International Journal of Students' Research In Technology & Management
Vol 3 (8), November-December 2015, Pg 451-454
ISSN 2321-2543, DOI: 10.18510/ijsrtm.2015.384

Bullet Proof Vest using Non-Newtonian Fluid

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Article History: Received on 15th July 2015, Revised on 07th September 2015, Published on 05th November 2015

***Abstract*—Bullet proof vests, made of Kevlar are used for preventing projectiles from injuring humans. Soft armours are capable of protecting humans from low energy projectiles while hard-plate reinforced armours use metal plates, which weigh over 14+ kg for protection against high energy projectiles. Non-Newtonian fluids which have time dependent properties (particularly viscosity) are prepared and tested for energy absorbing properties. It was proved that when Kevlar was used with Oobleck sample, the deformation produced in test plate was reduced considerably as compared to that of only Kevlar sample.**

***Keywords* - Kevlar, Non-Newtonian fluids, Time-dependent properties, viscosity, impact force, mobility**

I. INTRODUCTION

Body Armour is protective clothing that is used to protect humans from different attacks. They are mainly used by military personnel, police, security guards and even private citizens. Currently, there are two types of body armours – soft armour and hard plate reinforced personnel armour. Conventional soft armours are made using layers of Kevlar. For protection, hard plate reinforced personnel armours contains metallic plates which weigh over 14 kg.

Oldest known armors dates back to 1400 BC where they were made of iron rings. These were known as mail or chainmail. Greek sources mentions the use of a linen laminate known as linothorax. In modern days, soldiers use fibers reinforced with metal or ceramic plates. Metallic components or tightly-woven fiber layers can give soft armor resistance to stab and slash attacks from a knife. Mail armor gloves continue to be used by butchers and abattoir workers to prevent cuts and wounds while cutting up carcasses.

Kevlar is the registered trademark for a para-aramid synthetic fiber, related to other aramids such as Nomex and Technora. Developed by Stephanie Kwolek at DuPont in 1965, this high-strength material was first commercially used in the early 1970s as a replacement for steel in racing tires. Typically it is spun into ropes or fabric sheets that can be used as such or as an ingredient in composite material components.

Kevlar is used as body armour in two types – Soft armour and hard plate reinforced personnel armour. Soft armours contains layers of Kevlar that are made into a form of vest. This provides protection from less powerful weapons such as pistols. Hard plated armours uses military grade Kevlars like KM2 or KM129. These are special type of kevlars that are used especially for armours. They have very high impact strength compared to basic ballistic grades.

II. TEST PREPARATION

A. Samples preparation

Three different test samples were fabricated. Kevlar (Fabric type – M1100d-AT9) was used. The thickness of Kevlar used is 0.26 mm and its mass is 200 g/m2. The fabric was cut into small squares of size roughly around 1 ft X 1 ft. Sample 1 was only Kevlar tile. It was fabricated by fastening 12 layers of Kevlar. Fastening was done by using araldite and also a stitch was provided along the ends.

Sample 2 was Kevlar sandwiched with Oobleck and sample 3 was Kevlar sandwiched with Polyethylene Glycol & Silica mixture. Oobleck and PEG & SiO2 mixture are the two Non-Newtonian fluids that were taken for experimentation. Oobleck is a mixture of corn flour and water. 500 mL of corn flour was mixed with 250 mL of water and stirred continuously till the desired property was achieved. The volume ratio of corn flour and water is 2 : 1. 50 mL of the fluid was transferred into cylindrical rubber containers and sealed. Four such containers were placed between layers of Kevlar. In total, 200 mL of the fluid would be present in the test sample. Rubber containers were used because they won't allow the fluid to leak, has considerable strength and are highly flexible (which means transfers the force by deforming without being cut). 10 pieces of Kevlar were fastened to make the front side while 2 pieces were fastened to make the rear. Rubber containers were placed between these front and rear parts. 10 layers was used in the front because that would stop the bullet and transfer only the force to the fluid. Sample 3 was fabricated in a similar fashion but the instead of oobleck, PEG & SiO2 mixture was used.

