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A REVIEW ON BIOCOMPOSITES AND BIORESIN BASED COMPOSITES FOR POTENTIAL INDUSTRIAL APPLICATIONS

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Abstract. This review presents the survey of performance of biocomposites prepared using different natural fibres reinforced with polymers. Reviewing of bioresin was also done in this article to understand the importance of replacing the polyester and epoxy resin or to reduce the usage of epoxy and polyester resin to make the biocomposites which is partially biodegradable, environment friendly and also to utilize such partially biodegradable biocomposites to make products for industrial, structural and many other applications.

1. INTRODUCTION

Nowadays in the case of fibre reinforced polymer (FRP) composites, the fibre phase is mainly replaced with natural fibres to ensure the utilization of natural resources or to avoid using artificial fibres to make the composite a biocomposite. Even the food crops also being utilized as the natural fibres and the biocomposite made of wheat starch is tested for its mechanical and thermal properties to ensure the enhancement in the properties by varying the fibre content, fibre length and also introducing cellulose fillers [1]. Also in some cases to attain better properties than the composite materials coupling agent and catalyst were also introduced. To reduce the cost of composites and to utilize the waste materials, fibres were extracted from biowaste [2,3]. Introducing filler materials to improve the mechanical properties of the biocomposites was followed in many fabrication processes and nanocrystallite fibres were also added as filler substances to the biocomposites, in such case ramie cellulose was used as filler material for biocomposites to decrease the water sensitivity of the product [4]. Red algae fibre were also used as the reinforcement material for biocomposites to improve the storage modulus and flexural modulus of the specimen, here it states that coefficient of friction decreases with increasing the fibre content and the dimensional stability of the specimen gets improved thus making the red algae suitable reinforcement material for making biocomposites with Poly (butylene succinate) as matrix materials [5]. Natural fibres like coconut coir, banana pseudo stem, pineapple leaves, and sugarcane bagasse fibres were taken to conduct thermal stability test and activation energy test. Generally fibre will have cellulose, hemicelluloses and lignin in it, causes the fibre material act differently upon

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processing temperature. Lignin content in fibre makes the fibre more thermally stable, therefore the natural fibre coir having good content of lignin shows better thermal stability compared to the other natural fibres taken for testing [6].

Fibre content, fibre length, filler materials, fibre treatment are some major parameters which enhance the properties of the biocomposites and find improvement in the thermal, mechanical, physical properties were reported in detail in this survey.

2. BIOCOMPOSITES WITH EPOXY RESIN AS MATRIX PHASE

All polymer matrix composite materials generally use two phases namely matrix phase and reinforcement phase. No exceptions for biocomposites too, it will also have both the phases to be used in practical applications. Biocomposites utilizes the natural waste plant fibres as reinforcement material. Shailesh Kumar Singh et al. [7] studied biocomposites made of sunhemp fibres reinforced with epoxy resin (araldite AY-103). Samples were prepared according to ASTM standards and flexural properties of the test specimens were carried out in flexural testing machine. The main focus of this work is to replace the glass fibres by a natural fibre as better improvement in its mechanical properties and concluded that usage of sunnhemp fibre increases the flexural property of the bio-composites. Also they suggests that these bio-composites were prepared for manufacturing car door panels and house hold appliances like door windows etc. Ashok Kumar et al. [8] in their work takes sansevieria cylindrica as the natural fibre and epoxy resin is taken as matrix element for making up the bio-composites, the sample were prepared by varying the content of sansevieria cylindrica fibres, to enhance the property of these sansevieria cylindrica fibres it was treated with alkali water and both alkali treated whereas the non treated were undergone various testing for its dynamic mechanical analysis, thermogravimetric analysis, Differential scanning calorimetry analysis, Fourier transform infrared analysis, Scanning Electron Microscopic analysis, degradation temperature, flexural and tensile tests. It is noted that alkali treated fibre secure stable mechanical property and thermal degradation. Storage modulus and tan β gave good performance at 9% volume of treated sansevieria cylindrica fibres. While flexural and tensile were increased by 35% and 13% for sansevieria cylindrica fibre treated composites respectively.

