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Applications of SHEAR THINNING FLUID (STF) as *NANOTECHNOLOGY on the KEVLAR Materials FOR BALLISTIC Protections*

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ABSTRACT

The aim of the present study is to perform a ballistic characterization of composites by means of the fundamental machine parameters have high non-linearity theoretical behavior hereafter experimental preliminary results of a prototypal device are presented and results were discussed. An intriguing issue of nano-science research for aerospace applications is to produce a new thin, flexible, lightweight and inexpensive material that have an equivalent or even better ballistic properties than the existing Kevlar fabrics. The primary objective of body armor research is to develop a low cost, lightweight, wearable garment system with improved impact resistance. Currently used body armors, particularly those for military use, are considered too heavy, limiting the agility and mobility of the wearer and eventually leading to increased casualties. Body armor standards require that an impactor should be stopped under impact, and the penetration depth into a backing material to the armor should not exceed 1.73 inches. If penetration depth exceeds this value, a wearer can acquire serious blunt trauma1. Therefore, the demand for substantial improvement in the performance-to-weight ratio of body armor as well as the performance-to-thickness ratio is very high. The research results demonstrated that ballistic penetration resistance of Kevlar fabric is enhanced by impregnation of the fabric with a colloidal SHEAR THICKENING FLUID (STF). Impregnated STF/fabric composites are shown to provide superior ballistic protection as compared with simple stacks of neat fabric and STF.

Keywords:- Kevlar, Ballistic Impact, Nano-Particles, Shear Thickening Fluid (STF), etc..

I. INTRODUCTION

Textiles designed for stab resistance require dense weaves to prevent yarns from being pushed aside from the tip of sharp-pointed objects such as knives, needles, awls, and ice picks.[1]

Figure (1):- The body Armoured & Protective Clothing as application of KEVLAR.

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Dense weaves that prevent punctures can lead to premature or punch-through failures in ballistic impacts. "Liquid Armor" (shear thickening fluid) its nano-particle based coating material allows fabric to remain flexible, but upon impact becomes hard. Used for body armor vests, helmets, and gloves as shown in Figure (1). However, techniques like supercritical fluid technology and particle repulsion in non- wetting templates (PRINT) have been also used in modern days. The principal factor that dictates the design of body armours is the type(s) of threat(s) for which protection is required (that is, ballistic, fragment, blast, stab, slash, chemical, fire, etc.). Armours optimized for protection against one threat type may not, however, be suitable for other threat types. Multithreat armours are commonly designed by integrating separate armouring solutions a process that achieves only minimal synergistic efficiencies at best. Armours that combine multiple defeat elements are often categorized as "in-conjunction" armours in which each component provides an enhanced level of protection for a given threat or multiple threat types.[2]

Design parameters for optimizing both ballistic defence and stab defence often work against each other. Traditionally, soft body armours for ballistic protection were manufactured using layers of woven fabrics stitched together; now they include laminates stacked with nonwoven, unidirectional (UD) layers and combinations of woven/nonwoven laminates. Considering the UD laminates, fibers within each UD layer are aligned in a parallel arrangement and are reinforced with a compliant polymer resin or matrix such as Kraton that binds the fibers together. The UD layers are produced in very thin sheet forms and are stacked, for example, in an alternating 0°/90° cross-ply fashion as shown in Figure (2). Polyethylene films are added to protect the layers, and the final laminated shape is attained by applying heat and pressure. Commercial UD laminates used for ballistic protection include Honeywell's Spectra Shield (ultrahigh molecular weight polyethylene (UHMWPE) fibers) and Gold Shield (Kevlar fibers) 1 and DSM's Dyneema (UHMWPE fibers).[3 & 4]

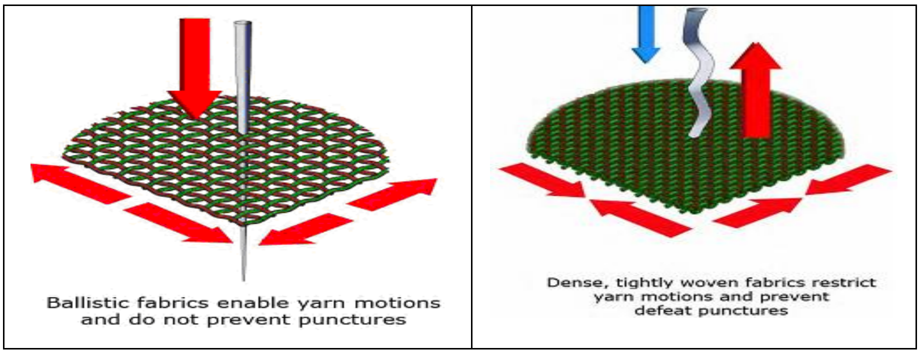

Figure (2):-: Puncture Behavior of Ballistic Versus Stab - Resistant Woven Fabrics.

