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Review on Mechanical Characteristics of Kevlar Composites

S.Rajesh[1*], B. Vijaya Ramnath[2], M. Jayasooriya[3] and R. Ragavan[4]

[1*]*Associate Professor, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai, Tamil Nadu, India-600044. E-mail: rajeshsri02@gmail.com*
[2]*Professor, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai, Tamil Nadu, India-600044. E-mail: vijayaramnathb@gmail.com*
[3,4]*Student, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai, Tamil Nadu, India-600044.*

Abstract

Nowadays, industries are focusing on developing new materials which must have good durability, bio degradable and with ease of fabrication. For military application, aramid fiber is mostly preferred due to their high impact resistance property. If natural fiber is also combined with aramid fiber then industries can produce biodegradable material. Hence, this paper reviews aramid fiber (Kevlar) composites fabricated with natural fibers. In this paper, the mechanical characteristics of Kevlar composites and various combinations of natural with Kevlar composites have been discussed in detail.

Keywords: *Review, Aramid Fiber, Natural Fiber, Mechanical Characteristics.*

1.0 Introduction

Natural fibers are very high in demand due to their superior mechanical properties in various industries. The processes of all the natural fibers are also very easy due to their availability based on the region. Due to their low cost, the natural fibers are replaced on behalf of carbon fibers which are very high in cost. Natural fibers possess very good tensile strength, eco-friendly, high strength to weight ratio, biodegradable characteristics, etc. mechanical properties of natural fibers having high stability due to its interfacial bond between the fiber and medium either thermoplastics or thermosetting plastics. Aramid fiber (Kevlar) is a high demand material used for defense and military applications. Kevlar has got high mechanical properties especially it is used for ballistic and missile applications. And moreover, it has been implemented with various applications such as automobile body, tyres, helmets, bullet proof jackets, thermal and cut resistant gloves, sports equipment, and musical drums where high impact resistance is needed.

1.1 Introduction of Kevlar Composites

Nowadays, there are numerous materials which are used to replace traditional materials to reduce the cost, overall weight etc. to build the product. In particular, recent trends show that modern usage of products has been tremendously increasing. Through polymerization techniques, Kevlar fiber is made by joining the long chain molecules from thousands of synthetic materials. Its internal structure has very good mechanical properties because of an arrangement of molecules in parallel and regular lines that are knitted rigidly together [1].

Stephen Kwoley introduced a preparatory

material namely Kevlar. Kevlar 29 and Kevlar 49 are the two varieties of Kevlar. Molecules of Kevlar have a ring like structures are aromatic. To form a long chain aromatic molecules joined together. Poly para phenylene terephthalamide is a chemical made of Kevlar. Hydrogen atoms in ammonia are replaced by amides. To make a super strong structure, condensation process is done when ammonia reacts with organic acids.

Kevlar polymers are turned into fibers by a wet spinning process which induces concentrated solution of poly para phenylene terephthalamide through spinner and to make the strong, long and thin. Then they are wounded by the drums. Then the fibers cut into woven and length into a tough material which makes Kevlar a super strong and stiff material. [1].

2.0 Mechanical Characteristics of Kevlar composites

2.1 Kevlar – Natural Fiber Composites

Kabir et al [1] have reviewed the structure of Kevlar, its grades, various properties, uses and its applications. Various applications such as military and body armor jackets show that Kevlar has got good impact resistance and high strength to weight ratio. Various characteristics like high modulus, high tenacity, high strength, and also high resistance to organic solvents except chlorine. Good resistant to abrasion and cutting. It is resistant to thermal degradation and low flammability with good fabric integrity.

Jeswin et al [2] investigates the absorption of water characteristics of reinforced kevlar fiber with glass fiber. The chosen fibers are kenaf, Sisal and aloe vera all infused with glass fiber and their original fibers. The fabrication is done using a mold cavity and the layers of the composite are placed while it is heated at the bottom half. Tensile test is conducted using ASTM D638. The highest breaking load and ultimate stress is observed in Sisal glass fiber composite of 7080N and 121 N/mm^2 respectively. The reason behind the result is evaluated to be because of its high elongation% of 28.16% which proves it has higher flexibility than other combination specimens. The flexural tests are conducted and shows sisal fiber has got the highest breaking load of 561N of all the other combinations which was also true for impact strength. Due to its flexibility the sisal produced comparatively less hardness value than aloe vera glass fiber having the highest of 83.7HRL. Sisal glass fiber has the lowest water absorption percentage and thus proving to be better mechanically suited that other specimens and so the author has decided to further conduct research on Sisal glass fiber composite.

