Review paper on ballistic and impact absorption characteristics of Aramid fiber using the shear thickening fluids

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Abstract: In ancient times soldiers use heavy metal sheets to protect them from weapons. To make soldiers comfortable and save them from the ballistic and the stab injuries. Aramid fiber is used with treating shear thickening fluid which is called the liquid body armors. The aramid fibers with shear thickening fluids nowadays are used in body armor applications. Studies related to Kevlar's ballistic and impact strength impregnated with shear thickening fluids have various types of criteria to enhance the properties of liquid body armors. In this review paper studies conducted by different authors on characteristics of aramid fibre using the shear thickening fluids by varying its composition has been discussed. Various test has been conducted by different authors to measure the properties of the composite.

Keywords: Kevlar, shear thickening fluid, Aramid composite.

ERIC D.WETZEL [1] has discussed the four types of particles of silica based STF on different loading condition. Particle with dispersion ratio of 7:1 to needed concentration had been used. They studies the behavior of rheological properties of the STF with the rheometere and for the ballistic testing they use the various static and dynamic spike test and calculated the neat Kevlar results and results with the STf . Result are giving the difference of applying the STF to the Kevlar the properties can be enhanced by the various loading condition of the shear thickening fluid used

F.J GALINDO-ROSALLS [2] had studied a new apparent type viscosity function to be used in the application of shear thickening fluids they basically proposed the viscosity function by studies. First is the phenomenon of the slight shear thinning at the lower shear rates and the sudden and sharp viscosity increase over a thresholds shear rate. Shear had increased to an extent at that time the slight shear thinning they resulted that with increase in shear the threshold level of the shear rate crosses and the viscosity increases but there is some extraordinary thing is the shear thinning at very high shear rates it is called the shear thinning region at critical high rates

A.HARRIS [3] had conducted the ballistic, rheological and the shockwave mitigation tests on twaron fiber with the polyethylene glycol and the fumed silica particles. The different ratios of fumed silica particle in the PEG solution are directly effects the ballistic nature of the twaron fiber at the different rates of the velocities of the projectiles are tested .The peak rise and the peak pressure of the different solution which are prepare by the varying the concentration of the fumed silica are giving the results according to the concentration.it is observed

that the more will the concentration of the silica particles in the solution of STF the more will the peak rise in the results of the shock wave mitigation and the peak pressure is rising with the increase with increase in the silica concentration. The ballistic are conducted with the steel projectilesand the enhancement in impact absorption and ballistic performance were done with the experiments.

TARIG A.HASSAN [4]defined the types of the shear thickening fluids like the silica-polypropylene and the silica polyethylene glycol and uses the different method to prepare the silica based shear thickening fluid these method are the synthesis of ethylene glycol with silica Nano particle, solvent exchange method and the ultra sound technique to mix the PEG with the silica on which the piezoelectric and magnetostrictive materials are used. They use the sonochemical synthesis at high intensive ultrasound traveling in the liquid generate growing cavities. When these cavities attain critical size then the condition of intense heat and tremendous pressure that gives the unusual environment to chemical reaction in the combination of the PEG and the silica there was two samples made by mixing the solvent exchange method and also by the mechanical mixer and tests are done with the cone plate rheometre, and also the thermal test and the SEM and TEM samples are tested and verify the properties and complete dispersion of the STF on the fiber

VIJAY K.RANGEN and HASSAN [5]use the theories of the shear thickening behavior order to disorder theory and the hydro cluster theory which state that when the molecules in the dispersion are forced to leave their places by the applied shear then the viscosity of the fluid give the drastic change and it causes the shear thickening effect. They use the nylon and Kevlar fiber and the synthesis of the STF fumed silica and polyethylene glycol to prepare the samples .they conducted the quasistatic test and the drop tower test and the SEM images to read the structures and the TEM images to verify the how much is the dispersion is in the solution of the particles. Tests are done on the neat Kevlar and the Kevlar with STF and studies found that there is the properties enhancement of the Kevlar and nylon fiber to the extent of using the STF without affecting the flexibility and wear ability of the fabric.

A.BOHANNAN [6]done their work in the field of the liquid body armors the use of the hexahedral elements to model the solid structure to be used in the finite element method and the Kevlar STF and aluminum composites .these are the materials composed to be use in the aircraft and the space applications. The projectile of the aluminum material use to target the layers of Kevlar and aluminum with the STF impregnation. They used the different combination of layers to prepare a laminate in some they inner the aluminum and used as the odd number layers and reverse also done to maintain the more effective result of energy absorption then there is the comparison of the simulation part and the simulation of the FEM model and the comparison with the experimental values. the more research is needed to get the great results from the initial step.

