DEVELOPMENT CERTIFICATE

Shear thickening fluid (STF) ballistic adhesive / Textile-based Hybrid ballistic panel

General purpose
Soft bendable Ballistic panel for car and architectural armoring

Description of Development
Soft ballistic panel made of para-aramid fibers bonded with shear thickening fluid (STF) ballistic adhesives. The idea of using STF Adhesive for Aramid surface modification is to enhance structural integrity through friction.

Use, Production methods and components of shear thickening fluids (STF) ballistic Adhesive
The application of shear thickening fluid (STF) Adhesive for ballistic protection has protective applications for low velocity bullet impact applications as well as for high velocity ballistic impact applications. Shear thickening fluid (STF) is a non-Newtonian fluid having two phases, namely dispersed phase and dispersion medium. Initially with the application of shear, STF shows shear thinning behaviour. However, after achieving a particular shear rate, called critical shear rate, viscosity increases abruptly and the liquid suspension attains an almost solid like state. The STF ballistic Adhesive consists of nano-scale or sub-micron particles of silica, polymethylmethacrylate (PMMA) and silicon liquids. Sonochemical technique, high speed homogenization, ultrasound sonication are used for proper dispersion of particles in STF by breaking intermolecular interactions of nano particles. Addition of Nano-fillers are used to tune the onset of shear thickening so as to suit ballistic requirements with graphene oxide (0.1% to 0.3%) into a silica/ PMMA -based STF to modify the shear thickening behaviour, The presence of Nano-fillers facilitates the formation of clusters by the particles as the latter agglomerate around the former. Thus, critical shear rate reduces, and peak viscosity increases.

Improve the impact resistance
Improve impact resistance of Aramid woven fabrics with a novelty coat/bonding process of Aramid layers with shear thickening fluid (STF) ballistic adhesive that modifies fabric surface by developing Nanorods to enhance structural integrity through friction, thickness mechanical properties and improved the load bearing capacity along the thickness.

MANUFACTURER	TANUS ARMOR GROUP S. de R.L. de C.V
PRODUCT DESCRIPTION	STF ballistic adhesive / ARAMID Textile-based ballistic panel
PRODUCT BRAND	TANUS ARMOR
PRODUCT MODEL	**TANAR FLEX** BALLISTIC SOFT PANEL
UTILITARIAN PURPOSE	**Ballistic Protection “CIVIL USE ONLY”** FOR CAR ARMORING / ARCHITECTURAL ARMOR / BULLETPROOF SYSTEMS / SHIELDS
AMBIENT CONDITIONS OF USE	Temperature: 21 °C ± 2.9 °C (70 °F ± 5 °F). Relative humidity: 50 % ± 20 %.
BALLISTIC MAXIMUM PERFORMANCE	Semi Jacketed Hollow Point (SJHP) bullets with a specified mass of 15.6 g (240 gr) and a velocity of 436 m/s ± 9.1 m/s (1430 ft/s ± 30 ft/s).

TANAR FLEX SOFT PANEL BALLISTIC COMPONENTS
para-aramid fibers
non-Newtonian ballistic adhesive

PARA-ARAMID FIBERS CHARACTERISTICS / APPLICATION METHOD	
FIBER TYPE	ARAMID THREAD
THREAD LINEAR DENSITY	3000 / 3000 +/- 3%
TYPE OF LIGAMENT	PLAIN
ARAMID FABRIC 3000D 17X17 weave	14 layers/sheets
MASS PER AREA (g / m2)	442
WARP WEAVE DENSITY (Yarns / cm)	6.5
WEFT WEAVE DENSITY (Yarns / cm)	6.5
DENSITY	0.53 – 0.64 mm
THICKNESS	5/10mm According material weave and density
LAYER PLACEMENT ORIENTATION	Overlapped Layers each other 0° /45° , 0° /90°, 0° /30°/60° According material weave and density
LAYER PLACEMENT SEQUENCE	1-1
MINIMUM PANEL SIZE	100 X 100 CENTIMETERS
MAXIMUM PANEL SIZE	1.20 x 1.20 METERS
WATER REPELLENCY	Min. 80 grade

ARAMID DENSITY, TENACITY AND MODULUS

Fibre properties are of paramount importance for this ballistic panel development. The aramid used must have low density, high tensile modulus, high tenacity and low elongation at break. The aramid recommended has lower modulus (96 GPa) and higher tensile strength (3.39 GPa) and lower elongation (3.5%)

STRUCTURAL PARAMETERS

Yarn twist

Aramid high performance multifilament yarns are twistless, making their handling a little difficult due to tendency of defilamentation. Therefore, twist may be applied for ease of operation and better performance. It is well established that twist insertion to a fibre strand increases its strength initially. However, after a certain level of twist, obliquity effect takes precedence and strength reduces. Tests showed that an optimum twist angle of about 7° provides maximum tensile strength; an angle beyond this reduces the tensile strength and increases the breaking elongation.

Fabric structure

Structures, such as warp knitted used as soft body armor materials also affect the ballistic performance of the panels.
For ballistic applications, fabrics must have an optimum level of thread density. Very tight fabrics will cause the yarns to deteriorate during weaving, while too loose a construction will not be able to stop the bullet from piercing through; a phenomenon commonly called as ‘wedge through’. In fact, it has been reported that fabric cover should have a value ranging from 0.6 to 0.95 for effective ballistic performance. tight structures woven from yarns consisting of large number of filaments with finer denier are beneficial for efficient ballistic protection, particularly for finer projectiles. The influence of fabric construction for ballistic protection jammed fabrics inhibited movement of yarns during impact, consequently, preventing the critical shear rate, needed for STF, from being achieved.

