Natural Fiber as a Fibrous Reinforced in Polymer Modified Mortar: A Review

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Abstract

The disadvantages of cement based material are due to its brittleness, thus perform low tensile strength and poor fracture toughness. This poor performance can be improved by using fiber as reinforcement. Fiber such as carbon fiber, glass fiber is widely used to enhance the properties of the cement-based material, especially in the form of thin sheet/plates. While global scenario has intensively moved towards green buildings, it is possible to use our local resources. It is to innovate local green building materials such as using natural fiber from agricultural waste such as oil palm fiber, coir fiber, kenaf and wood fiber. Therefore, this paper highlights the review of the literature regarding the use of natural fiber in polymer-modified mortar.

Keywords: Natural fibre, fibre reinforced, polymer modified mortar.

1.0 Introduction

Concrete possesses high compressive strength but also have low tensile strength. This brittle material has to be reinforced with steel reinforcement system to gain good compressive and tensile strength with appropriate post crack deformation due to strain softening. These advantages, however, lack of resistance towards penetration of water and other aggressive elements due to its high permeability characteristic that lead to carbonation and chloride attacks resulting to corrosion of the steel rebar. Gjorv's (as cited in Pacheco-Torgal&Jalali, 2011) reported that serious deterioration occurs to almost 25% of bridges built after 1970 in Norway. Meanwhile Ferreira's estimated that 40% of 600,000 bridges were affected due to corrosion in U.S.

The aspect of high-cost maintenance due to this deterioration should be improvised by adopting materials that provide durability and performance of the material used. Meanwhile, the current global scenario in construction has intensively moved towards green buildings approach such as adopting various aspects of materials recycling, reused and energy conservation. Thus, it is possible to use our local resources to innovate local green building materials such as using natural fiber from oil palm fiber, coir fiber, pineapple leaf, kenaf and wood fiber as the reinforcement. By adopting these natural fibers, it is possible to enhance brittle materials such as OPC structure but with fewer problems of deterioration.

This abundant source of natural fiber has not been fully utilized and most likely will be left untreated and rotten with some of the fiber will later pollute the environment as well. Various researches have been undertaken to understand and utilized natural fiber in the form of composite materials. However, the development of natural fiber reinforced in the cement based composite are limited due to incompatibility under cementitious environments such as high permeability and lack of resistance to crack growth.

ACI Committee 544 (2002) concluded that fibers can swell in the presence of moisture and resulted to some deficiencies in their durability aspects. Previous studies have also shown that most of composite system has similar problems that related to cracks propagation due to the deterioration of the fiber in alkalinity of cement environment. Several researchers had used matrix modification approaches such as reduce the alkalinity of the cement matrix, modification of natural fiber surface using chemical and also involving process technique.

While OPC have common issues of permeability, modifications of the cement properties have significant potential to enhance the matrix by using filler additives and cement replacement methods. Polymer modified cement in concrete and mortar has been intensively adopted to enhance durability and strength. Applying natural fiber in polymer modified matrix may lead to the opportunity of reducing similar problems of corrosion and offer surface coating to fiber.

2.0 Fiber characteristic and properties

Fiber can be classified into two parts of organic fiber. There is a natural fiber that consists of a vegetable origin and animal origin. The other type of organic fiber is man-made fibers. Man-made fibers consist of the natural polymer and synthetic group. The classification of fiber is shown in Figure 1.

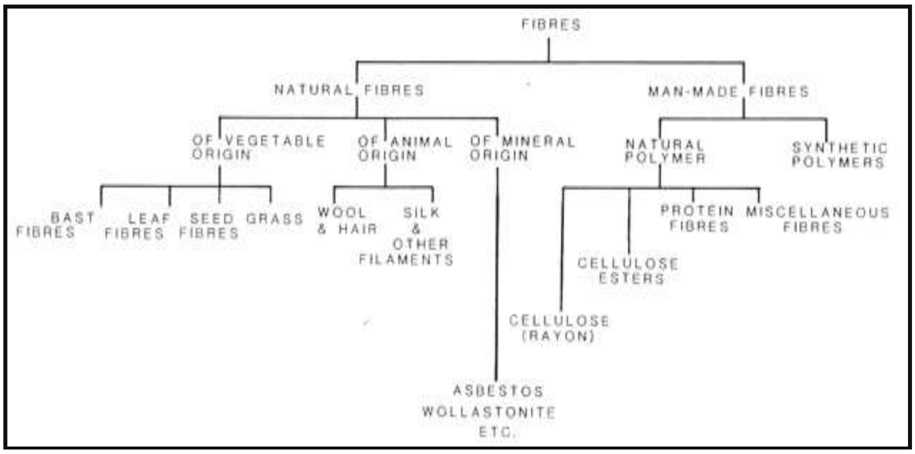

Figure 1: Classification of fiber(Z.Fordos, 1988)

Table.1: Properties of vegetable fibers(Savastano, Warden, & Coutts, 2000).

