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Using Flexible Composite for Retrofitting the Installations against Man-made Hazard

Analysis and simulation using the AUTODYN simulation package

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Abstract— One of the greatest threats from a terrorist bomb attack comes from fragmentations pieces of walls, windows, fixtures, and equipment flying at high speeds can result in extensive injury and death. A key tactic to defeating this threat is to ensure the exterior wall of a building can survive the bomb blast without breaking apart and contributing to the fragment problem. The usual approach is to add strength and mass to the wall- to "beef" it up, usually with concrete and steel. Such "fortress" approaches are difficult to implement, time-consuming, and prohibitively expensive. An easier, less expensive, and lighter weight solution was needed so the architects began looking for ways to introduce ductility and resilience into building walls. The use of textile and flexible composites for the containment of high-speed fragmentation is well established; the design of body armour, fragmentation curtains and bomb blankets are end products, routinely deployed. In this paper a simulation program is conducted to test, by simulation, a mitigation effect of a new composite material of (3D-weaveTM Kevlar-129/ LINE-X xs-350), which is a two-component spray-in-place flexible 100% solids Polyurea/Polyurethane system. Mitigation response of this new composite is compared to that of (3D-weaveTM) Kevlar-129; the multi-layered targets of the two materials are subjected to impact by 20 Kg TNT equivalent. The pressure and impulse values are calculated. Calculations show that the composite (Kevlar-129/ LINE-X xs-350) targets are generally more efficient than the Kevlar targets in defeating impacting blast waves.

Index Terms—Mitigation, Flexible composite, Installations, Hazard, Protection, Architecture

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1 Introduction

When subjected to explode impact loading, polymer textile composites resist the impact by absorbing the blast's kinetic energy. The following reviews previous work in the field of mitigation of textile and composite materials.

Leech, C.M. (1) introduced a modelization of the mitigation of high speed threat by orthogonally woven cloth and nets obtained by using a variation principle. Their work based on the idea of the wave front generated by a localized impact on orthogonally woven cloth and dense nets was theoretically shown to be rhomboidal. They obtained an approximate solution for the behavior of both linear (small deflection) and non-linear (large deflection) systems.

Mahmoud, E.H. (2) explored a class of structure' elevation with convex elevation technique, this structural form offered a significant reduction for impulse and pressure values, attractive facades and, potentially, good protection levels. This façade covered by an elastomer material as an external coating. The elastomer material is a highly ductile polymer that can be sprayed onto building surfaces. That work indicate the coating applied to the interior surfaces of a lightweight portable building can offer protection for occupants against an explosive charge at a relatively close distance. The polymer bonds to the wall forming a tough elastic skin. Although structural failure of the supporting walls does occur, the elastomer material remains intact and contains the debris. A group of scenarios simulated and examined by analysis the concept of using new protection techniques, as assessed using the AUTODYN softwear simulation package in 2D & 3D V3.1.17.

Shim, et al (3) examined the dynamic mechanical properties of Twaron fabric via high-speed tensile tests on specimens. The load-deformation and failure characteristics at different rates of stretching were determined, from which constitutive equations representing its viscoelasticity and strain-rate dependence were formulated. This facilitated modeling of the material response to impact and perforation. Experimental results indicated that Twaron is highly strain-rate dependent; the tensile strength and modulus increase with strain rate while the failure strain decreases. Twaron specimens were also observed to fail in a more brittle fashion as the strain rate increases; this phenomenon significantly reduces the amount of energy absorbed at high strain rates.

DeLuca, et al (4), tested different sizes of S2-glass-fabric-reinforced plastic (GFRP) laminate plates by impacting them with two different sizes of fragment simulating threat at various velocities below the limiting velocity of perforation. The impacted specimens were examined with computed tomography to deter

Mine the extent of damage in the specimens, and then those specimens were tested in compression until failure. Laminates were made of S2-glass woven roving in polyester resin matrix with resin content 32 % by weight. All targets were made of GFRP panel 20×20 mm in size, and were rigidly fixed.