J.M.HOGHON and E.D.WETZEL [7]the hypodermic needle puncture tests for the Kevlar impregnated with the silica based shear thickening fluid were done. The stab resistance and the spike resistance of the Kevlar fiber has been investigated because in some cases the soldier is needed the protection from the spike type danger and the knife cuts .so they test the hypodermic needle ranging from the 12 gauge to the 22 gauge tip. The quasi-

static needle puncturing test is done with the INSTRON under the NIJ standard. In the results the comparison of depth of cut and the penetration depth is compared and the 22 gauge needle is found more responsive to the stab resistance because the larger tip the fiber give its more resistance reverse for the 16 gauge needle which having more penetration for the fiber due to its smaller tip. The tests are conducted on the Kevlar 706 with STF and only Kevlar.

PU-YUN CHEN [8] has investigated the shear thickening fluids with the protection fibers. Basically they use the silane agent SiH_4.which is connected to the functional group and silicon atom.to check the properties of newly develop Kevlar STF hexagonal paper (honeycomb). The shear thickening used in the experiment is having the silane agent with the polyethylene glycol and to some extent of silica particles are used, Kevlar is weaved with the hexagonal structure paper which is called the honeycomb due to its shape it can absorb the large number of the impact energy. The rheological and the drop tower test is conducted. Silane is the coupling agent which is giving the property enhancement the more yarn to yarn strength. And result found that the STF impregnated Kevlar has the more resistance to the impacts and the rheological properties of STF are enhanced.

MELIN CEMAL KUSHAN [9] using a novel approach for the liquid armor applications in the industry of aviation. STF Mechanism had been understood by Rheometers and stokesian dynamics. The studies defined the factors like particle volume fraction, particle shape, size, particle interaction, hardness, temperature on which the STF behavior depends. They used to change the shape of the particle in the dispersion and also the carbon Nano tubes are applied into the PEG and noted that increases the disposability of silica particle in the suspension of colloidal solution. For the fabric protection the fabric is made of the high strength which will give the high energy absorption.

HULIN LI[10] studied the tribological behavior of the hybrid which is prepare by the PTFE and the Kevlar composites with using Nano SI3N4 and the submicron size WS2 filler .where PTFE is the polymerized tetraflouroethlyene. In this study they check the morphology of worn surfaces, transfer film ,and the debris with the SEM images the results are like that single Nano Si3N4 filler can effectively reduce the rate of wear and some extent to the co-efficient of friction by with the Si3N4 and WS2 filler.

RUI WANG and TING-TING LI [11] in this study, low rate and flexible compound was fabric. Kevlar fiber and the glass fiber and nylon polyester non-woven via needle puncturing and the thermal processing effect of the Kevlar position in the laminate and the inter laminar bonding, number of layers are tested. The shear force at the primary layer is lower and the reaction and cause is different and varies in the dynamic puncture resistance. In statics there are more layers than the resistance to static punctures but in the dynamic resistance the single yarn pull out on the test spike pushing away the fibers and penetrate through the sample G-CF and K-CF demonstrate the different effects of puncture resistance. The work on cut resistance and volume density of puncture in the fabric was tested.

ZHENQUIN LU [12] used the WSKF to be impregnated with STF with polyethylene glycol basically the WSKF is the warp knitted spacer fabric which are used by the aeronautics. The size of the fumed silica used is 12nm particle. The rheological, drop tower test are conduct and also the impact compression, compressive test were conducted and Results indicate that STF has higher shear thickening at critical shear levels with greater particle concentration in the STF solution. Compressive rigidity as strengthened by using the STF in the impact test is higher than the untreated fabric with STF. Stiffness increase with increase in impact absorption property. As low velocity applications, STF impregnated WKSF has the strain rate effect under quasi-static. WSKF considered as damping material which is used for the personal protection.

LIWEI WU[13] have studied the warp knitted impact spacer fabric with the shear thickening fluid at the 23% fraction volume to the total volume are tested .Impact test were conducted to check the energy absorption where parallel the FEA model is prepared by the microstructure of warp knitted spacer fabric .The fiber tows of the warp knitted fabric is used as the geometrical representation of fabric and the shear thickening fluid mixed properties of the WSKF are used in the ABAQUS software to have the impact-load displacement curve. And the reaction of fiber tows and STF having the cushioning effect while impact loading .The comparison of the neat WKSF and the STF/WSKF will be used to get the more impact absorption with lower weight and high flexibility.

