INVESTIGATIVE EXPERIMENTAL STUDY OF DIFFERENT STRUCTURAL MATERIALS UNDER SHOCK WAVE LOADING

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by

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Certificate

This is to certify that the thesis entitled "Investigative experimental study of different structural materials under shock wave loading" being submitted by Mr. Khushi Ram to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy in Mechanical Engineering is a record of original and bona fide research work carried out by him under our supervision and guidance. The thesis work in our opinion has reached the requisite standard for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or in full, to any other University or Institute for the award of any degree or diploma.

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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 Indian Institute of Technology, 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.

सार

राष्ट्र-विरोधी तत्वों द्वारा इम्प्रोवाइज्ड एक्सप्लोसिव डिवाइस (IED) के इस्तेमाल ने विस्फोट-रोधी सामग्री प्रणालियों की आवश्यकता पैदा कर दी है। विस्फोट-रोधी सामग्री या तो एक एकल सामग्री होती है या किसी चार्ज के विस्फोट के दौरान उत्पन्न होने वाली विस्फोट तरंगों से बचाने के लिए विभिन्न सामग्रियों का संयोजन होता है।

आम तौर पर, विस्फोट-रोधी सामग्री या तो मोटी धातु की प्लेटें, सैंडविच संरचनाएँ या कार्यात्मक रूप से वर्गीकृत सामग्री प्रणाली होती हैं। विस्फोट तरंगों से बचाने के लिए स्टील के विभिन्न ग्रेड की मोटी धातु की प्लेटों का उपयोग किया जाता है। हालाँकि, उनका क्षेत्रीय घनत्व अधिक होता है। सैंडविच संरचनाएँ जिसमें आगे और पीछे की प्लेटें या तो पतली धातु की चादरों से या FRP द्वारा बनाई जाती हैं और कुछ फोम या मधुकोश की सामग्री से भरी जाती हैं, भी एक व्यवहार्य विकल्प हैं। अंत में, कार्यात्मक रूप से वर्गीकृत सामग्री प्रणाली जिसमें विभिन्न सामग्रियों को संरचित तरीके से मिलाकर एकल सामग्री प्रणाली बनाई जाती है, का उपयोग विस्फोट तरंगों के प्रभावों को कम करने के लिए किया जा सकता है।

इस शोध कार्य का उद्देश्य सबसे पहले 100 मिमी व्यास की शॉक ट्यूब को डिजाइन करना और बनाना था, ताकि विभिन्न विस्फोट दबाव या पीक-ओवर-प्रेशर के तहत धातु शीट (एल्यूमीनियम, माइल्ड स्टील और अल्ट्रा-हाई हार्डनेस स्टील) और फाइबर-प्रबलित पॉलिमर (FRPs) कंपोजिट (ग्लास और बेसाल्ट) के व्यवहार का अध्ययन किया जा सके, जिसका अंतिम लक्ष्य यह था कि यह सेटअप भारतीय दिल्ली संस्थान में बॉडी आर्मर लैब की एक संपत्ति बन जाए। इस कार्य में एल्यूमीनियम, माइल्ड स्टील और अल्ट्रा-हाई हार्डनेस (UHH) स्टील की पतली शीट पर विचार किया गया। इन सामग्रियों की तन्य शक्तियों को निर्धारित करने के लिए तनाव परीक्षण किए गए। उच्च कठोरता और उच्च शक्ति वाले UHH स्टील पर शॉक वेव लोडिंग के प्रभाव की तुलना कम कठोरता और कम शक्ति वाली एल्यूमीनियम शीट से की गई। साहित्य के परिणाम बताते हैं कि शॉक लोडिंग के खिलाफ संरचनाओं की रक्षा करने के लिए उन्हें