Fayed, et al (5), studied normal perforation of threat into textile /epoxy composite targets. They used a Kevlar-129 and S-2 glass textiles for manufacturing the composite which had a

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new weave shape (3D weaveTM). Tests were performed to determine their mechanical properties and an analytical model was presented to describe the mitigation process. Experimental results were compared with model predictions; good agreement was generally obtained. Results show that the tested composites have a limited blast resistance.

One of the greatest threats from a terrorist bomb attack comes from fragmentations pieces of walls, windows, fixtures, and equipment flying at high speeds can result in extensive injury and death. A key tactic to defeating this threat is to ensure the exterior wall of a building can survive the blast waves without breaking apart and contributing to the fragment problem. The usual approach is to add strength and mass to the wall- to "beef" it up, usually with concrete and steel. Such "fortress" approaches are difficult to implement, time-consuming, and prohibitively expensive. An easier, less expensive, and lighter weight solution was needed began looking for ways to introduce ductility and resilience into building walls. The use of textile and flexible composites for the containment of high-speed blast is well established; the design of fragmentation curtains and bomb blankets are end products, routinely deployed.

To address this need, the Air Force Research Laboratory at Tayndall Air Force Base (6), began a series of tests to investigate the use of an elastomeric polymer coating to prevent fragmentation from lightweight structural elements such as concrete block walls and temporary lightweight buildings. The elastomer material is a highly ductile polymer that can be sprayed onto building surfaces.

Mahmoud, E.H. (7) discuss the result of series of simulations, by AUTODYN software package 2D & 3D V4,2007, indicated that the coating applied to the interior surfaces of a lightweight portable building can offer protection for occupants against an explosive charge at a relatively close distance. The polymer bonds to the wall forming a tough elastic skin. Although structural failure of the supporting walls does occur, the elastomer material remains intact and contains the debris. During the explosive simulations, the retrofitted building experienced significant deflections but no bricks fragments were observed entering the room. Post –simulation observations indicate the ductile response of the polymer membrane can effectively contain the splintered wall components and can prevent serious injury to persons inside a room. The convex elevation technique covered by polymer retrofit technique can reduce the standoffs required to limit damage and casualties by approximately 50%, and is an effective tool in providing military commanders in the field with an expedient method to protect method to protect deployed forces from terrorist and enemy bomb attacks. The present work encompasses the following main objectives:

- To construct a flexible composite target using LINE-X (350 type) polymer and the Kevlar-129 fabric and find out how the blast waves resistance compares to that of the Kevlar-129 fabric alone.

2 Simulation Work

In general, the scheme of the simulation work performed in this study included the following phases:

i) Target material choice and preparation.
ii) Preparation of Composite.
iii) Material Characterization.
iv) Parameters and limits of simulations.

2.1 Target Material Choice and Preparation

The polymeric composite used in this study consists of Polyurea/Polyurethane P.P. polymer, reinforced by (3D weaveTM) Kevlar-129 textile. It was chosen because it has high energy absorption during failure, which makes it ideal for blast protection. It also has low density, high strength-to-weight ratio, and high modulus-to-weight ratios.

2.1.1 Description

LINE-X XS-350 is a two-component spray-in-place flexible 100% solids Polyurea/Polyurethane system. It is designed for processing through LINE-X dispensing equipment. It is fast-set and fast-cure material. It also exhibits excellent adhesion to most materials including steel, concrete, wood, fiber glass, and Kevlar. LINE-X is suitable as a protective abrasive impact liner for pipelines, tanks, industrial floors, sea water vessels, helicopter decks, and proved for blast mitigation. In this study it was simulate for improving the blast resistance. It has high resistance to sun ultra violet radiation and severe weather conditions. It has low density and outstanding abrasion resistance, impact strength, tensile strength, tear strength and high elongation percent. Table [1] lists the mechanical properties of the LINE-X XS-350 (8). Figure (1) illustrates the microscopic photography of produced composite. The coating is a two-component spray in place flexible 100% solids Thermoplastic Polyurethane (A) and Polyurea (B) system. It is designed for processing through dispensing equipment. It is a fast set, fast cure, and textured surface, multi-purpose material designed for commercial and industrial applications. It exhibits its excellent adhesion to most materials including steel, concrete, wood, fiber glass. Both components A & B shall be pumped to the high pressure, preheated spray in place; Mix (3 sec.), Gel (6 sec.) and Cure (24 hours)