ABHIJIT MAJUMDAR [14] did their work on the optimal designing for the soft body armor which is silica based shear thickening fluid. The treated Kevlar fiber is studied under BOX and BEHKEN method which is used for the design optimal solutions. In this method they use the basic parameter as the variables on which the results are depend properties of the fiber and STF. The values of the parameters are to be in the range then the results can be predicted by lesser number experiments to the more numbers of vibrational results. The plots of the add on percentage of the STF versus padding pressure were plotted. The impact energy absorption is higher with silica concentration and impact resistance. Lower critical shear rate and higher concentration is needed but the sufficient add on % is required to get the best results. At which concentration the impact is at the higher value to be absorbed. The three parameters silica concentration, padding strength, and solvent ratio are used to improve the Kevlar properties.

BHUPINDER SINGH BUTOLA [15] used to get the results of deformation and the energy absorption modes of the STF tested Kevlar fiber as soft body armor. The treated Kevlar fiber and the neat Kevlar fiber are studied under various tests. Without shear thickening fluid there is the testing of the Kevlar fabric for the impact absorption test. When the neat Kevlar was tested, the energy is absorbed by single yarn. Its elasticity to pull out and smash the single-yarn phenomenon is the week point for the fiber to fail and When using the silica-based shear thickening fluid the yarn to yarn attraction becomes more of a single fiber friction then plays a vital role in the strengthening process.

BRIAN.A ROSEN [16] studied the multi threat performance by using the kaolin based shear thickening fluid. The use shear thickening fluid is prepared by the mixing the kaolin clay and glycerol with the polyethylene glycol which is already have the concentration of silica particle in it. Various studies are conducted ballistic

test, quasi-static stab test was performed for the number of the varying layers of impregnated fiber and for the neat Kevlar fiber. The kaolin clay basically has the platelets like particles which can give the more hydro cluster whereas the silica particle was spherical in nature and the kaolin clay is continually thicken when the 12MPa shear rate was crossed. And the silica performance for STF use is different from that. According to quasi-static test of stab resistance on four layers of kaolin impregnated, NIJ standard 160N can be prevented. Where the neat Kevlar can give penetration to the 35N and where it has been found that the 0.22 caliber spherical projectiles are 50 percent higher energy absorption of the shear thickening fluid centered on kaolin clay.

HN.CHOI [17]studied the aramid fiber which are impregnated with the fumed silica and the add on% of the fumed silica with in the colloidal solution with polyethylene glycol and the methanol used as the diluent of the STF .the main attention is given to cut resistance from the spike and the sword like weapon according to tests which are conducted like the cut resistance test rheological test of colloidal solution of silica STF quasi-static stab resistance test .Also the dynamic stab resistance were conducted with prepared sample of the fumed silica and the fiber. The analysis of the stab resistance material is done. there is the Kevlar fiber used in manufacture by 4 layer first 500 de fabric, second spun yarn fabric, third200 de fabric and the last layer was non−woven layer and the cut resistance material is used epoxy resin with acetone is pour into silicon panel after 25 minutes used the hot pressing to get the dotted type of the stab resistance materials the hard particles are treated with STF fumed silica of 10nm with the solution diluted by glue. But the use of that totally increase the weight materials is hardened therefore The STF has a low glue value and the yarn pull-out test examines the friction activity of an individual fiber. Results were same like the other studies the neat Kevlar having the more absorption than the untreated. Samples were giving the mixed type penetration and single yarn fracture for the stab resistance and the puncture resistance tests.

YO HO KIM [18] developed empirical study for the absorption of high velocity impacts on shear thickening fluid properties. Using the STF in body armor technology allows for more ballistic resistance enhancement without reducing the fiber impregnation process versatility. The studies which were conducted or the researcher had tested a limit of the 700m/s, but this study is related to high velocity range muzzle effect the 100nm silica Nano particle were used to dilute in the methane. The tests are carried out with the 2-stage light helium gas gun. The impregnation of shear thickening fluid gives more energy absorption in terms of volume areal density and the processing materials. The results showed that the 5 layers of STF / Kevlar give the energy absorption equivalent to the 8 layers of the neat Kevlar. The flexibility increases and the weight of the fiber to be wear will reduce. To prepare the STF, the sonication and homogenisation are used. The experiment was performed at a speed of 1-2km/s.

D.P KALMAN [19] developed the polymer dispersion based STF foe the protective application. The uses of the silica Nano particles are usually well known this study giving the idea about particle strength of the STF. When the polyethylene glycol is mixed with the silica hard particles and on other hand PMMA which is poly methyl methacrylate dispersed in shear thickening fluid .which is contains the softer particles then the silica. The particles of PMMA are less hard than the silica particles in the testing the both type of STF with PMMA

and silica hard particle and also the mixture of the PMMA silica with STF of PEG are used. Kevlar intercalated with STF tested on the quasi-static and the puncture resistance. The results found that PMMA effect the quasi-static penetration but with behavior of post thickening the light particles also affect the rheology and ballistic performance. PMMA particles are diffusing into the solution on the higher shear rate application. These results show the significance particle hardness to get the more resistance from stab and spike danger.