Samson Rwawiire et al. [9] developed bio-composite with green epoxy polymer and natural cellulose fabric (bark cloth). The fibres were alkali treated and specimen was prepared for both alkali treated and untreated fibres. Optimum Curing time noted for the green epoxy polymer is 120 °C. Mechanical and thermal property of the biocomposite was measured and it is found that tensile strength of bio-composite is 33 MPa, flexural strength is 207 MPa and glass transition temperature ranges from 163-185 °C. Also the adhesion between the matrix and fibres is good for alkali treated fibres. It is consummate that the tensile strength needed for an automobile interior panel is 25 MPa were as here the bio-composites having the tensile strength as 33 MPa, so it is clear from the study that bark cloth reinforced green epoxy composites used as an alternative material for interior automotive instrumental panels. An attempt was made to study the mechanical and physical properties of betel nut fibre reinforced with epoxy resin and further they have done hybridization to enhance the mechanical properties of the composite by adding sansevieria cylindrica short fibres to the composite. Samples were prepared by varying the content of betel nut fibre and it is found from the testing that betel nut fibre of 10% wt. gave improved mechanical properties like tensile, impact and flexural strength.

Further Ramachandra Reddy et al. [10] measured the dielectric strength, water absorption capacity of the hybrid composite and it is found that 30% addition of betel nut fibre having reasonable dielectric strength. It is inferred that the optimum ratio to get enhanced hybrid composite out of betel nut fibre, sansevieria cylindrica short fibres reinforced with epoxy resin is *(*Betel Nut fibre *10:* Sansevieria Cylindrica *10: Epoxy: 80).*

Acacia leucophloea and epoxy resin were used in this work to prepare composites specimen by varying the fibre content and treating the fibres with chemical solution in order to enhance the mechanical and thermal properties of the biocomposites. Arthanarieswaran et al. [11] used NaOH solution for chemical treatment of fibres and fibre content are varied from 5-25%. It is postulated that 20% wt. content of untreated fibre and treated fibre shows better mechanical and thermal properties compared with other specimens. Fourier transform infrared analysis, AFM and SEM were also performed to know the qualitative analysis of the composites prepared. Compared to untreated fibre, 19.98% and 13.33% increase in the tensile strength and modulus and 6.74% in flexural and 7.32% in impact strength increase of the epoxy composite were noted when treated ALF were used as reinforcement.

Abdul Jabbar et al. [12] taken woven jute fibre and undergone various treatments like enzyme, CO_2 pulsed infrared laser and ozone, characterization was done using SEM and Fourier transform infrared spectroscopy. These treated fibres were reinforced with green epoxy resin to make it as composite by hand layup and compression moulding methods, work confirms that the treatment enhances the impact and flexural properties of the composites. DMA revealed treated composites have good storage modulus and reduction in tangent delta peak was also observed which in turn improves the adhesion between the fibre and matrix. Jiri Militky et al. [13] present the creep behaviour and dynamic mechanical test of jute fabric reinforced with epoxy resin composites. Jute fibres were treated with CO_2 pulsed infrared laser, ozone, enzyme, and plasma. Creep and dynamic mechanical testing was done by DMA and the specimens were prepared using hand layup technique and compression molding method. It is found that creep strain is high for untreated fibres when compared with the treated fibres. Out of all treatments to the fibres the laser treated fibres exhibits good performance in terms of creep deformation. Here for the work they uses burgers four parameter model to fit the experimental creep values and theoretical values were obtained by *R* statistical computing software and the experimental creep values shows good acceptance to the theoretical values. Due to the improved adhesion between fibre and matrix for the laser treated fibres there is an reduction in tangent delta height. It is inferred that laser treated jute fibres can be effectively used as reinforcement materials for bio-composites.

