Int. J. Pure Appl. Sci. Technol., 24(2) (2014), pp. 39-48

International Journal of Pure and Applied Sciences and Technology

ISSN 2229 - 6107

Available online at [***www.ijopaasat.in***](http://www.ijopaasat.in)

Review Paper

A Review on Investigation on the Influence of Reinforcement on Mechanical Properties of Hybrid Composites

H.B. Vinay[1,*], H.K. Govindaraju[2] and Prashanth Banakar[3]

[1] Department of Mechanical Engineering, Government Engineering College, Huvinahadagali-583219, India

[2] Department of Mechanical Engineering, BMS Institute of Technology, Bangalore-560064, India

[3] Department of Mechanical Engineering, Sambhram Institute of Technology, Bangalore-560097, India

* Corresponding author, e-mail: (vinayhb083@gmail.com)

(Received: 9-8-14; Accepted: 9-10-14)

Abstract: *The hybrid composites have emerged with a potential reinforcement material used as a light weight structure has attracted many researchers. This is mainly due to their inherent qualities like low density, low Cost, renewable, biodegradability and environmentally harmless. Hybrid composite material shows the highest mechanical properties. This High performance hybrid composite material has extensive engineering applications such as transport industry, aeronautics, naval, automotive industries. In the recent decades the application of laminated composites are finding increasing in many engineering applications, due to their Low thermal expansion, low corrosion resistance, high strength to weight and stiffness to weight ratios. The majority of engineering composites materials in demanding applications consists of continuous fibers of glass, Graphite or carbon & other few reinforcement in thermosetting polymer. There has been a tremendous advancement in recent days. The mechanical property of the composite becomes complex with the addition of fibers. When subjected to compression, tension and flexure tests polymeric composites are susceptible to mechanical damages that can lead to interlayer delamination. Catastrophic failure of the component can occur due to the increase in the external load.*

Keywords: Hybrid composite, Reinforcement, Biodegradability, Stiffness, Thermosetting polymer, Catastropic failure.

Introduction:

Composite materials consist of a combination of materials that are layered together to achieve specific structural properties. The individual materials do not dissolve or merge completely in the composite, but they act together as one. Normally components can be physically identified as they interface with one another. The properties of the composite material are superior to the properties of the individual materials from which it is constructed. The composites provide various advantages like they are dimensionally stable in space during temperature changes. They constitute an outstanding feature of high strength to weight ratio & also possess high corrosion resistance property. This has provided the main motivation for the research and development of composite materials.

In practice, most composites consist of a bulk material ('matrix'), and reinforcement added primarily to increase the strength and stiffness of the matrix. The reinforcement used usually in the form of fiber, composites can be divided into three main groups:

1) Polymer Matrix Composites (PMC's) - Polymer composites materials are widely used in aerospace, aircraft, marine, sports and military industries. The materials provide unique mechanical and tribological properties combined with a low specific weight and a high resistance to degradation in order to ensure safety and economic efficiency. Also known as FRP - Fiber Reinforced Polymers (or Plastics) - these materials use a polymer-based resin as the matrix, and a variety of fibers such as glass, carbon and Kevlar/aramid as the reinforcement.

2) Metal Matrix Composites (MMC's) - Increasingly found in the automotive industry, these materials use a metal such as aluminum as the matrix, and reinforce it with fibers such as silicon carbide.

3) Ceramic Matrix Composites (CMC's) - Used in very high temperature environments, these materials use a ceramic as the matrix and reinforced with short fibers, or whiskers such as those made from silicon carbide and boron nitride.

An advanced composite material is made up of a fibrous material embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness. Wood is the most common fibrous structural material

Applications of composites on aircraft include:

• Fairings
• Flight control surfaces
• Landing gear doors
• Leading and trailing edge panels on the wing and stabilizer
• Interior components
• Floor beams and floor boards
• Vertical and horizontal stabilizer primary structure on large aircraft
• Primary wing and fuselage structure on new generation large aircraft
• Turbine engine fan blades
• Propellers

Fibers/Reinforcement Materials:

2.1. Introduction to Fibers

Organic and inorganic fibers are used to reinforce composite materials. Almost all organic fibers have low density, flexibility, and elasticity. Inorganic fibers are of high modulus, high thermal stability and possess greater rigidity than organic fibers and notwithstanding the diverse advantages of organic fibers which render the composites in which they are used. The different types of fibers are glass fibers, silicon carbide fibers, high silica and quartz fibers, alumina fibers, metal fibers and wires, graphite fibers, boron fibers, kevlar fibers and multi phase fibers are used. Among the glass fibers, it is again classified into E-glass, S-glass, A- glass, R-glass etc.

