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Coir fibres as a partial substitute material for gypsum-based and fibre-cement-based ceiling tiles: a review

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Abstract— The construction sector is one of the largest exploiters of non-renewable resources which also can be a major obstacle to achieve a sustainable environment. Eco-friendly, renewable, large quantities of coir fibre left over from coconut processing are disposed in vain. Since coir fibres are used as reinforcement in concrete, many researchers have attempted to make ceiling tiles using coir fibres to improve the desired properties of the ceiling. This review presents the potential applicability of coir fibers for gypsum-based ceiling tiles and fiber-cement-based ceilings used in almost every type of building. The reviewed data were organized into three sections. Under the first section, it was able to ascertain low thermal conductivity, acoustic insulation, moisture resistivity, high strength, and combustibility, are the main intrinsic properties of coir fibres. In addition, the mechanical and physical properties of coir fibers are summarized in this section. Under the second section, the properties of gypsum and fibre-cement ceiling tiles mixed with various proportions of coir fibre were compared. Coir fibers should be mixed with gypsum at a rate of 30% of the total weight of the mixture, and when mixed with cementitious materials, the rate should be 4% to 10% of the total weight of the mixture to obtain the desired results. Moreover, the most effective length of coir fibre lays between 2.5 cm to 5 cm. The available data has proved that, coir fibres can be used as a potential material to improve internal properties of gypsum and fibre-cement ceiling tiles. Further, the chemical treatments, required for enhancing the weak properties of coir fibres like; Alkali treatment, adding dispersant and defoaming agents, chemical coupling methods, etc. were discussed in the third section.

Index Terms— ceiling tiles, coir fibres, fibre-cement, gypsum

1 INTRODUCTION

The construction and building sectors play a significant role in generating GHG emissions from the sources of materials through the construction, usage, and disposal [1]. At the same time, the construction sector is considered as the largest exploiter of non-renewable resources. Therefore, as a solution for both the cases, most of the local and global communities and organizations are taking steps towards in introducing and promoting eco-friendly construction materials to establish sustainability in the construction industry. Most of the tropical countries in Asia, especially Thailand, Philippine and Malaysia, discharge large amounts of agricultural wastes which leads to social and environmental problems [2]. These waste contains seed-hair fiber obtained from the outer shell (endocarp) or husk of the coconut [3] which is called as coir fibres. Coir fibers from tropical nations plays a role in achieving a sustainable future based on renewable resources [4]. Sri Lanka and India are claiming about 90% of global coir fiber productions. However, this renewable resource is not properly utilized even in those countries since local coir mills in those countries process just a small portion of the available husks, which accumulate as a waste throughout the year as a result of coconut processing. Coir fibre is obtained by de-husking coconut and separating it from the pithy material of the fibrous mesocarp by a process of retting [5]. The de-husking of coconut can be performed using a variety of methods, including retting, which is a traditional method, using bacteria and fungi, mechanical and chemical processes [6]. Satyanarayana et al., 1981 [5] has further elaborated that, retting process can either be carried out by soaking the husks in freshwater or saline water, flowing water or stagnant water, deep waters or back waters and has revealed that, husks retted in saline water are stronger and have a better colour. Coir fibres are available in two types; brown fibres and white fibres [7]. Brown coir fibres (**Error! Reference source not found.**) are extracted from matured coconuts which contain more lignin and less cellulose and are stronger but less flexible. White fibres (**Error! Reference source not found.**) are extracted from immature coconuts which are smoother and finer, but also weaker [8]. Among these two types, brown coir fibres are recommended to use for construction purposes due to its massive advantages and qualities [4].