2.1.2 Features

1. Continuous, seamless and monolithic liner for flat, curved and sharp cornered surfaces.
2. Fast set 3-5 sec. at any thickness without intervals.
3. Used with fresh concrete and high humidity.
4. Fast cure for service at ambient temperature after 24 hours.
5. No volatile organic content, 100% solids, environmentally friendly.
6. High resistance to sun UV and severe weather conditions.
7. High resistance to broad range of chemicals, sea water, crude oil and sewage.
8. Outstanding abrasion resistance, impact strength, tensile strength.
9. high eclectic resistance (18 k w @ 1500 u m)

TABLE 1

MECHANICAL PROPERTIES OF LINE-X XS-350

Properties at 24o C	Value	Unit
Density	1.123	gm / cm3
Permeability	None	grain / hr. / m2
Hardness	87 / 60	Shore (A) / shore (D)
Abrasion resistance	0.6 %	Per 1000 cycles
Tensile strength	20.4	N / mm2
Shear strength	21.94	N / mm2
Elongation	475 %	Percent
Tear resistance	301.3	Pli
Impact strength	Pass	
Adhesion	25	Mpa
Holiday	3	KV
Pin hole	Free	
Cathodic disbondment	7.6	mm diam

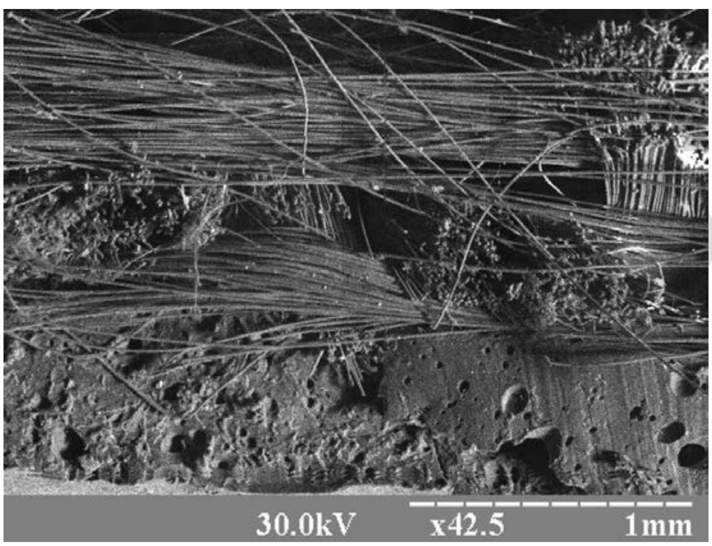

Fig. 1 Microscopic photography of produced composite

2.2 Preparation of Composite

The composite used in this study is laminated composite, which consists of layers of Kevlar textile sprayed with layers of polyurea polyurethane on one side. Applying the plolyurea polyurethane layers needs the following equipment Fig. (2, 3, 4),: LINE-X dispensing equipment ,10 HP compressor 1m3/minute, refrigerated air dryer, high temperature/pressure hose, and sprayer gun, shown in Fig. (3). Equipment settings are as follows: Pressure: 10.4-15.2 MPa.

Preheated temperatures were for component (A): 50°-60°C, components (B): 50°-60°C and the hose temperature is 50°-60°C. Steps of the process go as follows: (9)

1. Feeding pumps suck the two components separately from the barrels to the LINE-X dispensing equipment Fig. (4).
2. In the LINE-X dispensing equipment the pressure is then increased to the required pressure (10.4-15.2 MPa).
3. Then the two components were heated separately to 50°-60°C.
4. The two materials were then transferred through the hoses to the sprayer gun.
5. The sprayer gun is then triggered which allows mixing of the two components (1:1 by volume) and also to control the spread of the final material.
6. The required thickness of the LINE-X layer is applied on the Kevlar textile.
7. Then the final composite is cut to 15×15cm panels.