Waste corn on the cob was used to reinforce with epoxy resin to produce bio based composites. Here Hanifi Binici et al. [14] studies water absorption capacity, compressive and flexural strength of the sample made with epoxy resin and the fibres from corn on the cob. The purpose of producing these composites is to make replacement for the commercially available insulation materials used for building constructions. Ultrasonic sound penetration velocity coefficient test was conducted to check effectiveness of the insulation for the biocomposite prepared. Thermal conductivity coefficient was also measured. They made Gypsum as binder material to replace epoxy resin which will provide the properties of commercially available insulation material and all testing were done on these biocomposites to compare the properties and it is found that the epoxy resin based biocomposites shows better results. It is inferred that since the biocomposite is made from waste i.e left over material it will be more cost effective and when these insulation material made of biocomposites is applied in building construction will help saving energy in huge margin.

Hanifi Binici et al. [15] use cotton waste, fly ash and epoxy resin to prepare the insulation material with chipboards. They initiated this work to prevent the huge amount of energy consumption in the country, various testing like sound insulation, thermal conductivity, bending strength were carried out for the sample containing cotton waste, fly ash and epoxy resin with chipboards and barite was added with fly ash to few samples to measure the radioactivity, which makes these composite as a perfect insulation material to be used in building construction. It is understood that the results obtained from the study proves that light weight construction material made of cotton waste and fly ash were effectively increasing the engineering properties of chipboards, thus it makes the chipboard a prefect insulating material for building construction.

3. BIOCOMPOSITES WITH POLYESTER AS MATRIX PHASE

Low stress applications uses polyester resin as matrix phase for biocomposites. Apart from varying the fibre content, fibre length, and fibre treatment, fibre orientation also plays major role in enhancing the properties of biocomposites. Bennet et al. [16] reveals the effect of stacking sequence and fibre chemical treatment on the composite properties. Here for their study they have taken sansevieria cylindrica fibers and coconut sheath mats reinforced with polyester matrix to produce a hybrid biocomposite. For the chemical treatment they used alkali and silane, and it is known that for composites the strength of the chemical treated fibres will be high in this order silane treated, alkali treated and untreated. The specimen were prepared by compression molding, six layering sequences have been followed for composite preparation and it is found SCS stack sequence with silane treated fibres composites shows better mechanical and dynamic characteristics. Morphological observation from SEM shows that better compatibility for both treated and untreated fibres for alternative stacking order. Mayandi et al. [17] describe the reinforcement ability of veldt grape bast fiber (Cissus quadrangularis) with polyester resin. They prepared the samples by varying the fibre content and fibre length and the tensile property of the VGF was also measured to compare with commercially available natural fibres and the results was good in terms of tensile strength and modulus. The composite made of VGF and polyester resins with various fibre content and fibre length were tested for mechanical properties to find the optimum length and content of fibres. It is concluded that impact strength and flexural strength increases with increase in fibre content and it is noted that 40% wt. fibre content composite shows better mechanical property and tensile strength. Optimum fibre length was noted as 40mm in which high impact and flexural strength observed for the composite made of VGF/polyester composites. SEM analysis was done to observe the various failures and morphological structure of the composite. Comparison on mechanical, static, dynamic and thermal property of the sansevieria ehrenbergii reinforced polymer composite and wood fibre reinforced wood composite was done to check the suitability of sansevieria ehrenbergii fibre as reinforcement material for polymer composite. These two composites were further compared with other composites also. Here to enhance the mechanical properties like tensile strength, flexural properties and impact strength, Sansevieria ehrenbergii is treated with $KMnO_4$. The storage modulus of the commercial hardboard sheet and $KMnO_4$ treated sansevieria ehrenbergii polymer composite is highest in glassy and rubbery regions. Thermal stability and water absorption capacity were high for hardboard sheet compared with SEF polymer composite. Sathishkumar [18] done machining studies for all the wood based composite and sansevieria ehrenbergii fibre polymer composite the parameters taken was delamination factor and thrust force and drilling operation was done on all the specimen and comparison is made clear that treated SCF polyester composite showed lower DF and TF compared to hardboard sheet and ply wood composites. It comes to an end that sansevieria ehrenbergii fibre polymer composites can be effectively replacing the existing wood based composite materials in all applications. Ramanaiah et al. [19] introduced sansevieria natural fiber as reinforcement material for polymer composites. Here in this work the fibre content is increased to enhance the mechanical properties and the tensile and impact strength of the composites were increases 2.55 and 4.2 times when adding maximum content of sansevieria fibre compared with pure resin. It is noted that the thermal conductivity of the composites gets decreases with increase in fibre content. Fire behaviour of the composite was studied and adding sansevieria fibre reduces the heat release rate and also the peak heat release rate by 10.4% and 25.7%, but the composite ignite earlier, release more amount of carbon dioxide and release more smoke during combustion when comparing with neat polyester resin.