Dinesh et al [3] investigates the composites fabricated from the specimen 1 made from Kevlar, banana bract fiber followed by the specimen 2 with Kevlar, palm fiber composite and specimen 3 with Kevlar, banana, palm fiber respectively. The tensile test is conducted followed by the SEM analysis of the specimen. The water absorption test was conducted and found out that the water absorption was the least in specimen 1 followed by specimen 3 and 2. It is found that the specimen 1 had generated the maximum tensile strength followed by the specimen 2 and 3 respectively. The morphological SEM analysis is done for the tensile test specimen after the test and the fiber pull out, air bubbles and debonding are identified.

Guru Raja et al [4] have experimented the hybrid composites of Kevlar glass with various fiber orientation effects. To improve mechanical properties, three different angle orientation combinations have been done by using vacuum bagging technique. In this epoxy resin acts as a matrix and Kevlar is the reinforcement. It results in significant tensile strength, modulus and peak stress due to angle with horizontal/ vertical orientation.

Abu Talib et al [21] have experimented the effects with and without cut holes on Kevlar 29 fiber with various fiber orientation angles. The results of quasi static compression and tensile properties have been experimentally studied. They concluded that the ultimate load of failure is low at 450 when compared to 900 orientation angles. And also, comparison has been done with theoretical and practical applications using the simulation software AutoDyn under Ansys software and the result of maximum difference found to be 5.8%.

Channabasavaraju et al [6] have compared various characteristics of Kevlar fiber along with graphite and glass fiber reinforced with polymer matrix composites. In order to improve better adhesion among the reinforcement and matrix, vacuum molding technique is used in the hand layup method. By increasing the specimen thickness, it is observed that there is a tremendous increase in the mechanical characteristics of Kevlar fiber compared to other specimens.

Valenca et al [7] experimentally investigated the epoxy reinforced Kevlar plain fiber along with glass fiber. In this study, comparison and mechanical behaviour for various fabric conditions has been discussed in detail. Kevlar plain fiber and hybrid fiber were manufactured using a hand layup method and it shows a significant improvement in the mechanical properties. The minimum curing time of the epoxy resin has been ensured by Fourier Transform InfraRed spectrometer for performing mechanical tests. Three different fabric conditions have been incorporated namely Kevlar 49, Kevlar 49 with s glass combination and s glass fiber with either side Kevlar 49 fiber in both weft and warp direction. Various mechanical tests have been performed to determine the tensile and yield strength with respect to specific modulus. Finally, morphological analysis is done to determine the cohesiveness between the matrix and the reinforcement. It is prepared by hand layup process using innovative architecture. Impact, bending and tensile tests were carried out in both directions of the wrap as well as vertical direction.

Yahaya et al [8] have examined the chemical treatment on kenaf fiber composite. In this work, it deals with the study of layering sequence on mechanical properties fabricated by hand layup method. The result shows that the addition of 6% sodium hydroxide treated fibers is very high in mechanical strength when compared to untreated fibers. Scanning electron microscope has been done on the fibers which highly influenced mechanical characteristics.

Jackson Singh et al [9] has studied in detail about the various properties of mechanical behaviour of the Kevlar composite material such as modulus, tensile strength and strength to weight ratio. Kevlar fibers are used as reinforcement in various applications.

Jiang Bo et al [10] have identified the tear resistance of Kevlar fiber. In this work, the parameters like notch sensitivity and fracture behaviour of Kevlar fibers were investigated. The Kevlar fibers are reinforced with thermoplastic polyurethane film and the result shows that the notch sensitivity increases when the hole size increases and also it decreases only a less percentage when compared to unnotched specimens. To measure fracture toughness and notched strength, the four types of specimen are implemented. Their results are compared to each other. Static tension and tear test has been carried out using the MTS system. Tear resistance exists at significant notch sensitivity.

Yue et al [11] have experimented the temperature effect of Kevlar 29 and also the impact on physical properties. It has been found that the tensile strain and strength is decreased when the treatment temperature increases. And also, there is no effect in young's modulus and vacuum treatment on the tensile strength.

