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EXPERIMENTAL STUDIES OF MITIGATION MATERIALS FOR BLAST INDUCED TBI

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Abstract. The objective of this experimental study is to compare the effects of various materials obstructing the flow of a blast wave and the ability of the given material to reduce the damage caused by the blast. Several methods of energy transfer in blast wave flows are known or expected including: material interfaces with impedance mismatches, density changes in a given material, internal shearing, and particle fracture. The theory applied to this research is that the greatest energy transfer within the obstructing material will yield the greatest mitigation effects to the blast. Sample configurations of foam were varied to introduce material interfaces and filler materials with varying densities and impedances (liquids and powders). The samples were loaded according to a small scale blast produced by an explosive driven shock tube housing gram-range charges. The transmitted blast profiles were analyzed for variations in impulse characteristics and frequency components as compared to standard free field profiles. The results showed a rounding effect of the transmitted blast profile for all samples with the effects of the low density fillers surpassing all others tested.

Keywords: Traumatic brain injury, blast mitigation, primary blast injury, improvised explosive device.
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INTRODUCTION

As evidenced by current injury theories, traumatic brain injury (TBI) studies have begun to focus inwardly towards shock wave propagation and flow effects through targets at risk. Unfortunately, it is impossible to fully eliminate the risks that are responsible for this type of injury facing service men and women in today's military conflicts. However, procedures can be established to mitigate and reduce the effects that cause these injuries.

Many studies have been surfacing over the past years presenting means of confinement and attenuation of blast effects for explosive threats. In a large majority of the studies, typical experiments focus on the critical nature of the mechanical properties and configuration of the mitigant materials in question. Mechanical properties contribute largely to the behavior of shock wave interactions at material interfaces. Depending on the acoustic impedance of the interacting medium, the shock wave will reflect, transmit, and dissipate to differing degrees. By definition, the acoustic impedance of the medium is dependent on density and sound speed (which is in and of itself also dependent on density as well as a coefficient of stiffness) [1, 2]. It has, therefore, been the focus of many studies to vary the types of materials being used in terms of layers, densities, and porosities.

Consequently, it is the intent of this current work to advance the area of experimental material studies which effectively attenuate the damaging blast characteristics potentially causing harm.

MATERIALS AND METHODS

In order to accommodate large energy transfers resulting in significant blast attenuation, composite structure material samples were established. A common material was defined as the control material in which filler materials would be added. This control material was a vinyl-nitrile VN-600 foam from Der-Tex Corporation. The samples following the control consisted of the same outer control foam with a single-cavity removed core. The cavity was then filled with varying materials in a loose fill manner and sealed to prevent escape upon loading. Refer to Figure 1 for a diagram of the general sample configuration.

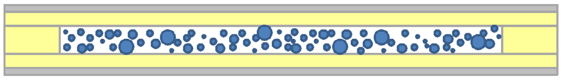

Figure 1. Blast mitigation composite structure material sample: Plexiglass (gray), VN-600 foam (yellow), filler (blue).

The main material characteristics that have initially been studied with this work were viscosity, density (and therefore impedance and sound speed), and particle size. The effects of viscosity were studied by comparing the attenuating features of water filled foam samples and glycerin filled foam samples for viscous dissipation or increased resistance to the flow field resulting in energy absorption. In addition to viscous effects, the liquids also varied in density, therefore affecting sound speed and acoustic impedance. Particle size was varied between three powders: aerogel, CAB-O-SIL®, and glass shot. The difference in particle size could allow for variation in packing density and particle contact. Increased particle contact might suggest better wave transmission as the wave would be passing through interfaces with matching impedances. Density was essentially varied between every material. Aerogel and CAB-O-SIL® provided low-range densities; water, glycerin, and an expanding spray foam provided mid-range densities; and the glass shot and tuff volcanic rock provided high-range densities.

Each sample was subjected to a blast overpressure of approximately 25 psig, in a direction perpendicular to the sample face. The interaction of the blast wave was introduced by means of a uniquely designed explosive-driven shock tube (Figure 2) in order to direct the blast energy toward the target. The blast profile parameters of the attenuated wave were measured behind the material sample using PCB model 113A22 and 113B22 dynamic pressure sensors. The mitigated parameters were compared to unmitigated blast parameters of equivalent standoff distance for attenuation effectiveness.

