A review on characteristics of natural fibre composite

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Abstract. Since the last we saw huge growth in innovation and research in field of natural fibre composite (NFC). Availability of Natural Fibres (like coir, abaca, banana, jute, sisal, cotton) are huge in India. It is not surprising that the natural fibre composite is attracting the researchers all around the world because of superiority of its compared to other fibre composites and their capabilities in wide range of applications. The present study aims at various applications of natural fibre composite and their mechanical characteristics. This review also provides the various aspects that affects the mechanical characteristics of natural fibre.

Keywords: Natural Fibre, Composite, Mechanical Properties, Applications

1. Introduction

1.1. Natural fibre composites
Over the closing 30 years’ composite were the dominating and rising materials due to gradual growth of its applications. Composites have established their value as light weight substances; the present venture is to make composites non costly. It is obvious that just by improving the manufacturing techniques is not sufficient particularly for composites to triumph over the price barrier. Therefore, it is so much essential to have incorporated attempt in manufacturing, design and material selection. [15]

Composites are material structures that offer properties no longer obtainable from any single material and they are structures of compatible materials made by physically combining materials which are specific in characteristics and composition.

High specific strength of Fibre-reinforced composites have performed a dominant role in a various application. The manufacturing sector consider elimination of traditional fibre composites critical due to environmental troubles. By natural fibre composites we suggest a substance which is combined with fibres from natural/renewable resources. Classification of Natural fibres is done according to their place of origin that include fibres crafted from plant, animal and mineral.

Animal fibre normally contain proteins; examples animal hair, silk fibre and avian fibre. We can get animal hair fibres from furry mammals, for example hair of horse, goat and sheep. Examples of silk fibre are the fibres from silk worms. Avian fibre is a fibre from flying animals and its examples are feathers and feather fibre.

Mineral fibres can be divided into the three classes: First one is Asbestos which is unique natural mineral fibre. Second is Ceramic fibres which consist of glass fibres, Al₂O₃, SiC, and B₄C and last one is Metal fibres which includes aluminium fibres.
Plant fibres usually contain cellulose. Cellulose-based fibres serve inside the making of paper as well as cloth. Seed fibres are obtained from a seed. Leaf fibre are fibres obtained by plant leaves. Skin fibres are accumulated by plant stem. Fruit fibre are gathered from plant having fruit. Stalk fibre are the fibres that are truly plant stalks.

1.2. Advantages and limitations of NFC (Natural Fibre Composite)
Figure below showcase some of the key advantages and limitations of NFC, i.e. Natural Fibre Composite.

1.3. Study of natural fibres
Abaca fibre is a form of tough natural fibres specially produced in Philippine, which uses the Musa plant leaf. Musa plant is like banana but the fruit of musa is not edible. Abaca fibre said to have a specific flexural strength, high rotting resistant and has high tensile strength as much as glass fibre. That’s why bags, paper and ropes uses it as raw material. Abaca fibre application in latest years has prolonged to car enterprise, for example Mercedes-Benz. Stringent quality required by the outdoor components of street vehicles is also stated to satisfy by abaca fibre with a great resistance to elements, stone strike as well as dampness. It’s widely known fact that the properties of substance are influenced by
microstructure of substance. As a result, researchers often by changing the microstructure of material, the mechanical properties of material gets improve. As structure of natural fibre is dependent on fibre growing circumstance, there is possibility to achieve natural fibres of required characteristics through deciding on fibres from one-of-a-kind positions of plant. [8]

Jute is not so unusual agricultural fibres that are cultivated almost solely in India, Thailand and Bangladesh. Jute fibre show off reasonably high mechanical properties that other fibres. 2500000 tones are a total yearly international production of jute. In Europe the flax is also the most crucial as well as demanding bast fibres. Spain, Belgium, Holland, France and UK produces nearly 80% of the total worldwide flax. Relatively flax fibres are stiffer to handle, crisper and stronger. Flax and jute fibres won brilliant attention of everyone during past decade as a material for reinforcing of composites. Out of total worldwide jute production Bangladesh and India supplied ninety percent jute. [8, 15, 16]

Sisal have a botanical name of Agave sisalana. It’s an agave species native to southern Mexico but largely naturalized and cultivated in lots of different nations. Different products are made by using stiff fiber which is yield by sisal. It’s once in a while called "sisal hemp", because for hundreds of years' hemp changed into main supply for fibre, and different fibre assets. [8, 15]