Many dynamic effects observed in ballistic impacts on soft, woven body armours parallel that which occurs when a baseball is caught in the webbing of a catcher's mitt. Both projectiles initially contact a minimal number of yarns; these are known as the primary yarns. The primary yarns begin to compress in the "through-thickness" direction, and stress waves initiate and propagate along both yarn directions, dissipating energy away from the impact site. Body armours must be worn to be effective. Weight, mobility, and comfort therefore are vital to ensuring their use; the armours must conform to the user's body, properly distribute their weight over the body to minimize user fatigue, provide sufficient breathability for extended use especially during high temperatures, and must not interfere with or restrict the user's mobility. The significant challenge is to balance the level of

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protection required for specific threat type(s) against weight, comfort and flexibility, cost, environmental exposure (heat, ultraviolet light, moisture, etc.), and service life.[5 & 6]

II. LITERATURE REVIEW

The main trends and materials in protection technologies are briefly reviewed, emphasizing the properties and limitations of p-aramid fibres, widely used in amour systems, particularly in terms of their susceptibility to UV radiation, humidity and chemical attacks. Then, a novel nanotechnology capable of effectively diminishing these effects is described, as well as its application for an actual commercial ballistic vest. Protection represents an important industry, both economically and socially speaking, that includes, in the broad sense, industrial, laboratory, home and, of course, military protection, with an enormous variety of products, from simple plastic gloves to sophisticated and confidential military amour.[7] Defense personnel face multiple threats from different quarters, like terrorist groups and rogue nations, who own not only advanced lethal weapons but also chemical and biological warfare weapons. The present day protective clothing systems used by the defence sector is vulnerable to modern weapons and also have some inherent weaknesses like high cost, bulkiness and discomfort in wearing. Nanotechnology based materials offer a promising future in this area due to their extraordinary physical, chemical, mechanical, and electrical properties at nano-level.[8 & 9]

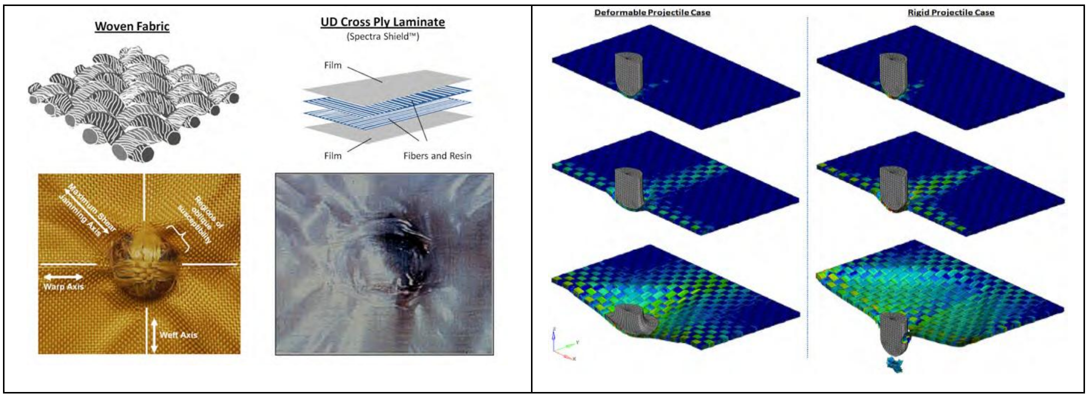


Figure (3):- Numerical (Finite Element Analysis) Models of a 4-Ply, Plain-Woven Fabric System Subject to Ballistic Impact Showing Yarn Stress Wave Color. Contours, Projectile Blunting (Deformable Projectile Case) and Fabric Penetration Failure (Rigid Projectile Case).[10]