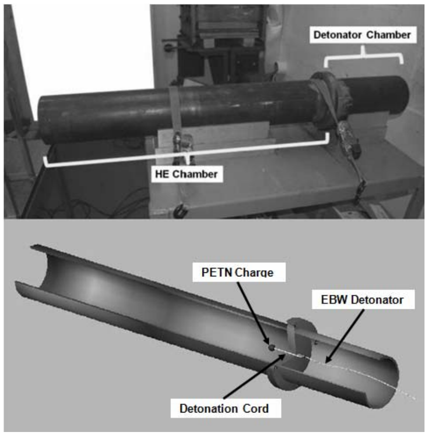

Figure 2. Explosive driven shock tube.

RESULTS AND DISCUSSION

The final results of the mitigation experiments suggested significant attenuation characteristics for each sample. The most significant characteristics that emerged from these sample trials were density and porosity. Due to the porosity (and therefore air composition) of the aerogel, CAB-O-SIL®, and expanding spray foam fillers, the transmitted waves for the samples containing these materials retained blast profiles more closely resembling air blast profiles. Specifically, negative phases were present in the transmitted waves as opposed to the remaining filler materials. Furthermore, positive pulse durations were small compared to the remaining fillers. Peak pressure magnitudes were close to that of the solid foam sample, therefore greater than the magnitudes measured from the remaining fillers. The transmitted wave profiles for these porous fillers also exhibited greater initial slopes from arrival time to time of peak magnitude, slowly approaching a shock front. However, the rate of rise was still less than the solid foam control sample and the free field profile. The resulting behavior similar to air blast profiles suggests the importance of the impedance mismatching characteristic. The three fillers currently being compared have the lowest impedances of the fillers being studied, therefore presenting the least mismatch between air and the respective filler. This would suggest the greatest transmission of the wave and, therefore, the least attenuation. Overall, the porous, low-range density solid materials exhibited 91% - 92% attenuation according to impulse and 93% - 95% attenuation according to peak overpressure. Refer to Figure 3 for the comparative plots between the low-range density effects fillers and the solid control sample.

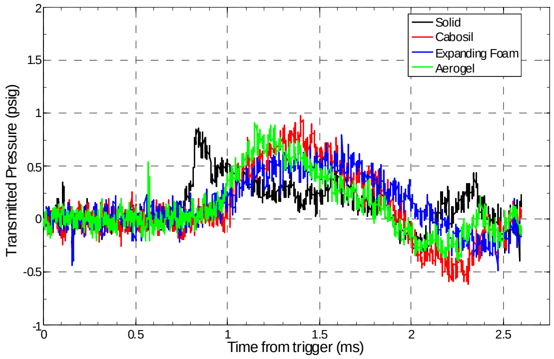

Figure 3. Attenuated blast profiles of low-range density fillers in comparison to solid foam control sample.

The higher density solid materials (glass shot and tuff volcanic rock) exhibited superior attenuation behavior. Although the tuff should be considered porous, the porosity is on a smaller scale and less of a factor than the expanding spray foam and low-range density powders. Since the tuff and glass shot were a less porous material, each filler material acted more like a solid layer with varied density from the foam. Both filler materials exhibited transmitted wave behavior with peak pressure magnitudes nearly half that of the low-range density fillers and the solid foam control sample. The glass shot sample exhibited the longest positive pulse duration of all materials tested, with a 48% extension of duration over the free-field loading condition. The tuff sample exhibited a more average positive pulse duration with only a 16% extension of duration. Rise times for both samples also were on an average scale. Overall, the high-range density fillers exhibited 94% - 95% attenuation according to impulse and 96% - 97% attenuation according to peak overpressure. Refer to Figure 4 for the comparative plots between the high-range density effects fillers and the solid control sample.