Fig. 1: Brown coir fibre

Fig. 2: White color coir fibers

Fibrous materials are used as reinforcements in concrete as it adds strength and stability to the structure. Coir fibres are able to resist the post-cracking of concrete structure and increase the strength [1]. Since coir fibres have been using as reinforcement in concrete, most of the researchers have striven on, using coir fibres to form ceiling tiles in order to enhance required properties of a ceiling, such as thermal and acoustic insulation, strength, moisture resistivity, flame-retardant, light-weight, resistant to fungi and rot, and the durability. Guna et al., 2021 [1] has stated that, ceiling tiles are one of the most widely used building materials, especially in industrial and commercial building structures. Most of them such as gypsum boards, calcium silicate tiles, polymer composite based ceiling tiles, mineral fibre ceiling tiles etc. are very expensive in the market while cheaply available ceiling tiles like Asbestos are highly toxic in nature which is even prohibited to use in some countries. Therefore, a natural fibre-based ceiling tile has become one of the most popular materials to manufacture ceiling tiles in the industry. There are plenty of researches which evaluate the qualities and the mechanical and physical properties of coir fibres and how coir fibres can be used as a composite. Gypsum based ceiling tiles are being widely used in commercial and public buildings especially because its appearance and other important mechanical and physical properties. However, properties like being unsusceptible to moisture intrusion, make the occupants discourage to choose it. Hence this review paper will unfold how inherent properties of coir fibres can mitigate such disputes. The current trend of using fibrous materials into ceiling tiles is combined with cementitious materials. Fibre-cement-based ceiling tiles are becoming one of the popular types of ceiling tiles even in residential houses due to its properties as well as the inexpensiveness. This research is focusing on how coir fibres are compatible with cementitious materials to bring about desired properties of a ceiling. This research review comprises main three sections. The first section will elaborate the intrinsic properties including the morphology, physical and mechanical properties of coir fibres. Under the second section, the properties of gypsum and fibre-cement ceiling tiles mixed with various proportions of coir fibre were compared. Both the theories are individually reviewed and a clear image of the results is interpreted. To obtain the hundred percent results, coir fibre composite required additional chemical treatment, such as Alkali treatment, adding dispersant and defoaming agents, chemical coupling methods, etc. The third section gives a broader explanation about such treatments which also will be aided to enhance weak properties of coir fibres.

2 **Intrinsic properties of coir fibres**

2.1 Physical and mechanical properties of coir fibres

It is important to examine the physical state and the mechanical properties of coir fibers in combination with other materials, as the properties of the composite material are determined by the physical and mechanical properties of each material. Table 1 shows summarized and statistically interpreted data of the both physical and mechanical properties of coir fibres taken from the study of Sengupta & Basu, 2016 [9] for the reference before analysing other significant features of coir fibres related to ceiling tiles.

Table 1: Physical and Mechanical Property parameter of coir fibres [9]

Characteristics	Sample size	Minimum	Maximum	Mean	Mode	Coefficient of variation	Skewness	Standard error of Skewness for normal distribution	Kurtosis	Standard error of kurtosis for normal distribution
Length (cm)	102	3.8	26.4	12.9	5.8	50.9	0.221	0.239	-1.328	0.473
Diameter (μm)	102	83.3	550	200	166.6	52.9	0.818	0.233	-0.445	0.463
Linear Density (tex)	102	4.6	140	25.2	Multiple	80.4	0.993	0.23	0.05	0.469
Breaking tenacity (cN/tex)	62	3.85	47.1	11.8	10.3	47.3	1.65	0.3	3.12	0.61
Breaking extension (%)	62	7.7	51.6	28.3	Multiple	37.5	0.19	0.31	-0.66	0.6
Specific work of rupture (mJ/tex-m)	62	7.1	172.4	51.3	Multiple	56.6	0.92	0.31	0.99	0.6
Flexural rigidity (mN-mm2)	33	36.8	2084.3	864.1	1121.4	69.7	0.68	0.42	-0.08	0.82
Specific flexural rigidity (mN-mm2) × 10^4	34	500.3	15343.6	2554.5	Multiple	94.3	2.58	0.4	7.1	0.78

2.2 Chemical composition

Coir fibres are having three main constituents as cellulose, hemicelluloses, and lignin [6]. In addition to that, water particles and ash can comprise. The contents of the constituents are not constant because in different stages of the coconut plant, the percentages of cellulose, hemicelluloses, and lignin may vary [5].

