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Simulation and Hardness Test of Kevlar and Glass Fiber Composite for Bullet Proof and Stab Resistant Vest

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Abstract: India records the second highest number of murders in the world every year. With a youth bulge, large unemployed male population, chaotic urbanization and increasing drug abuse, India is a ticking time-bomb of everyday violence, Most of these fatalities are due to hand guns and knife stabbing hence our aim is to provide a counter measure for the people by fabricating a vest which would hold up against such attacks. Our team will be testing the combination of composites such as Kevlar, Glass fiber and Nylon by running simulations in SOLIDWORKS (2013) for blunt trauma, impact for sharp object and practically testing the composite specimen for hardness according to ASTM D2240. Finally considering the test result the vest will be fabricated.

Keywords: ASTM D2240, Blunt trauma, Glass fiber, Kevlar, Nylon

I. INTRODUCTION

Throughout the history of mankind there was always been wars, conflicts and some kind of violence. Even though there were many attempts to keep evil at bay it still prevails in many parts of worlds. There has always been a race in making the most destructible weapon and also finding a better counter/defensive measure against the weapons. Our focus is on the defensive side.

Earlier it was believed that a hard, tough, heavy material was required to stop a speeding bullet, but was proved wrong. Meanwhile the Japanese had a different take on the matter they used several layers of silk, which made the armor more lighter, comfortable and proved to be more effective as it dissipated most of the impact energy of the bullet before it could reach the body of the user giving rise the invention of the first bullet proof vest. Since then many researches and upgrades have been made to the vests by using various composite materials. One such material which brought about a revolutionary change in the field is Kevlar which has high tensile strength and 10 times stronger than steel. Now scientists have synthesized spider silk in laboratories which is 10 times stronger than Kevlar, and can be used in the future.

Now considering the above facts our team will be fabricating a special purpose vest after running simulations in SOLIDWORKS (2013) and conducting practical shore D hardness test.

A. Types Of Bulletproof Vest

- 1) *Type I (.22 LR; .380 ACP):* This defensive layer secures against .22 long rifle lead round nose (LR LRN) projectiles, with ostensible masses of 2.6 g (40 gr), affecting at the very least speed of 320 m/s (1050 ft/s) or less, and against.
- 2) *Type II-A (9mm; .40 S&W):* Type II-A body defensive layer is appropriate for full-time use by police offices, especially those looking for assurance for their officers from lower speed 9mm and 40 S&W ammo.
- 3) *Type II (9mm; .357 Magnum):* Type II body reinforcement is heavier and more massive than either Types I or II-A. It is worn full time by officers looking for insurance against higher speed .357 Magnum and 9mm ammo.
- 4) *Type III-A (High Velocity 9mm; .44 Magnum):* Type III-A body defensive layer gives the largest amount of security as of now accessible from concealable body covering and is commonly appropriate for routine wear much of the time. Be that as it may, offices situated in hot, muggy atmospheres may need to assess the utilization of Type III-A defensive layer cautiously.
- 5) *Type III (Rifles):* This covering ensures against 7.62mm full metal jacketed (FMJ) shots (U.S military assignment M80), with ostensible masses of 9.6 g (148 gr), affecting at the very least speed of 838 m/s (2750 ft/s) or less. It likewise gives assurance against Type I through III-A dangers.
- 6) *Type IV (Armor Piercing Rifle):* This covering ensures against .30 bore reinforcement penetrating (AP) projectiles (U.S. military assignment M2 AP), with ostensible masses of 10.8 g (166 gr), affecting at any rate speed of 869 m/s (2850 ft/s) or less. It likewise gives somewhere around single-hit insurance against the Type I through III dangers.

- 7) *Special Type*: A buyer who has an exceptional necessity for a dimension of insurance other than one of the above standard risk levels ought to determine the definite test rounds and least effect speeds to be utilized and show that this standard will oversee in every single other regard.

