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Natural Fiber Composites as Potential External Strengthening Material – A Review

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Abstract

Synthetic Fiber Reinforced Polymer (FRP) composites have been widely accepted by the construction industries as an effective external strengthening material to rehabilitate the existing structures deficiencies. These materials possess outstanding performances like high strength-to-weight ratio, resistance to corrosion, and lightness. However, the drawbacks include high costs during the manufacturing and end-life services, less environmental-friendly and cause adverse effects to human health. Environmental issues on global warming have triggered rapid development of natural fibers as sustainable materials for the strengthening of Reinforced Concrete (RC) structures. This paper presents a detailed review on the potential use of natural fibers as reinforcement in polymeric strengthening materials. A comparison was made between various types of fibers in terms of their chemical and mechanical properties. Bamboo fiber has demonstrated great potential among other natural fibers due to its superior physico-mechanical and thermal properties.

Keywords: Bamboo Fiber, External Strengthening, Natural Fiber, Natural Fiber Composites, Structural Application

1. Introduction

The meritorious services of the artificial Fiber Reinforced Polymer (FRP) composites in construction industry are already encouraging since last few decades. The most common synthetic fibers in practice are glass, carbon, and aramid. It has been concluded that the synthetic FRP composites are capable to upgrade the stiffness, durability, ultimate load-carrying capacity, and retard the cracks propagation of structures[1,2]. However, such material does not address the issues of sustainability of the non-renewable sources and imposes a higher cost during manufacturing. In addition, the human health will be affected adversely especially in skin and respiratory system. Thus, the research community had given more attention to natural fibers as an alternative to the artificial fibers.

The benefit of the natural fibers are life cycle sustainability, low density, light-weight, non-toxicity, renewable and biodegradable instantly[3], non-abrasive nature to process equipment and good thermal insulation property[4]. The production cost of natural fiber is economical as it consumed lesser energy compared to artificial fiber. Moreover, natural fibers are non-carcinogenic and safe during processing and handling.The commercially natural fiber can be gained easily from the natural resources that surrounds us, such as bamboo, coir, jute, abaca, ramie, pineapple leaf, hemp, oil palm empty fruit, sugar cane bagasse, sisal, kenaf, wood, flax and animals[5].More than hundreds of lignocellulosic fibers can be found in temperate and tropical zones around the world[6]. For instance, the flax, *Linumusitatssimum*, is one of the oldest crops in the world and classified to the bast fiber. It is previously utilized in the high value-added textile markets. On the other hand, the abaca (banana) fiber is resistant to seawater and durable. While, pineapple leaf fiber is a by-product of cultivation, which is abundantly available and inexpensive. The mechanical properties of

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these natural fibers are influenced by their fiber structure, cellulose content, microfibrillar angle, cross section and polymerization degree. The combination of these variation resulted to a complicated design and performance predictions of composites[7]. Hence it was revealed that not all kind of the natural fibers can be utilized as reinforcement in structural composites. The present paper aims to review the natural fibers such as jute, kenaf, sisal, and silk as current reinforcement in Polymer Matrix Composite (PMC) for strengthening of Reinforced Concrete (RC) structural members externally in building industry. This review also provides a thoughtful overview towards the bamboo fibers as the potential alternative to others artificial fibers.

2. Jute Fibers Composites

Jute fiber can be separated from the ribbon of the stem[8]. The common functions of jute fiber are wall decoration, ropes, yarn, and packaging material. The jute rope composite plates were fabricated for the strengthening of RC beam in flexural zone[9].The ultimate tensile strength of the jute rope composite was 99.97 MPa at fiber content of 25%. It is approximately reach the 40% of the yield strength of mild steel plate. Their experimental findings revealed that jute rope composite improved the load carrying capacity of RC beam by approximately 58% as compared to unstrengthened beam. In addition, the jute rope composite plate effectively reduced the deflection at initial stage and enhanced the ductility during the testing period. The comparison of Jute Textile Reinforced Polymer composite (JFRP), Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) for the flexural strengthening of RC beams externally was done[10]. JFRP possessed an ultimate tensile strength of 189.479 N/mm^2 which was the 21% of the CFRP (923.056 N/mm^2) and 28% of the GFRP (678.571 N/mm^2). On the other hand, JFRP also exhibited the maximum flexural strength of 208.705 N/mm^2, which was 13% of the CFRP (1587.134 N/mm^2) and 32% of the GFRP (666.871). The load-carrying capacity of the JFRP strengthened beam increased by 62.5% and promoted a ductile failure without any concrete crushing, JFRP rupture and debonding. JFRP also depicted higher deformability index. The ultimate flexural strength of the RC beams strengthened using GFRP and CFRP showed an increment by 125 and 150%, respectively with fully wrapping technique.