Sansevieria cylindrica fibres were fully studied for its physical, mechanical and chemical properties and the micro-structural analysis was done to see the structural fibres and arch fibres in sansevieria cylindrica, and cross sectional area, porous density, fibre density, fineness were estimated and found to be 0.0245 mm^2, 37%, 0.915±0.005 g/cm^2 and 9 Tex. Fourier transform and XRD showed that the fibre consists of cellulose with 60% crystallinity index. Tensile tests were also carried out for the sansevieria cylindrica and tensile strength noted was 658 MPa for the youngs modulus of 7 GPa, total elongation was between 10% and 12%. Hierarchical cell structure with primary wall, secondary wall, fibre lumen and middle lamellae was found during microscopically analysis of sansevieria cylindrical, [20]. Sathishkumar et al. [21] tried using new natural fibre from snake grass, here fibres were extracted from the snake grass plant manually and tensile property of the snake grass fibre is studied and the values gained from the experiments is compared with other natural fibres. Snake grass fibre is mixed with the matrix isophthallic polyester resin to prepare the composite specimen by varying the fibre content, fibre length, and it is concluded that the maximum tensile strength and tensile modulus is found when increasing the volume fraction to 25% with 30 mm fibre length, similarly the flexural property shows good results when the fibre content is 25% with 150 mm fibre length. SEM micro graphical analysis were made on tensile and flexural tested samples to find the fibre failure, fibre pull out, matrix cracks during loading condition.

In this work oil palm mesocarp fibre was processed using superheated steam to make these fibres suitable to be reinforced with poly (butylenes succinate) for preparing bio composite. When the OPMF is processed in SHS the impurities in the fibre gets cleaned and the fibre surface roughness increases with decrease in the hemicelluloses. The bio composite sample was prepared with 70:30 ratios of OPMF and PBS. Yoon Yee Then et al. [22] confirm from the experimental work that there is an improvement in the tensile, impact and flexural properties of the bio composite when the OPMF is SHS treated. OPMF is treated at 220 °C for 60 minutes in oven. It is noted that the percentage increase in tensile strength, tensile modulus and elongation at breakage as 40%, 480%, and 26% respectively, further flexural modulus, flexural strength and impact strength of the bio composite were enhanced by 45%, 19%, and 14%, respectively. Dimensional stability of the SHS treated OPMF reinforced PBS bio composite were found to be enhanced by 48%. SEM analysis noted the adhesive property of the fibre and the matrix. Poly Lactic Acid reinforced with a extracted natural fabric from manicaria saccifera palm were made into biocomposite samples and characterization was done by thermal analysis(TGA) and SEM and mechanical testing's like tensile test, flexural test and izod impact was done. The tensile strength, elastic modulus and impact resistance were enhanced by 26%, 51%, and 56%, respectively, SEM images shows the mechanical interlocking of poly lactic acid into the fabric and improvement in the mechanical properties. Porras et al. [23] discuss about the Good energy absorption capability of Manicaria Saccifera Fibre/ Poly Lactic Acid biocomposite proves that natural fabrics from manicaria saccifera palm can be used as reinforcement for the biocomposites.