Table 1. Mechanical characteristics of synthetic and natural fibre.

| Fibre  | Length (mm) | Density (gm/cm³) | Failure Strain (%) | Young’s Modulus (GPa) | Tensile Strength (MPa) | Specific Young’s Modulus (GPa/gm cm³) | Specific Tensile Strength (MPa/gm cm³) |
|--------|-------------|------------------|--------------------|-----------------------|-----------------------|----------------------------------------|----------------------------------------|
| E-glass| Continuous  | 2.5              | 2.5                | 70                    | 2000-3000             | 29                                     | 800-1400                               |
| Coir   | 20-150      | 1.2              | 15-30              | 4-6                   | 131-220               | 3.3-5                                  | 110-180                                |
| Cotton | 10-60       | 1.5-1.6          | 3-10               | 5.5-13                | 287-800               | 3.7-8.4                                | 190-530                                |
| Sisal  | 900         | 1.3-1.5          | 2-2.5              | 9.4-28                | 507-855               | 6.7-20                                 | 362-610                                |
| Hemp   | 5-55        | 1.5              | 1.6                | 58-70                 | 550-1110              | 39-47                                  | 370-740                                |
| Flax   | 5-900       | 1.5              | 1.2-3.2            | 27-80                 | 345-1830              | 18-53                                  | 230-1220                               |
| Jute   | 1.5-120     | 1.3-1.5          | 1.5-1.8            | 10-55                 | 393-800               | 7.1-39                                 | 300-610                                |

A good way to use Coconut as reinforcement in resin of polyester was studied by chemically modifying the coconut fibres by using alkaline treatment. Coconut fibres had been reformed for the duration of one hour with NaOH solution of 1% weight/volume. The reformed fibres were assessed by means of Fourier Transform infrared spectroscopy, thermal analysis, X-ray diffractometry and scanning electron microscopy. Compression molding technique have been used to prepare the composites of 10% weight of fibres. Fatigue and tensile tests were used to evaluate the mechanical properties. The fractured specimen’s surfaces were inspected with a purpose to evaluate the fracture mechanisms. Fatigue performance of composites shows reduction in fatigue lifespan on application of higher tension. Total worldwide production of coconut fibre is 250 thousand tons. Sixty percent of worldwide white coconut fibre is supplied by India. [2, 16]

2. Key performance affecting factors of natural fibre composite

2.1. Matrix choice

The vital part of a fibre-composite is matrix as it offers an obstacle in opposition to detrimental environments and shields the fibre surface from mechanical abrasion. It also handovers load into fibres. As polymeric matrices can be treated at lower temperature and are lighter in weight, they most commonly utilized in Natural Fibre Composite. Thermoset as well as thermoplastic polymers along with natural fibres were utilized for matrices.

Matrix choice is constrained via temperature when natural fibres starts to degrade as so many natural fibres are thermally unsteady beyond 200°C. However, under few instances it’s feasible to be treated at better temperature aimed at brief time frame. Because of this drawback, only those thermoplastics that become softer beneath this temperature is useable as a matrix (polyethylene (PE), polystyrene, polyvinyl chloride, polyolefin, PP and thermostets). Indeed, PE and PP are the 2 maximum usually followed
thermoplastic matrices used for natural fibre composites. The most important thermosets used are VE resins, phenol formaldehyde, epoxy resin and unsaturated polyester (UP). [4]

2.2. Fibre choice
Fibre kind is normally categorized on the basis of its foundation like mineral, animal, or plant. Cellulose is a main structural element of entire plant fibres (flax, ramie and hemp fibre are among the cellulose centered natural fibres with the best tensile strengths and specific Young’s moduli). Plenty of greater stiffness and strengths are attainable with the better performing plant fibres compare to easily accessible animal fibres (Silk is an exception). Silk may have great strength, however is enormously costly and has poor stiffness. Therefore, to get a composite satisfying structural requirements the most appropriate choice is plant centered fibres. Commonly, plant based fibre can be harvested in quick durations and can properly be grownup in many nations. Furthermore, geography regarding fibre obtainability has a primary role in fibre choice. The consciousness, for example interest on flax fibre has been in Europe, while Asia have been more interested in sisal, kenaf, ramie, jute and hemp. Generally, better performance is accomplished with types that have greater cellulose content and with alignment of cellulose micro fibrils greater with fibre direction which have a tendency to happen in bast fibres (ramie, jute, hemp and flax). The characteristics of natural fibres range significantly dependent on structure and chemical composition, which is related to storage procedures, extraction method, harvesting time, growing conditions, fibre type as well as treatment. Strength has been reported to decrease through 15% over period of 5 days afterward optimal harvest time. By hand mined flax fibres have 20% more strength than mechanically extracted fibres.