Table 2 Composition of coir fibres (wt.%) [5]

Maturity	Hemicellulose	Lignin	Cellulose	Total water soluble	Hot water soluble	Ash
Very young nuts	0.25	41.02	36.11	15.50	4.00	-
Young nuts	0.15	40.52	32.86	16.00	2.75	-
Matured nuts	0.25	45.84	43.44	5.25	3.00	0.13

The three different main ingredients make different influences on the morphological structure as well as the physical and mechanical behaviour of coir fibres. Hemicellulose is a type of branched polymers, which is made of various polysaccharides [10]. It is connected to the molecular structure by making hydrogen bonds with cellulose fibrils. With comparison to the cellulose, molecular weight of hemicellulose is lower than cellulose and hemicellulose is fully amorphous and branched unlike cellulose. Since hemicellulose has hydroxyl and acetyl groups in its molecular structure, it shows hygroscopic behavior in nature, as part of it dissolves in water [11]. Lignin of coir fibres are made of phenylpropane units and the molecular structure is highly complex [11]. Therefore, it is an amorphous and heterogeneous mixture of condensed aromatic polymers [10] but has the least water absorption of the natural fibre components [12] . The best thing about lignin is, it acts as the cementing agent in fiber, which bind the cellulose fibers together [13]. Cellulose is known as the primary component of all natural fibers [3]. It is a glucose-based linear polymer with crystalline sections [10]. It takes hollow and spiral shape in nature. This shape causes to lower the stiffness of dry fibres, but when the cellulose is surrounded by a polymer metrics it performs better when mix with other components [14]. Despite the natural shape of the cellulose, when coir fibres are boiled or washed, it gets stiffer and tougher [3].

2.3 Thermal conductivity

Most of the researches have proven that, the thermal conductivity of coir fibres is comparably lower and appropriate to use as an ingredient in ceiling tiles. Asasutjarit et al., 2005 [3] has showed that, coir fibres will reduce heat transfer into the building through building façade, which reduce energy consumption of building facilities such as air conditioning and enables good balancing of indoor humidity and temperature inside the building. When critically exploring about the behavior of the thermal conductivity in coir fibres it is required to see how thermal conductivity varies according to different parameters. Guna et al., 2021 [1] have experimentally explored the thermal conductivity of coir fibres as 0.305 W/mK and recommended as a good combination with gypsum. However, Paramasivam et al., 1965 [15] has proved that, the thermal conductivity of coir fibres composite will change according to that amount of coir fibre added. For the volume fractions of coir fibres 2%, 3%, 4%, and 5% the thermal conductivity of coir fibre composites ranges between 0.61 to 0.68 W/m°K. Asasutjarit et al., 2007 [13] has investigated about how the generic properties of coir fibre based ceiling boards vary according to the length of the coir fibres. According to the research, the length of the coir fibres is inversely proportional to the thermal conductivity of the fibre-based board. That means when the length of the coir fibre is higher, the board would be lighter and the thermal conductivity will be lower. Brose et al., 2019 [16] has investigated about using coir fibre panels in order to reduce energy consumption in terms of heat. The researcher has further elaborated that; coir fibre-based boards can act as a cladding to the building because it can even be used to reduce air infiltration into the building. That means coir fibres are indirectly appropriate to lower the energy consumption of a building, as well the house hold bills and maintaining cost of the building.