प्लास्टिक विरूपण के माध्यम से ऊर्जा को नष्ट करना चाहिए। एल्यूमीनियम शीट को अर्ध-स्थैतिक और शॉक लोडिंग दोनों में प्लास्टिक रूप से विकृत करने के लिए दिखाया गया है। इस प्रकार, शॉक तरंगों को नष्ट करने के लिए कठोरता के साथ-साथ लचीलापन भी आवश्यक है। इस अध्ययन के परिणाम यह भी संकेत देते हैं कि पतली एल्यूमीनियम और हल्के स्टील की चादरें ऊर्जा अवशोषण और प्लास्टिक विरूपण द्वारा शॉक-प्रतिरोधी गुण प्रदान कर सकती हैं। इसलिए, एल्यूमीनियम और हल्के स्टील की चादरों का उपयोग किसी भी हल्के सैंडविच कम्पोजिट ब्लास्ट शमन प्रणाली के विकास के लिए फेस और बैक शीट के रूप में किया जा सकता है। जेसी स्ट्रेस-स्ट्रेन प्लास्टिसिटी मॉडल का उपयोग करने वाले एफई संख्यात्मक मॉडल ने 15% से कम त्रुटि के साथ प्लास्टिसिटी और विरूपण व्यवहार को सफलतापूर्वक कैप्चर किया। वर्तमान शोध में, अर्ध-स्थैतिक और गतिशील स्थितियों में ग्लास और बेसाल्ट फाइबर-प्रबलित पॉलीप्रोपाइलीन कंपोजिट के व्यवहार का भी अध्ययन किया गया था। कंपोजिट को वैक्यूम-सहायता प्राप्त संपीड़न मोल्डिंग विधि द्वारा तैयार किया गया था। अर्ध-स्थैतिक तनाव और संपीड़न स्थितियों के तहत समग्र प्रणालियों की विफलता बेसाल्ट/पीपी की तन्य शक्ति औसतन 226 एमपीए और ग्लास/पीपी सिर्फ 92.83 एमपीए है जबकि बेसाल्ट/पीपी की संपीड़न शक्ति 435 एमपीए और ग्लास/पीपी 333.6 एमपीए है। बेसाल्ट/पीपी पैनलों ने 50 जूल तक नगण्य विरूपण के साथ कम-वेग प्रभाव (एलवीआई) के खिलाफ कोई प्रवेश नहीं दिखाया। हालांकि, ग्लास/पीपी पैनल 50 जूल पर छिद्रित थे। शॉक लोडिंग घटना के दौरान तनाव को मापने के लिए, स्ट्रेन गेज को एक्स और वाई दिशाओं में समग्र लेमिनेट के केंद्र में रखा गया था। प्रयोगात्मक परिणामों से पता चला कि डेटा अधूरा और कम सटीक था और स्ट्रेन गेज क्षतिग्रस्त हो गए थे। इस समस्या को हल करने के लिए, पूर्ण-क्षेत्र विकृति को मापने के लिए डिजिटल छवि सहसंबंध (DIC) का उपयोग किया गया, जिससे तनाव की गणना की गई। इस समस्या को हल करने के लिए 30 परतों के क्षेत्रीय घनत्व के संदर्भ में बेसाल्ट/पीपी 5.9 है और बेसाल्ट/पीपी-एल्यूमीनियम फाइबर मेटल लेमिनेट 3.16 है। इसलिए, दोनों लेमिनेट का प्रदर्शन लगभग बराबर है,

लेकिन बेसाल्ट/पीपी-एल्यूमीनियम फाइबर मेटल लेमिनेट के मामले में वजन में बचत देखी गई है, जो दर्शाता है कि सामग्री प्रणाली का एक विचारशील चयन किसी भी खतरे के लिए बेहतर विस्फोट शमन प्रणाली की ओर ले जा सकता है। प्रायोगिक परिणामों से पता चला कि फाइबर-मेटल लेमिनेट का प्रदर्शन एकल सामग्री प्रणालियों की तुलना में बेहतर था क्योंकि वे हल्के होते हैं, इस प्रकार किसी भी अखंड धातु या मिश्रित सामग्री प्रणाली की तुलना में एक वैकल्पिक समाधान प्रदान करते हैं।

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