![Figure 3. Coconut, Banana and Sisal Fibre](image)

Generally, strength will increase as moisture level increase and reduces with increase in temperature. The ratio of transverse Young’s modulus to longitudinal Young’s modulus of jute has been predicted equal to 1/7. Fibre length, used in aspect ratio of fibre (which is l/d), is a crucial aspect that influences the mechanical characteristics of composites. Tensile load in case of short fibre composite transmitted from the matrix right into a fibre. Fibre load bearing efficiency usually increases as fibre length increases. However too lengthy fibres can also get tangled at some stage during mixing which may cause terrible fibre dispersion that may lessen the general reinforcement performance. [4]

2.3. Fibre orientation
The finest mechanical characteristics are usually being found in composites where the fibre is line up parallel to the path of applied load. Yet, obtaining alignment of natural fibre is more challenging than of continuous synthetic fibre. More or less alignment is accomplished at some stage in injection moulding. However, elongated natural fibre may be carded and positioned by hand in sheets previous to matrix to obtain greater level of fibre alignment. On the other hand, to facilitate an unbroken yarn production conventional fabric processing of fibres may be hired along with spinning. We might use wrap spinning to get aligned fibre, which can convert short into a continuous form by using an uninterrupted strand bound around irregular fibre.
Dynamic Sheet Forming (DSF) is a lately applied substitute for the textile path with its widespread infrastructure necessities to take along fibre alignment in composite. Conventionally in paper manufacturing DSF is used for aligning fibre. In DSF, small fibres are mixed in water and sprayed with the help of a nozzle on a spinning drum. Spinning drum is blanketed by wire net to eliminate the water, which brings alignment inside the rotation path and spray. This has supplied enhancements of mechanical performance in comparison to different small fibre processing techniques. [4]

![Figure 4. Different types of fibre orientation](image)

An organized numerical examination of conical heater become carried out for assessing the orientational consequences and the fabric is studied below 35 and 50 kW/m² irradiances for the fire response properties of wool-PP/flax-PP composite. The examine virtually shows a huge impact of the pattern orientation on fire reaction properties of NFC. [6]

2.4. Interface strength

The Interfacial bond between matrix and fibre performs critical function in figuring out mechanical properties for composite. As stress is transmitted among fibres and matrix throughout interface, desirable interfacial bond is essential for obtaining best reinforcement. However, there is generally restricted interaction aimed at plant centred fibre composite among the matrices and hydrophilic fibres that might be usually hydrophobic causing weak interfacial bond. Weak interfacial bond restricts mechanical performance of plant centred fibre composite. Matrix and fibre need to be carried into intimate touch for occurrence of bonding; wettability is a vital originator for bonding. Interfacial defects may arise due to inadequate fibre wetting which might cause stress concentration. Wettability of fibre can be enhanced by chemical and physical treatment.

Interfacial bonding can arise by using mechanical interlocking mechanisms, chemical bonding, inter-diffusion bonding and electrostatic bonding. For rough fibre surface the mechanical interlocking take place to extra volume. Electrostatic bonding simply has substantial impact on metallic interfaces. When chemical groups within the matrix and the fibre surface can react to formulate bonds then chemical bonding occurs. Chemical bonding may be carried out by using a coupling agent which acts as passage among matrix and fibre.

