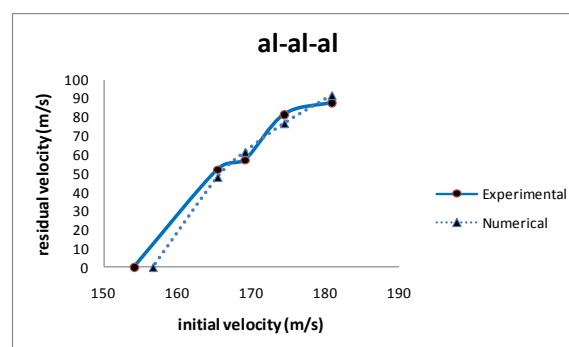


Figure 5. Diagram of residual velocity - initial velocity for target No. 1

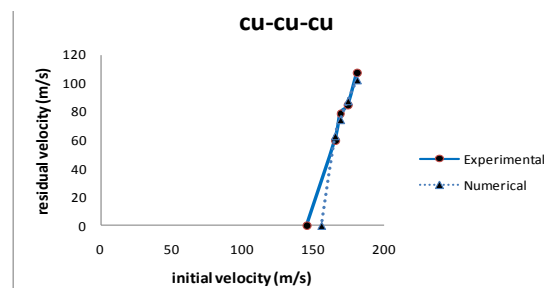


Figure 6. Diagram of residual velocity - initial velocity for target No. 2

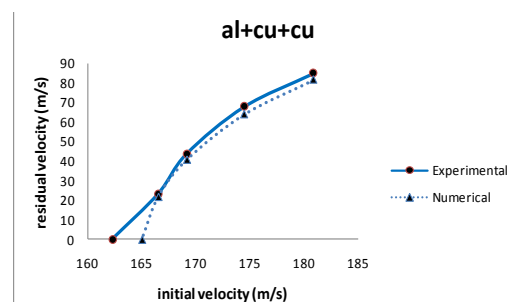


Figure 7. Diagram of residual velocity - initial velocity for target No. 3

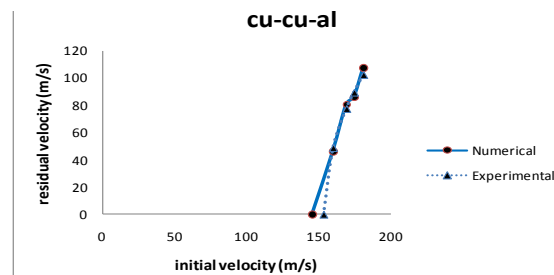


Figure 8. Diagram of residual velocity - initial velocity for target No. 4

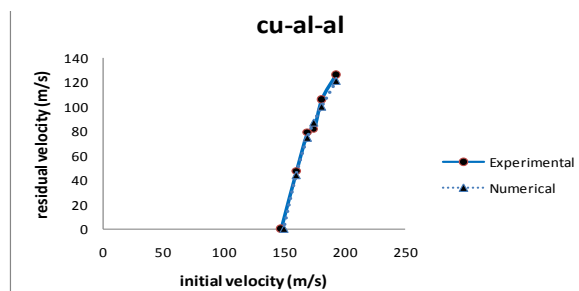


Figure 9. Diagram of residual velocity - initial velocity for target No. 5

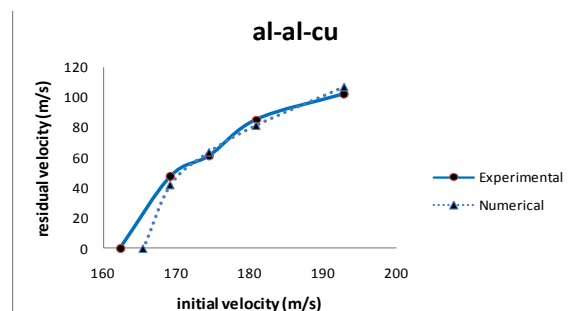


Figure 10. Diagram of residual velocity - initial velocity for target No. 6

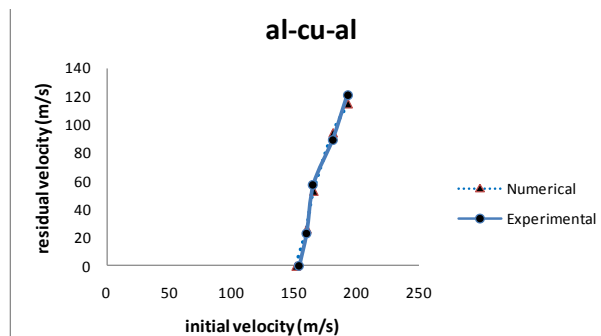


Figure 11. Diagram of residual velocity - initial velocity for target No. 7

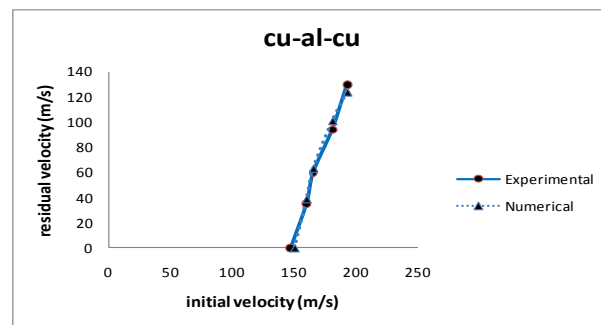


Figure 12. Diagram of residual velocity - initial velocity for target No. 8

4. Perusing the effect of different parameters

To study sequence of layers arrangement, 8 possible arrangements of layers are considered. The difference between maximum and minimum ballistic velocity is about 16.67 m/s. The maximum ballistic velocity belongs to targets number 3 and 6 and is about 162.3 m/s and the minimum ballistic limit velocity belongs to targets number 2 and 4 and is about 145.63 m/s.

4.1. Comparing target number 1 (al-al-al) with target number 2 (cu-cu-cu)

The results show that if all of the layers are chosen from the hard material (in this case; aluminum), the resistance against penetration is more in comparison with the state that all of the layers are chosen from a more ductile material (copper). Consequently target number 1 with ballistic limit velocity of 154.11 m/s is more resistant than target number 2 with ballistic limit velocity of 145.63 m/s.

4.2. Comparing target number 3 (al-cu-cu) with target number 4 (cu-cu-al)

The results in this state show that if the harder layer is placed as the first layer, its resistance is more in comparison with the state that it is placed as the last layer (from left to right). Consequently target number 3 with ballistic limit velocity of 162.3 m/s is more resistance than target number 4 with ballistic limit velocity of 145.63 m/s.