Multi-axial aramid fabrics have a wide range of applications in the construction of composite structures for body armour. Nano-particles, which include nano-silica, are one of the most common nano-fillers for these structures. The particles of nano-silica possess nano-meter dimensions with high specific surface area. [11] Silane coupling agents are mostly used for modifying nano-silica surface in order to prevent silica agglomeration. Incorporation of nano-silica treated with silane adhesion promoter, in the matrix part of the hybrid composite form, leads to increased resistance to the bullet shock impact. The bullet-shooting test was applied to all the composites by two different bullet types. The structural design of the samples improved the ballistic resistance after the bullets were shot. Some ballistic image analyses for print and penetration depth of the samples were performed using Image Pro-Plus software as shown in Figure (3) right, result compared with real test on left.[12]

Use of nanotechnology allows textiles to become multifunctional. New principles will be combined into durable, multifunctional textile systems without compromising the inherent textile properties. Because it offers better built, longer lasting, cleaner safer and smarter products. Nano-science is study and Nano-technology is exploitation of the strange properties smaller than 100nm. Being so small they can be added to other materials and thus lending their properties to overall performance of composite objects.[13 & 14]

III. MATERIALS & METHODS

The Kevlar fabric is to be taken for various tests so as to check its strength and various properties, tests are to be conducted under the application of various loads and their effects are to be noted down. Kevlar behavior under various loads and environmental conditions are to be specified. Kevlar fabric being the toughest has several effects when exposed to UV and under the application of water. The fabric is taken in the neat form firstly for the testing and then the nano-particles impregnated fabric is taken for testing. Testing of neat fabric taken in four layers, Shear Thickening Fluid (STF) preparation, Coating of STF on the neat fabric by Soaking, Sandwich pattern, Drying of the fabric, Testing of the coated fabric.

Figure (4):- Details of Kevlar Fabric Material.

Although Kevlar is stronger than steel, it's about 5.5 times less dense (the density of Kevlar is about 1.44 grams per cubic centimeter, compared to steel, which is round about 7.8-8 grams per cubic centimeter). That means a certain volume of Kevlar will weigh 5-6 times less than the same volume of steel. Think back to medieval knights with their cumbersome suits of armor: in theory, modern Kevlar gives just as much protection but it's light and flexible enough to wear for much longer periods. Kevlar is a polymer; this means that it is made up of a large number of the same basic unit, called a monomer, which are attached to each other to form a long chain. The monomer in this case is made up of an amide group and a phenyl group.

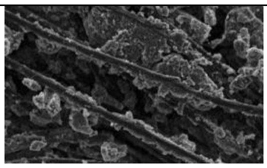
Methodology: - First, all the fabrics are prepared along with the solution. Minimum 4 fabrics are cut into size 19 X 31cm. The STF is diluted with the diluents so as that fabric will be able to completely dipped in the solution. The STF was composed of silica particles in polyethylene glycol medium. The silica sol used in this study was composed of SiO_2 and methanol, and the nominal average diameter of the silica particles was 15 nm. Ethylene glycol is known to be an index matching solvent of silica particles. The procedure of fabric impregnation / nano-particles coating consists in the simply methods which is either by dipping within a bowl filled with the suitable solution amount, or by sandwiching the STF between the layers then the layers are squeezed and put inside the oven for the solvent evaporation Finally, the treated layers are enveloped with polyethylene sheets in order to minimize the loss of material not perfectly stuck on the surfaces and to avoid unwanted interaction at the interfaces between neat / treated surfaces (lubrication or degradation of fluid incompatible fabrics).

Figure (5):- The impregnation of nano particles solution can be done in two ways; By soaking, & by sandwiching the solution into layers.

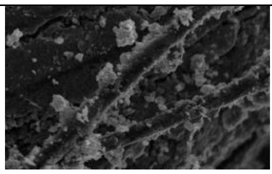
IV. ANALYSIS

The strength of Kevlar comes from its unusually regular internal structure; this has implications for the Hydrogen bonding which occurs between the electron dense oxygen atom and the electron deficient hydrogen. [15 & 16] The all trans-configuration, giving long straight chains, means that the hydrogen bonding can occur very regularly to form a very strong lattice, similar to those formed in crystals. The fibres consequently have very few flaws and so are very difficult to break up. The development of strong materials still continues, both for new fibres and for ways to use them. And undoubtedly the range of uses will continue to expand as new pursuits and the need for lightweight materials increases. [17]