B. Test frame

Frame was the structure using which testing was done. It a steel structure provided with a slot to place the test samples. The samples would rest on bottom plate and the back plate of the frame. The front side is open so that bullets could hit the sample tiles. Mild Steel plates of 16 mm thickness were used to fabricate the frame. The top portion of the frame which is mounted on 3 legs, consist of a slot in which the test samples can be inserted for testing purpose. It consists of a bottom plate, a back plate, two side plates and two front plates. The test tiles are placed over the bottom plates. They rest on back plate on their rear side. In the front, the plates would just prevent the tiles from falling off. So, they are provided only for a short length from the ends. The front side is partially open, whereas the top side is completely open. Front side is partially open to allow bullets to hit the target tiles. The top side is completely open for placing and removing of test tiles. Holes were made near the edges on the plates, and tapping was done. The frame was assembled using bolts and nuts. Temporary fastening was preferred because permanent fastening would have made transportation difficult, since testing was done in Madurai. The net weight of the frame was around 61 kg.

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III. TESTING

To determine the effectiveness of using Non-Newtonian fluids, testing was done. Testing involved shooting the target tiles with a weapon to find out how efficient the samples would be in absorbing the impact.

Testing was done using a .30-30 Winchester rifle. Initial velocity and energy of the bullet are 728 m/s and 2570 J. The barrel length of the rifle is 60 cm. The cartridge's weight and length are 21.3 g and 64 mm. The mass of the projectile is 9.7 g.

Two series of tests were carried out. First was with glasses and second without glasses. Glass tiles of varying thickness were placed behind test tiles and tested. Glasses were put in a sack individually and was inserted in the slot of the frame along with the test tiles. Shooting was done from a distance of 50 m. The same test procedure was carried out for all the test samples. The second series of tests were done by placing the test samples alone in the slot without the glasses. These samples were made to rest directly on the back plate of the frame and were shot.

There were dents produced on the back plate of the frame when shots were made in all the tests. These dents were of different sizes corresponding to different test samples and method. The dimensions were analyzed to find out the effectiveness of using Non-Newtonian fluids.

IV. RESULTS

During the first series of tests, glasses broke in all the cases. The depth of the dent produced when direct hit made (without any test sample or glass) was 4.22 mm. Before the bullet strikes the back plate, the glasses would have absorbed some amount of energy as they break. But then as same thickness glasses were used for every sample, the glasses should have absorbed same energy for fracture. So, for same thickness, it is possible to compare the depth of the dent.

For 4 mm, glass plates, the depth was 2 mm for sample 1. For sample 3, it was reduced to 0.8 mm. For sample 2 (the one with Oobleck), no deformation was observed. There was only marks made on the plate when the bullet was hit. For 6 mm glass plates, the depth was 1.9 mm for sample 1, whereas it was only 0.38 mm for sample 3. Again in sample 2, there was no dent hardly leaving any indication for a bullet hit.

Since the testing with glass did not yield the desired results, testing was done with frame directly. When the frame was hit directly, the depth of the dent was 4.22 mm. When only Kevlar was used, it was reduced to 3.9mm. When the tile with Oobleck was used, the depth was further reduced to 2.7 mm.

The depth in third case was reduced by 1.2 mm. Creating a dent with 1.2 mm and diameter 14 mm requires appreciable force. That force would be a potential danger for humans. Hence, in this case, Oobleck sample has absorbed the impact that was caused by this force. Also for same number of rounds, only Kevlar has taken up more damage at the rear whereas the damage is comparatively less on Kevlar with Oobleck. It proves that the tile with Non-Newtonian fluid will be more efficient in absorbing impact than the tile with Kevlar alone.

BULLET PROOF VEST USING NON-NEWTONIAN FLUIDS – TEST SAMPLE

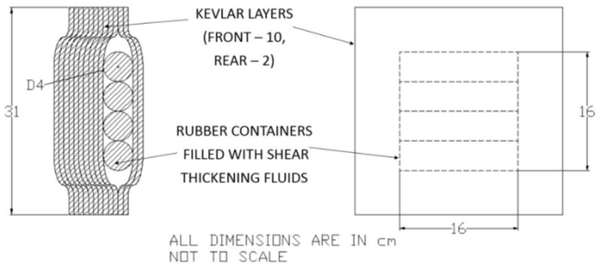

TABLE 1 Results of test keeping glass behind each sample

SAMPLE NO.	SAMPLE DESCRIPTION	GLASS THCKNESS (mm)	DEPTH (mm)
1	Kevlar	4	2
1	Kevlar	6	1.9
2	Kevlar with Oobleck	4	-
2	Kevlar with Oobleck	6	-
3	Kevlar with PEG & SiO_2	4	0.8
3	Kevlar with PEG & SiO_2	6	0.38