Figure 2 LINE-X Dispensing Equipment

Figure 3 Sprayer Gun

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Figure 4 Two components barrels.

2.3 Material Characterization

The general assumption that fabric behavior is linearly elastic up to fracture has also been used by many investigators, e. g. Lim (10)

By this simplification the behavior of the material can be described by two parameters, the fracture strength and the corresponding fracture strain.

Simply then the modulus of elasticity can be calculated by getting the slope of the stress strain curve. The tensile properties of the Kevlar-129 were taken from the data sheet (11), and the tensile properties of the LINE-X xs-350 were taken from the data sheet, of the company. The main properties are listed in Table (5) respectively.

The weight per unit area, areal density, was measured for one layer of both Kevlar 129 and composite Kevlar/LINE-X. Kevlar areal density was equal to 0.6411 kg/m2, whereas composite areal density was equal to 1.6214 kg/m2.The properties are listed in Table 2. (12),(13)

TABLE 2

PROPERTIES OF KEVLAR 129 TEXTILE, LINE-X AND COMPOSITE LAYER

Property	Kevlar 129 textile layer	LINE-X	Composite layer
Density,[kg/m3]	1.45×103	1.123×103	1.233×103
Areal density [kg/m2]	0.6411		1.6214
Volume fraction	0.336	0.664	0
Weight fraction	0.3954	0.6046	0
Strength [MPa]	3.4 (GPA)	20.4	646.39 (MPa)
Strain, [%]	4.4	475	14
Modulus of Elasticity,	143 (GPa)	143 (GPa)	4617 (MPa)

2.4 Parameters and limits of simulations

The Reference scenario, with which all simulations will be compared, is an explosion in front of a structure. The AUTODYN simulation package 2D & 3D V4 (14) was used to evaluate the pressure and impulse values on the structure and the ConWep program (15) validated these values.

Several scenarios were prepared to represent typical geometries,figure 5 & 6 shown the variables which taking into consideration :

