# Investigative experimental study of different structural materials under shock wave loading

## Abstract

The use of improvised explosive devices (IEDs) by anti-national elements has created a need for blast-resistant material systems. A blast-resistant material is either a single material or a combination of different materials to protect against blast waves generated during the explosion of a charge.

Generally, the blast-resistant materials are either thick metal plates, sandwich structures, or functionally graded material systems. Thick metal plates of different grades of steel are used to protect against blast waves. However, they have high areal densities. Sandwich structures in which front and back plates are made either of thin metallic sheets or by FRPs and filled with some foam or honeycomb material are also a viable option. Lastly, functionally graded material systems that consist of different materials combined in a structured way to form a single material system can be used to mitigate the effects of blast waves.

The scope of this dissertation work was first to design and fabricate a 100 mm diameter shock tube to study the behaviour of metal sheets (aluminium, mild steel and ultra-high hardness steel) and fiber-reinforced polymer (FRPs) composite (glass and basalt) under different blast pressure or peak-over-pressure with the ultimate goal that the setup would become an asset of the Body Armour Lab at IIT Delhi. Thin sheets of aluminium, mild steel and ultra-high hardness (UHH) steel were considered in this work. Tension tests were conducted to determine the tensile strengths of these materials. The effect of shock wave loading on high hardness and high strength UHH steel was compared with low hardness and low strength aluminium sheets. Results from the literature indicate that to protect structures against shock loading they must

dissipate energy via plastic deformation. The aluminium sheets have been shown to deform plastically both in quasi-static and shock loading. Thus, hardness along with ductility are required to dissipate shock waves. Results from this study also indicate that thin aluminium and mild steel sheets can offer shock-resistant properties by energy absorption and plastic deformation. Hence, aluminium and mild steel sheets can therefore be used as face and back sheets for the development of any lightweight sandwich composite blast mitigation system. The FE numerical models utilizing JC stress-strain plasticity model successfully captured the plasticity and deformation behaviour with less than 15% error.

In the present research, glass and basalt fiber-reinforced polypropylene composites' behaviour in quasi-static and dynamic conditions was also studied. Composites were fabricated by the vacuum-assisted compression moulding method. Failure of composite systems under quasi-static tension and compressive conditions were studied as a precursor along with their failure behaviour under low-velocity impact and super-sonic shock loading under dynamic conditions. Tensile strength of Basalt/PP is an average of 226 MPa and Glass/PP is just 92.83 MPa while compressive strength of Basalt/PP is 435 MPa and Glass/PP is 333.6 MPa. The Basalt/PP panels showed no penetration against low-velocity impact (LVI) with negligible deformations till 50 J. However, the Glass/PP panels were perforated at 50 J.

To measure strain during the shock loading event, strain gauges were mounted at the center of composite laminates in the x and y-directions. Experimental results showed that the data was both incomplete and less accurate the strain gauges were damaged. To resolve this problem, digital image correlation (DIC) was used to measure full-field deformations from which strain was calculated.

Finally, basalt/aluminium fiber metal laminates were also studied under shock wave loading. In terms of areal density of 30 layers Basalt/PP is 5.9 and Basalt/PP-Aluminium fiber metal laminate is 3.16. So, both laminates performance is nearly equal but in case of Basalt/PP-Aluminium fiber metal laminate weight saving is observed which indicates that a thoughtful selection of material system can lead to better blast mitigation system for any threat. Experimental results showed that fiber-metal laminate's performance was better than single material systems as they are lighter, thus providing, an alternate solution in comparison to any monolithic metal or composite material system.