2.3 Acoustic insulation

One of the most required facilities from a ceiling system is a good insulation for noise entering into the building. There are several researches who have governed about how much coir fibres are effective to resist sound infiltration to the building. Researchers like, Brose et al., 2019 [16], Ali et al., 2012 [7] and

Sampaio & Santos, 2010 [17] has stated that, coir fibre is a good acoustic resistant material and suitable to use as an ingredient for ceiling tiles. According to the research done by Coir Board, 2016 [18] about coir pith, it has explicate that, coir fibre have some amount of sound absorption ability. Because the research have proved that, since coir fibres and pith has large number of voids in it, the part of the acoustic energy passing though it may dissipated. If the volume of the voids are higher, the sound absorption coefficient would also increaeses [19] as shown in the figure 3. Qui & Enhui, 2018 [20] has explain the reason behind it as when the interaction of the edge of voids and the air is accelerated by air vibrations between fibers and hence a powerful viscous force is emmerged in the voids. This force will significantly absorb some amount of sound energy and converted to heat. Following that, heat moves quickly between the pores of the fibers. The findings of Guna et al., 2021 [1] has further proved that, the interaction of sound waves are higher in coir fibres since the out surface is rougher, hence coir fibres have better absorptivity of sound and noises. The article [19] has stated that, when sound hits with surface manufactured with fibre composites, non-vertical, angularly situated fibres will absorb more acoustic energy. Moreover, the article has revealed that, shorter the fibres higher the acoustic absorption. Paramasivam et al., 1965 [15] has proved that, in addition to above mentioned factors, the thickness of coir fibres also has a significant impact on the absorption coefficient of sound. The research has proved that, coir fibres having lower thickness have better acoustic absorptivity. Several researchers have critically evaluated how the frequency of the sound combined with the thickness of coir fibres affects sound insulation property of coir fibres-based productions. According to the research done by Paramasivam et al., 1965 [15] the sound absorption coefficient will increase with the increasing frequency of the incident sound waves. According to Qui & Enhui, 2018 [20] acoustic waves with high frequencies are absorbed by the surface of fibre composites products. Since the extent of energy that can be absorbed by any kinds of surface is limited, more acoustic energy would not transmit into the building or house. In addition to the inherent features the sound absorptivity od coir fibres can be increased even by performing alkali treatment in to coir fibres.