Extensive studies have been done so one can acquire enhanced interfacial bonding for natural fibre composites. These studies can be broadly distributed into chemical and physical approaches. Physical treatments consist of fibre beating, electron radiation, heat treatments, ultraviolet (UV), plasma and corona while chemical treatments consist of acrylonitrile treatments, alkali, acetyl, silane, benzyl, acryl, isocyanate, titanate, zirconate and coupling agent. The most frequently used chemical treatments are maleated anhydride embedded coupling agent, alkali, acetyl and silane. However, enzyme treatment is
turning into more and more famous with its specific advantage related to environmental friendliness. For enhanced interfacial bonding alkali treatment eliminates fibre constituents which uncover cellulose and rises surface roughness per area. [4]

![Figure 5. Matrix-fibre interface](image)

2.5. Porosity
Porosity an is a part of natural fibre composite, acknowledged to have massive effect on mechanical characteristics of composite. Plenty of attempt has been gone to lower the porosity in synthetic based fibre composite. It rises because of addition of air in the course of processing, inadequate fibre wettability and different hollow structures inside fibre bundles (that may turn into closed in the course of high pressure processing). Porosity also rises because of less compaction abilities of fibres. In natural fibre composites porosity increase with increase in fibre content. It will increase more quickly after surpassing the geometrical compaction limit. Depend on fibre orientation and type of fibre; composites of flax/PP had been seen to have growing porosity of 4% to 8% of volume for increase in fibre content from 56% to 72% of matrix. [4]

2.6. Thermal effect on machinability
In an examine which specializes in the combined results of sample temperature and tool rake angle when slicing one directional flax fibres reinforced polypropylene composites investigates the effect of these 2 essential parameters on cutting performance of natural fibre composites and cutting contact stiffness. In this study, the chip formation and in-situ cutting forces are noted for each cutting situation. Scanning Electron Microscopy (SEM) observations are used to evaluate the state of machined surface. Under unique sample temperatures and tool rake angles orthogonal cutting of one directional flax fibres/polypropylene has been accomplished. This is done to investigation the thermal aspect of flax fibres on tribological cutting performance. The removed chip remains continuous beneath every slicing situation due to the excessive ductility prompted with the aid of PP matrix and flax fibres. Nevertheless, decreasing the temperature of sample reduces the curling of chip and increases the obvious material stiffness which result in improvement in machinability of uni-directional flax fibre / polypropylene (UDF/PP) composites. Excessive flax fibres deformations at some point of cutting interaction is induced by negative value of rake angle which degrades machinability of the UDF/PP. However, the machinability and cutting contact stiffness of UDF/PP can be improving by machining using slight positive rake angle. [1]
2.7. Flammability
For the improvement in composite products and the material selection it is exceedingly essential to have the information of flammability and thermal decomposition of the bio-centered fibres, their composites and polymers. Natural fibre composites has high flammability which is a major disadvantage for applications of engineering (ex. building insides and aerospace). The reason behind the high flammability of NFC is combustible fibres and hydrocarbon polymers. Therefore, greater innovative studies associated with the material choice, flame retardant treatments or production procedure is necessary to attain an equilibrium among flammability and overall mechanical performance of composites. [10]

2.8. Fibre configuration (Banana)
In a research of polypropylene (PP) composite, with reinforcement of continuous banana fibre by weightiness percentage ratio of 70:30 of polymer to fibre, were have been developed. The mechanical characteristics of composite materials were investigated for the outcomes of dissimilar configurations of continuous banana fibre. Raw banana fibre, banana fibre mat, and banana fibre yarn are three dissimilar configurations of banana fibre as shown in underneath table.

| Table 2. Configuration of fibre and matrix (wt.%) in the polymer composites. |
| Composites                  | Fibre (%wt.) | Matrix (%wt.) | Total (%wt.) |
|-----------------------------|--------------|---------------|--------------|
| Unreinforced PP             | 0            | 100           | 100          |
| PP/Raw Banana Fibre        | 30           | 70            | 100          |
| PP/Banana Yarn             | 30           | 70            | 100          |
| PP/Banana Mat              | 30           | 70            | 100          |

The bar diagram in figure 6(a) shows three exceptional configurations of banana fibre with Tensile Strength for the PP/Banana fibre composites. Banana fibre reinforced natural composites gives higher tensile strength in comparison to unreinforced PP, which confirmed that the higher mechanical strength is possessed by banana fibre reinforced composites than unreinforced PP. The best enhancement of tensile strength is given by composite of PP/Banana yarn. Composite of PP/Banana yarn yields very best tensile strength of 77.74 MPa compare to 33.27 MPa of PP/Banana mat and 66.26 MPa of PP/Raw banana fibre.