There is a greater market and higher degree of commercial movement of organic fibers. The potential of fibers of graphite, silicon carbide and boron are also exercising the scientific mind due to their applications in advanced composites.

2.2. Types of Fibers

1) Glass Fibers

Around 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced. They have low density, resistance to chemicals, insulation capacity one of the major disadvantages in glass is that it is prone to break when subjected to high tensile stress for a long time of loading, temperature, moisture and other factors also dictate the tolerance levels of glass fibers.
the wide range of glass fiber variety lend themselves amicably to fabrication processes like matched die moulding, filament winding lay-up and so on. Glass fibers are available in the form of mats, tapes, cloth, continuous and chopped filaments, roving and yarns. Addition of chemicals to silica sand while making glass yields different types of glasses.

2) Kevlar Fibers

Kevlar fibers are made up of aromatic polyamides which are long polymeric .chains and aromatic rings. They are structured in six carbon atoms are bonded to each other of hydrogen atoms. In kevlar fibers, these rings occur and reoccur to form the fibers. They were initially used to reinforce automobile tires also used in bullet proof vests; power boats. Kevlar have high tensile strength, high modulus and low weight. Impact- resistant structures can be produced from kevlar. The density of kevlar fibers is less than that of glass and graphite fibers.

3) Graphite Fibers

The use of carbon for graphite is permissible; there is one basic difference between them. Elemental analysis of poly-acrylo-nitrile (PAN) base carbon fibers show that they consist of 91 to 94% carbon. But graphite fibers consist of 99% carbon. The difference arises from the fact that the fibers are made at different temperatures. The properties of graphite remain unchanged even at very high temperatures, but its willingness to react readily with most metals at the fabrication stage or during use at very high temperatures is often a stumbling block. Graphite fibers are some of the stiffest fibers. The stiffness of the fiber is as high as the graphite content.

4) Boron Fibers

They are basically composites, in which boron is coated on a substance which forms the substrate, usually made of tungsten. Boron-tungsten fibers are obtained by allowing hot tungsten filament through a mixture of gases. Boron is deposited on tungsten and the process is continued until the desired thickness is achieved. The tungsten however remains constant in its thickness. Properties of boron fibers generally change with the diameter, because of the changing ratio of boron to tungsten and the surface defects that change according to size. However, they are known for their remarkable stiffness and strength.

5) Metal Fibers

Metal fibers reinforcements, have many advantages. They are easily produced using several fabrication processes and are more ductile, apart from being not too sensitive to surface damage and possess high strengths and temperature resistance. Steel wire is the most extensively used reinforcement in most large-scale metal filament applications. Wire is used for its capacity to enhance the tensile strength of concrete and continuous metal fibers are the reinforcing constituents in metal and ceramic composite materials.

6) Carbon Fibers

Carbon-fiber offers the maximum weight reduction of all composite materials whilst maintaining the rigidity and strength required in most of the applications. Carbon fiber composites are becoming widely adopted in the transportation, sporting goods and wind energy sectors among others. This is because “carbon-fiber composites weigh about one-fifth as much as steel, but can be comparable or better in terms of stiffness and strength, depending on fiber grade and orientation. In addition, carbon fiber show good creep resistance and good compatibility.

Matrix Materials:

3.1 Thermoplastic Resins

Thermoplastic materials can be softened repeatedly by an increase of temperature and hardened by a decrease in temperature. Processing speed is the primary advantage of thermoplastic materials. Chemical curing of the material does not take place during processing, and the material can be shaped by molding or extrusion when it is soft.

1) Semi Crystalline Thermoplastics

Semi crystalline thermoplastics possess properties of inherent flame resistance, superior toughness, good mechanical properties at elevated temperatures and low moisture absorption. They are used in secondary and primary aircraft structures. Combined with reinforcing fibers, they are available in injection molding compounds, compression-moldable random sheets, unidirectional tapes, prepregs fabricated from tow (towpreg), and woven prepregs. Fibers impregnated in semicrystalline thermoplastics include carbon, nickel-coated carbon, aramid, glass, quartz, and others.