1. Distance of the structure from the blast.
2. Threat Equivalence.

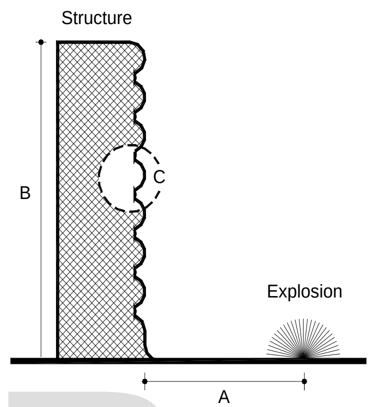

Fig. 5 Parameters and Limits of Simulations

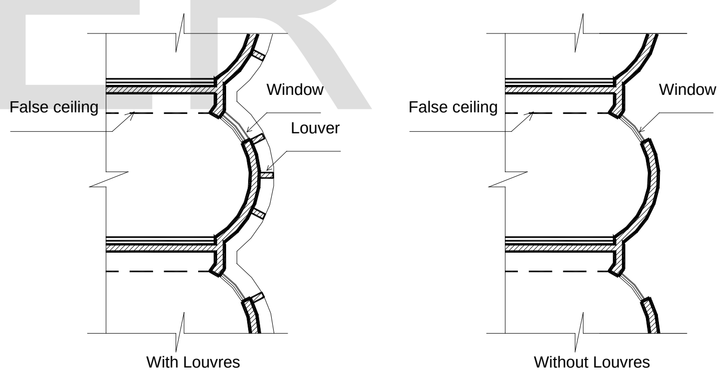

Fig.6 Curved Elevated Technique

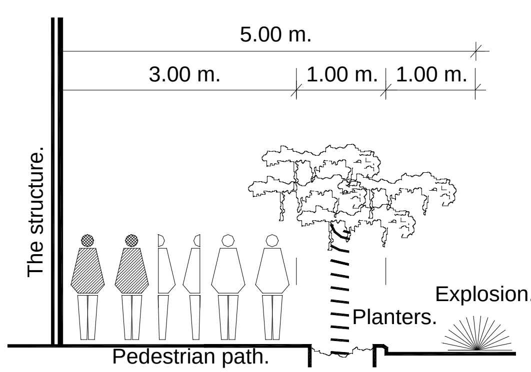

Fig. 7 Distance of the structure from the blast

2.4.1 Distance of the structure from the blast

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The worst case scenario was taken to be when a vehicle bomb is located at a stand-off of 5m from the structure, as shown in figure 7. This was based on:

- An assumed minimum pedestrian path width of 3m.
- An assumed planting zone width of 1m.
- 1m distance between center of explosion and the plants.

2.4.2 Threat Equivalence

The TNT equivalence of explosive material (known as home-made explosive or HME) is too difficult to define precisely because of the variability of its formulation and the quality of the control used in its manufacture. TNT-equivalent factors ranging from as low as 0.4 up to almost unity have been suggested as shown in table 3 (16), (17)

TABLE 3

CONVERSION FACTORS FOR EXPLOSIONS

Threat	Mas specific energy Qx(KJ/Kg)	TNT equivalent Qx/QTNT
compound B (60% RDX 40% TNT)	5190	1.148
RDX (Cyclonite)	5360	1.185
HMX	5680	1.256
Nitroglycerin (Liquid)	6700	1.481
TNT	4520	1.000
Blasting Gelatin (91% nitroglycerin, 7.9% nitrocellulose, 0.9% antacid, 0.2% water) 60%		
nitroglycerin dynamite	2710	0.600
Semtex	5660	1.25

The simulations are based around a 25m high, 8 - story reinforced concrete structure. The first story is 4m high, all others are 3 m high. These characteristics were chosen to be representative a typical structure in this category.

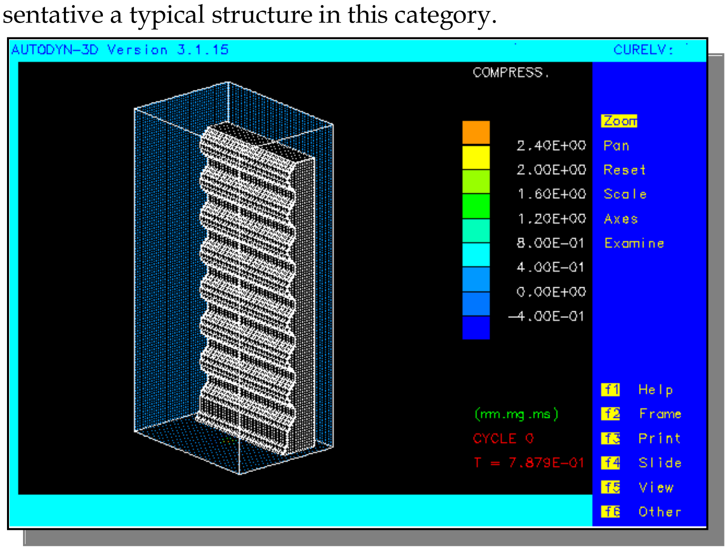


Fig. 8 AutoDYN Simulation in 3D

3 SIMULATION RESULTS

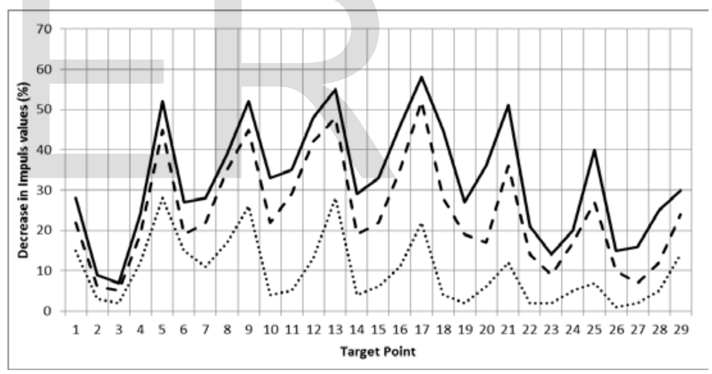
Pressure and impulse values

The performance of the new Kevlar/LINE-X composite is promising. Simulations were conducted to discover whether the addition of the flexible composite retrofit technology has a beneficial effect. Analysis of the simulation output reveals that the The flexible composite offer a reduction in the effects of the blast waves on the structure, as shown in figures 9 and10 .