II. METHODOLOGY

- 1) The simulations were carried out in SOLID WORKS 2013
- 2) The Simulation included blunt trauma and impact of sharp object for stress, displacement and strain
- 3) We did the combination of Kevlar, Glass fiber and nylon 6/10 using epoxy resin
- 4) The ratio used for combination is 1:2 hardener and epoxy resin respectively.
- 5) Preparation of composite specimen was done using vacuum method
- 6) Hardness test was conducted on the composite specimen
- 7) Finally the vest was fabricated with the composite material.

A. Mechanical Properties Of Materials Used

- 1) *Kevlar (Thickness: 0.37 mm)*

Property	Value	Units
Elastic Modulus in X	1.31e+011	N/m ²
Poissons's Ratio in XY	0.35	N/A
Shear Modulus in XY	2900000000	N/m ²
Mass Density	1440	Kg/m ³
Tensile Strength in X	3620000000	N/m ²
Compressive Strength in X	517100000	N/m ²
Yield Strength	1800000000	N/m ²
Thermal Expansion Co-efficient in X	-	/K
Thermal Conductivity in X	-	W/(m-K)
Specific Heat	-	J/(Kg.K)
Material Damping Ratio	0.0917	N/A

Table 2.1.1 Properties of Kevlar

- 2) *Nylon (Thickness: 0.3mm)*

Property	Value	Units
Elastic Modulus in X	8300000000	N/m ²
Poissons's Ratio in XY	0.28	N/A
Shear Modulus in XY	3200000000	N/m ²
Mass Density	1400	Kg/m ³
Tensile Strength in X	142559000	N/m ²
Compressive Strength in X	-	N/m ²
Yield Strength	139043000	N/m ²
Thermal Expansion Co-efficient in X	3e-005	/K
Thermal Conductivity in X	0.53	W/(m-K)
Specific Heat	1500	J/(Kg.K)
Material Damping Ratio	-	N/A

Table 2.1.2 Properties of Nylon

3) Glass fiber (Thickness: 0.18 mm)

Property	Value	Units
Elastic Modulus in X	8.69e+010	N/m ²
Poissons' s Ratio in XY	0.22	N/A
Shear Modulus in XY	3.5e+010	N/m ²
Mass Density	2480	Kg/m ³
Tensile Strength in X	2480	N/m ²
Compressive Strength in X	-	N/m ²
Yield Strength	-	N/m ²
Thermal Expansion Co-efficient in X	-	/K
Thermal Conductivity in X	-	W/(m-K)
Specific Heat	737	J/(Kg.K)
Material Damping Ratio	-	N/A

Table 2.1.3 Properties of Glass Fiber

4) Epoxy

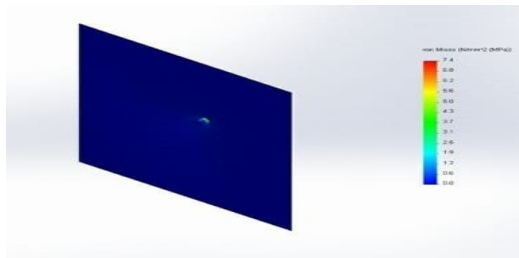
Property	Value	Units
Elastic Modulus in X	2415000000	N/m ²
Poissons' s Ratio in XY	0.35	N/A
Shear Modulus in XY	-	N/m ²
Mass Density	1100	Kg/m ³
Tensile Strength in X	28000000	N/m ²
Compressive Strength in X	104000000	N/m ²
Yield Strength	-	N/m ²
Thermal Expansion Co-efficient in X	-	/K
Thermal Conductivity in X	0.188	W/(m-K)
Specific Heat	-	J/(Kg.K)
Material Damping Ratio	-	N/A