Lin et al [12] have examined the reinforcement effect and the chemical treatment effect on mechanical behaviour. They examined the two categories of thermal bismaleimide using thermogravimetry, differential scanning calorimeter and thermo mechanical analysis. Also, it has been absorbed that by using chlorosulfonic acid treatment, there is a significant improvement in the interfacial strength.

Dinesh et al [13] examine the natural fiber composites made from hen, goat hair fiber, human hair, Kevlar followed by the tensile, flexural and water absorption test. It was found that the sample made from the composition of Kevlar and human hair had resulted in the best sample for tensile and flexural applications as it generated very high values of strength. The flexural strength was achieved the least in the case of the composite made from the Kevlar goat hair fiber, hen hair fiber, and Kevlar sandwich the sample prepared with Kevlar, goat hair, hen hair, human hair had averaged in between the other two composites. Morphological SEM analysis is done to analyze the surface topology after failure during the test.

Elanchezhian et al [14] have researched natural fibers to find a great alternative for synthetic fibers. The natural fibers like acacia, jute and sisal seemed promising as they have done research on these materials. In this paper the composite is fabricated using all the three fibers at varying compositions to test the best combinations for its mechanical properties. The mechanical tests for impact, tensile and flexural strength were experimented and found that sisal fiber and the composite containing it on higher composition proved higher strengths than those other composites. The SEM analysis is done on the tested materials to find the reason for such strengths and found the cracks and void formations are less in sisal fibers which prevented easy crack propagations and thus increasing its mechanical strength.

Shan Sham Shin et al [15] have fabricated sandwich composites of carbon fiber and aluminium honeycomb. Here, Kevlar fiber is used as an interfacial bond between the sandwich composites. They examined bending, uniaxial compression, feasibility and the effectiveness of short Kevlar fibers. They concluded that there is an increase in adhesion bond between the sandwich composites which forms the strong bridge between them. They also compared which has been done for peak load and energy absorption. Interfacial toughening and the internal structure have been dis- cussed in detail using fractography observations.

Sanborn et al [16] have studied the effect on Kevlar KM2 at different loading conditions. They concluded that there is an effect on both fatigue stiffness and strength of the fiber. And also, comparison has been made between the warp and weft direction of fiber which influences the fiber orientation results in lower modulus of rigidity and failure stresses. The hydrophobically treated fiber influences high mechanical properties.

Gang Li et al [17] experimentally investigated the Kevlar fibers at different concentrations of phosphoric acid. They examined interfacial and inter laminar shear strength along with various combinations of composites by comparing its mechanical properties. It has been observed that, by adding hydroxyl groups of Kevlar fibers and surface oxygen increased widely and comparison has been done with Kevlar fiber composite exhibits excellent mechanical properties. The micro structural analysis has been done which revealed better interfacial adhesion results in improved behaviour of the hybrid composite.

Rajesh et al [18] have reviewed the tensile behaviour of the matrix material of the Kevlar composite arranged at the horizontal and vertical orientations alternatively up to 4 plies respectively. The fabricated composite is made by manual method with usage of binding agent as the epoxy resin hardener. The tensile test results had generated greater values when compared to homogeneous orientation of the composite. The SEM analysis was done to observe the micro behaviour of the composite and to identify the fiber breakage and air bubbles trend.

Vijaya Ramnath et al [19] have conducted tests on twisted Kenaf and neem fibers which is fabricated to composite at varying composition and orientations to test the tensile and flexural tests along with impact test, where the composite containing neem fibers in vertical position with glass fibers in horizontal position produced higher tensile, flexural and impact strengths which is proven effective by the presence of twisted neem fibers and 450 fiber orientations. This proves their theory that the presence of twisted fibers and proper fiber orientation affects overall behaviour of the composite.

Vijaya Ramnath et al [20] have fabricated the composite of jute and banana fiber with the help of hand layup method with epoxy resin and bonding agent. The mechanical tests show that the tensile strength of the sample containing all the natural fibers in varying composition showed higher ultimate strength with higher elongation. That sample also performed well under flexural and impact strength thus proving that the banana jute GFRP composite has superior mechanical properties than separate composites made of only one fiber with GFRP.

2.2 Kevlar – CNT Composite

Parswajinan et al [27] have investigated iron powder and carbon nanotubes (CNT) at various weight percentages such as 0.25, 0.50, and 0.75 which were fabricated using compaction and sintering processes. Mechanical tests such as the compression, hardness test are performed followed by the wear analysis. SEM analysis is done and the microstructure of the various combinations of the CNT is observed. FEA has been done in order to determine the stress strain acting on the specimen and was observed that the 0.75wt% CNT specimen had generated the optimum value for the wear analysis and for the mechanical tests performed respectively.