1. For the curved elevation **without The flexible composite**, the impulse values were reduced by up to 29 % and the pressure values were reduced by up to 40 % when compared with the initial case.

2. For the curved elevation **with The LINE-X composite**, the impulse values were reduced by up to 51 % and the pressure values were reduced by up to 63 % when compared with the initial case.

3. For the curved elevation **with The Kevlar/LINE-X** composite, the impulse values were reduced by up to 58 % and the pressure values were reduced by up to 75 % when compared with the initial case.



.... Curved Elevation Technique only

— — — Curved Elevation Technique with LINE-X composite

——— Curved Elevation Technique with Kevlar/LINE-X

Fig. 9 The decrease in **impulse** and pressure values (%) vs specific target points on structure. (Values compared with reference scenario)

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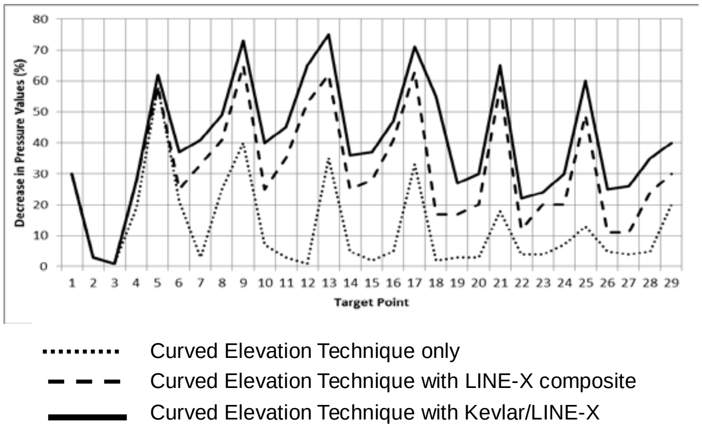

Fig.10 The decrease in **pressure** and pressure values (%) vs specific target points on structure. (Values compared with reference scenario)

Impact on Standoff

A long with saving lives, one of the key benefits of improving the blats resistance of a structure is to permit reduced standoffs between a threat and a building. Reduced standoffs give a military commander and his security planners much greater flexibility in accomplishing their missions. As an example, for a non –retrofitted structure the standoff from a small car bomb (220 pounds TNT) is approximately 40m at failure and 6m for sever damage, using the FPB curves If the structure is retrofitted with a Kevlar/LINE-X coating, the standoffs are reduced to 27m at failure and 3m for severe damage, up to 67.5 % reduction. Reductions of this magnitude can greatly ease the challenges faced by land use planners to implement security measures.

4 Conclusion

This paper has provided a summary of the methods of blast load quantification from external explosions and allow the designer to obtain the pressure and impulse values necessary to allow the design process to be used to produce a structure capable of resisting these loads. It should be noted that the level of damage suffered by a structure cannot be determined solely from knowledge of the pressure and impulse values from a particular explosion.

It is also important to know the characteristics of the blast-loaded building, in particular the dynamic properties of the materials of construction and the form of the structure. Although still a very new and immature technology, the Kevlar/LINE-X composite retrofit technology shows exceptional promise for affordably improving blast protection in existing buildings.

Employing exceptional ductility and good strength, along with the ability to clade onto existing surfaces in a retrofit fashion, polymers have proven themselves capable of controlling much of the building fragmentation associated with explosion threat.

In planning protection against specific threats, this technique can reduce the standoffs required to limit damage and casualties up to 67%. As part of a comprehensive security program, the Kevlar/LINE-X composite retrofit technique can greatly increase options available to military commanders in executing their force protection duties.