The bar diagram in figure 6(b) shows three exceptional configurations of banana fibre with flexural strength of the composites of PP/Banana fibres. It’s miles clear that the three specific reinforced PP
composites of banana fibre gives greater flexural strength than unreinforced PP. The findings indicate compared to former 2 arrangements banana yarn arrangement gives finest results as it demonstrates the very best 52.88 MPa of flexural strength. Therefore, PP/Banana yarn composite possesses the best flexural strength in addition to tensile strength and as a result, it could be realized that for getting the finest mechanical properties, the greatest choice of fibre configuration in PP composite is banana fibre yarn. [3]

2.9. Time at temperature
Temperature is usually considered as restricting criteria for the production of natural fibre composites (commonly not surpassing 200°C). The impact for time at temperature of natural fibres is showcase by a study on fibres of jute weighing 880 gm⁻². It studies fibre mechanical properties after air heating for different times and temperatures, by means of taking batches of fibre which have been heated by using oven to fixed temperatures (step of 10°C and 180-220°C) for predetermined times/instances (5, 10, 15, 30, 60 and 120 minutes). Five models each at mixture of time and temperature had been tested and below ambient situations the mechanical properties for jute fibres had been measured. The study shows quick degradation at upper temperature and at low temperature prolonged heating. The statistics used by the observe is based on a restricted set of assessments and subsequently deciding most appropriate processing values of time-temperature has not been feasible yet. [7]

3. Applications of natural fibre composite
Many researchers have paid their attention on the usage of natural fibres in cementitious centered structural materials as reinforcements. Natural fibres usage in structural applications isn't cutting-edge as far hundred years ago in lots of small cities in Korea and China people already mixed straws and dust to construct partitions in rural areas., Natural fibre composites in automotive business are suitable to feature as front sheets of automobiles and they're no longer prime structural constituents. Weight and cost of cars might be partly reduced though replacing conventional aluminium and fibre glass composites with natural fibre composites in those components. [5, 16] Even though the high strength fibre consisting of carbon fibre has more strength than the natural fibre, strength of glass fibre is comparable to natural fibre. Natural fibre is able to be carried out as very valuable composite if the suitable resin is selected. The eco-friendly hood shape design for automobile is feasible via the usage of natural fibre composite. [9]
The coconut fat collected from feedstock’s can be carefully chosen as bio based Phase Change Material (PCM) due to its decent Thermal Energy Storage (TES) properties. This PCM can be included in a laboratory prepared composite matrix of cellulose fibres and natural clay. Coconut fat can be chosen as bio based PCM. [11] Kinetic energy of air is converted into electrical power via tool named wind turbine. Amongst the wind turbine parts which includes blades of wind turbine, nacelle, tower, gear field and hub are normally prepared from carbon fibres and glass fibres for resistance to corrosion, light weight and higher strength. The most important drawbacks of these fibres (carbon and glass fibres) are the health risk, non-biodegradable, their fabrication value and availability. Consequently, the goal of investigation is to update those materials by using natural fibres. Bio-degradable substances with greater mechanical properties can be formed via natural fibre composites. Reinforced composites of natural fibre can be a capable nominee in which they are able to substitute conventional material for the manufacturing of various sections of a wind turbine. [12]
Natural fibres signify ecological option to be used both in noise manipulate engineering and constructing production compared to traditionally used synthetic materials. Due to hydrothermal characteristics of natural fibres, they are mainly engaged in the constructing industry. However, opportunity to additionally use natural fibres for acoustic will significantly rise their attraction in the market. An experimental examination of hemp-fibres diagnosed the effect of every step of the manufacturing method and shows use of natural hemp fibre can enhance the sound absorption property of sustainable thermal insulating materials. [13]
Currently, less costly housing and power conservation are a number of the topical problems in building creation. Few researches have shown the feasibility for incorporating the plant-based natural fibres in construction materials as it reduces heat transfer in structures and cost of material handling. A study found out that mud bricks with fibre reinforcement were light in weight than traditional mud brick, however fibre reinforced bricks possessed greater compressive strength than traditional mud brick. [14]

So many car enterprises have done very much of research with the purpose of use of NFCs for their products. Various examines has been done in Europe by the car manufacturing enterprises to rise the applications of NFCs in automobile business, particularly in car interior for instance door-trim panels, truck linens, door linens, parcel shelves and seat backs. [15]

4. Conclusion

Much research and growth has taken place in current a long time within the mechanical performance of natural fibre composite. The properties (mechanical and physical) of natural fibres varies from fibre to fibre. This paper has reviewed the studies that focusses on composite of natural fibre and factors affecting the performance of natural fibre composite (like fibre choice, orientation, configuration, matrix choice as well as thermal parameters). Natural composites such as sisal, jute, abaca and coconut are utilized in lots of applications of engineering, due to its superior properties (which include light weight, specific strength, worthy mechanical properties, lower cost, eco-friendly as bio degradable). Overall, growth of natural fibre composite uptake maintains at a fast rate and there would seem like a very tremendous destiny beforehand for their utility.