2) Amorphous Thermoplastics

Amorphous thermoplastics are available in several physical forms, including films, filaments, and powders. Combined with reinforcing fibers, they available in injection molding compounds, compressive moldable random sheets, unidirectional tapes, woven prepregs, etc. Fibers used are primarily carbon, aramid, and glass. The specific advantages of amorphous thermoplastics depend upon the polymer. Typically, the resins are noted for their processing ease and speed, high temperature capability, good mechanical properties, excellent toughness and impact strength and chemical stability. The stability results in unlimited shelf life, eliminating the cold storage requirements of thermoset prepregs.

3) Polyether Ether Ketone (PEEK)

Polyether ether ketone, better known as PEEK, is a hightemperature thermoplastic. This aromatic ketone material offers outstanding thermal and combustion characteristics and resistance to a wide range of solvents and proprietary fluids. PEEK can also be reinforced with glass and carbon.

3.2 Thermosetting Resins

Resin is a generic term used to designate the polymer. The resin, its chemical composition, and physical properties fundamentally affect the processing, fabrication, and ultimate properties of a composite material. Thermosetting resins are the most diverse and widely used of all man-made materials. They are easily poured or formed into any shape, are compatible with most other materials, and cure readily (by heat or catalyst) into an insoluble solid. Thermosetting resins are also excellent adhesives and bonding agents.

1) Polyester Resins

Polyester resins are relatively inexpensive, fast processing resins used generally for low cost applications. Low smoke producing polyester resins are used for interior parts of the aircraft. Fiber-reinforced polyesters can be processed by many methods. Common processing methods include matched metal molding, wet layup, press (vacuum bag) molding, injection molding, filament winding, pultrusion, and autoclaving.

2) Vinyl Ester Resin

The appearance, handling properties, and curing characteristics of vinyl ester resins are the same as those of conventional polyester resins. However, the corrosion resistance and mechanical properties of vinyl ester composites are much improved over standard polyester resin composites.

3) Epoxy

Epoxies are polymerizable thermosetting resins and are available in a variety of viscosities from liquid to solid. There are many different types of epoxy, and the technician should use the maintenance manual to select the correct type for a specific repair. Epoxies are used widely in resins for prepreg materials and structural adhesives. The advantages of epoxies are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing. Their major disadvantages are brittleness and the reduction of properties in the presence of moisture. The processing or curing of epoxies is slower than polyester resins. Processing techniques include autoclave molding, filament winding, press molding, vacuum bag molding, resin transfer molding, and pultrusion. Curing temperatures vary from room temperature to approximately 350 °F (180 °C). The most common cure temperatures range between 250° and 350 °F (120–180 °C).

3.3 Curing Stages of Resins

Thermosetting resins use a chemical reaction to cure. There are three curing stages, which are called A, B, and C.

- **A stage:** The components of the resin (base material and hardener) have been mixed but the chemical reaction has not started. The resin is in the A stage during a wet layup procedure.

- **B stage:** The components of the resin have been mixed and the chemical reaction has started. The material has thickened and is tacky. The resins of prepreg materials are in the B stage. To prevent further curing the resin is placed in a freezer at 0 °F. In the frozen state, the resin of the prepreg material stays in the B stage. The curing starts when the material is removed from the freezer and warmed again.

- **C stage:** The resin is fully cured. Some resins cure at room temperature and others need an elevated temperatures cure cycle to fully cure.

Literature Review:

G. Kertsis [1] reported that hybrid composites having two or more types of reinforcing Fibres in a polymer matrix can be classified according to the way their constituent Fibres are mixed such as; sandwich hybrids, interply hybrids, and intermittently mixed hybrid composites. Interplay hybrid composites are gaining attention because hybridization facilitates the tailoring of mechanical properties according to need by having a selective amount of extra reinforcement at some selective position in the laminate. Presented a comprehensive review on the properties of hybrid composites. The relative volume fraction of reinforcing Fibres and their positioning in the hybrid layup act as the determining factors in the enhancement of flexural properties. Therefore, for structural laminates under flexural loading, material can be designed for better flexural properties by investigating the effect of the stacking sequence.