In this paper, an attempt was made to utilize the textile industrial waste to produce biodegradable composites. Muhammad Umar et al. [24] has made eight samples according to factorial design for various levels of parameters like weft material, weft count, picks/inch for the cotton fibre to conduct various mechanical tests like impact strength, specific tensile strength and bending strength and ninth sample was composite made of glass fibres. The mechanical properties were compared between all the nine samples and it is seen that impact strength of the sample made of cotton fibres having comparable properties with glass fibres, but flexural as well as tensile strength was less. It is inferred that composites made of industrial waste cotton can be useful in less structural applications since it is biodegradable and eco friendly.

Mehmet Safa Bodur et al. [25] concentrates on improving the tensile strength of the composites made of industrial cotton waste reinforced with polymer matrix. They follows two methods to improve the tensile strength maleated anhydride polyethylene was added as a coupling agent to the composite as one method to improve tensile strength and a totally new glass fibre and glass fabric laminated hybrid composite structure was designed in second method. Low density Polyethylene was used as matrix element for composite preparation. By introducing the coupling agent the tensile strength improves by 50% of 15 MPa strength with 5 wt.% of coupling agent. Glass fibres were introduced as WGF layers between composite plates makes laminated hybrid composite which is the new approach done in this work in order to improve tensile strength of composite and the results shows that the tensile strength improves 200% with 20 MPa and additionally young's modulus was also increased by 322% as effect of hybridization.

T. Alomayri et al. [26] made an attempt to improve the thermal and mechanical properties of fly ash based geo polymer reinforced with cotton fabric. Ordinary Portland cement replaces fly ash in a little quantity to improve the setting and hardening of geopolymers. For mechanical testing eight samples were made one is pure geopolymers, geopolymers with different composition of OPC percentage and cotton fabric reinforced with geopolymers with different composition of OPC to it. AL samples were tested for fracture toughness, Flexural strength and impact strength and thermogravimetric analysis also done to study the thermal stability of the samples. It is concluded that the addition of OPC to CF reinforced geopolymer increases the flexural strength and impact strength and also improves the adhesion between matrix and fibres, the work pointed out the results by concluding, the increase in OPC beyond 5% will leads to reduction in fracture toughness.SEM analysis were made to prove this phenomena of fracture surface of the samples.

Hossein Khanjanzadeh et al. [27] contributed their work to minimize the usage of wood, here in this study particle board is chosen for the research purpose since it is vastly used and made of fully wooden based materials. Cotton stalks and underutilized paulownia were added to the production of particle board to reduce the usage of wood in preparing particle board, using urea formaldehyde resin these composite were made and testing was conducted to check the mechanical property and physical properties of the composites made from cotton (*Gossypium hirsutum* L.) stalks and underutilized paulownia (*paulownia fortunie*) in wood-based composite particleboard. Hossein Khanjanzadeh concluded that addition of cotton stalk up to 50% and paulownia wood particles up to 70% improved the mechanical properties of the resulting boards, whereas there is decrease in the physical properties when these natural fibers were added more in percentage to particle board.

4. HYBRID BIOCOMPOSITES

For utilizing the good properties of more than one fibre in some cases more than one fibre is used to reinforce the matrix of the biocomposites such biocomposites are called as hybrid biocomposites. Kazuya Okubo et al. [28] develop a novel hybrid biocomposite with biodegradable poly (lactic acid) PLA reinforced with microfibrillated cellulose (MFC) and bamboo fibre. Here in this work cellulose is taken as interphase in polymer matrix around the bamboo fibre bundle to prevent the sudden crack growth. The dispression of 1 wt.% of MFC in PLA matrix drastically improves the strain energy of the bamboo/PLA composite upto 200%. It is also inferred that adding MFC of 1 wt.% to the composites made of PLA and bamboo fibre gives enhancement to the biocomposites in terms of mechanical properties.

Paki Turgut [29] uses cotton waste to replace the limestone powder waste to reduce the thermal conductivity of the artificial limestone composites, various percentage content of cotton waste is added to replace the limestone powder waste, among the various content 40% of cotton waste when added to limestone composites there is reduction in thermal conductivity and unit weight value of 51% and 29% when compared with normal specimen. Ultrasonic pulse velocity, thermal conductivity and unit weight forms a strong relationship between each other, here the work concludes that by replacing limestone powder waste with 40% cotton waste the limestone composites shows improved properties.