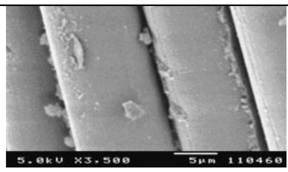
The modified silica particles mixed with the PEG result in agglomerations ranging from approximately 6 to 15 micrometers. Figure (6) demonstrates significant improvement corresponding to the adhesion of STF to the fabric layers. There is still consistent coating on the surface of the tows and between adjacent tows. This adhesion to the tows is credited to the silane coupling agent that was used to modify the silica particles and as a result, this adhesion feature visible even after a fibre has been impacted from spike during the test. It is projected that, the loss of impact resistance at higher impact energy in target 3 was due to the larger agglomerations, where size of majority of particles was beyond the nanoscale range in the mixture that coat the Kevlar fabric, seen in Figure (6) more details are available Kungarani, S.[10]



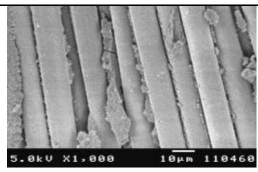
(a) ADHERING to the Surface.(100μm).



(b) Agglomeration 6μm to 15μm.



(c) Adhesion of the functionalized silica



(d) PEG coating over the Kevlar tows.

Figure (6):- The silica-PEG mixture (a) adhering to the surface of the Kevlar tows, (b) agglomeration on the Kevlar fibre with a size range of approximately 6μm to 15μm,(c) The silica-PEG mixture adhesion to the surface of the Kevlar tows, (d) Functionalized silica particle adhesion to the tows of the Kevlar fabric. For the MSEC 15.0kV *.0mm * 300 SE.

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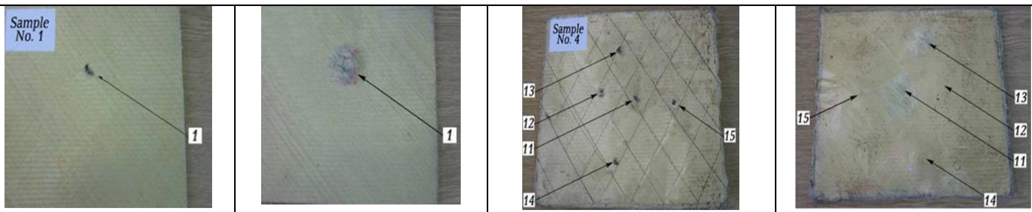
V. RESULT & DISCUSSIONS

Comparison of the changes occurred in coated fabric and the neat fabric. Thus different samples are made as per the methodology. Samples include Sample A, Sample B, Sample C. Sample A is taken as the neat Kevlar fabric in four layers, cut in the dimensions of 19cm x 30 cm without impregnating with any STF. Actual fabrication procedures include the mixing of silica particles, polyethylene glycol and ethanol. This ratio eventually results in a mixture of silica and polyethylene glycol after drying out ethanol. The addition of ethanol aids in the dispersion and breakup the silica agglomerations and to aid the infusion of STF mixture into the Kevlar fabric. After an hour of continuous stirring, the mixture was used to soak 4 layers of Kevlar fabric. The Tensile Strength (N) and Elongation (%) is Tabulated below in Table [1].

SAMPLE	*Tensile Strength (N)*	*Elongation (%)*
Single Layer Neat Kevlar **(Sample A)**	250	**3.8**
Nanoparticles impregnated fabric obtained by soaking **(Sample B)**	6305	4.5
Nanomaterials impregnated fabric obtained by sandwitched **(Sample C)**	7007	6.6

Table [1]:- Results for Tensile Strength & Elongation of KEVLAR.



Front side.	Back side.	Front side.	Back side.

Figure (7):- Front side & Back Side of shot for sample No.1 & No.4.

Bullet shooting showed that the composites of *p*-aramid poly (vinyl butyral) could not always act as a full protection against bullets. This is obvious from the complete penetration of bullet No.1 in sample No.1. Figure (7) show the entrance and the exit of the bullet in the target.

VI. CONCLUSIONS

The impregnation of Shear Thickening is a non-newtonian Fluid (STF) to a fabric increases the frictional force of a single yarn in the fabric which consequently increases the apparent modulus of the yarn. The laminating sequence was found to be a very important factor in improving the protective performance of STF impregnated fabric hybrid multilayer panels. Ropes and cables, Auto hoses and belts, Composite materials, Mooring lines, Tires, Fiber optic cables, Climbing ropes, Escape ropes for firefighters, Umbilical hoses on offshore, Oil and gas refineries, Sporting goods, such as, Tennis rackets, lacrosse, Sticks and canoes. Flame-resistant clothing, Protective clothing and helmets. Body armor, although it is being replaced by stronger polyethylene products such as Dyneema. As a composite material it is often combined with carbon fiber.