Properties	Specific gravity [Kg/m^3]	Water absorption [%]	Tensile strength [MPa]	Modulus of elasticity [GPa]
Sisal	1370	110	347-378	15.2
Coconut	1177	93.8	95-118	2.8
Bamboo	1158	145	73-505	10-40
Hemp	1500	85-105	900	34
Caesarweed	1409	182	300-500	10-40
Banana	1031	407	384	20-51
Piassava palm	1054	34-108	143	5.6
Date palm [7]	1300-1450	60-84	70-170	2.5-4

The variation of fiber properties has encouraged over fiber pre-treatment. Pre-treatment of the fiber changes the composition and effect to the properties of the fibers. Other related treatment includes reducing the alkalinity of the cement matrix and also by acquiring technical process.

3.0 Natural Fiber as Reinforcement in Cement Composites

The advancement of natural fibers reinforced in cement-based composite has gained attention since scientist knows that asbestos composite causes the health hazard. The attention to replacing asbestos has led to numerous studies on natural fibers composite. However, with vast technology, high-performance man-made materials such as carbon fiber composite and other synthetic fibers composites has gained popularity. However, due to economic reason, most of the man-made fiber are not cost viable anymore for the industries. For the last decade, there has been a positive interest again in natural fibers due to its potential advantages of renewable resources as well of its offerings towards weight saving and lower raw material price. As an example, there have been numerous investigations on fiber treatment to improve their low strength and durability as similar to glass fiber properties.

Among the advantages that the fibrous cement exhibits are such as its ductility, flexural capacity and crack resistance. It also performed toughness strength as compared to non-fiber reinforced cement-based materials. The major advantage of fiber reinforcement is the behavior to resist post cracking in brittle material such as the cement and mortar. The cracking strain of the matrix does not change where the fiber has successful bridges across the crack.

The attention to produce a systematic and durable construction material has been taken into various researches on the natural fiber mechanical properties and physical performance. Fibers from coconut husk, sisal, sugar cane bagasse, bamboo, jute, wood, akwara, elephant grass, water-reed, plantain and musamba were introduced in the cementitious matrix. Their mechanical properties adaptation was also investigated (M. Ramli&Dawood, 2010).

The achievement in fibrous cement composites is quite remarkable whereby their application in housing can only be seen in the exterior application such as the siding and roofing. Previously most of the available products are non-structural building materials. With the natural fiber substituting the typical steel reinforcement, it can achieve a desirable tensile rupture and stress strength. The behavior of natural fiber in cement composite materials shows that it could act as a primary reinforcement to increase the strength and toughness. It also acts as secondary products in controlling cracks induced by temperature and humidity (Golbabaie, 2006).

3.1. Natural Fiber Reinforced Composite.

Investigation of natural fiber reinforced cement composites has been done by numerous researches involving most of the common natural fibers as mention before. The physical and mechanical of the fibers may sometimes appear differently in which is strongly influenced by their growing environment. Some of the properties of particular fiber may have huge difference even though the diameter is approximately the same, but the magnitude of tensile strength is different. Other examples such as the density of different fiber may show a different value, and this variation of properties may not be considered to be used as construction materials (Majid, 2009).

There are several factors affecting the properties of natural fiber reinforced cement composite such as fiber type, fiber geometry, fiber form, fiber surface, matrix properties, mix design, mixing method, placing method, casting method and last but not least is the curing method. According to Aziz, Paramasivam, & Lee (1981), all the factors are almost equally important. As an example, the optimum fiber length and volume concentration for coconut fiber are at 38mm and 4% respectively but for jute fibers are at 25mm and 3% respectively.