Reis et al [22] have experimented that the impact responses on the Kevlar laminate various percentages of carbon nanotubes. They used nanoclay cloisite 30B which are immersed in the system with varying weight percentages. The performances of the nanoclays are obtained with respect to penetration threshold and elastic recuperation. It has been concluded that 6% nanoclays dispersed in the system have the best optimal solution when compared to 1.5% and 3% in weight. They also found tensile residual strength to confirm the best impact resistance with increase in content of the filler and the variations are shown as the result of impact energy.

Majumdar et al [23] have studied the impact response with low velocity on a kevlar with thickening fluid which is in the form of nano silica. In this work, it has been studied the various factors and the concentration of the nano silica fluid. The process improves impact resistance because of the increase of fluid viscosity and the factors are determined by using the dynamic impact tester and the velocity with which it imparts can be investigated using the low speed impact bullet test. The increase in the padding pressure increases the impact energy and the shear thickening fluid concentration reduces addon percentage in the hybrid composite material.

Taragi et al [24] have investigated the response on low velocity impact on a kevlar laminate. For better performance of the impact energy and the penetration threshold, energy profile diagrams have been incorporated to determine the best optimal solution and also to impart various samples by considering the same energy level of 45J. It has been concluded that the increase on multiwalled CNTs increases the response on impact and the size of the damage is restricted to the specimen. Also, noted that the addition of CNT increases the capability of energy absorption under ambient and low temperature conditions.

Vijaya Bhaskar et al [25] synthesized and characterized the property of CNT with multi walls which is used to reinforce sintered magnesium matrix composite. The fabrication process consists of a sintering process with powder materials of Mg with varying quantities of MWCNT which is mixed with 10wt% of SiC which is tested with SEM with EDS to prove the presence of SiC and CNTs in the composite and to find their mixing ratios. AFM proves that the addition of multi wall carbon nanotubes has reduced the surface roughness and produced clear grains which thus help in increasing its mechanical properties. The micro hardness and density are also increased due to the fine grain structure formed due to the proper sintering process.

Venkatesh et al [26] have decided that due to high mechanical strength the CNTs will be the better material to be used to reinforce resin glass fibers and resin alone. These two composites are fabricated using a casting method in room temp. The EDAX test is done to measure the spectrum emission and structural stability of the composites along with SEM analysis. Thus, the composite having great mechanical properties and good chemical resistance is formulated and fabricated.

Sakthivel et al [38] have fabricated a variety of composites made with stainless steel, glass fiber and epoxy resin with variable weight percentage to determine the weight percentage of the resin and glass fiber to resist tensile, flexural, impact, shear, inter delamination properties followed by thermo-gravimetric analysis. The morphological SEM analysis is done for the tested samples. The improper breakage of fibers, fibers pullout, failure due to shear and impact test are observed respectively.

2.3 Kevlar - Nano Composites

Hulin li et al [28] has observed the effects of Nano Si_3N_4 and submicron size WS2fillers with Kevlar composites. The addition of both the fillers influences the reduction of wear rate but it doesn't lower the coefficient of friction. Hybrid composite reduces the fillers efficiency considering both the coefficient of friction and wear rate of the hybrid composite. Various graphs have been plotted for various compositions of Si_3N_4 and WS_2 fillers with Kevlar fiber composite and the result shows that improved properties of the resultant composite is less than mono composite with unfilled fillers. There is a tremendous drop in the wear rate by decreasing the Si_3N_4 nanoparticles.

2.4 Kevlar - Polymer Composites

RongxianOu et al [29] have studied the performance of effects on Kevlar fiber being reinforcement for the wood flour and HDPE composites to improve various mechanical properties. Surface grafting of Kevlar fiber is achieved by mixing allyl chloride with 3 chloropropyl trimethoxysilane, which results in further improvement of physical properties and the increase in interfacial compatibility between the two compositions.

Sirui Fu et al [30] have experimentally investigated the combination of fiber orientation and interfacial strength of short fiber reinforced polymers by considering the mechanical properties. Olefin block copolymer (OBC) is poor strain mechanical strength and stiffness to bear the load. So, their defects are rectified with Kevlar reinforcements. Tensile properties have been increased due to the incorporation of hydrolyzed coated fiber with OBC matrix. Compression molding composites have low strength than injected molded composites, it has higher strength. It has been concluded that the performance of the resultant short fiber reinforced elastomer could be improved significantly by enhancing the fiber orientation as well as interfacial strength.