5. References

[1] Faissal Chegdani, Behrouz Takabi, Bruce L. Tai, Mohamed El Mansori and Satish T.S. Bukkapatnam, “Thermal effects on tribological behavior in machining natural fiber composites” 2018 46th SME North American Manufacturing Research Conference, Procedia Manufacturing 26 305–316

[2] Mulinari, D.R., Baptista, C.A.R.P, Souza, J. V. C., Voorwald and H.J.C, “Mechanical properties of coconut fibers reinforced polyester composites” 2011 Procedia Engineering 10, 2074–2079

[3] N. Amir, Kamal Ariff Zainal Abidin and Faizzaty Binti Md Shiri, “Effects of fibre configuration on mechanical properties of banana fibre/pp/mapp natural fibre reinforced polymer composite” 2017 Advances in Material & Processing Technologies Conference, Procedia Engineering 184 573 – 580

[4] K.L. Pickering, M.G. Aruan Efendy and T.M. Le, “A review of recent developments in natural fibre composites and their mechanical performance” 2016 Composites: Part A 83 98–112

[5] Kin-tak Lau, Pui-yan Hung, Min-Hao Zhu and David Hui, “Properties of natural fibre composites for structural engineering applications” 2018 Composites: Part B 136 222–233

[6] Swagata Dutta, Nam Kyeun Kim, Raj Das and Debes Bhattacharyya, “Effects of sample orientation on the fire reaction properties of natural fibre composites” 2019 Composites: Part B 157 195–206

[7] Alexander Hart and John Summerscales, “Effect of time at temperature for natural fibres” 2017 3rd International Conference on Natural Fibers- Advanced Materials for a Greener World, Procedia Engineering 200 269–275

[8] C.Elanchezhian, B.Vijaya Ramnath, G.Ramakrishnan, M.Rajendrakumar,V.Naveenkumar and M.K.SaravananKumar, “Review on mechanical properties of natural fiber composites” 2018 Materials Today: Proceedings 5 1785–1790

[9] Changduk Kong, Haseung Lee and Hyunbum Park, “Design and manufacturing of automobile hood using natural composite structure” 2016 Composites: Part B 91 18–26

[10] N.K. Kim, S. Dutta and D. Bhattacharyya, “A review of flammability of natural fibre reinforced polymeric composites” 2018 Composites Science and Technology 162 64–78

[11] Lisa Boussaba, Amina Foufa, Said Makhlof, Gilles Lefebvre and Laurent Royon, “Elaboration and properties of a composite bio-based PCM for an application in building envelopes” 2018
Construction and Building Materials 185 156–165
[12] Ganesh R Kalagi, Rajashekar Patil and Narayan Nayak, “Experimental study on mechanical properties of natural fiber reinforced polymer composite materials for wind turbine blades” 2018 Materials Today: Proceedings 5 2588–2596
[13] Andrea Santoni, Paolo Bonfiglio, Patrizio Fausti, Cristina Maressotti, Valentina Mazzanti, Francesco Mollica and Francesco Pompoli, “Improving the sound absorption performance of sustainable thermal insulation materials: Natural hemp fibres” 2019 Applied Acoustics 150 279–289
[14] Obinna Onuaguluchi and Nemkumar Banthia, “Plant-based natural fibre reinforced cement composites: A review” 2016 Cement and Concrete Composites 68 96-108
[15] Layth Mohammed, M. N. M. Ansari, Grace Pua, Mohammad Jawaid and M. Saiful Islam, “A Review on Natural Fiber Reinforced Polymer Composite and Its Applications” 2015 International Journal of Polymer Science
[16] D Saravana Bavan and GC Mohan Kumar, “Potential use of natural fiber composite materials in India” 2010 Journal of Reinforced Plastics and Composites OnlineFirst 1-4