3.2. Properties of Fresh Natural Fiber Reinforced Composite.

An investigation by Toledo et al., (2005) to evaluate shrinkage and creep behaviour of vegetable fiber reinforced composite using sisal and coconut fiber was conducted to establish the influence of the fibers on the free and restrained plastic shrinkage, early drying shrinkage cracking, crack self-healing and long-term drying shrinkage of mortar matrices. In this study specimen were subjected to a wind speed test of 0.4–0.5m/s at 40°C temperature for up to 280min. Drying shrinkage tests were carried out at room temperature with about 41% relative humidity for 320 days. The influence of curing method, mix proportions and a partial replacement of ordinary Portland cement (OPC) by ground granulated blast-furnace slag and silica fume on the drying shrinkage of vegetable fiber reinforced composite (VFRC) was also investigated. This investigation established findings that concluded the benefits of fibers incorporation. Free plastic shrinkage is significantly reduced by the inclusion of 0.2% volume fraction of 25mm short sisal fibers in cement mortar. An addition of 0.2% volume fraction of 25mm sisal and coconut fibers delays the initial cracking for restrained plastic shrinkage and effectively controls crack development at the early age of composite. The presence of sisal and coconut fibers promotes an effective self-healing of plastic cracking after 40 days at 100% relative humidity. The drying shrinkage is increased by up to 27% when up to 3% volume fraction of sisal or coconut fibers is present.

Fibers incorporation in matrix usually tends to stiffen the matrix, harsh when static but still manage to be vibrated. The stiffening effect will eventually disappear under vibration respond and with proper FRC design mix may intend to be handled the same way as plain concrete in terms of mobility and ability to flow. In measuring static condition such as slump test, it is seen to be inappropriate to use this method as it can show misleading result as in the fact that concrete can be workable when vibrated. It is suggested that dynamic approach are to be used when conducting workability for fresh FRC. As such, VeBe, flow table and time flow through inverted slump cone are more compatible to measure FRC workability (Bentur, 1990).

Researchers in this particular area usually measure the workability and flowability of the composite. In cement based composite such as concrete, it was reported that the inclusion of oil palm trunk fiber in fresh concrete had significantly changed the flowability behavior. It was found that the workability decrease due to the addition of fiber which resulted in the increase in surface area. The test was conducted using three methods comprises of slump test, compacting factor and Vebe. For slump test, it was found that the slump shows loss of about 73% from 130mm to 30mm (100mm loss) with fiber inclusion at 3%. However, there was no significant slump loss when the fiber content is at 1 to 2%. This result shows that the moisture content of the mixture has decreased which resulted in the fiber stiffened the mixture and stabilized the cohesiveness but apparently reduce the workability. The compacting factor of fresh concrete shows a value of 0.83 with the inclusion of 1% and reduces to 0.7 and 0.65 respectively with the inclusion of 2% and 3%. Neville (1995) suggested that value of 0.85 and lower has a low workability. Result from VB test shows with 3% and 2% fiber inclusion in concrete; it has higher time to spread compared to that with 1% and without fiber. According to Naik, (2004) concrete with 3% and 2 % fiber has good workability with references to ASTM C995, which recommended that the time of flow of fiber reinforced concrete is 8-15 sec.

Incorporation of cellulose pulp in cement matrix exhibits a low workability and increase the void content of the composites. The volume fraction of 10% and higher has discouraged mixing ability where it found that the fibers tend to cluster together resulting in inhomogeneity of the board and reduction in strength. Additional of water ratio was required to avoid fiber lump and for most cases an optimal ratio of water to solids should be 10:1 or 20:1 (Z.Fordos, 1988). This is also been reported by ACI Committee 544, (2002) which explained the reduction of workability due to the increased surface area and water absorption of the fiber.

3.3. The Properties of Hardened Natural Fiber Reinforced Cement-Based Composite.

According to Z. Fordos (1988), for natural fiber, reinforced composite, low fiber contents (<3% by mass) gives almost the same strain capacity as unreinforced cement pastes or mortars in its dry state , during matrix cracks. At higher fiber contents (>3% by weight), the strain capacity and bending strength of the composites shows increase strength in the dry or semi-wet state. Fibers inclusion in the matrix can act as crack arrester and can absorb a significant amount of energy if the considerable proportion of the fibers is pulled out from the matrix in its semi or wet state. The ultimate strength of the composite is much dependable on the fiber type, length and volume fraction of fibers and fiber distribution and also the matrix properties. Other factors that remain important are the type of pulp and also pulp process.