3. Kenaf Fiber Composites

Kenaf fiber can be obtained from the stems bast of the plants, *Hibiscus*, Malvaceae family, *cannibinus* species. It has an average yield of 1700 kg/ha[11], due to its rapid growth rate. The fatigue behaviour of unidirectional kenaf/epoxy composites laminate was examined[12]. The findings showed that the ultimate tensile strength of neat epoxy was 36.56 MPa, and improved to 57.95 MPa and 100.56 MPa by reinforced with 15% and 45% of kenaf fiber volume fraction, respectively. The homologous increment was 58% and 175%. The young modulus of pure epoxy also recorded an increase of 34% and 166% at fiber volume fraction of 15% and 45% respectively. It can be summarized that composites with higher fiber content contributed to higher load carrying capacity. The suitability of such lignocellulosic fiber reinforced with different types of thermoset polymer (epoxy, vinyl ester and polyester) composite at 0/90° and 45/-45° were assessed in terms of physical, mechanical and morphological properties[11]. The composites were prepared using vacuum infusion technique at a fiber weight content of 35% ± 2%. The kenaf epoxy composite owns the highest tensile strength followed by polyester and vinyl ester at the orientation of 0/90° which is similar with the literature[13]. This could be explained by the uniform distribution of stress transfer with the application of tensile load in both transverse and longitudinal directions. According to the author, the biocomposites with the orientation of 0/90° possessed the highest mechanical strength and greater capacity for stress uptake. In 2014, Hafizah et al. carried out an investigation on the structural behaviour of strengthened reinforced concrete (RC) beams using different types of kenaf fiber reinforced polymer composite laminates with a fiber volume content of 50%[14]. The kenaf/epoxy, unsaturated, and vinyl ester composites exhibited the similar ultimate tensile strength of 78, 77, and 79 MPa, respectively, at 50% fiber content. The ultimate young modulus was recorded by kenaf/epoxy composites at 36 GPa. The structural performances of composites upgraded progressively by increasing fiber volume content. The ultimate flexural strength of strengthened RC beams was increased by 40% whereas the deflection reduced by 24%, respectively. In[15] performed an experimental investigation on the shear strengthening of RC beam using kenaf fiber reinforced polymer (KFRP) laminate[15]. The KFRP laminate with the optimum fiber content (25%) provides the highest tensile strength of 119.6 MPa. It was found that KFRP laminate was capable to restrict the cracks width in the shear span of the beam. The strengthened beam exhibited an increase in the failure load by 33% as compared to the un-strengthened beam. The ductility, crack patterns, and failure load of KFRP strengthened beam were witnessed to improve and comparable with CFRP strengthened beam.

4. Sisal Fiber Composites

Sisal fiber could be extracted from the sisal plant leaves through hand extraction machine, either serrated or non-serrated knives[16]. The development of sisal fabric reinforced polymer composite (SFRP) system in flexural strengthening of RC beams externally was attempted[17]. The tensile strength of woven SFRP was 223.367 N/mm^2, which were 24% and 33% of the CFRP and GFRP. Whereas, SFRP exhibited a flexural strength of 350.034 N/mm^2, which was 22% and 52% of the CFRP and GFRP, respectively. SFRP was capable to improve the flexural strength of RC beams by 112.5% compared to the control beam and demonstrated an improvement in the load-deflection which is identical to CFRP and GFRP strengthening behaviour. Moreover, the SFRP strengthened beam had the highest ductility amount, control the cracks formation without rupture failure similar as in the case of synthetic FRP strengthened beam.

5. Silk Fiber Composites

Natural Silk Fiber Reinforced Polymer (NSFRP) composite has been produced to retrofit the RC beams[18]. The silk is a kind of natural protein which can be extracted from the cocoon.Silk fiber owns a relative low tensile strength (130 MPa), modulus of elasticity (9 GPa) and moderate specific weight (1.32 g/cm^3). While the NSFRP possessed an average tensile strength of 5.11 MPa and Young's modulus of 94.69 GPa respectively. A total of nine beams were tested, included three control beams and six beams were strengthened with NSFRP. All the tested beams were failed in flexure and shear mode.The control beams recorded an average ultimate load capacity of 36.53 kN.On the other hand, the ultimate load carrying capacity of beams strengthened at tension and flexure zone showed an improvement of approximate 39% and 36% as compared to unstrengthened beams.