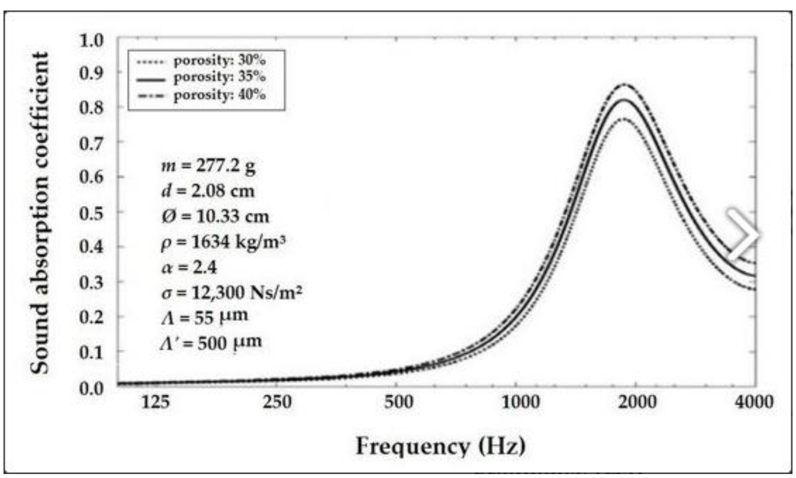

Fig. 3: Effect of porosity on sound absorption coefficient

2.4 Moisture resistivity

A Ceiling should obviously be susceptible for the moisture intrusion since it is indirectly connected with the building envelope. If there are cracks in the roof, during rainy seasons, water can be seeped through those cracks in the roofing sheets and develop multiple defects which cause severe damages in the ceiling system. Therefore, the ceiling panel must be stronger enough to stand against those defects by being resistant to water seepages. Researches like Guna et al., 2021 [1], Ali et al., 2012 [7] and Sampaio & Santos, 2010 [17] have mentioned the moisture resistivity as one of the prominent features of coir fibres. Sengupta & Basu, 2016 [9] has found that, the moisture regains of coir fibres as 11.7% and it is apparently hydrophobic in nature. The hydrophobicity of natural fibres varies according to the content of lignin and the hemi-cellulose. The amount of lignin is directly proportional to the water resistivity while the amount of hemi-cellulose is inversely proportional [21]. “Nat. Fibers, Plast. Compos.,” 2004 [12] has also proved that, the water absorptivity of lignin is very poor. When consider about the content of fibres, lignin are significantly saturated in coir fibres, which means that the water repellence of coir fibres are higher in nature. Even though the water resistivity of coir fibres is generally higher, when combined with other materials, this property may change according to the proportions of the ingredients and the properties of the mixture. Asasutjarit et al., 2005 [3] has evinced that, when coir fibres are mixed with cement, adding high content of fibres gives high moisture retain in the mixture. Because when high content of cement is added to the mixture it makes internal bonds with each other more than with coir fibres. This phenomenon increases the porosity of the mixture by allowing water retaining inside the voids. However, Khedari et al., 2004 [21] has recommended to add more coir fibres when forming ceiling and partition board because the cross linking between fibres reduce the porosity of the composite mixture. The investigation of Asasutjarit et al., 2007 [13], has shown that the length of the coir fibres significantly effect on the moisture absorption. Longer coir fibres cause to reduce the workability during manufacturing and hence it leads to create voids inside the final output. Higher the number of voids more water absorption can be expected. Asasutjarit et al., 2007 [13] has found that, when using with other building materials, coir fibres can be subjected to generic pre-treatments such as washing and boiling, which would increase the water repellence of the composite mixture.

2.5 High strength

Strength is the other property that every manufacturer expects from the building materials. The ceiling panel should definitely be stronger enough to resist the force applied by the walls and in case of that, it is required to analyse the strength of the coir fibres and its behavior when composited with other materials. Many researchers have investigated about the strength of coir fibres. According to different studies, the strength of coir fibres can be varies upon several reasons. Satyanarayana et al., 1981 [5] has said that, the strength of coir fibres may vary from place to place but has not resolved that if it is due to the environment where the plant grows or the place where retting processes taken place. The researcher has further revealed that, the length of the coir fibres also correlated with the strength because when the gauge length of coir fibres is higher, the strength will be decreased. Asasutjarit et al., 2005 [3] has studied about chemical compositions of coir fibres and has found that strength of coir fibres is higher when the content of lignin and cellulose is higher in natural fibres. The researcher has concluded that, when coir fibres are subjected to boiling and washing, the content of lignin and cellulose get increased therefore, the level of the strength can be improved more the natural level. The study conducted by Paramasivam et al., 1965 [15] has shown that, the strength of pre-treated coir fibre are slightly lower than the naturally available coir fibres. However, to regain the loosen strength, treated coir fibres can be washed to remove undesirable substances left from the treatments which cause to reduce the strength.

2.6 Combustibility

When choosing ingredients to form ceiling tiles, it is very important to consider about the combustibility of the contaminants because if a fire occurs inside the building, the ceiling must be able to withstand the fire hence prevent spreading inside the building. Most of the researchers have shown that, coir fibres are highly flammable and easily catch fire. Coir fibres belongs to the class of flammable solids [9]. This is especially because coir fibres are lignocellulosic materials which fire can easily disseminate forthwith. Guna et al., 2021 [1] has experimentally proved that, when coir fibres are mixed with non-combustible material, the ability to resist the fire may be dropped. Using 100% of gypsum for ceiling tile has brought better fire resistant while adding 30% of coir fibres 70% of gypsum was able to make a detectable dripping in the specimen. The study of Akash et al., 2017 [22] says that, increasing the percentage of coir fibre in composites will increase the flammability of the final output.

3. COIR FIBRES AND GYPSUM COMBIANTION

Gypsum which is obtained from crushing or calcining of natural gypsum [2] is frequently used as ceiling tiles in most of the commercial and public buildings. Nowadays gypsum has become one of the most popular ceiling materials even residential buildings. Early hardening, fine finish [2], low thermal conductivity and fire resistivity [1] are the main advantages of gypsum for using as ceiling tiles. But the sensitivity of water, fungal growth, weight, etc, has limited the application of gypsum ceiling tiles and also, reduces the tensile strength. To eliminate such limitations, coir fibres have been investigated by several researches to add with gypsum as reinforcement to form ceiling tiles.