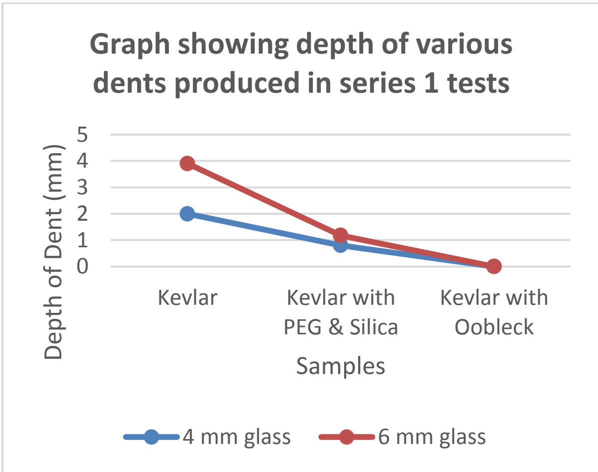

TABLE 2 Results for testing without glasses

Sample	Depth (mm)
None (Direct Hit)	4.22
Kevlar-1	3.9
Kevlar with Oobleck-2	2.72
Kevlar with Oobleck-2	2.7

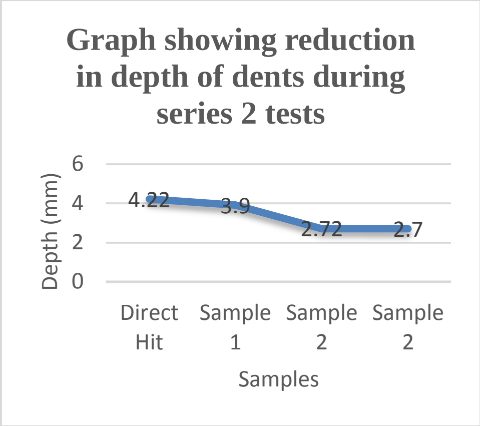

Figure 1 Test Sample

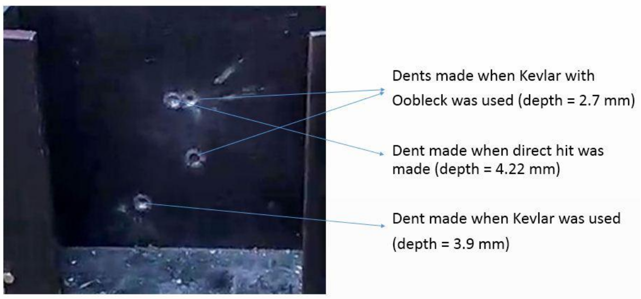

Figure 2 Dents made when second test was done

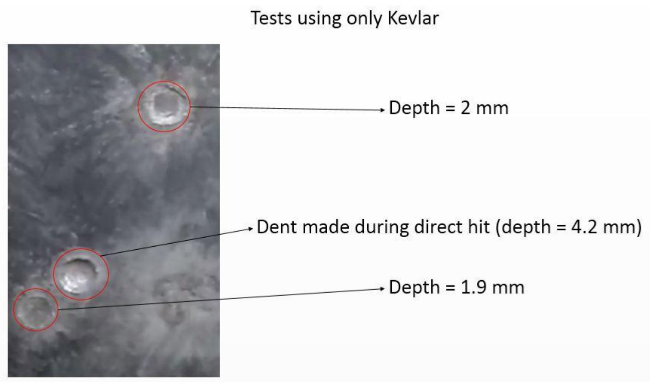

Figure 3 Front side test

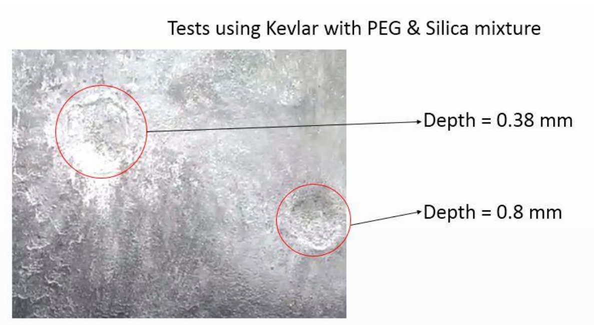

Figure 4 Front side test

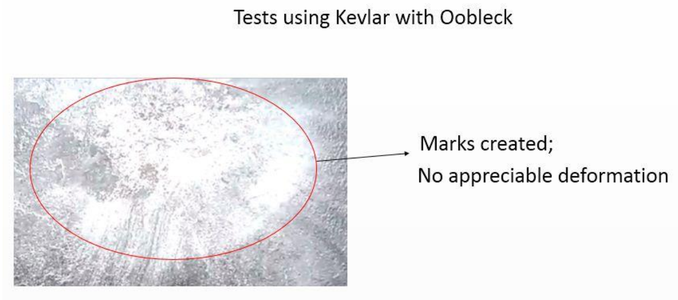

Figure 5 Front side test

Figure 6 Front & Rear side of sample 1 - After taking up damage

Figure 7 Front & Rear side of sample 2 - After taking damage

V. FUTURE SCOPE OF THE PROJECT

Kevlar is a material that is not readily available in our country. The material was procured with much difficulty and the fabrication was carried out. There are quite few aspects that would have made our work better

First, better grade of Kevlar could have been used. For testing, Winchester rifle was used. For absorbing the impact of rifles, military grade Kevlar like KM2 or KM129 must be used. But only basic ballistic grades were available. This would not stop the bullet completely as a result of which the bullet penetrated through the samples. At least if better ballistic grades were used, the test would have given better results.

For testing with high caliber weapons, it is recommended that 30 layers of Kevlar must be used. But only 12 layers were used since test was planned with low caliber weapon. While testing, high caliber weapon was used. The projectile's mass is twice and velocity is also twice. So, the Kinetic Energy of the bullet will be 8 times higher. Because of this reason, test tile was not able to stop the bullet from penetrating. If enough layers had been used or if test was done with low caliber weapon, results would have been much more satisfactory.

Ordinary rubber containers were used for holding the fluid. These are capable of transmitting only the force. But these didn't work efficiently because, the bullet itself penetrated through them. If better containers were used, the results would have been much better.

Another difficulty faced was that the fluid would become thick at the bottom and thinner at the top if kept undisturbed for few days. A suitable additive could help maintain the stability of fluid and it would have absorbed more impact. Few suggestions were asked from chemical professionals, but that did not work out well. More work could be done with chemical professionals to find out a suitable additive to make the solution stable.