Nanostructures and nano-composites are being developed for the following defense applications. Lightweight protective clothing, flexible antiballistic textiles, chemical and biological warfare protection and self-decontaminating nano-fibre fabrics. Adaptive suits like switchable fabrics for improved thermal control, switchable camouflage. Micro-sensors for body and brain sensing, Environmental and situational awareness, integrated into a smart suit or a smart helmet. Wearable and/or flexible displays for visual feedback auxiliary supports: Flexible/rigid textiles for additional strength, exoskeletons, and robotics to assist the human tasks.

REFERENCES

[1.] Aleksić, R. R., (2012), "The viscoelastic properties of modified thermoplastic impregnated multi-axial aramid fabrics", *Polymer Composites*, *33*, pp. 158-180.

[2.] Daoshun Xue, Hu, Hong., (2013), "Mechanical properties of biaxial weft-knitted flax composites", Materials Design, pp. 264-269.

[3.] Decker, M. J., Halbach C. J., Nam C. H., Wagner, N. J., Wetzel E. D., (2007), "Stab resistance of shear thickening fluid (STF)-treated fabrics", *Composites Science and Technology*, *67*, pp. 565-578.

[4.] Grujicic, M., Bell, W.C., Arakere, G., He, T., Xie, X., Cheeseman, B. A., (2010), "Development of a Meso-Scale Material Model for Ballistic Fabric and Its Use in Flexible-Armor Protection Systems", *Journal of Materials Engineering and Performance, 19*, pp. 22-39.

[5.] Hassan, T.A.; Rangari, V.K. & Jeelani, S., (2010), "Sonochemical synthesis and rheological properties of shear thickening silica dispersions", Ultrasonics Sonochemistry, pp. 947-952.

[6.] Jacobs, M. J. N., Van Dingenen, J. L. J. (2001), "Ballistic protection mechanisms in personal armor", *Journal of Materials Science*, *36*, pp. 3137–3142.

[7.] Jong Lyoul Park, Byung Il Yoon, Jong Gyu Paik, Tae Jin Kang, (2017), "Ballistic performance of p-aramid fabrics impregnated with shear thickening fluid", Textile Research Journal.

[8.] Johnson, W., Collins, C., & Kindred, F., (1968), "A Mathematical Model for Predicting Residual Velocities of Fragments after Perforating Helmets and Body Armor," Technical Note 1705, Army Ballistic Research Laboratories.

[9.] Karahan, M., Kus, A., Eren R., (2008), "An investigation into ballistic performance and energy absorption capabilities of woven aramid fabrics", *International Journal of Impact Engineering*, *35*, pp. 499-510.

[10.] Kungrani, S.K., (2017), "Experimental Studies of Applications of Nanotechnology on Kevlar Fabric", a M. Tech Thesis for Sant Gadge Baba Amravati University, Amravati, COE&T, Akola,444104, pp. 1–103.

[11.] Lee, Y. S., Wetzel, E. D., Wagner, N. J., (2003), "The ballistic impact characteristics of Kevlar® woven fabrics impregnated with a colloidal shear thickening fluid", *Journal of Materials Science*, *38*, pp. 2825-2833.

[12.] Mahfuz, H., Clements, F., Rangari, V., Dhanak, V., Beamson, G., (2009), "Enhanced stab resistance of armor composites with functionalized silica nanoparticles", *Journal of Applied Physics*, *105*, 064307.

[13.] Pinto, R., Carr, D., Helliker, M., Girvan, L., Gridley, N., (2012), "Degradation of military body armor due to wear: Laboratory testing", *Textile Research Journal*, *82*, pp. 1157-1163.

[14.] Prat, N., Miras, A., Rongieras, F., Voiglio, E., Sarron, J.-C., (2012), "Contemporary body armor: technical data, injuries, and limits", *European Jr.l of Trauma & Emergency Surgery*, *38*, 95–105.

[15.] Szczepanski, J.M., (2011), "Modification and integration of shear thickening fluids into high performance fabrics", Paper 761, MS Thesis.

[16.] Thandavamoorthy, S. Gobinath, N. & Ramkumar S.S; (2006), "Self-assembled honeycomb polyurethane nanofibres"; J. Appl. Polym. Sci., 101(5), pp. 3121-124.

[17.] Víctor M. Castaño, Rogelio Rodríguez et al., (2013); "Nanotechnology for Ballistic Materials from Concepts to Products", Review article, Materials and Technology.