Turning Natural Fiber Reinforced Cement Composite as Innovative Alternative Sustainable Construction Material: A Review Paper

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Abstract— *In recent years, a great deal of interest in concrete leads to the most frequently used sustainable construction material. Using of natural fiber as fiber reinforcement effectively improved strength, ductility and durability requirements of high performance cement composites. Regretly, natural fibers are dumped as agricultural waste (e.g. coconut, bamboo, wood or chips, bast fiber, leaf fiber, seed and fruit fibers, etc), so can be easily available low cost. The applications of natural fiber for sustainable construction material design can be done as filler or masonry composites, reinforcement, thermal conductivity, cementations/binder, etc. Previous and current researchers focusing the natural fiber to improve the properties of lightweight composites still required a lot of investigations to make it improved. However, the present work consists of the availability of natural fiber waste substance, sustainable construction materials are evaluated for their physico-mechanical properties of sustainable construction materials, method of production and environmental impact of several materials. No doubt, the application of natural fiber provides a solution to conservation of natural resource and energy.*

Keywords— Natural fiber, construction material, reinforcement, thermal conductivity, cement composites.

I. INTRODUCTION

Nowadays, construction sector is focusing in developing sustainable, green and eco-friendly building materials. Construction materials including bricks, wood, cement, aggregate, steel, aluminum, cladding and partitioning material are increasing in demand due to rapid growth of construction activities for housing and other building. The current world economic circumstances are unstable because of the world exchange currencies are getting very competitive and the cost of building materials also soared. This situations led to several ongoing construction projects are having trouble in getting the materials at lower cost. Therefore, there are needs to search an alternative material in order to fulfill the constructions demand while maintaining the cost at minimum level and having sustainable material.

Concrete being one the important material in building construction is produced from the mixtures of cement and aggregates. There are several innovations in building construction, especially in concrete technology and material which involves new construction techniques and utilization of waste materials for cement and aggregate replacement. In recent years, some researcher carried out the past used wood ash waste as a replacement for cement in concrete or mortar mixtures it showing the great improvement in mechanical properties [1]. Turgut [2] shows the feasibility of producing artificial limestone brick with wood sawdust. Bouguerra et al. [3] including wood chipping size 3-8 mm in cement and clay matrix and tested the composite material is a good thermal and insulation properties. Coatanlem et al. [4] described the physio-chemical properties of wood chipping proposed highly water absorption on sawdust. Sulieman et al [5] found the paper fiber has good ability to diffuse noise in paper fiber reinforced foam concrete as wall paneling system.

In considering the renewable and sustainable nature, natural fiber is growingly being used in composite material especially in building construction. Natural fiber generally offers low production cost, friendly processing low tool wear and less skin irritation, and good thermal and acoustic insulation properties [6]. Natural fiber also enhances mechanical and reinforcement for composites includes straw for bricks, mud and poles, plaster and reeds [7]. There are six types of natural fibers. They classified as follows: bast fibers (jute, flax, hemp, ramie and *kenaf*), leaf fibers (abaca, sisal and pineapple), seed fibers (coir, cotton and *kapok*), core fibers (*kenaf*, hemp and jute), grass and reed fibers (wheat, corn and rice) and other types (wood and roots) have been used in cement-sand based products [6]. The addition of natural fiber also reduces the thermal conductivity of the composite specimens and yielded a lightweight product [8, 9]. Thermal conductivity range within 0.15 to 0.82 W/m^{o}C for 3-5% moisture content [10].

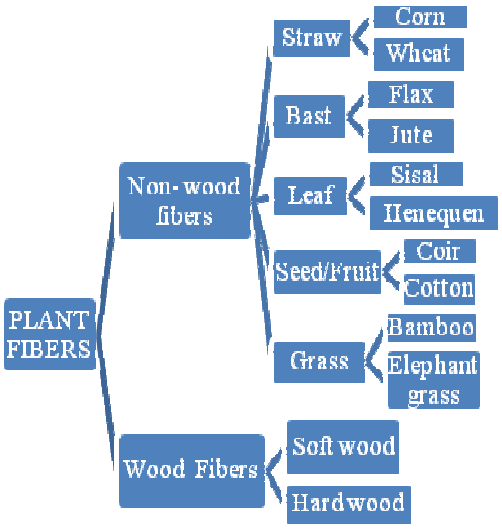

Fig.1. Classification of plant fiber (Biagiotti et al., 2004)

Previous research indicated that natural fiber has limited by its low compressive strength and need to understand their limitations before use it. The advantages of natural fiber are offers considerable reduction in weight of structure, thereby reducing the dead loads transmitted to the foundation, high economy when compared to and normal weight concrete, reduce damage and prolonged life of formwork due to lower pressure being exerted, easier handling, mixing and placing as compared with other types of concrete, improved sound absorbent properties due to its high void ratio, improved thermal insulation because the incorporation of wood aggregates in concrete decreases its thermal properties.