The tiles could have been fabricated in better manner, ensuring better fastening for Kevlar layers and air tight packing of Non-Newtonian fluids. These would have made the sample tiles better, thus absorbing more impact.

Since many shots were made on each tile, they were intact only during the first round of firing. If they had remained intact, results would have been much more satisfactory.

Research on sandwiched Non-Newtonian fluids – There are research work going on by impregnating these fluid molecules into layers of Kevlar. This may ensure same flexibility as Kevlar, but then the properties of the Non-Newtonian fluids are not up to the fullest. So, more research work can be done by sandwiching Non-Newtonian fluids in fluid form between layers of Kevlar. Only constraint is that thickening of the solution. Once this problem is solved, this can even replace metal plates in the armours completely.

For holding the fluid, the plastic films that are used in soft armours could be used. The plastic films that make up the covering portions of conventional soft armours could be made into form of cylindrical containers and fluid could be pressurized into this. This would be an ideal container for holding the fluid.

These things would make soft armours safer. These would not increase weight too much. But makes them safer to wear. Research work could be done more on fluids. If proper techniques are found, then these can be tried in hard plate armours. Instead of those 14 kg metal plates, these fluids could be used; thus reducing the weight to just 1or 2 kg. There will be more than 10 kg weight reduction. This means ease of mobility for the soldier. Light weight armours will be easier to wear and also allows them to move freely. This will probably be the best armour. Now, a basic work is done to prove that the use of these fluids (in sandwiched form) could absorb impact. Hence more research work should be done in this field so that, there can be fluid filled armours instead of heavy solids.

ACKNOWLEDGEMENT

We would like to thank our officials Rev Dr Francis P. Xavier SJ, Dr Jose Swaminathan, Rev Dr John Pragasam SJ, and Mr.S.Francis Jeyapathi for their constant encouragement in research activities. We would like to render our special thanks to Mr. Edward Jeyaseelan Kennedy and Mr. J. Surendran Manuel for their help in testing process.

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