Mukherjee [31] have studied the behaviour of composites containing short Kevlar fiber. Matrix used is syndiotic polystyrene and the reinforcement used as Kevlar fiber. The reinforcement and the matrix increase the crystalline, thermal, dynamic and mechanical properties. It has been concluded that the presence of Kevlar fiber improves the thermal stability and crystal structure of the resultant matrix material.

Yan Wang et al [32] have examined the Kevlar effect of oligomer functionalized graphene (FGS) for polymer composites. The reinforcement given above is synthesized for the polymer and their properties are studied. It is noted that the strength and the tensile modulus of the resultant polymer composite increases the reinforcement behaviour. FGS is present in PMMA and PI less than 0.2% of weight. Up to 0.2% of FGS addition to the polymer increases the properties above that the property does not change.

Songfang Zhao et al [33] have investigated the thermal and physical properties of crystallization behaviour of isotactic polypropylene reinforced Kevlar fiber and PA6. Kevlar fibre was modified with caprolactam using toluene diisocyanate. Thermal and mechanical properties were improved with the Kevlar fiber. Interfacial adhesion of PA6/isotacticPP/KF composite is increased. The compatibilizer content has a major role for improvement of thermal and physical behaviour. It has been concluded that modification of Kevlar fibre has increased the thermal and mechanical behaviour of the hybrid composites.

Prabhakar et al [34] have studied the overall change in treatment in glass fiber surface which is then used for fabricating the composite with nano clay particles with compression molding process. It results that each combination has a property greatly increased and some properties greatly reduced which tells us that it is very application specific. On further analysis the specimen is proven to have more increased properties than other specimens.

Venkatesan et al [35] have fabricated the glass fiber with and without 1% CNT forming the polymer composite with resin casting method. The wear test is conducted for both the sample composites to study the tribological properties. The results of the test are analyzed and it is found that the increase of friction coefficient by increasing the sliding duration and also decreasing of friction coefficient by decreasing the sliding load with and without 1% CNT. Here, wear rate increases the increase of load while the time doesn’t play a huge part in the rate of wear. The overall rate of wear was low in reinforced composite which proves that the CNT helps in reducing wear. SEM is conducted on the wear surface to further analyze the pits, voids and cracks. The material is further analyzed using energy dispersion X-ray analysis to study the internal structure.

Balachandar et al [36] have fabricated the bamboo-sugar tree-sisal fiber and bamboo-sugar tree-hemp fiber by hand layup method incorporating epoxy resin and hardener. The impact test, tensile, flexural tests are performed with universal ASTM standards. The results show that flexural, impact and tensile values were highest in case of bamboo-sugar tree hemp fiber materials respectively.

Balachandar et al [37] have fabricated the bamboo-sisal-glass fiber and bamboo-sisal fiber with epoxy resin and hardener as the binding agent followed by the mechanical testing of the composites such as impact, tensile and flexural properties at 00 and 450 orientations respectively. It has been concluded that the 450 orientation composite outperformed the bamboo-sisal fiber in the case of flexural and tensile properties. In case of impact strength, the bamboo-sisal-glass fiber had high impact energy.

3.0 Conclusion

This paper reviewed the various properties and types of Kevlar composites. The characterization has been dealt with hybrid composites and hence results in thermal and mechanical behaviour of Kevlar composites. Kevlar with various combinations of natural fibers, CNT, polymer and Nanocomposites are discussed in detail.