The current paper reviews the possible application of natural fiber for sustainable construction material design such as filler or masonry composites, reinforcement, thermal conductivity, cementations/binder, etc. Based on the availability of natural fiber waste substance, sustainable construction materials are evaluated for their physico-mechanical properties of sustainable construction materials, method of production and environmental impact of several materials. The application of natural fiber provides a solution to conservation of natural resource and energy.

II. Development of Construction Material from Natural Fiber

Natural fiber reinforced cement composites has gained increasing interest of researchers and manufacturers in improve construction materials. The increased interest in natural fiber reinforced cement composites is due to high performance in mechanical properties, chemical resistance, low cost and low density. Using of fibers from renewable resources, such as reinforcing fibers, to provide positive environmental benefits with respect to ultimate disposal utilization. In recent studies indicate that plant-based natural fibers can be used as filler or reinforcement, thermal conductivity and binder in cement composites, replacing the expensive and non-renewable steel reinforcement, because of potential for recyclability.

2.1 Pre-treatment

There are many method have proved successful in pre-treatment of natural was mainly to facilitate adequate removal of all trace of inhibitory chemical substance which may delay the setting of the cement. For example, washed and clean [11-13], sodium hydroxide [14-15]. The natural fiber need to treatment to reduce water absorption of particles and increase compressive strength. Sawdust can be used as alternative substitute for fine aggregate in concrete production. Before used it, sawdust should be washed and cleaned before use as concrete constituent because of large amount of bark, which can affect setting and hydration of cement [12,16]. While, Usman et al. [12] suggested sawdust treated by boiling for 5 hours and rinsed with water and sun dried. According to Vijay et al 2013;Obasi et al., 2014 [13, 15] reported wet extraction method that used hot water. The palm oil fiber thoroughly washed with distilled water to removes impurities and sun drying for 5 days. The dry fiber was the treated with 5% solution of NaOH for 2 hrs to avoid fibers damage. The fiber later washed with distilled water to removed excess of NaOH and dried at 80^{o}C for 12 hrs.

Alkaline treatment of fiber aimed to improving the adhesion between the fiber surface and the cement matrix may not only modify the fiber surface but also increase fiber strength [17]. Alkaline removes a certain amount of lignin, wax and oils covering the external surface of fiber cell wall, amorphous cellulose content at the expense of crystalline cellulose. These researchers observed that alkaline treatment has two effects on the fiber. First, it increases surface roughness resulting in the better mechanical interlocking. Second, it increases the amount of cellulose exposed on then fiber surface, thus increasing the number of possible reaction sites. Several researcher [14-16] reported that using 5% NaOH treated sawdust composites had better tensile strength than 10% NaOH treated composites. The tensile strength of the composite decreased drastically after certain optimum NaOH concentration. They observed that the chemically extracted fibers have higher tensile strength than the raw fibers but the different between those values was very less. Alkaline treatment also significantly improved the mechanical, impact fatigue and dynamic mechanical behavior of fiber-reinforced composites.

2.2 Filler (masonry composites)

Filler or inclusions are used as particles or grains of various shapes and dimensions [18]. Using of natural fiber as a filler to improve the mechanical properties by hard particles in sufficient volume fraction, to control

crack propagation or small particles, to control the movements of dislocations. Natural fiber easily cheap and porous filler are using to decrease the material cost or to improve the thermal insulation properties. The filler is made of super hard particles, crushed stone, sand, void filled with air or specially produced gas, etc. [18]. Sawdust is one of natural fiber that used as filler. Sawdust is collected of fine particle of hard and soft woods. This material is produced from cutting of wood with saw. In United State, sawdust has been used as an aggregate for more than 50 years for floor, wall and roof units, but not widely.