Banerji and Nirmal [2] stated that In a hybrid composite, the two reinforcing Fibres differ in their mechanical properties and the interface they make with the matrix it was observed that there was an increase in flexural strength of unidirectional carbon Fibre/ 35 Poly (methyl methacrylate), composite laminates having polyethylene Fibres plies at the lower face.

Mallick P.K [3] did research on Polymer matrix composites are predominantly used for the aerospace industry, but the decreasing price of carbon Fibres is widening the applications of these composites to include the automobile, marine, sports, biomedical, construction, and other industries.

Li and Xian [4] studied incorporation of a moderate amount of carbon Fibres into ultra-high-modulus polyethylene (UHMPE) Fibres reinforced composites greatly improved the compressive strength, flexural modulus while the addition of a small amount of UHMPE Fibres into a carbon Fibre reinforced composite remarkably enhanced the ductility with only a small decrease in compressive strength.

Luo and Netravali [5] studied the tensile and flexural properties of polymer composites with different pineapple fibre content and compared them with the virgin resin.

Jawad Kadhim Uleiwi [6] Investigated the effect of fibre volume fraction on the flexural properties of the laminated composite constructed of different layers, one of them having reinforced glass fibre and the other layer reinforced with Kevlar fibre has been investigated experimentally and the results illustrate that tension stress decreases with the increase in fibre volume fraction of glass fibre of the lower layer while it increases with the increase of Kevlar volume fraction of the upper layer.
Huang et al. [7] studied on effect of water absorption on the mechanical properties of glass/polyester composites. It was concluded that the breaking strength and tensile stress of the composites decreased gradually with increased water immersion time because the weakening of bonding between fibre and matrix.

Kolesnikov et al [8] Investigated the effect of joining structural composites for aerospace applications. Structural joining enhances the disturbance in the optimized structure and results in increase in overall weight of the structure and results in increase in over all weight of the structure. The potential of the light weight composite materials made of carbon Fibre reinforced polymers are affected because of these joining and fastening capabilities. The titanium layers are embedded at these 32 joints where fastening and bolting is done which resulted in improvement in structural efficiency. Hence this demonstrates the influence of titanium hybridization with the carbon Fibre reinforced polymer materials and results shows advantages of this hybridization.

M. Raghavendra et al [9] Investigated studies on woven glass Fibre reinforced polymer matrix and determined the tensile strength, compressive strength and in plane shear strength at room temperatures and at high temperatures and at high temperatures. The test data is statistically analyzed it was found that the specimens at higher temperatures showed low strength when compared with the specimens at room temperature.

Kutty and Nando [10] studied the effect of processing parameters on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite and observed that processing parameters like nip gap, friction ratio and mill roll temperature have extreme influence on the fibre orientation and hence on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite.

M. Davallo et.al [11] Investigated the Mechanical behaviour of unidirectional glass polyester composites to identify performance differences of composites with different glass lay-ups and laminate thicknesses during flexure and tensile testing formed by hand lay-up moulding (HLU). The damage generated in the composites exhibited matrix cracking on the lower face followed by the coalescence of delaminations formed within the reinforcing plies.

Wang et al. [12] studied the mechanical properties of fibre glass and kevlar woven fabric reinforced composites and observed that mechanical behaviour depends strongly upon the fibre types.

Chauhan et al. [13] Studied on the effect of fibre loading on mechanicalproperties, friction and wear behaviour of vinyl ester composites under dry and water lubricatedconditions and reported that the density of composite specimens is affected marginally by increasing the fibre content.

Gill, R.M [14] stated as Carbon Fibre polymer-matrix composites have started to be used in automobiles mainly for saving weight for fuel economy. The so-called graphite car employs carbon Fibre epoxy-matrix composites for body panels, structural members, bumpers, wheels, drive shaft, engine components, and suspension systems. This car is 570 kg lighter than an equivalent vehicle made of steel. It weighs only 1250 kg instead of the conventional 1800 kg for the average American car. Thermoplastic composites with PEEK and polycarbonate (PC) matrices are finding use as spring elements for car suspension systems.

Dixit et al. [15] reported a remarkable improvement in the tensile and flexural properties of hybrid composites compared to the un-hybrid composites. It was also found that the hybrid composite offers better water absorption resistance.