Reference

1. Engr. Re ashad Bin Kabir, Eng R. Nas rin Ferdous (2012) Kevlar - the super tough Fiber. *Int J Text Sci* 1(6): 78-83.
2. Arputhabalan J, Adaikalaraj R, Priyan S (2019) Investigation of Glass Fiber influence on Mechanical characteristics and resistance to Water absorption of Natural fiber reinforced pol- yester composites. Mater Today Proc 16.
3. Dinesh S, Elanchezhian C, Vijaya Ramnath B, Sathiyanarayanan K, Adinarayanan A. (2020) Experimental investigation of banana bract fiber and palm fiber reinforced with epoxy hybrid composites. Mater Today Proc 22:335–341.
4. Guru Raja MN, Hari Rao AN (2013) Effect of an Angle-Ply Orientation on Tensile Properties of Kevlar/glass Hybrid Composites. *Int. J. Theoretical and App Res in Mech Eng*, 2:63-67.
5. Abu Talib AR, Ramadhan AA, Mohd Rafie AS, Zahari R (2013) Influence of cut-out hole on multi-layer Kevlar-29/epoxy composite laminated plates. *Mater Des* 43:89–98.
6. Channabasavaraju S, Shivanand HK, SanthoshKumar S (2013) Evaluation of Tensile and Flexural Properties of Polymer Matrix Composites. *Int J mod* 3:3177-3180.
7. Silvio Leonardo Valenca, Sandro Griza, Vandalucia Gomes de Oliveira, Eliana Midori Sussuchi, Frederico Guilherme Carvalho de Cunha (2015) Evaluation of the mechanical behaviour of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric. *Compos B Eng* 70 1–8.
8. Thingujam Jackson Singh , Sutanu Samanta, (2015) Characterization of Kevlar Fiber and Its Composites: A Review. *Int J Adv Eng Technol* 3:108-112.
9. BAI Jiang bo, XIONG Junjiang, CHENG Xu (2011) Tear Resistance of Orthogonal Kevlar -

PWF-reinforced TPU Film. *Chinese J Aeronaut* 24:113-118

10. Yahaya R, Sapuan SM, Jawaid M, Leman Z, Zainudin ES (2016) Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application. *Def Technol* 12:52–58.
11. Yue CY, Sui GX, Looi HC (2000) Effects of heat treatment on the mechanical properties of Kevlar-29 fibre. Compos Sci Technol 60:421-427.
12. Lin TK, Wu SJ, Lai JG, Shyu SS (2000) The Effect of chemical treatment on reinforce- ment/ matrix interaction in Kevlar fiber/ bismaleimide composites. *Compos Sci Technol* 60:1873-1878.
13. Dinesh S, Elanchezhian C, Vijayaramnath B, Adinarayanan A, Guru Anantha Raman S (2020) Evaluation of mechanical behaviour for animal fiber Reinforced hybrid fiber composite for marine application. IOP Conf Ser: Mater Sci Eng 912:1 -11.
14. Elanchezhian C, Vijaya Ramnath B, Ramanan V, Saisundararam R, Siddarth CS (2015) Evaluation of Mechanical Properties of Acacia-Jute-Sisal-Glass fibre reinforced Composite. *Appl Mech Mater* 813–814: 51–56.
15. Shan-shan Shi, Zhi Sun, Xiao-zhi Hua, Hao-ran Chen (2014) Carbon-fiber and aluminum-honeycomb sandwich composites with and without Kevlar-fiber interfacial toughening. *Compos: Part A* 67:102–110.
16. Sanborn B, Weera sooriya T (2014) Quantifying damage at multiple loading rates to Kevlar KM2fibers due to weaving, finishing, and pretwist. *Int J Impact Eng* 71:50-59.
17. Gang Li, Chen Zhang, Yang Wang, Peng Li, Yunhua Yu, XiaolongJia, Haiyang Liu, Xiaoping Yang, ZhongminXue, SeungkonRyu (2008) Interface correlation and toughness match- ing of phosphoric acid functionalized Kevlar fiber and epoxy matrix for filament winding composites. *Compos Sci Technol* 68:3208–3214.
18. Rajesh S, Vijaya Ramnath B, Elanchezhian C, Abhijith M, Dinesh Riju R, Kathir Kishan K (2018) Investigation of Tensile Behaviour of Kevlar Composite. Mater Today Proc 5: 1156–1161.
19. Vijaya Ramnath B, Rajesh S, Elanchezhian C, Santosh Shankar A, Pithchai Pandian S, Vick-neshwaran S, Sundar Rajan S (2016) Investigation on mechanical behaviour of twisted natural fiber hybrid composite fabricated by vacuum assisted compression molding technique. *Fibers Polym*, 17: 80–87.
20. Vijaya Ramnath B, Sharavanan R, Chandrasekaran M, Elanchezhian C, Sathyanarayanan R., Niranjan Raja R, Junaid Kokan S. (2015) Experimental determination of mechanical properties of banana jute hybrid composite. *Fibers Polym* 16: 164–172.
21. Parswajinan C, Vijaya Ramnath B, Vetrivel M., Ranjith A, Rohit BK, Vasanth S, Vignesh S (2018) Determination of Mechanical Behaviour of Fe-CNT MMC Mater Today Proc 5: 1176–1185.
22. Reis PNB, Ferreira JAM, Zhang ZY, Benameur T, Richardson MOW (2013) Impact response of Kevlar composites with nanoclay enhanced epoxy matrix. *Compos B Eng* 46: 7–14.
23. ImanTaraghi, AbdolhosseinFereidoon, FathollahTaheri-Behrooz (2014) Low velocity impact response of woven Kevlar/epoxy laminated composites reinforced with multi-walled carbon nanotubes at ambient and low temperatures. *Mater Des* 53:152–158.
24. Abhijit Majumdar, Bhupendra Singh Butola, Ankita Srivastava (2014) Development of soft composite materials with improved impact resistance using Kevlar fabric and nano-silica based shear thickening fluid. *Mater Des* 54:295–300
25. Vijaya Bhaskar S, Rajmohan T, Palanikumar K, Bharath Ganesh Kumar B, (2016) Synthesis and Characterization of Multi Wall Carbon Nanotubes (MWCNT) Reinforced Sintered Mag-nesium Matrix Composites. *J. Inst. Eng.* (India): D, 97:59–67.
26. Venkatesan M, Palanikumar K (2015) Material Characteristics of Fabricated Resin Carbon Nanotube Reinforced and Resin Glass Fiber Carbon Nanotube Reinforced Composites. *Appl Mech Mater* 766–767:362–367.
27. Sakthivel M, Vijayakumar S, Ramnath BV (2018) Investigation on Mechanical and Thermal Properties of Stainless Steel Wire Mesh-Glass Fibre Reinforced Polymer Composite. *Silicon* 10: 2643–2651.
28. Hu Lin, Zhong Wei Yin, DanJ iang, YaJun Huo, Yu Qing (2014) Tribological behaviour of hybrid PTFE/Kevlar fabric composites with nano-Si3N4 and submicronsizeWS2 fillers. *Tribol Int* 80:172–178.
29. Rong xianOu, Hui Zhao, Shujuan Sui, Yongming Song, Qingwen Wang (2010) Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-density-polyethylene composites. *Compos: Part A* 41:1272–1278.
30. Sirui Fu, Bowen Yu, LingyanDuan, Hongwei Bai,

