An Investigation into the Penetration Behavior of Monolithic and Multi-layered Metallic Targets Subjected to the Projectile Impact

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ABSTRACT

In the current study, an experimental study and modelling of the penetration behavior of single-layered and multi-layered targets made of either aluminum alloy or mild steel or a combination of these materials impacted by a spherical projectile were introduced. For conducting 66 experiments, eight different layering configurations consist of monolithic aluminum and steel plates with the thickness of 2 mm and 3mm, double-layered aluminum and steel plates with the total thickness of 2 mm, triple-layered aluminum and steel plates with the total thickness of 3 mm, and triple mixed layered plates of Aluminum-Steel-Aluminum and Steel-Aluminum-Steel configurations with the total thickness of 3 mm were considered under various impact velocities of 42 to 158 m/s. The impact velocity and maximum permanent deflection of specimens were measured in all experiments. In the numerical modeling section, the Group Method of Data Handling neural network was used to present a mathematical model based on dimensionless numbers to predict the maximum permanent deflection of monolithic and multi-layered metallic plates under the rigid projectile impact. In order to increase the prediction capability of the proposed neural network for this process, the experimental data were divided into two training and prediction sets. The results showed that good agreement between the proposed model and the corresponding experimental results is obtained and 94% of data points are within the ±10% error range.

KEYWORDS

Ballistic resistance, Multi-layered plates, Single-layered plates, Neural network, Modelling.

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1. Introduction

Generally, protection versus impact loads is an important topic in the design of impact and shock absorbers, ballistic armor, and expansion of high-grade aerospace, automobile, marine, and civil structures [1-3]. Accordingly, many investigations are performed on the dynamic plastic response of different structures subjected to impact loading in the last two decades [1-3]. In most impact issues, plastic deformation generally happens and elastic solutions are merely creditable for the first step of high-velocity impact or in the low-velocity impact. In the other word, perforation and penetration is the main response form of targets for the case of high-velocity impact and the deformation of impact point region can be significantly considered so that the global structure response can be approximately separated from local deformation behavior. Different factors like nose shape, velocity, and size of the projectile and mechanical properties and geometry of target impress on the response form of targets. To analyze the penetration process of projectiles with different nose shapes into ferrous and nonferrous targets, many theoretical solutions have been proposed. However, because of scientific developments, the researchers' endeavors have kept on expanding novel approaches to solve the problems.

Taking into consideration the aforesaid investigations, the principal objective of this paper is to present empirical equations for predicting maximum permanent transverse deflections of monolithic and multi-layered metallic square targets due to the normal impact of a rigid spherical projectile. Hence, a complete set of dimensionless parameters is defined based on the Buckingham-π theorem and dimensional analysis for nondimensionalization of the governing equations of quadrangular plates due to dynamic loads. Then, the empirical equations are obtained by proposing appropriate dimensionless numbers through the dimensionless governing equations as well as applying the GMDH method. To evaluate the accuracy of empirical equations performance, the results of obtained models are compared with a large number of impact tests results on monolithic and multi-layered metallic square targets that were conducted by using a single-stage gas gun apparatus.

2. Methodology

Experimental investigations were performed for examining the behavior of the monolithic, double, and triple-layered square targets made of either Aluminum alloy Al-1100 and mild steel ST13 or a composition of these materials impacted at the center by rigid spherical steel projectiles. The experiments are carried out by a single-stage gas gun impact test apparatus.

The test set-up device includes 200 bar pressure tank where nitrogen is applied as propellant gas, projectile launching mechanism, eight 6 m long smooth barrels with different diameters ranging from 3.8 to 18.8 mm, velocity-measuring instrumentation, and rotary support stand to hold the sample, and containment chamber. The throwing mechanism consists of a 2 L compressed gas composite cylinder, the 2/2 way solenoid valve (Co-ax valve-KB 15) to prompt the release valve, and a 24 V universal pressure sensor (XML-F600D2025). The projectile is derived from the compressed gun and the launching velocity is governed by the nitrogen pressure in the gas composite cylinder. To measure the projectile velocity, two pairs of laser velocity probes with a 15 cm distance between them are located before the specimen. By altering the nitrogen pressure in the composite cylinder, projectile velocity is changed up to 158 m/s. After propulsion, the spherical projectile with a mass of 25.1 g and a diameter of 18.29 mm is surrounded all over its route towards the containment chamber by a protecting hollow rod which is applied to protect the user of the gas gun apparatus from unexpected stray shots.