The efficiency stress transfer of fiber reinforcement in composite depends on several important aspects in hardened natural fiber composite. It depends on the relative fiber-matrix stiffness, fiber-matrix interfacial bond and strain compatibility. Higher elastic modulus of fiber compare to the matrix will result in the effectiveness of fiber in restraining pre-cracking of the composite. It is quite impossible to achieve due to its minimum modular ratio (ϵfiber/ϵmatrix). Due to low modulus and high elongation characteristics, strength improvement is less important to be achieved but it is capable of absorbing large strain energy and explosion as compared to other high modulus rigid fibers. (S.S. Rehsi, 1988 cited Krishnamoorthy, S. and Ramaswamy, H.S. 1982).

The strength of the interfacial bond between the matrix and the fiber determines the effectiveness of stress transfer from the matrix to the fibers when the matrix tends to crack. A strong bond is essential for the improved tensile strength of the composite. It is a common observation that, at the point of failure in a fiber reinforced concrete, fibers invariably are pulled out but do not fail in tension. This result shows that it is the interfacial bond strength that is the limiting factor rather than the high tensile strength of the fiber. In post cracking stage, natural fibers with relatively low tensile strength perform equally well provided that the interfacial bond is adequate.

Udoeyo, F. F. &Adetifa, A. (2012) reported an investigation towards the flexural and toughness characteristic of Kenaf fiber-reinforced mortar composites. The dimension of the mortar sheet was 650mm x 450mm x 8mm. The content of fiber inclusion are from 0.5%, 1.0% and 1.5% with four length ranges of 20mm, 30mm, 40mm and 50mm were considered in the experimental program. The mixing method applies the following procedure; by mixing the sand and cement thoroughly until homogeneity then the required amount of fiber are mixed until reaches uniformity. The water are added later until it achieved a workable paste condition. In this investigation, the characteristic of kenaf fiber in the cement mortar composites on bending capacity shows decreased strength result with fiber volume increment. However, it also shows that with higher fiber content the flexural toughness and impact resistance significantly improved. The result shows that at fiber volume of 0.5% and 20mm fiber length gives the maximum bending capacity.

4.0 Polymer Modifiers in Concrete and Mortar

Polymer modified concrete (PMC)/mortar (PMM) using latex has been in use since the 1950s. PMC is a Portland cement concretes with polymer modifier such as acrylic or styrene-butadiene latex (SBR), polyvinyl acetate and ethylene vinyl acetate (Fowler, 1999).

Japan has been in developing polymer modified mortar for almost 50 years and has contributed to vast multifunction and sustainable, popular construction materials application as compared to conventional cement mortar and concrete. The polymer modified mortar and concrete use polymeric admixtures. In 1960's this material has played major parts in Japan construction industry. Polymer modified mortar being applied as repair and finish works and polymer modified concrete established on limited application only (Bhutta&Ohama, 2010).

In polymer modified cement mortar, the inclusion of polymer into cement system was found to develop a unique interpenetrating network structure between the cement paste and aggregate. The process is governed by the hydration of cement and the formation of the polymer film in the binder. The long-term durability of polymer modified cement concrete/mortar (PMM) has been significantly effects by several factors. It depends on the degree of the microstructural integration of the polymer phase and the cement binder. Styrene-butadiene rubber (SBR) is among the common polymer used as PMM in the form of latex.

A work on PCC microstructure adopting water soluble polymer conducted by Knapen& Van Gemert (2009) was reviewed. The result demonstrated that polymer tend to retard the flocculation of cement particles and minimize the formation of a water-rich layer on the aggregate surfaces. It found that the unhydrated cement particles are distributed uniformly in the matrix without noticeable depletion near the aggregate surface and, as a result, reduced the ITZ that establish more cohesive microstructure and reduction of microcracks.

According to Ohama et al. (1991), total pore volume tends to decrease with an increase in polymer/cement ratio and the decrease in water/cement ratio. Furthermore, SBR latex has the ability of bonding agents and may enhance the interfacial bonding between the fiber and cement matrix. Incorporating SBR latex may also reduce and even replace the need of superplasticiser (SP) for the flowability of the paste. The inclusion of SBR latex can increase the workability of fresh mortar as effectively done by adding superplasticizer into the cement paste. However, with fiber inclusion into the matrix and with the respect to gain high-performance mortar the requirement of water has to be practically less but at the same time possessed good workability. Therefore, to achieve high-performance mortar, the water content is vital and must be optimum at lower content. With the addition of SBR, it is, therefore, can reduce or replace the SP but still achieve good workability and high strength.