Table 2.1.4 Properties of Epoxy

B. Simulation

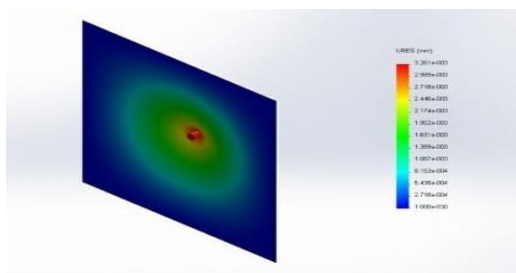
- 1) Simulations were done in SOLIDWORKS (2013)
- 2) Kevlar, glass fiber material properties were defined manually
- 3) First a rectangular sketch of 100*100mm was made
- 4) The surface was made planar
- 5) 3D Object for blunt trauma and sharp object was made
- 6) Assembly of rectangular sketch and one of the object with coincident mate command
- 7) Simulation mode was selected
- 8) Non linear study was selected to determine stress, displacement, strain
- 9) Rectangular sketch was defined as composite with material property and thickness of each layer
- 10) And fixtures were applied at the edges
- 11) A force of 250N was applied on the object in the direction of the composite material
- 12) The assembly was meshed and run to get results.

a) Impact Test For Blunt Trauma



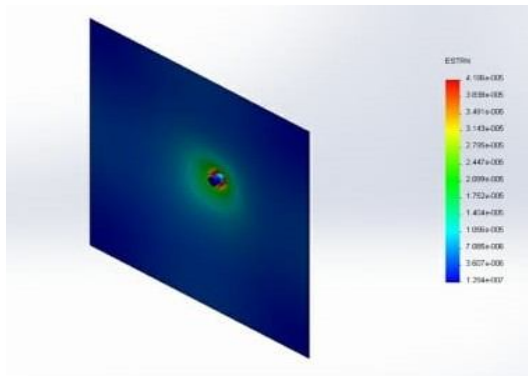
Name	Stress1
Type	VON
Min	1.59206e-006 N/mm ² (MPa) Node : 124
Max	0.855751 N/mm ² (MPa) Node : 62

Fig 2.2.1(a) Stress for blunt trauma



Name	Displacement1
Type	URES
Min	0 mm Node : 124
Max	0.000189465 mm Node : 26

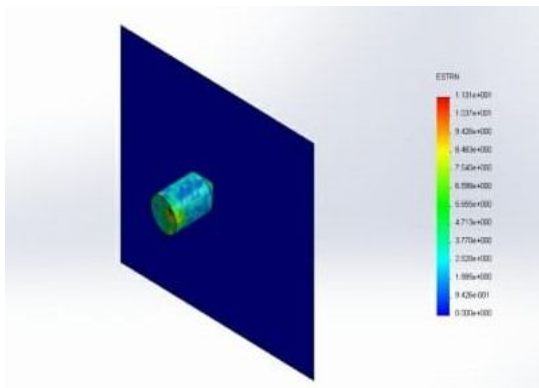
Fig 2.2.1(b) Displacement for blunt trauma



Name	Strain1
Type	ESTRN
Min	2.17766e-008 Element : 21
Max	4.0347e-006 Element : 2671

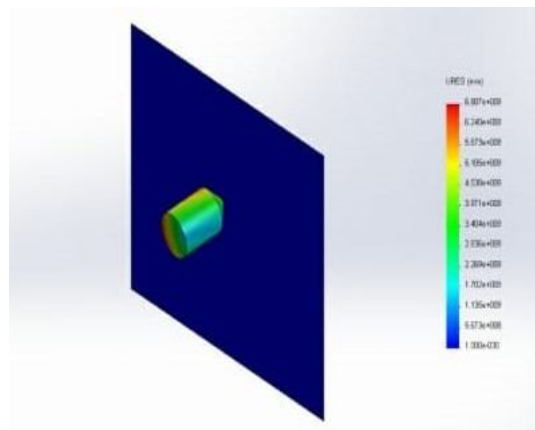
Fig 2.2.1(c) Strain for blunt trauma

b) Sharp Object Penetration



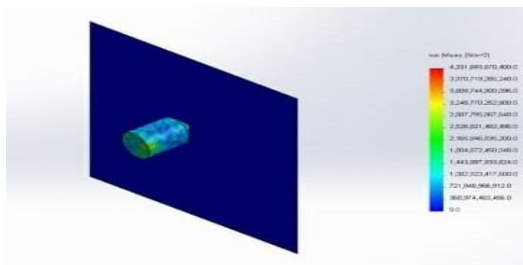
Name	Stress1
Type	VON
Min	0 N/m ² Node : 2780
Max	4.331169e+012 N/m ² Node : 1955