1. Adding the Kevlar/LINE-X composite retrofit technique for the convex elevation form can offer a beneficial reduction in the effects of the blast waves and fragments on the structure.
2. The Kevlar/LINE-X composite retrofit technique can reduce the standoffs required to limit damage and casualties by approximately 67%,
3. The Kevlar/LINE-X composite retrofit technique can be used without affecting the functionality of the structure or the street.
4. Adding the Kevlar/LINE-X composite retrofit technique for the convex elevation can offer benefits of robustness whilst having good aesthetic appeal and other architectural advantages.
5. The Kevlar/LINE-X composite retrofit technique is an effective tool in providing military commanders in the field with an expedient method to protect deployed forces from terrorist and enemy bomb attacks.

References

[1] C. Leech, J. Hearle, J. Mansell "A Variation Model for the Arrest Projectiles by Woven Cloth and Nets". *International Journal of Textile Institute* 1979; No.11: 469-478.

[2] E. H. Mahmoud "The Use of curved Elevation Technique to reduce the effects of blast waves and fragments on structures". *In proceedings of 3rd International Conference on SHOCK & IMPACT LOADS ON STRUCTURES* 1999, Singapore.

[3] V. Shim, C. Lim, K. Foo "Dynamic mechanical properties of fabric armor". *International Journal of Impact Energy* 2000; vol. 25: 1-15.

[4] E. DeLuca, J. Prifti, W. Betheney, S. Chou "Ballistic Impact Damage of S2-Glass-Reinforced Plastic Structural Armor". *Composite Science Technology* 1998. vol 58:1453-1462.

[5] A Fayed, A Raid, S Salah. "Perforation of a Small Caliber Projectile into Textile/Epoxy Composite Targets". *In proceeding of 10th International Conference on Aerospace Science & Aviation Technology*- ASAT 2003, Cairo, Egypt.

[6] A. Fayed, E. Elawad, M. Abdelkader "Ballistic Impact of Flexible Compsite". *In proceeding of 11th International Conference on Aerospace Science & Aviation Technology* 2005, Cairo, Egypt.

[7] E. H. Mahmoud "Retrofitting the Installations Against Blast Wave Propagation" *In proceeding of 5th International Science Conference on Deensive Technologies* – OTHE 2012, Ministry of Defence, Belgrade, Republic of Serbia.

[8] K. Knox, I. Micheal, T. Hammons, R. Jonathen "Polymer Materials for Structural Retrofit" *Air Expeditionary Force Technology Division*, New York, NASA-19000, 1996

[9] E. Masters, M. Portanova "Standard Test Methods for Textile Composites" *Material Technology Division*, New York, NASA-19000, 1996.

[10] C. Lim, V. Shim, Y. Ng "Finite-Element Modeling of the Ballistic Impact of Fabric Armor" *International Journal of Impact Energy* 2003, vol. 28:13-31.

[11] H. Billon, D. Robinson "Models for the Ballistic Impact of Fabric Armor" *International Journal of Impact Energy* 2001, vol. 25:411- 422.

[12] M. Abdel-Kader "Effect of Projectile Impact Velocity and Target Thickness on Penetration Resistance of Mild Steel" *In proceeding of 4th International Conference on Aerospace Science & Aviation Technology* 1991, Cairo, Egypt
[13] A. Almohandes, M. Abdel-Kader, A. Eleiche "Ballistic Performance of Single and Laminated Mild Steel Plates" *In proceeding of 6th International Conference of AMME* 1994, Cairo, Egypt.
[14] AUTODYN program 2D & 3D V3. 2007. Century Dynamics Limited.
[15] ConWep program. 2006. U.S. Army Engineer Waterways Experiment Station.
[16] G. Mays, P. Smith "Blast Effect on Buildings". Redwood Books. Wilts, British Lib. 2005.
[17] M. Barakat, J. Hetherington "The Architecture of Protection Structures" *RMCS, Cranfield Univ.*, 1998, UK. p. 72-81.

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