The polymer can also enhance the workability of the paste due to fiber inclusion because of the ball bearing effects from the polymer molecules. It is also observed that high water content is potential for greater volumetric shrinkage than a stiffer mixture with low water content. Therefore, polymer content such as SBR may eliminate the need to add extra water while mixing to have an adequate plastic form of a paste (Pelisser et al., 2010).

4.1 Natural Fibrous system in Polymer Modified Cement Binder.

The characteristic of the matrix plays an important role of adhesion between the fiber and matrix due to the development of the interfacial transition zone (ITZ) between both surfaces. These adhesions of fiber to the matrix are highly dependent on the density between the fibers and cement matrix gaps. Therefore, the interfacial transition zone contributes to porosity, cracks development and also the content of calcium hydroxide crystal which affects the bond between the fiber and matrix. Several authors had also concluded that 200µm thickness of ITZ at 180 days. (Savastano et al, 2005).

As for fiber composite such as cement composite, a stronger interface does not necessarily produce stronger composite and may result into brittle and flaw-sensitive composite material. The effect of the transition zone in fiber composite was discussed by several researchers in the relation of the fiber to matrix bonding. As vegetable fibers are a concern, it is prone to absorb as high as 80% of water that inhibits the narrow region between the fiber and matrix. This reaction cause’s high porosity in this transition zone with thickness varies from 50 and 100µm. Alternatively, in cement composite, low porosity and portlandite (calcium hydroxide crystal) concentration in transition zone will positively improve the fiber-matrix bonding. Thus increase the elastic tensile strength and could also reduce ductility (Savastano&Agopyan, 1999). Therefore, the integration of polymer modifiers in cement could enhance a unique bonding of fiber and the matrix.

Investigation on the crack behavior characteristic such as linear elastic fracture mechanics and elastic-plastic fracture mechanics are often incorrectly assumed particularly in particle filled polymer composites, cement concrete and mortar with the inclusion of synthetic fibers as the reinforcement. On the other hand, natural fiber gives some interesting value concerning of its mechanical properties. Therefore improvement of the mechanical behavior of polymer concrete led to the study of chopped coconut, sugar cane bagasse and banana fibers as reinforcement in the matrix. This investigation feature fracture toughness and fracture energy by using the two parameter fracture model (TPFM). These models proposed the critical stress intensity factor, KIc, and the critical crack tip opening displacement CTODC by performing three points bending test. Fracture toughness, fracture energy absorbed and flexural strength were determined in comparison to unreinforced polymer concrete. Chopped Coconut fiber and sugarcane bagasse fiber increase the fracture toughness at 15.7% with coconut reinforcement and 17.8% increment for sugar cane bagasse reinforcement. The fracture energy of 100.8% increment is obtained when coconut fiber is used as reinforcement. A 15.9% and 41.1% increment is observed for sugar cane bagasse and banana pseudostem fiber, with respect to unreinforced polymer concrete. The result also successfully established that coconut fiber reinforcement display an increment flexural properties in polymer concrete when compared to glass and carbon fiber from their previous investigation (Reis, 2006).

Ghazali et al., (2008) conducted a research using electron beam irradiation doses to study the interaction of the microstructure chains of blended cement with polymer emulsion SBR latex. In the research, polymer emulsion acts as the binder of the cement paste with the sugar cane bagasse fiber. The composite samples were hot pressed and tested for the mechanical strength and fracture surface morphology. Samples that exhibit the highest tensile strength result were selected to be irradiated in air at ambient temperature. The results show that SBR latex at 6% exhibit the highest tensile strength and with exposure to the irradiation at 30kGy also increase the strength value. Both parameters of SBR latex and irradiation doses resulted in increments of mechanical strength but decreased when higher percentages of SBR latex and irradiation doses were incorporated.

The observation concluded that the water loss through evaporation and absorption of polymer latex in a substance resulting the suspended resin or polymer particles to crowd together. It is due to the higher magnitude of capillary forces that significantly overcome the forces of repulsive forces of the water- air interfaces between the polymer particles. These create an increase in the concentration of the material soluble in the water phase.

5.0 Conclusion

From the literature review, natural fibers as reinforcement in Polymer Modified Mortar, in general, have the potential of other Natural Fiber Reinforced Composites. There is great potential in using these materials since polymer modified mortar/concrete has unique properties of durability and ability to close the gap of the disadvantages of natural fiber in the OPC environment. In the context of Malaysia, the information and technical aspects of the potential of Natural Fiber in Polymer Modified Mortar/Concrete are still lacks and therefore progressive effort need to be taken as part of the green material approach.

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