Orientation of fabric layers

Multiple layers of high-performance fabric are required to get enough protection against high velocity impact. Stacking of multiple layers to make a single panel can be done in different ways. Orientation of fabric laying affects impact energy absorption. Impact energy absorption is always lower when all the fabric layers are aligned in 0°. The highest impact energy absorption is obtained for two, three, four and eight layered fabric panels using the angle of orientations [0/45], [0/90], [0/30/60], [0/22.5/45/67.5] and [(0/22.5/45/67.5) × 2], respectively. Overall 11.4 to 18.5% increase in the impact energy absorption was obtained by using different orientations of fabrics in different layers. This is because as the different fabric layers are oriented along different axes, the assembly approaches isotropy.

Crimp

Yarn crimp is known to slow down the speed wave propagation in ballistic impact. When a projectile strikes a fabric having high crimp, the fabric shows less resistance against the projectile as yarn stretching occurs without much difficulty. This is because the crimped yarns in the fabric take more time to absorb energy, as they initially straighten and then stretch. Higher the crimp, more is the deflection in transverse direction and larger is the back face signature or blunt trauma. It is interesting to note that the experimental results showed that plain woven outperformed the other weaves in terms of impact resistance performance. This might seem contradicting, given that a plain-woven fabric has higher crimp in comparison to twills and satins. This, perhaps, suggests that there must exist an optimum balance between number of contact points and crimp level. The use of hybrid fabric in which weft yarns have higher failure strain. Thus, during impact, weft yarns will take more time to break, resulting in both warp and weft yarns to break about the same time. Logically speaking, a more feasible approach is to develop fabrics with same amount of crimp in both directions. However, crimp imbalance in woven fabrics has a substantial effect on the energy absorption, stating that there exists an optimum level of crimp imbalance that would give maximum level of energy absorption for a particular threat. For fully perforating impacts, a crimp-balanced structure reflected higher back wave energy from the site of impact, negatively affecting the ballistic performance.

Number of fabric layers and stitching

A single layer of high-performance fabric is insufficient to ensure protection against high velocity impact. Therefore, a soft ballistic armor against high velocity impact is generally comprised of several layers of high-performance fabrics sewn or stitched together. Expectedly, as the number of layers increases, the trauma depth and diameter decrease. With the increase in the number of layers (from 20 to 32), trauma depth (by 35.4%) and trauma diameter (by 12.7%) decreased.

The requirement of multiple layers necessitates adhesion or stitching of layers for considerable thickness. This extra adhesion or common stitching process increases the stiffness of the fabric assembly. STF ADHESIVES stitching plays the important role of binding the layers together, thus preventing delamination from occurring. Tests conducted on unbounded and bonded neat and STF coated fabrics showed that, in general, bonded fabrics performed better than the unbounded ones.

SHEAR THICKENING FLUID (STF) ADHESIVE CHARACTERISTICS / APPLICATION METHOD	
VISCOSITY (cps)	35000
HOMOGENIZATION	Ultrasound sonication
RESPONSIVE ABILITIES	Thermosensitive
DISPERSED NANOPARTICLES	SiO2 PMMA (polymethylmethacrylate)
SIZE OF PARTICLES	NANO
DISPERSING MEDIUM	Silicone-based liquid

Application of STF Adhesive on Aramid fabric

STF-Adhesive impregnated fabrics refer to those fabrics made of high strength, high modulus polymeric yarns impregnated with shear thickening fluids to promote shear thickening properties. As shear thickening fluids can keep flowable after impregnation, thus the flexibility of the fabrics will not be influenced, meanwhile the coefficient of friction between yarns in the fabrics is improved. The application of shear thickening fluid enhance the impact resistance of Kevlar fabric.

Thickness of the STF-Aramid fabric

In order to exclude the influence of STF Adhesive on the thickness of the fabrics, the untreated fabric was covered by Adhesive films with thickness of 0.3mm.

Bonding processes

The final distribution of the adhesive in the gap depends on the compressing normal load, velocity and kinematics, the adhesive properties, but above all on the initial adhesive distribution. The latter is also largely responsible for trapped air and the adhesive squeezes out at the edges. This model has been developed for the simulation of the flows during compression processes in adhesively bonded joints. This extends towards shear rate-dependent viscosity, a phenomenon crucial for most industrial adhesives.

Behaviour of shear thickening ballistic adhesive

When the shear stress intensively rises, the original types of forces, like hydrogen bonding and Brownian motion, between the particles are broken up. Then these particles aggregate together driven by hydrodynamic lubrication forces to form jamming particles clusters, which results in the fact that the particles cannot move freely and the flow of liquid is retarded. Thus shear thickening fluid adhesives become denser with a higher viscosity and eventually are transformed into a rigid phase. As the shear rates become lower, the repulsive force between the particles is higher than the reduced shear force, particles keep a distance from each other and their movements are balanced. So the particles once again move freely in the suspensions, in other words, the shear thickening fluid is more like a liquid.

Dilution and evaporation

In order to ensure that the performance of the STF-impregnated fabrics is not affected by the process of dilution and evaporation, the rheological properties of the STFs treated through diluting and evaporating were tested, and the results demonstrate that the impregnating process does not influence the properties of the STF