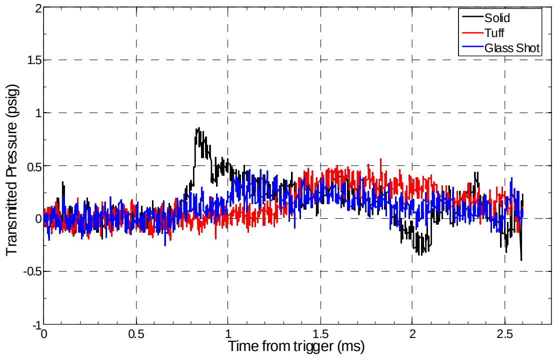

Figure 4. Attenuated blast profiles of high-range density fillers in comparison to solid foam control sample.

The remaining two fillers, water and glycerin, exhibited similar trends to each other as well as the high-range density fillers. Specifically, peak pressure magnitudes were nearly half that of the solid foam control sample and the low-range density samples. Durations were again lengthened compared to the air blast profile, the solid foam control sample, and the low-range density fillers. Rise times for both liquids were on the average scale while the positive pulse durations were among the highest, second only to the previous glass shot sample. The anticipated viscous effects did not show significant behavior. Several distinctions were noticeable between the two fillers but were minimal. Positive pulse durations between the two liquids differed by only 5%. Furthermore, the peak pressures and impulse values differed by only 1% between the two liquids. Although the distinctions between the two liquids were minimal, the increased flow resistance and shear between fluid layers might suggest additional energy dissipation and wave delay superior to water as evidenced by the slightly varied measured profile. Additionally, although the viscous effects did not stand out significantly, the liquids did exhibit significant attenuation behavior. Comparatively, these two liquid fillers suggest 93% - 94% attenuation according to impulse and 96% - 97% attenuation according to peak overpressure. Refer to Figure 5 for the comparative plots between the viscous effects fillers and the solid control sample.

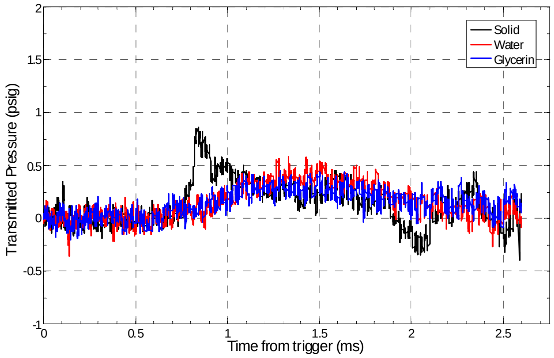

Figure 5. Attenuated blast profiles of viscous effects fillers in comparison to solid foam control sample.

Further experimental trials with the aerogel at higher blast intensities suggested continued attenuation at a gradually decreasing percentage

CONCLUSIONS

The goals of this blast mitigation work were to develop reasonable small-scale testing methods in order to test various materials against defined blast loading conditions. Using the defined methods, the attenuation effectiveness of the materials could be compared in order to distinguish characteristics which improved attenuation the most.

Composite structure material samples were constructed using Der-Tex VN-600 vinyl-nitrile foam as a control material. The foam was tested alone as a control reference. The composite structures were then tested with various filler materials packed in the central cavity. The fillers varied density, viscosity, porosity, and particle size.

The results of the mitigation work showed successful blast wave attenuation with each sample (reduction of overpressure and impulse by up to 97% and up to 48% increased temporal distribution). Varying degrees of attenuation were seen, however. The effects of particle size were non-distinguishable on the scale of the measured transmitted profiles. Although additional energy dissipation might be enhanced through variation of particle size, those effects were not noticeable according to the measured profile characteristics. Furthermore, viscous effects were observed to be present but minimal. The difference in attenuation levels between low and high viscosity liquids was approximately 1% for impulse and 5% for pressure. The material characteristics which resulted in the most distinguishable attenuation were porosity and density. High porosity, high density materials significantly retained traditional air blast characteristics. A goal of blast mitigation, especially in consideration to personnel protection, is the decrease in overall peak pressure and impulse but also the increased temporal distribution. Although significant attenuation was still achieved through the porous low density materials, shorter durations, larger peak pressure magnitudes, and steeper wave fronts were exhibited. Additionally, the negative phase was retained with these materials. Essentially, the result was a scaled air blast with a small degree of temporal transformation. Finally, the most effective blast attenuation was observed through the application of low porosity, high density materials.

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