Composites were prepared using natural fibres sansevieria (sansevieria trifasciata) and banana pseudostem (musa sapientum) reinforced with epoxy resin. The mechanical and thermal properties were checked for both composites made from two different fibres, mechanical damping factor is 0.35 for sansevieria epoxy composite which shows it has stronger interfacial bonding between fibre and matrix when compared with banana epoxy fibre with mechanical damping factor is 0.44. In case of glass transition temperature banana fibre has 120 °C whereas sansevieria fibre has 100 °C. Samson Rwawiire et al. [30] conclude that optimum temperature for working of sansevieria and banana fibres is 50 °C.

5. EPOXY BIORESINS IN PREPARING BIOCOMPOSITES

Lagel et al. [31] prepared a bioresin with furfuryl alcohol and quebracho tannins as the major ingredients and some more additives like PEG 400, tung oil, DC 193 (silicone oil), neo-prene, graphite and glycerol phosphate acid were added to increase the properties of the Bioresin. Finally ethylene glycol solution of (para-toluene sulfonic acid) pTSA was added as a catalyst. These made Bioresin matrix was used to replace the automobile brake pads.

Niedermann et al. [32] synthesized glucose based epoxy resin and it was tested with jute and carbon fibre reinforced composites and the samples were compared with the mineral oil based commercially available resins for the dynamic mechanical properties, glass transition temperature, tensile and bending strength and modulus. They made a conclusion that the glucose based epoxy resin can be used in high temperature application up to 160 °C. Especially the bioresin based composites can be used in aircraft interiors. Manthey et al. [33] also joins in research to find a noval bioresin to be reinforced with natural fibre to get an efficient bioresin based biocomposites. Here in this work epoxidized hemp oil-based biocomposites containing jute fibre reinforcement was produced using hand layup process. EHO based bioresin were prepared by mixing EHO with base epoxy resin. Tensile strength, flexural properties, impact test, SEM analysis and water absorption properties were observed and found to be advantageous when compared with epoxy soyabean oil based biocomposites. Campanella et al. [34] made biocomposite material by using northern red oak leaves from the falls and the bio based resins were prepared from two vegetable oil based resins were employed CREY4 [that contains maleinated acrylated epoxidized soybean oil and styrene] and CREY5 [that contains a mixture of acrylated epoxidized soybean oil, maleinated acrylated epoxidized linseed oil and styrene]. Since the leaves having smoothy surface for water resistance purpose the adhesive property of leaves and resin matrix may be affected. For this purpose the leaves were treated before to remove the waxes present in the leaves. The bio based resins prepared have good viscosity which can be applicable for high temperature resin transfer molding (RTM) and vacuum-assisted resin transfer molding (VARTM) processing. Leaves before it is reinforced to the bioresins, it was treated with saline water to improve the interfacial adhesion between leaves and the resins. Another method also followed to remove the waxes from the leaves with saline water. Here the work consummate that composite made using bio based resin and northern red oak leaves produces good properties.

Scalici et al. [35] prepared biocomposites using fibres extracted from the leaves of giant reed Arundo donax L. and bio epoxy resins. They compared the properties of biocomposites when the fibre treated with plasma and without plasma. The thermal behaviour and the mechanical properties were investigated using various analyses like Fourier transform infrared spectroscopy analysis, thermo gravimetric analysis and tensile tests. Fibre content and fibre length also varied while manufacturing the biocomposites by hand layup and compression moulding techniques. The work shows that plasma treatment doesn't vary any physical or mechanical behaviour of the composites but it increases the adhesion between fibre and matrix. Jean-Mathieu Pin et al. [36] focus on the increase of bio based materials toughened mechanical properties based on addition of epoxy linseed oil. They used cross linking process to produce the commercially available epoxy linseed oil into a material having more tough mechanical properties. Cross linking was performed initially by selecting suitable hardener and finally flavouring the side reaction of polymerization. This work concludes that after cross linking the materials will have better mechanical properties and very high glass transition temperature which makes the material usage in industrial applications.