Pandya et al. [16] found that on placing glass fabric layers in the exterior and carbon fabric layers in the interior of the hybrid composites gives higher tensile strength and ultimate tensile strain than hybrid composites with carbon fabric layers in the exterior and glass fabric layers in the interior.
Zsolt R’ACZ [17] studied the analysis of the flexural strength of unidirectional composite carbon fiber composites and estimated the magnitude of size effect in carbon fiber composite and result revealed that specimen with lower span to thickness ratio exhibits a lower flexural strength.

Mauricio et al. [18] predicted the elastic behaviour of hybrid plain weave fabric composites with different materials J. Kosoric, et al [19] has carried out research using E-glass fiberglass and epoxy resin with catalyst addition as matrix for the composite material. The modal test was carried out for the measurement of flexural properties and modulus elasticity on flexural testing machine the analysis showed that the glass fiber reinforcing the laboratory composite resins have greater effect on the flexural strength than modulus of elasticity. Mechanical properties of monodirectional fiber reinforced composite have been extensively studied by Jones [20].

Toshio ogasawara and Tet suoka Sai [21] investigated the influence of fullerenes dispersion on the carbon –Fibre reinforced epoxy matrix for its mechanical properties. The various mechanical properties like flexural test and short beam shear strength were conducted and it was observed that by dispersing of fullerenes into the matrix there was an increase in the mechanical properties.The inter laminar fracture toughness was enhanced by 60%. The small amount of fullerenes will increase the failure strain of epoxy resin and in turn improves the carbon Fiber reinforced polymer strength.

J.Lee and C.Soutis [22] investigated the influence of thickness on the compressive behavior of the laminated composites with different stacking sequence with a open hole at the centre. It was observed that the strength of the specimen with increasing thickness was increased. Measured failures strength was compared with the predicted values.

Pegoretti, E. Fabbri, C. Migliaresi, F. Pilati [23] reported as Flexural loading causes stresses in the polymer laminated composites that may vary through the thickness. These flexural stresses are the maximum at the outer surfaces and are minimum (zero) in the middle at the neutral axis. In the laminates subjected to pure bending, the composite failure initiates on either the tensile or compressive side depending upon whether the composite is stronger in compression or tension respectively. The stress in an individual ply depends upon the stiffness of that ply and its distance from the laminate's neutral axis. By including, one or more extra components having relatively better elastic properties in the laminate can help in improving the flexural properties of the composite structures. This class of composite materials consisting of more than two types of constituents is commonly known as a hybrid composite.

Cho et al. [24] studied the mechanicalbehaviour of carbon fibre/epoxy composites and found that the composites reinforced with nano particles improved mechanical properties such as enhanced compressive strength and in plane shear properties.

Marom et al. [25] studied the hybridization i.e. positive or negative hybrid effect of a selected mechanical property from the rule of mixture behavior of carbon/carbon/epoxy and glass/carbon composites. None of the mechanical properties, excluding the fracture energies show signs of a positive hybrid effect.

Manders and Bader [26] studied hybrid effect and failure strain enhancement of up to 50% for the glass fiber /carbon fiber/ epoxy composite. The authors considered different glass: carbon ratios and states of dispersion of the two phases. The failure strain of the carbon phase increased as the relative proportionof carbon fibre was decreased, and as the carbon fibres were more finely dispersed.

Yerramalli and Waas [27] have considered carbon/glass hybrid composite with an overall fibre volume fraction of 30%. With varying carbon/glass fibre ratios, maintaining same fibre volume fraction, ranging from pure glass to pure carbon including hybrid laminates were tested for compression loading to study the failure mechanisms. To study the failure mechanisms, modeling like iso-stress and iso-strain models were considere d. splitting and kinking failures were noted while loading the hybrid laminates under static and dynamic loading rates.

Ashok Kumar et al. [28] studied on epoxy hybrid composites reinforced with sisal/glass fiber on frictional co-efficient, impact, hardness and chemical resistance as function of fiber length. Hence proved that, mechanical properties were optimized at 2cm fiber length.
Sreekala et al. [29] concluded that incorporation of small volume fraction of glass fibre in composites results in enhanced tensile and flexural properties.

