

**LARGE DEFORMATION IN PLATES  
SUBJECTED TO BALLISTIC IMPACT OF SMALL  
ARMS  
KINETIC ENERGY PROJECTILES**

**By**

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## **CERTIFICATE**

This is to certify that, the thesis entitled '**LARGE DEFORMATION IN PLATES SUBJECTED TO BALLISTIC IMPACT OF SMALL ARMS KINETIC ENERGY PROJECTILES**' by Mr. Shailendra V Gade has been prepared under our supervision and has attained a standard required for a Ph. D. degree of the institute. The thesis is a record of bonafide research work carried by him and its contents have not been submitted to any other University or Institute for the award of any degree or diploma.

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## ABSTRACT

The present work is an experimental and numerical study of impact of Small Arms projectiles against Steel and Aluminium targets. The Small Arms projectiles are jacketed, contain multi-material inserts and deformable against hard targets. A standard 5.56 mm projectile containing Steel and Lead insert and two new specifically designed projectiles are used in the study for comparison purpose. One of the new projectiles contained Aluminium and Lead while the other contained Lead as insert material. The projectiles have been developed and manufactured in large numbers for conduct of experiments. The projectiles were impacted on 1, 2, 3.5 and 5 mm thick Mild Steel and 1, 2, 3, 4, 5, 6, 8, 10 mm thick Aluminium plates at 0, 35, 45 and 62 deg angle of obliquities. The impact velocity was in the range of  $890 \pm 10$  m/s. The ballistic tests were conducted at Small arms range using a standard Rifle. Impact, residual velocities and crater dimensions were measured in these experiments. The objective of the study was to evaluate the effect of three different configurations of the deformable, multi-material projectiles and understand the phenomenon of their impact on hard targets. The study could be useful in designing the projectiles from lethality point of view as well as targets from protection point of view.

Based on the experimental results, the velocity drop curves of the target material with respect to the target thickness and angle of obliquities were constructed and compared. It was found that, the internal construction i.e. insert material along with nose shape plays a significant role in the failure mode of the target during penetration.

A relative comparison of the three projectiles impacted on steel plates in respect of velocity drop is presented. The drop in velocity was found almost equal for 1 mm thick plate for all the projectiles. The velocity drop was least for Lead-Steel

whereas maximum for Lead-Aluminium projectiles impacted on 2, 3.5 and 5 mm thick steel plates. The variation of front and rear mean crater dimensions with respect to the plate thickness and angle of obliquity is presented. At 0 and 62 deg angle of obliquity, the mean front crater dimensions were found to be the least for Full-Lead and maximum for Lead-Aluminium projectiles. At 45 deg angle of obliquity, the mean front crater dimensions were found to be more or less same for all the projectiles and found to vary linearly with the plate thickness.

A relative comparison of the three projectiles impacted on Aluminium plates is presented. The drop in velocity was maximum for Lead-Aluminium projectiles followed by Full-Lead projectiles. The drop in velocity was the least for the Lead-Steel projectile. The velocity drop was minimum for Lead-Steel projectiles at all the plate thicknesses. At 62 deg angle of obliquity, also the drop in velocity for Lead-Aluminium projectiles was highest followed by Full-Lead and then the least for the Lead-Steel projectiles. The Lead-Aluminium projectile created a higher crater damage leading to higher energy absorption and consequently the higher velocity drop.

Finite Element Simulation of the impact situation has been carried out by using the explicit finite element code ANSYS AUTODYN. The computer code was employed in full Lagrange mode to simulate all the three projectiles impacting on different target materials. The analyses were conducted with AUTODYN-2D as well as 3D. For 2D, axial symmetry about the axis of projectile was used. The numerical analysis of oblique impacts was carried out with AUTODYN 3D. For modeling purpose, Shock equation of state was used for all the materials. The Strength model was Von-Mises for lead & copper whereas for the steel insert, aluminium insert & for target plates, Johnson Cook model was used. The target plates and projectiles were modeled as deformable bodies. The target plates were constrained at the side surfaces

while the projectiles were assigned with initial velocity. The mesh density was made higher in the impact zone. Surface to surface contact between the projectiles and the plates were modeled by using a kinematic contact algorithm. The projectiles were considered as the master surfaces and the contact surface of the plates as the slave surfaces. The results comprising detailed plots showing perforation process at different time steps, deformed shapes of the targets as well as the projectiles, Von-Mises stress profiles at the targets and projectiles, projectile velocity variation within the targets and energy absorbed are computed and presented for a large number of cases involving normal and oblique impact.

The analysis helped in finding the actual deformation process at micro time steps revealing the element distortions, time of penetration, variation of the velocity of the projectiles at different time steps, variation of stresses at the target plate and projectile body, elastic recovery of the plates and ultimate plastic deformation. The predicted petalling of the target plate matched well with those of the experiments. The participation of the inserts of the projectiles in the penetration process played a significant role. It was observed that, the steel insert is highly penetrative as compared to Aluminium and Lead. The Aluminium insert was found to bulge and created a higher crater size on the target as compared to the Steel insert.

Results of numerical simulations are discussed and compared with those of experiments. Comparative evaluation of three projectiles w. r. t the deformation patterns & size of perforations on two different target materials of varying thicknesses and at different angles of obliquities have been done. The relative comparison has also been done for the exit velocity of the projectiles while passing through the targets. Failure mechanism of the target plates predicted by the numerical results was found to match well with that of the observed results. A close correlation between the actual

and predicted residual velocities was also found. The study has helped in studying the performance of the small arms projectiles against hard targets and optimization of the projectile design. The study has also helped in evolving the numerical model for such non linear dynamic analysis involving multi material penetrator at ordnance rate of loading.

The present work has culminated into design of a new efficient projectile to offer higher lethality. The work has also helped in establishing a numerical model for the multi-material deformable projectile successfully. The results of experiments and numerical simulations are compared and tabulated. The effect of each type of projectile composition on the penetration mechanism and transfer of energy to the target was worked out. These studies have shown how core material properties such as density and deformability influence both projectile penetrability and its residual potential for damaging the hard targets. Results reveal that, the projectile with lesser density material as insert has better damage potential at the target. Good agreement has been observed between experimental results & AUTODYN predicted outputs. The energy transferred to the target by the Lead-Aluminium projectile was higher as compared to Lead-Steel or Full-Lead projectile.

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