Nathan Manthey et al. [37] synthesised bioresins with acrylated epoxidized hemp oil and applied it to woven jute fiber for characterization. Three types of matrixes were formed for sample preparation vinlyester, 50/50 vinylester and AEHO, AEHO. The flexural properties and inter laminar shear strength of all the samples were checked and it is found that 50/50 and pure AEHO sample has low flexural strength when compared to the commercially available vinlyester and when these matrixes reinforced with the woven jute fibre the AEHO reinforced with fibre shows greater improvement in terms of both inter laminar stresses and flexural strength. Also acrylated epoxidized hemp oil bioresin improves the adhesion between the matrix and the fibres.

Amir Fam et al. [38] tried to add bioresin (two types of organic furfuryl alcohol) from renewable resources corncobs for fabricating glass-FRP (GFRP) laminates by wet layup. Thus samples were prepared and compared with commercially available epoxy resins for tensile strength and modulus. Further they investigate the type and dosage of catalyst, efficient overlap splice of laminates and the work pointed that proper selection of density of bioresin helps to improve the mechanical properties. Curing time was also studied properly and it is found that full strength was attained on 13 days of curing and noticed 84% of strength gained within 2 days. It is observed that parameters related to bioresins have slight effect on the modulus whereas bigger effect on the tensile property. Proper lap splice length has to be maintained to produce high performance biocomposites. Paul et al. [39] made an attempt to create a biocomposite using banana fibre and resin made from banana sap and carried out various testing and characterization to study the properties of biocomposite made with and without banana sap. Mechanical testing indicated 15% increase in tensile strength, 12% improvement in tensile modulus and a 25% improvement in flexural modulus.SEM analysis was done to check the compatibility between the fibre and matrix. Finally they did degradation tests like soil burial test and fungal growth tests using optical images, which show increased microbial activity which means improved degradation rates.

Harekrishna Deka et al. [40] tried a new method for increasing the mechanical properties by introducing the bio fillers to the bio epoxy resin (diglycidylether of bisphenol-A based resin and epoxidized soybean oil). Bio filler is nothing but the corn based distillers dried grains (DDG). Differential scanning calorimetry and temperature-modulated fourier transform infrared spectroscopy shows the acceleration in curing process due to addition of bio fillers. Dynamic mechanical analysis shows that there is 12% increased storage modulus when compared with composites without bio fillers. SEM images show there is improved interfacial adhesion between matrix and the DDG. Flexural properties were also found to be good when compared with the neat polymers.

Sushanta Sahoo et al. [41] made a study on composite made of woven sisal fiber reinforced with unmodified petrol based epoxy and bioresin modified epoxy. Here they used epoxidized soybean oil and epoxy methyl soyate (EMS) to modify the epoxy resin. Both type of bioresin shows better improvement in properties likes fracture toughness and loss modulus compared with modified epoxy resins. Dynamic mechanical analysis shows enhancement in the storage modulus. Impact strength was good for the unmodified epoxy resins. Interfacial adhesion between fibre and the matrix where found to be good in case of modified epoxy resins and it was confirmed by SEM analysis. Alejandrina Campanella et al. [42] made different combination of bio resins by adding various diluents to the maleinated acrylated epoxidized soybean oil (MAESO) by decreasing amount of styrene used since it is having more hazardous substances in it.

Work performed with twelve different samples for testing viscosity and gel time of bio resins, dynamic mechanical analysis was also conducted to check the storage modulus and glass transition temperature. It is surprised with the results that MAESO gets versatility with different reactive diluents like as styrene, vinyltoluene, divinylbenzene, and methyl methacrylate and methacrylated fatty acid and these compositions can be varied to achieve required mechanical and thermal properties.