B. Gommers et.al [30] determined the mechanical properties of composite materials by tensile tests.
Mauricio et al [31] predicted the elastic behavior of hybrid plain weave fabric composites with different materials and undulations in the warp and weft directions by formulating a 3D analytical micromechanical model.

John and Naidu [32] evaluated the tensile behavior of sisal/glass/polyester hybrid composites and reported higher properties for higher glass fiber incorporation and overall fiber volume fraction.
Cicada [33] studied some hybrid synthetic/natural composites and reported that hybrid glass/epoxy composites showed good tensile properties and lower cost and weight compared to pure glass/epoxy composites.

Discussion:

After exhaustive literature survey it's clearly mention that hybridization is more convenient for the composite materials. In the process a more ductile and low priced fiber is introduced in certain proportions to improve the mechanical properties. Hybrid composites normally contain a high modulus, high strength and costly fiber such as graphite or carbon fiber. The second fiber is usually a low modulus fiber and cheap fiber like Kevlar, PE or Basalt fibers. The intrinsic mechanical properties of both reinforcement material gives rise to unique structural materials in terms of toughness and strength. Glass fiber may also be a good candidate for the preparation of hybrid composites of this type. It has good toughness properties, low price and relatively good interfacial adhesion to the matrix.

Conclusion:

From the above literature survey most of the engineering applications were made by hybrid composite material so that it can reduce the cost of the fibers and having high strength & stiffness for different usages. It is imperative that the use of polymer laminated composites is an emerging field in all sectors of the industries because of its benefits of high strength to weight ratio in order to enhance performance.

References

[1] G. Kertsis, A review of the tensile, compressive, flexural and shear properties of hybrid reinforced plastics, *Composites*, 18(1) (1987).

[2] N. Sasha and A.N. Bannered, Flexural behavior of unidirectional polyethylene-carbon biers-PMMA hybrid composite laminates, *J. App. Poly. Sci.*, 60(1996), 139-142.

[3] P.K. Malice, Composite Engineering Handbook, Marcel Dekker Inc., NY, USA, 1997.

[4] K.J.Y. Xian, C.L. Choy, M. Goo and Z. Zhang, Compressive and flexural behavior of ultra-high-modulus polyethylene fiber and carbon fiber hybrid composites, *Comp. Sci. & Tech.*, 59(1999), 13-18.

[5] S. Luo and A.N. Netravali, Mechanical and thermal properties of environmentally friendly green composites made from pineapple leaf fibres and poly (hydroxybutyrate-covalerate) resin, *Polymer Composites*, 20(3) (1999), 367-378.

[6] J.K. Uleiwi, Experimental study of flexural strength of laminate composite material, *Eng. & Technology*, 25(3) (2007), 454-466.

[7] G. Huang and H. Sun, Effect of water absorption on the mechanical properties of glass/polyester composites, *Materials & Design*, 28(2007), 1647-1650.

[8] B. Kolesnikov, L. Herbeck and A. Fink, CFRP/titanium hybrid material for improving composite bolted joints, *Composite Structures*, 83(4) (2008), 368-380.

[9] M. Raghavendra, C.M. Manjunatha, M.J. Peter, C.V. Venugopal and H.K. Rangavittal, Effect of moisture on the mechanical properties of GFRP composite fabric material, *International Symposium of Research Students on Material Science and Engineering*, (2004).

[10] S.K. Kutty and G.B. Nando, Effect of processing parameters on the mechanical properties of short kevlar aramid fibre-thermoplastic polyurethane composite, plastic, rubber, *Composites Processing and Applications*, 19(2) (1993), 105-110.

[11] M. Davallo and H. Pasdar, Comparison of mechanical properties of glass- polyester composites formed by resin transfer molding and hand lay-up technique, *International Journal of Chem Tech Research CODEN (USA): IJCRGG*, 1(3)(July-Sept) (2009), 470-475.

[12] Y. Wang, J. Li and D. Zhao, Mechanical properties of fibre glass and Kevlar woven fabric reinforced composites, *Composites Engineering*, 5(9) (1995), 1159-1175.

[13] S.R. Chauhan, B. Gaur and K. Dass, Effect of fibre loading on mechanical properties, friction and wear behaviour of vinylester composites under dry and water lubricated conditions, *International Journal of Material Science*, 1(1) (2011), 1-8.