Guna et al., 2021 [1] has examined about the proportions that the coir fibres should be added with pure gypsum. Coir fibres are able to increase the tensile properties of the gypsum-coir composite about 89% but the research has pointed out that, adding coir fibres cannot make any changes on the modulus of pure gypsum boards. However, the research has evidenced that, adding 30% of coir fibres and 70% of gypsum are able to increase the flexural properties in strength and elongation [1].

Ability to absorb water/ moisture in higher amount is the most prominent disadvantage in gypsum products. This may even cause for fungal growth, which have substantial impact on the physical and mechanical properties of moisture-exposed gypsum board samples, with tensile strength and weight dropping by more than 80% in some cases [22] . The nature of hydrophobicity due to the large content of lignin in coir fibres is able to mitigate this phenomenon [21]. Guna et al., 2021 [1] has investigated, coir fibres are able to drop down the water sensitivity of pure gypsum. But the researcher has stated that, coir fibres are not a greater water repellent material when mixing with gypsum. Adding 30% of coir fibres has slightly increased the hydrophilic nature of the composite mixture. *Coconut Fiber Reinforced Wall Panelling System Mohd Hisbany Bin Mohd Hashim Universiti Teknologi Malaysia*, n.d. [2] has also proved that, increasing coconut fiber content has little effect on water absorption. The research has investigated that adding wool with coir fibres to reduce the extent of gypsum is more effective than just adding coir fibres with gypsum. The hydrophobic substances in wool can stimulate the hydrophobic property of coir fibres when mixing with gypsum. When adding wool in to the mixture, it is recommended to add 20% of wool, and 10% of coir fibres with 60% of gypsum.

Since the rough surface of coir fibres provides better sound absorption, it is highly recommended to mix with gypsum to improve the acoustic insulation of ceiling tiles. [1]. The findings of Guna et al., 2021 [1] have further shown that, adding coir fibres more than 30% from the whole mixture is not acceptable since there may not be sufficient amount of gypsum to bind the ingredients, hence it would cause to increase the shear in the ceiling tile.

4. COIR FIBRES AND CEMENT COMBINATION

The researches which have been conducted based on the utilization of coir fibres as reinforcement in concrete have proved that, coir fibres are able to enhance the tensile strength of concrete structures up to acceptable level. This phenomenon is really significant to broad the utilization of coir fibres with cementitious materials for other sort of applications as well.

Fibres and cementitious materials have become widely used composites to form ceiling tiles. The mechanical interlocking between the coir fibres and cement encompass several complex chemical and physical mechanism which ensures the strength in the mixture [13]. There are several investigations on using of coir fibres with cementitious materials in line with the advancements of the utilization of coir fibres as reinforcement. Ahmad et al., 2020 [24] has comprehensively investigated about the behavior of the composite of coir fibres and cement. The research has concluded that, when coir fibres are used with the cementitious materials it is required to add chemical agents such as dispersant, defoamer, or wetting agents since coir fibres and naturally available materials and tends to degraded and halted with time and chemical reactions with cement. However, the investigations have proved that, coir fibres are able to increase the flexural properties of the mixture.