COLIN D.CWARINN [20]studied MMOD resistance from the puncture of the EVA suits which have the armor absorber layers. Micrometroids and the orbital debris are the main problem for the astronauts performing extra vehicular activities. Combined with the STF intercalated with Kevlar, the EVA suits with absorbing layer are tested for hypodermic needle and hypervelocity effect. The improvement in the EVA against the hypodermic needle test achieved by replacing the neoprene-coated nylon with Kevlar coated shear thickening fluid. In needle test 0.17 caliber gas gun at NASA's white sands remote hypodermic test facilities were used. Target were tested zero degree normal to front nitrogen chamber .Impact velocities at 4-7km/s are used to test the samples. The result shows the faithful advancement from neoprene to the STF-Kevlar fiber can be used as more energy absorption materials. EVA suits due to flexibility of the STF and Kevlar can be made by replacing the neoprene coated nylon. But there is the thermal degradation had seen due to projectile temperature at higher velocities improvement are need to explore with the both the textile used and STF formulation as well.

SHILPA N.RAJA [21]studied the strain dependency of mechanical behavior for the Kevlar fiber and compare with the other polymers. The mechanical and structural properties of Kevlar 49 are studied. Kevlar processing to certain strength begin at drawing can increase the strengths. Usage of continuum dynamic analysis to determine the Kevlar 49 storage modulus and loss factor as a function of strain by quasi-static testing. The structure properties are correlated the dynamic viscoelastic of material. Various experiments were conducted with the synchronic radiation analysis and the RAMAN scattering frequencies. The rate dependent stress analysis the results were compared with the Nomex, spider silk, polyester, and nylon the results found that the loss factor is approximately equal to young's modulus.

GURU MURTHY B.RAMAIAN [22] studied the Kevlar fibers with a totally new approach of the ANN artificial neural networks for defense application. Because of its stronger fragmentation resistance and mobility, and also the ease of wearing, Kevlar use is popular for the body armors. This study is investigating and developing ANN to analyze the performance of the ballistic fiber made from the kevlar29.with this ANN approach exploring a new predictive model using the materials property (single layer fabric) data collection and the processing based on flame resistance, less weight, chemical resistance are collected and used as input in the neural network modeling. In the ANN, the data is divided into three sections of the training set, validation and testing set the operations are like basic, structured and multivariate. Specific modulus of fiber, specific tenacity, density fiber warp yarn denier and the weft yarn denier and the ends/can't pick are the variables which are used. Back propagation technique is used to collect the input. And with these results new materials can be prepare for the better performance under ballistic conditions.

P.N.B REIS [23]this study is the investigation of behavior of the Kevlar fiber. Under the impact load and the damage tolerance when it is used with the two filler materials. First is the cork powder and other is cloisite 30b Nano clays. The epoxy resin and cork powder and the cloisite 30b are used to increase the impact response of the aramid fiber basically have the different criteria to the failure as the glass fiber and carbon fiber are fail because of the brittle cracking but the Kevlar fiber is fail because of the reason of the fibril and strand breakage or single filament breakage so there is the more energy required to break the yarn to yarn bonding. The hand layup process is used to make samples of Kevlar and epoxy resin and cork powder are mixed with sonication to make the impregnated Kevlar samples .the results shows that the added filler increases the load to 21J and about 4.5 elastic recuperation .Adding clay increases the damage area the same result are given by the cork powder.

H.MAHFUZ [24] developed body armors with stab resistance using SIO2 particles which are dispersed into glutaraldehyde. The Kevlar fiber impregnated with the mixture of the STF polyethylene glycol with the diluent methanol was the main focus for the studies but in this study they use the glutaraldehyde which is mixed with the silica particles with the sonication process to improve the mixing level PEG and silica particles are also crosslinking agents. The glutaraldehyde that has the base nitrogen atom is used to produce the STF. Glutaraldehyde is used mainly in the medical and dental treatment to disinfect health equipment. And in some applications, because of its crosslinking properties, it produces the covalent bridge that gives it a stable mechanism and a hard structure. When tests were conducted spike test and the drop tower test then it gives the 4.5 times penetration resistance to spike test. Properties of Kevlar materials are enhanced by the glutanaldehyde.

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