6. POLYESTER BIORESINS IN PREPARING BIOCOMPOSITES

Mehta et al. [43] utilize the fibre mat which contains 90% Hemp fibre extracted from hemp plant with 10% thermoplastic polyester binder as reinforcement material and unsaturated polyester (UPE) resin as well as blends of UPE and functionalized vegetable oils as the polymer matrix to produce the bioresins. Bio composites made using bioresins shows 90% increase in its impact strength when compared with the pure UPE-industrial hemp fibre mat composites. Further the tensile property also shows improvement using vegetable oil based polymer matrix. Electron Microscopy studies were also done to observe the morphological changes of the composites.

Anup Rana et al. [44] has developed a bioresin with flaxseed oil and produced the biocomposites with flax fibres using vacuum assisted resin transfer molding technique. Here the composition of styrene is varied to improve the physical and mechanical properties of the biocomposites made using flax fibres and flaxseed oil based bioresins. Various studies like water absorption, varying fibre content, varying styrene content has been reported in this work. It is inferred that there is improvement in the both the physical and the mechanical properties when increasing the styrene content.

Mahmoodul Haq et al. [45] made an attempt to use the bioresin prepared from unsaturated polyester and soyabean oil to reinforce with the nanoclay and natural fibres(Industrial hemp). According to the experimental study it is seen that hybrid biocomposite made of bioresin lowers the mechanical parameters such as stiffness and ultimate tensile stress and increases the toughness properties like impact strength and ductility. The amount of bioresins and nano clays plays major role in balancing the stiffness and toughness. Further these multiphase hybrid biocomposite has improved barrier properties and thermal properties which enhance its usage in transportation and housing structures.

Soares et al. [46] worked to study the mechanical properties of basalt fibre and unsaturated polyester produced by resin transfer molding. Mechanical testing like tensile, compression and flexural testing was done as per ASTM standards and the results obtained shows that the tensile test values are similar to the calculated values with some error percentage as the compression and flexural tests shows sudden failure due to the first ply failure in the outmost layer prepared. The conclusion made from the work is to prepare more samples by following better manufacturing techniques and further study have to be done.

Sunil Kumar Ramamoorthy et al. [47] studied the performance of biocomposites from surface modified regenerated cellulose fibres and lactic acid thermoset bioresin. Silane treatment was done and various mechanical testing like Tensile, flexural and impact tests performed to check the interfacial strength between the matrix and the fibre. It indicated that surface treatment was done to improve the physico-chemical interactions at the fibre-matrix interface. When the biocomposite is silane treated there is increase in the bonding between fibre and matrix which helps the improvement of mechanical properties of the biocomposites. Storage modulus was also increased when silane treatment was done whereas damping intensity decreases for same composite. Work gets confirmation results using microscopic images.

Jamiluddin et al. [48] replaces the petroleum based matrix with green matrix i.e poly lactic acid from tapioca. It is found that the processing temperature place a major role for the bonding of the matrix and the fibre, by using green matrix it is evident that processing temperature can be optimized which results in improved mechanical properties, thermal property and physical property. Density test, hardness test, thermo gravimetric analysis, differential scanning calorimetric and tensile test were conducted in order to show the compatibility. It is presumed that 165 °C as the optimum processing temperature for making biocomposites with natural fibre and poly lactic acid tapiaco resin polymers.

Tshwafo Motaung et al. [49] produced biocomposites with natural fibres such as agave and sisal fibres reinforced with polyfurfuryl alcohol. Here both the natural fibres were treated with alkali and various testing was conducted between both fibres for chemical composition thermal mechanical properties. The result shows that sisal fibres are more likely to alkali treatment compared with agave fibres. Mechanical and thermal properties were improved when alkali treated sisal fibre reinforced with poly lactic acid matrix.

7. CONCLUSION

From the thorough review study the following conclusion can be drawn,

- The potential usage of bioresin for preparing environment friendly composites posses better results suitable for various industrial applications.
- The concept of green composite/ biocomposite found to be a better replacement for polyester and epoxy matrices for composite making.
- Also in addition the effect of hybrid composites enhances the various properties that create more attraction towards the new era of making composites for various applications.

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