Several past studies [19-22] were reported that the use of sawdust as a partial sand replacement material in concrete at all levels of sand replacement ranged between 5% and 30% reduces compressive strength of mortar mix produced relative to neat conventional cement brick for all curing aging. Adebakin et al. [19] they have studied about partial replacement of sand in concrete blocks by use of sawdust waste materials. The fine particle of sawdust passed through 4.76 mm test sieve British Standard. They produced hollow blocks used mix ratio 1:8 (cement: sand) at different replacement level of sand and sawdust (100:0, 90:10, 80:20, 70:30, 60:40). The water/cement ratio used 0.5, 0.54, 0.55, 0.56 and 0.57. They have found that the replacement of sand should not more than 10% to achieve the best result use of sawdust in block production. If attempt made by using the 50 % replacement of sand was not successful because there are weak bonding. They prove that the present of tannin in sawdust acts as retarded and adversely affecting the blocks.

Boob [20] investigated the performance of sawdust in cement sand-crete blocks using 1:6 cement and sand mix with 15% sawdust replacement gives strength of 4.5N/mm^2 which is reasonable and economical to be used for partition walls in frame structure multi-storey building. Turgut and Algin [21] used a combination of cotton wastes (CWs) - limestone powder wastes (LPWs) and combinations wood sawdust waste (WSWs) and limestone powder wastes (LPWs) for producing low cost and lightweight composite as a building material. They found compressive strength, flexural strength, ultrasonic pulse velocity (UPV), unit weight and water absorption values are satisfied according to International Standard (IS). The results, found that lighter weight composite having potential to be used for walls, wooden board substitute, an alternative to concrete block, ceiling panels, sound barrier panels and others. Paramaswam et al. [22] in their study of sawdust concrete obtained some encouraging results. Compressive strength values of up to 31 N/mm^2 at 28 days were obtained in a mix proportion of 1:1 that is one part by volume of cement to one part by volume of sawdust. When the mix proportion was changed to 1:2, the 28 days compressive strength reduced to 8.5 N/mm^2 and a mix ratio of 1:3 (cement/sawdust) by volume reduced the 28 day strength value further to only 5 N/mm^2. Ravindrarajah et al. [23] conducted experiments on concrete mixes containing sawdust as an air-entraining admixture in order to develop sawdust concrete for sand-crete block making. Volume proportion was used to determine the quantity of individual components in the experimental mix. They observed from the results obtained that sawdust concrete for sand-crete block making, with a sawdust content of 3% by volume and a wet density of 1920 kg/m^3 produced best results for compressive strength.

2.3 Reinforcement

As reported by coconut fiber has also tested filler or reinforcement in different composite materials [24]. Coir has potential to be used as reinforcement in concrete and its cheap and durable non structural element [25], reduced thermal conductivity of block specimen. The additions of coir also yield a lightweight product and it would resolve the environment and energy concern. Domke, [26] investigated the use of natural and agricultural waste products as coir and rice husk ash (RHA) to improve the properties of concrete. The study found that coir and RHA not only develop the properties of concrete but it also can reduce the agricultural waste and lead to proper disposal of these wastes and solve the environment problems. Ramli et al [27] investigated the mechanical properties of coir as a concrete admixture. The percentage amounts of fiber used 0.6% and 1.8% and length of coir were cut around 30 mm to 60 mm. The experimental results showed the compressive strength of concrete decreased as the percentages of total fiber in concrete mix increased. Concrete mix with fiber is less strength than normal concrete, but its strength still reasonable.

Abdullah et al. [38] reported fracture behavior of composite cement reinforced with coir can be used as reinforcement and substitute of sand. Increasing content of fiber will increase modulus rupture and compressive strength. The best results are using 9% of coir. The fracture behavior of high strength composite consists of crack bridging and fiber responsible to resist the crack propagation and improve strength of composite. Gampathi [29] research was focused on increase shear strength of cement hollow blocks using coir as reinforcement without change the compressive strength. The percentage of coir using are 1%, 2% and 3% by cement weight, the result percentage enhancements of shear strength are 31%, 38% and 41%. It can conclude that 2% of coir is suitable to increase shear strength of hollow blocks for building earthquake resistive wall.

According to Ramakrishna and Sundararajan [30] studied the variation in chemical composition and tensile strength of coir, sisal jute and hibiscus fibers, when they are subjected to alternative wetting and drying and continuous immersion for 60 days in three different medium of water, saturated lime and sodium hydroxide respectively. From the results it was observed that there a substantial reduction in salient chemical composition of all four fibers, after exposure in the various mediums. Coir fiber found to retain higher percentages of their initial strength than all other fibers, after the specified period of exposure in the various mediums. The compressive and flexural strengths of all natural fiber reinforced mortar specimens using corroded fibers less than strength of reference mortar and fiber reinforced mortar specimen reinforced with dry natural fibers.