Fig 2.2.2(a) Stress for sharp object penetration



Name	Displacement1
Type	URES
Min	0 mm Node : 2780
Max	6.8073e+009 mm Node : 77

Fig 2.2.2(b) Displacement for sharp object penetration



Name	Strain1
Type	ESTRN
Min	0 Element : 1717
Max	11.3107 Element : 1454

Fig 2.2.2(c) Strain for sharp object penetration

C. Preparation Of Composite Specimen

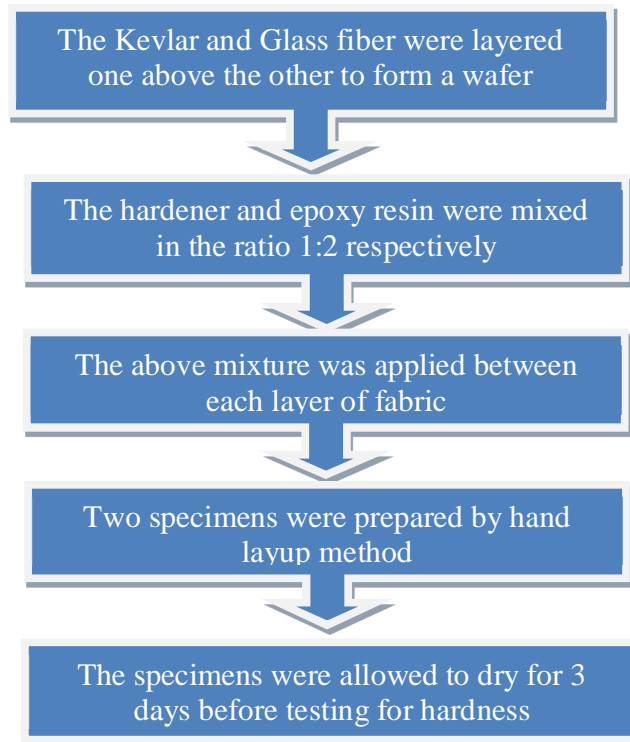




Fig 2.3 (a) Specimen 1



Fig 2.3 (b) Specimen 2

D. Shore D Hardness Test

The apparatus used for this test are

- 1) Durometer
- 2) Composite specimen which is a combination of
 - a) Kevlar
 - b) Nylon
 - c) Glass fiber
 - d) Epoxy

E. Procedure and Description Of Hardness Test

Shore hardness is a measure of the resistance of a material to penetration of a spring loaded needle-like indenter. Hardness of polymers (rubbers, plastics) is usually measured by Shore scales. Shore hardness is tested with an instrument called Durometer which utilizes an indenter loaded by a calibrated spring. The measured hardness is determined by the penetration depth of the indenter under the load.

Two different indenter shapes and two different spring loads used for two Shore scales (A and D) is shown in the picture below. The loading forces of Shore A: 1.812 lb (822 g), Shore D: 10 lb (4536 g). Shore hardness value may vary in the range from 0 to 100. Maximum penetration for each scale is 0.097-0.1 inch (2.5-2.54 mm). This value corresponds to minimum Shore hardness: 0. Maximum hardness value 100 corresponds to zero penetration.