Feng Chen, Ke Wang, Hua Deng, Qin Zhang, Qiang Fu (2015) Combined effect of interfacial strength and fiber orientation on me- chanical performance of short Kevlar fiber reinforced olefin block copolymer. *Compos Sci Technol* 108:23–31.

31. Mukherjee M, Dasa CK, Kharitonov AP, Banik K, Mennig G, Chung TN (2006) Properties of syndiotactic polystyrene composites with surface modified short Kevlar fiber. *Mater Sci Eng* A 441 206–214.
32. Yan Wang, ZiXing Shi, Jie Yin (2011) Kevlar oligomer functionalized graphene for polymer composites. *Polym* 52:3661-3670.
33. Songfang Zhao, Lei Cheng, Yong Guo, Yuying Zheng, Baoming Li (2012) PA6 and Kevlar fiber reinforced isotactic polypropylene: Structure, mechanical properties and crystallization and melting behaviour. *Mater Des* 35:749–753.
34. Prabhakar K, Debnath S, Anwar M, Palanikumar K (2019) Experimental Analysis on the Ef- fect of Surface Treatment of Glass Fibers & Nanoclay on Mechanical Properties of Glass Fiber Reinforced Polymer Nano composites. IOP Conf. Ser.: Mater. Sci. Eng. 495
35. Venkatesan M, Palanikumar K, Rajendra Boopathy S (2015) Comparison of the Wear Properties of Polymer Composites Having CNT With and Without Glass Fiber Reinforcement. *Trans Indian Inst Met.* 68: 91–97,
36. Balachandar M, Vijaya Ramnath B, Barath R, Bharath S, Sankar (2019) ScienceDirect Mechanical Characterization of Natural Fiber Polymer Composites. Mater Today Proc 16: 1006 - 1012.
37. Balachandar M, Vijaya Ramnath B, Jagadeeshwar P, Yokesh R (2019) Mechanical behaviour of Natural and Glass fiber reinforced with polymer matrix composite, Mater Today Proc 16: 1297-1303.