2.4 Thermal conductivity

Natural fiber is an enormous advantage of insulation; it is not only a low value of thermal conductivity but also the natural characteristic of fibers. For example, compared with synthetic fiber (e.g. carbon fiber, glass fiber and aramid), the insulation based on natural fiber has comparable and better thermal technical characteristics such as heat capacity or afore-mentioned thermal conductivity of synthetic fiber. However, in construction sector is still dominated by synthetic insulation materials then natural fiber based caused some negative characteristics such as it is a high wettability, absorbability, against biological attack (e.g. against fungi and parasites) and flammability.

Natural fiber can be modified by chemical treatment of fibers to against the weakness. Generally, natural fibers have been used by several researchers in order to improve thermal insulation, mechanical and physical properties of composite materials. For the thermal insulation composites, Khedari et al. [31] developed a new low cost board from durian peel and coconut coir mixture with a lower thermal conductivity, which was effective for energy saving when used as ceiling and wall insulation material. Xu et al. [32] presented a low density binder less composite from *kenaf* core, with thermal conductivity similar to those of insulation material (e.g. rock wool). The result revealed that the reinforcement fibers have greater effect on the thermal conductivity. Serri et al [33] found that the oil palm shell (OPS) are low conductivity, specific heat and thermal diffusivity of 0.59 W/mK, 1.352 MJ/m^3K and 0.4414 mm^2/s, respectively. As per RILEM classification, OPS mix consider as semi structure insulation which is thermal conductivity lower than 0.75 W/mK.

Thermal properties of cement composite reinforced with vegetable bagasse fiber was examined by Onesippe et al. [34] whose experimental investigations disclosed that addition of bagasse fibers decreased the thermal conductivity of composites and yields a weaker specific heat. Korjenic et al [35] carried out a research to develop a new insulating material from renewable resources (jute, flax and hemp) with comparable building physic-mechanical properties to commonly used insulation materials. There several possible materials such as bagasse, rice husk, coconut coir, corn stalk, durian peel and palm oil leaves are evaluated on the basic of physio-mechanical properties. Among studied natural fiber materials bagasse, rice husk and coconut coir have been observed to have lower conductivity.

2.5 Cementitious/binder

Sawdust ash (SDA) is generated as a by-product of combustion in wood fired power plants, paper mills and wood burning factories. Since wood is a potential source of energy and environmentally begin friendly material, there will be increased usage of wood in energy production in the future [36]. As a result the quantity of ash generated will also increased and raising the issues of disposal. Incorporation of wood ash as a partial replacement of cement material in blended cement and concrete will beneficial from both environment and economic point of views. This will give a solution to the waste management problem while minimizing the consumption of energy intensive hydraulic cement. Current wood ash frequently used as a soil supplement to improve the alkalinity of soil for agriculture applications and also as the filler material in the construction of flexible pavements for roads and highways. Several studies have analyzed the suitability of wood ash as a partial cement replacement material in the production of structural grade concrete and self compacting concrete for applications in building construction. Wood fly ash consists of particles which are highly irregular in shape with a highly porous surface. Physical, chemical and micro-structural properties of wood ash could significantly affect the pozzolanic and hydraulic reactivity. Therefore the properties of wood ash obtained from different sources should be characterized before being incorporated as cement replacement in production of concrete. A study was evaluated the physical properties of wood ashes from five different sources which included that wood ash samples have varying values of unit weight that range from 162 kg/m^3 [37]. The specific gravity of wood ash ranged between 2.26 and 2.60. Low unit weight and specific gravity of wood ashes indicate the possibility of the reduction in the unit weight of concrete material by the partial substitution of cement with wood ash [38].

Ling and Teo [39] developed bricks from agro-waste rice husk ash and Expanded Polystyrene (EPS) beads. RHA was used as fractional substitute cement replacement while EPS was used as partial aggregate replacement in

amalgamations. They found that the properties of the bricks were largely subjected to the content of EPS and RHA in the blend and also the curing condition used. Jaturapitakkul et al [47] stated the expansion and loss in compressive strength were reduced when the palm oil fuel ash (POFA) fineness was increased. The results suggested that ground POFA could be used as a pozzolanic material and could also improve the sulphate resistance of concrete.