6. Bamboo Fiber Composites

Bamboo is a collective of perennial evergreen growing woody plant in true grass family *Poaceae*, subfamily belongs to *Bambusoideae*, tribe *Bambuseae*[19].It is acknowledged as one of the fastest-growing plant in the world due to its unique rhizome-dependent system.In order to preserve the biodiversity and sustaining the development of agriculture without threatening the tropical forests, bamboo is the most favourable plant due to it can be harvested several times in a growing cycle. Besides that, bamboo has great productivity as the world production recorded at 30,000,000 tons[20]. The mechanical properties of bamboo fiber are advantageous primarily because of its unidirectional fiber arrangement in the tissue and cellulose being its major constituent[19]. The cellulose content contributed to the tensile strength and proportional to the modulus of elasticity. The microfibrillar angle of bamboo is comparatively small (2°-10°) and owns a moderate lignin content approximate 32% among various lignocellulosic fibers. The longitudinal modulus of elasticity of fibers is maximized by the nearly axially oriented bamboo cellulose fibrils in the fiber walls,and their lignification enhances the rigidity of transverse[19].The tensile modulus and strength of bamboo fiber can be upgraded remarkably after the lignin content was removed from the pristine bamboo fiber. The combination of these elements leads to the tremendously high flexural and tensile strength, as well as the rigidity of the polylamellate wall structure. Several attempts have been made known that bamboo fibers reinforced composites are capable to replace over the GFRP composite[21]. The bamboo fiber reinforced composites (BFRCs) have indicated an exceptional commitment which illustrating an increment in mechanical strength (10-20%) and rigidity (30-45%) as compared to pure polymers[22]. The natural fiber composite that made up by jowar, sisal, coir, banana and bamboo were compared under duplicate laboratory environment[23]. The experimental outcomes presented that bamboo fiber possess excellent physico-mechanical properties than other selected natural fibers as shown in Table 1.

Bamboo fiber owns the lowest density among others natural fiber which produce the lower density of natural fiber composite. In addition, four (4) years old bamboo fibers of *Dendrocalamus strictus* species as natural fiber reinforcement were reinforced with epoxy to produce the composite laminates[24]. The authors summarized that the mechanical properties such as compressive and tensile strength of the composite were influenced by the lamina configurations.The mechanical property of unidirectional bamboo fiber bundle reinforced with biodegradable resin was carried out[25]. The BFRC were manufactured using hot press process. The ultimate tensile strength and modulus of the composites were 265 MPa and 12.4 GPa with optimum fiber content of 70%. The tensile strength of the composites had increased directly proportional to the fiber volume fraction. The author also examined the heat resistance of bamboo fibers and bamboo fiber reinforced composites in which the fibers were heated at 140, 160, 180 and 200°C using an electric drying furnace for 15, 30, 60 and 120 minutes. In addition, findings reported that the maximum fabrication temperature for bamboo fiber reinforced composites should be lower than 140°C to avoid the reduction of strength.

Table1. Comparison of tensile properties of bamboo fiber and selected natural fibers

Fiber	Density (kg/m^3)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)
Sisal	1450-1500	227-700	9-22	3-14
Kenaf	1300	930	53	1.6
Jute	1400	400-800	30	1.8
Bamboo	910	140-800	11-46	1.4

7. Conclusion

Among the natural fibers, bamboo fiber is considered as the most potential fiber due to its lighter specific density and rapid growth rate. The BFRC possessed higher mechanical properties than kenaf, jute, and sisal fibers based composite. Due to its local availability and abundant accessibility in Malaysia, where a tropical rainforest climate is all year round apparently, bamboo can be obtained easily. Bamboo fiber is believed to be a nearly inexhaustible root of raw material for the raising demand for biocompatible products, environmentally friendly and have achieved the criterion of structural upgradation material. In the recent years, most of the findings on natural fibers composites are mainly confined to kenaf, jute, silk and sisal fibers for the work of retrofitting on the RC structural members. The principle parts of the researches on foreign species bamboo fiber have been focusing on the fiber separation techniques as well as mechanical and thermal properties of fibers in polymer matrices. Investigation of local species of bamboo fibers are still needed in an extensive manner especially as reinforcement for structural members. To date, researches in the application of using BFRC plate as an alternative external strengthening material to improve the properties and behavior of RC beam is rather limited and still lacking. Hence, it can become the latent substitute of the costly and non-sustainable synthetic fiber and also a new origin of raw material for other industries.

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