4.3. Comparing target number 5 (cu-al-al) with target number 6 (al-al-cu)

The results in this state show that if the layer that is more ductile is placed after two harder layers, its resistance against penetration is more in comparison with the state that it is placed as the first layer (from left to right). Consequently target number 6 with ballistic limit velocity of 162.3 m/s is more resistance than target number 5 with ballistic limit velocity of 147.13 m/s.

4.4. Comparing target number 7 (al-cu-al) with target number 8 (cu-al-cu)

The results in this state show that if the layer that is more ductile is placed between two harder layers, its resistance against penetration is more in comparison with the state that harder layer is placed between two layers that are more ductile (from left to right). Consequently target number 7 with

ballistic limit velocity of 154.11 m/s is more resistance than target number 8 with ballistic limit velocity of 147.13 m/s.

5. Conclusion

In the present study the penetration of projectile with semi-sphere head into the targets with one layer and three layers is perused experimentally as well as numerically and the numerical results compared with experimental ones. In most cases, the error was arising from numerical simulation was observed to be less than 10%. The result of this study can be briefed as below:

The sequence of layers arrangement according to the used material effects the ballistic operation and can change it.

Projectile with semi-sphere head, pierces targets with fracture mode between petaline and Plugging and the projectile velocity has a significant effect on the fracture mode. Increasing the velocity has the fracture take the Plugging mode and decreasing the velocity make the fracture happen in petaline mode.

Decreasing initial velocity of projectile increases the radius of plastic deformation zone near the impact zone.

It is declared in the present study that targets uses layers with different materials are more resistant in comparison with targets that are homogeneous.

6. References

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