Amin [41] studied sugarcane bagasse ash as a cement replacement in concrete. The results indicated that bagasse ash is an efficient and valuable mineral admixture and pozzolana when used with the original ratio of 20% cement, cut down the chloride diffusion by more than 50% with no undesirable effects on rest of the properties of the hardened concrete. Ganesan et al [42] in their study investigated the effects of bagasse ash content as partial replacement of cement on physical and mechanical properties of hardened concrete. The properties included compressive strength, splitting tensile strength, water absorption, permeability characteristic, chloride diffusion and resistance to chloride ion penetration. The results indicate that bagasse ash is an effective mineral admixture with 20% as optimal replacement ratio of cement. Several researchers had utilized various agro-waste by-products as pozzolanic or cementitious/binder materials in various classifications of concrete, to evaluated physic-mechanical properties like compressive strength and water absorption.

III. DISCUSSION

Observation from the review that researchers have used various natural fibers as materials in different proportions and also adopted various methodologies to produce different building materials and composites. For example particle board, thermal insulation wall and panels, bricks, cementitious or binder and pozzolana for concrete. There are many pre-treatment methods enhance strength and reduce water absorption of particles natural fiber. Alkaline treatment use to improve the adhesion between fiber surface and cement matrix and increase the fiber strength.

Natural fibers are suitable used as filler or reinforcement to improve the thermo-mechanical properties. There several thermo-mechanical tests were conducted on different materials and composites as various available standards. Common test parameters calculated by the various researcher for the brick or masonry is water absorption and compressive strength. Minimum range recommended for characteristic compressive strength for non load bearing and load bearing cement brick are 3-5 Mpa and 5-10 Mpa respectively. It observed that all the brick incorporating natural fiber satisfy the criteria of compressive strength where the water absorption value slightly exceeds the requirement of British Standard and needs the further investigations.

Several studies have analyzed the suitability of wood ash as a partial cement replacement material in the production of structural grade concrete and self compacting concrete for applications in building construction. Wood ash by-product of quality confirming by British Standard can be used as pozzolana in the manufacturing of concrete provided that there are satisfactory data on their suitability such as performance test on concrete containing ash. The performance test conducted on concretes containing various proportions of different natural fiber indicated that the characteristic compressive strength of concrete.

The overall performance and durability of the concrete is enhanced with the addition of natural fiber. The purpose of fiber reinforcement is to improve the properties of a building material but the weakness to use the natural fibers is the durability of these fibers in a cementitious matrix. The consumption of building components made of fiber reinforcement cement is increasing rapidly specially in development countries because with this type of material it is possible to produce lightweight building components, with good mechanical performance, suitable thermal-acoustic insulation and its economical feasibility. In reducing cost of construction, replacement of steel with suitable materials as reinforcement required further investigation. Coir - ones of natural fiber is cheap, ready in-availability and strong in tension and compression. Previous researcher found that using 2% of coir is suitable to increase shear strength of hollow blocks for building earthquake resistive wall [29].

IV. FURTHER WORK

The reviewed literatures mostly showed on the application of natural fiber for innovative construction materials. The reviewed physical and mechanical properties of these innovative materials indicate various characteristic of natural fiber. Several researcher reviews also stated about water absorption. Water absorption is a serious concern and needs further investigations. The combination of sawdust and coconut fiber as construction materials are not fully investigated yet. Further research need to done to carried out the potential combination of sawdust and coir as thermal insulation in construction material. Pre-treatment of natural fiber can enhance the strength of concrete block and reduce water absorption of natural fiber to develop innovative construction materials especially interlocking mortar less block.

V. CONCLUSION

Natural fibers are considered potential as a filler and

reinforcement in cement composites. Natural fiber such as sawdust and coir are reported as most ductile and as thermal insulator material. It is concluded that the natural fiber have potential to be used in composites for any different purpose. Various aspects of fiber reinforced composites have already been investigated and achieved the best result reported by previous researchers. Natural fiber when used as an aggregate in cement composite production can contribute in making the material and as a result: the structure enhancing the environment in a friendly manner. Buildup of unmanaged industrial or agricultural solid waste particularly in developing countries has resulted in a greater percentage than before the environment apprehension. Recycling or such wastes as a sustainable construction material comes into view as a feasible solution not only to solve pollution crisis but also as cost-effective solution for designing of green buildings concept.

Research based study on the use of natural fiber reinforcement cement composites production, is reasonably consider new. Hopefully, more research on long term toughness and durability of this sort of concrete can be materialized and would provide more self-assurance and confidence to the construction industry particularly in Malaysia as well as for global impact purpose.

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