Experimental investigations are performed on flat aluminum alloy and steel plates having 140 mm side lengths and different thicknesses of 1, 2, and 3 mm. The square plates are fully clamped at the edge boundaries by eight M12 bolts into a quadrangular steel frame with an exposed area of 90 mm × 90 mm. To characterize the mechanical properties of steel and aluminum materials, uniaxial tension tests have been performed by the INSTRON testing machine. The ASTM-E8 standard is applied for the tensile tests and they are carried out at three different quasi-static strain rates 1.67×10^{-3} s^{-1}, 3.33×10^{-3} s^{-1}, and 5×10^{-3} s^{-1}. Experimental tests are carried out in four different arrangements: monolithic, double, triple-layered, and triple-layered mixed to assess the importance of layering arrangements while altering the impact velocity gives different final displacements. The impact velocity or the velocity of the projectile at the impact point is changed in the range of 42–158 m/s.

3. Results and discussion

The results show that for the case while the impact velocity is 44 m/s, it is concluded that: firstly, the final displacements of double and triple-layered steel target are approximately 1.16 times larger than that of monolithic-layered steel target when the total thicknesses of the plate are 2 mm and 3mm, respectively; secondly, this quantity is smaller for the double-layered steel target in about 57.5% than for aluminum materials and thirdly, this ratio is changed to 62.5% by adding one layer to structure in monolithic-layered steel target. For the case when the impact velocity is 66 m/s, it is deduced that the AL-ST-AL layering arrangement can deform 1.22 times more than the ST-AL-ST layering arrangement. Also, it can be observed that when the impact velocities are 120 and 144 m/s, the final displacement of triple-layered steel targets is 0.76 and 1.13 times larger than that of a double and monolithic-layered steel target, respectively. It is noteworthy to mention that complete penetration does not occur for the monolithic, double, and triple-layered steel targets when the impact velocities are varied from 44m/s up to 155 m/s. For a better understanding of the aforementioned experimental results, the values of final displacement versus the kinetic energy are plotted in Figs. 1 to 3 for both monolithic and multi-layered metallic targets, respectively. Figs. 1 to 3 demonstrated that the final displacements increase with both the increase and decrease of impact velocity and target thickness respectively, as expected due to the increase of impact velocity and capability of energy absorption in thicker targets. Also, the results showed that for the case when the total thickness of the target is constant, the final displacements increase by increasing the number of layers, however, this difference is not considerable.

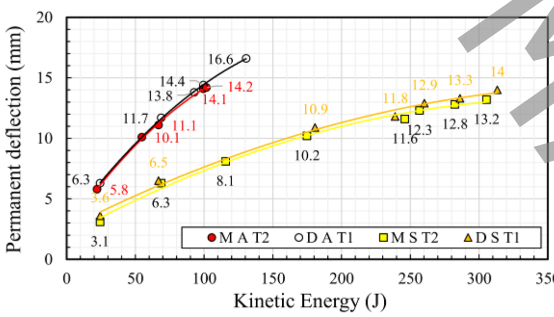

Figure 1. Maximum deflection versus initial kinetic energy for single- and double-layered plates with a total thickness of 2 mm.

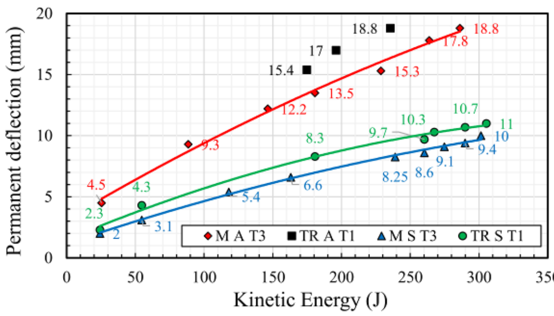

Figure 2. Maximum deflection versus initial kinetic energy for single- and triple-layered plates with a total thickness of 3 mm.

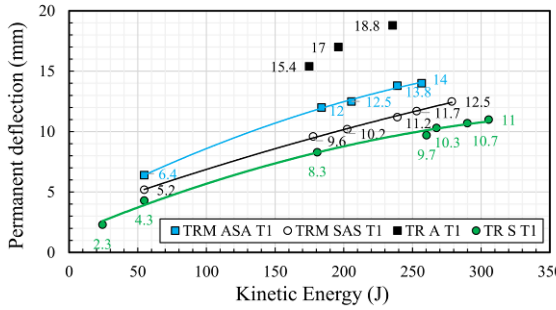

Figure 3. Maximum deflection versus initial kinetic energy for single and triple mixed layered plates.

4. Conclusion

In this paper, firstly, 66 experiments were carried out to investigate the large ductile transverse deformation of monolithic and multi-layered metallic targets made of both aluminum and steel or a combination of these materials struck normally by 25.1g rigid spherical projectiles with various impact velocities between 42 and 158 m/s. the main experimental results can be reduced to the following expressions:

- For the case while the impact velocity is 44 m/s, the final displacement of double-layered steel targets with a total thickness of 2mm and triple-layered steel targets with a total thickness of 3mm are approximately 1.16 times larger than that of the monolithic steel target.
- When the impact velocity is 66 m/s, it is deduced that the AL-ST-AL layering arrangement can deform 1.22 times more than the ST-AL-ST layering arrangement.

5. References

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