[14] R.M. Gill, Carbon Fibers in Composite Materials, Page Bros (Norwich) Ltd, England, 1973.

[15] S. Dixit and P. Verma, The effect of hybridization on mechanical behaviour of coir/sisal/jute fibres reinforced polyester composite materials, *Research Journal of Chemical Sciences*, 2(6) (2012), 91-93.

[16] K.S. Pandya, C. Veerraju and N.K. Naik, Hybrid composites made of carbon and glass woven fabrics under quasi-static loading, *Materials & Design*, 32(7) (2011), 4094-4099.

[17] ZsoltR'ACZ, Analyzing the flexural strength properties of unidirectional carbon/epoxy composites, *Hungarian Scientific Research Fund*, (2002).

[18] M.V. Donadon and M. John, A 3D micromechanical model for predicting the elastic behavior of woven laminates, *Composites Science and Technology*, 67(2007), 2467-2477.

[19] J. Kosoric, M. Cattani, S. Bouill, C.H. Godin and J. Meyer, Reinforcement of composite resins with unidirectional glass fibers, *European Cells and Materials*, 3(Suppl. 1) (2002).

[20] J.M.F. de Paiva and A.D.N. dos Santos, Mechanical and morphological characterizations of carbon fiber fabric reinforced epoxy composites used in aeronautical field, *Materials Research*, 12(3) (2009), 367-374.

[21] T. Ogasawara, Y. Ishida and Tetsuokasai, Mechanical properties of carbon fibre/fullerene: Dispersed epoxy composites, *Composites Science and Technology*, 69(11-12) (2009), 2002-2007.

[22] J. Lee and C. Soutis, Thickness effect on the compressive strength of T800/924C carbon fibre-epoxy laminates, *Applied Science and Manufacturing*, 36(2) (2005), 213-227.

[23] E.F. Pegoretti, C. Migliaresi and F. Pilati, Intraply and interply hybrid composites based on E-glass and poly (vinylalcohol) woven fabrics: Tensile and impact properties, *Polym Int*, 53(2004), 1290-1297.

[24] J. Cho, J.Y. Chen and I.M. Daniel, Mechanical enhancement of carbon fibre/epoxy composites by graphite nanoplatelet reinforcement, *Scripta Materialia*, 56(8) (2007), 685-688.

[25] G. Marom, S. Fischer, F.R. Tuler and H.D. Wagner, Hybrid effects in composites: Conditions for positive or negative effects versus rule-of-mixtures behavior, *Journal of Materials Science*, 13(1978), 1419-1426.

[26] P.W. Manders and M.G. Bader, The strength of hybrid glass/carbon fibre composites-Part 1: Failure strain enhancement and failure mode, *Journal of Materials Science*, 16(1981), 2233-2245.

[27] C.S. Yerramalli and A.M. Waas, Compressive behavior of hybrid composites, *Proceedings of 44th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference*, 07-10 April (2003), Norfolk, Virginia (AIAA-2003-1509).

[28] M.A. Kumar, G.R. Reddy, Y.S. Bharathi, S.V. Naidu and V.N.P. Naidu, Frictional co-efficient, hardness, impact strength and chemical resistance of reinforced sisal/glass fiber epoxy hybrid composites, *Journal of Composite Materials*, (2010), (Accepted).

[29] M.S. Sreekala, J. George, M.G. Kumaran and S. Thomas, The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibres, *Composites Science and Technology*, 62(3) (2002), 339-353.

[30] B. Gommers et al., Determination of the mechanical properties of composite materials by tensile tests, *Journal of Composite Materials*, 32(1998), 102-122.

[31] M.V. Donadon, B.G. Falzon, L. Iannucci and J.M. Hodgkinson, A 3D micromechanical model for predicting the elastic behaviour of woven laminates, *Composites Science and Technology*, 67(2007), 2467-2477.

[32] K. John and S.V. Naidu, Tensile properties of unsaturated polyester-based sisal fiber–glass fiber hybrid composites, *J Reinf. Plast. Comp.*, 23(17) (2004), 1815-9.

[33] G. Cicada, G. Cristaldi, G. Recca, G. Ziegmann, A. El-Sabbagh and M. Dickert, Properties and performances of various hybrid glass/natural fibre composites for curved pipes, *Mater Des*, 30(7) (2009), 2538-42.