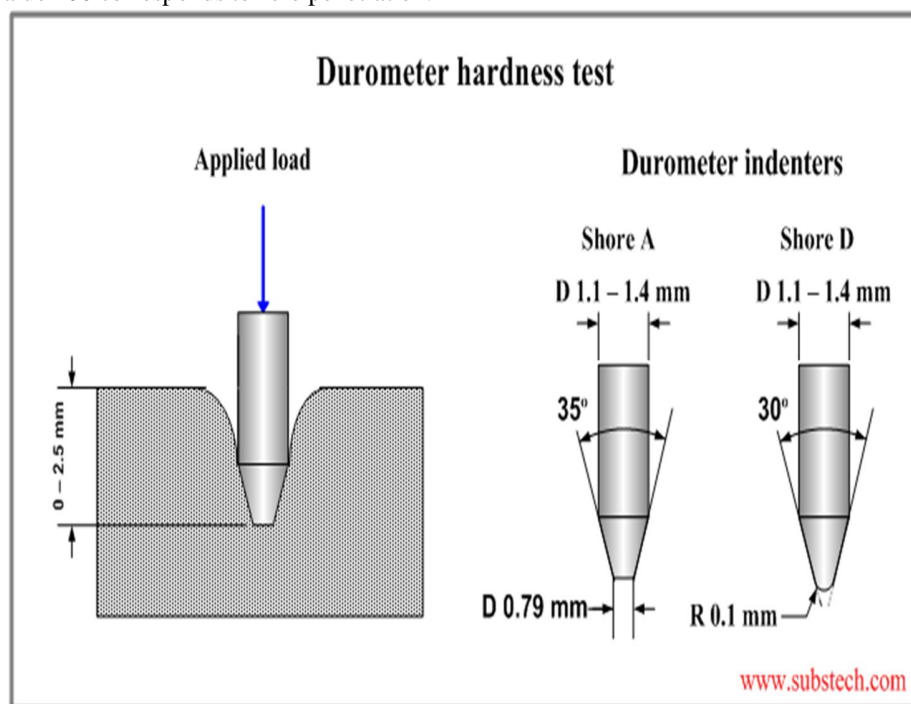


Fig 2.4 Durometer hardness test

F. Fabrication

- 1) The vest was required to be concealable hence pullover design was selected
- 2) The Kevlar and Glass fiber fabrics were cut according to large size dimension specification
- 3) The vest composes 4 parts- two chest pieces, one back piece and a flap to cover the zipper
- 4) Each part consists of 3 layers of Kevlar and 4 layers of Glass fiber
- 5) The Kevlar and Glass fiber were layered up just like the specimen
- 6) The hardener and epoxy resin mixture was applied to the composite in the regions which would lead to fatality (stiffness in the region)
- 7) The mixture was not applied around the edges to provide room for stitching
- 8) The composite was sandwiched between parachute material (Nylon) and stitched together, Nylon was used to protect the composite from water
- 9) Finally, a layer of cotton was provided inside the vest for the users comfort.



Fig 2.5 (a) Front pieces



Fig 2.5 (a) Back piece



Fig 2.5 (c) Front flap



Fig 2.5 (d) Fabricated vest

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Simulation Results

1) Impact For Blunt Trauma

a) Stress

Minimum	Maximum
4.06413e-005 N/mm ²	7.43925 N/mm ²

b) Displacement

Minimum	Maximum
0 mm	0.0032612 mm

c) Strain

Minimum	Maximum
1.29425e-007	4.18601e-005

2) Sharp Object Penetration

a) Stress

Minimum	Maximum
0 N/mm ²	4.331169e+012 N/mm ²

b) Displacement

Minimum	Maximum
0 mm	6.8073e+009 mm

c) Strain

Minimum	Maximum
0	11.3107

The minimum and maximum stress, displacement, strain values for the two simulations were obtained. The values for blunt trauma were obtained accurately whereas the values for sharp object penetration were not accurate as stiffness property was not available for the materials in the user defined function in SOLIDWORKS (2013).

B. Shore D Hardness Test Results

1) Specimen 1

Hardness	78
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2) Specimen 2

Hardness	79
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Fig 3.2 Shore hardness scales



The above figure shows the hardness scale which ranges from 0 – 100, where 100 is the maximum value and means there was no penetration. Our test specimens fall in the range of 80 which categories them as extra hard.

IV. CONCLUSIONS

The simulation, hardness test and fabrication of vest were successfully run and made by our group. Our objective to make the vest stab resistant, concealable, water proof and comfortable was met. The vest may hold good for a small hand gun but will not hold good for rifles hence actual field tests and more practical tests can be done to justify this claim. Overall the results were more than satisfactory. The budget of fabricating the vest also stayed on track and turned out economical. Hence we would like to thank THE LORD ALMIGHTY for showering his blessings on us and everyone who was a part of making our project a success.

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