Coir fibres are able to presence as reinforcement in the cement paste and enhance the tensile strength of the mixture. Lignin content of the coir fibres acts as an adhesive and tend to enhance the tensile strength and the bonding strength between particles [21]. Darsana et al., 2016 [8] has found that, the lignin and hemicelluloses content of wetted and dried coir fibres are able to retain 40-60% of their tensile strength. The researcher has recommended the tiles manufactured from coir fibres followed by wetting processes are suitable to use as floor tiles which. That means, subjecting to wetting process cause to decrease the natural tensile strength of coir fibres but, its impact is lower when manufacturing ceiling tiles, because ceiling tiles should be light weight and does not contribute to load bearing tasks. On behalf of enhancing the properties of mixtures, the volume fractions, and lengths of coir fibres directly affects. But increasing the acceptable volume fractions and use of lengthy fibres negatively effect on the mixture by reducing the strength [15]. Ali et al., 2012 [7] has found that, coir fibres with 38mm of length and 4% of volume fraction of the total mixture of the paste are able to increase the tensile strength up to sufficient level. Ali et al., 2012 [7] has examined the behaviour of the coir fibre-cement mixture by adding 1%, 2%, 3% and 5% of coir fibres by cements mass respectively with the fibre lengths of 2.5, 5 and 7.5 cm. The best performance of the tensile properties has been denoted by the mixture with the fibres length of 5 cm and 5% fibre content. Not only the tensile properties, but also the overall excellence could be able to achieve by those parameters.

Flexural properties which ensure the stability of ceiling sheets against the deformation are essential for a ceiling system. Paramasivam et al., 1965 [15] have obtained 22 N/mm^2 of flexural strength of coir fibre-cement paste by adding a volume fraction of 3% and a length of 25 mm of coir fibres. Sampaio & Santos, 2010 [17] has investigated the mechanical properties of coir fibre-cement mixture with two mixing designs. The volume fractions of 0.08, 0.16 and 0.32 % by total weight of cement, sand and water were added to the 1:2.75 and 1:4 of water: cement ratios in two different groups. Two specimens without adding coir fibres also have taken for the reference. The analysis of flexural properties has interpreted that, both design mixtures with coir fibres have shown good improvement in flexural properties than the samples without coir fibres. However, Sampaio & Santos, 2010 [17] also has found that, increasing the volume fraction and the usage of lengthy coir fibres cause to decrease the acquired properties of coir fibre-cement mixture. MOR (modulus of rupture) is another significant flexural property which indicates the strength before rupture. Khedari et al., 2004 [21] has stated that, the MOR is varying proportional to the increase of coir fibres. That means, when increasing the content of coir fibres MOR get increased and for low contents of coir fibres, MOR value would be lower. Khedari et al., 2004 [21] has explained that, it is due to the content of lignin which act as an adhesive in the mixture. Ali et al., 2012 [7] has experience that, coir fibres up to 38 mm fibre length and 4% volume fraction also can enhance the MOR of the coir fibre-cement mixture. Asasutjarit et al., 2007 [13] has found that, boiling and washing of coir fibres can ultimately increase the MOR of the composite mixture more than coir fibres that had not been washed. The research has given enough acceptable reasons; those are when coir fibres are taken for boiling and washing, it causes to increase the lignin and cellulose content which also simultaneously increase the strength.

Usage of lengthy coir fibres decreased the workability and increased the porosity of the mixture [13]. When the porosity is increasing, more water can be absorbed and hence the swelling thickness would also be higher. Asasutjarit et al., 2007 [13] has further revealed that, higher contents of fibres also increase the water absorpvity because, the density in the mixture decreases when adding coir fibres in to the mixture. The most relaible solution is recommended as adding more cement and make the mixture more denser. Higher the density, the porosity would be lower, and therefore water absoptiity get decreased. Eventhough there are no other evindences which ensures coir fibre stimulate water absoptivity when mixed with cementitious materials, the anlysis of Asasutjarit et al., 2007 [13] is acceptable when looking at the behavoir of coir fibres when mixed with pure gypsum.

Brose et al., 2019 [16] has stated that coir fibres bring good thermal comfort in to the building when use as ceiling tiles, as lower conductivity reinforcing cement composites with lignocellulosic materials regulate the thermal resistance inside the building. Studies of Paramasivam et al., 1965 [15] has compared the behaviour of coir fibres with other substances in terms of thermal conductivity and stated that adding coir fibres for cement is not significantly increase the thermal conductivity when compared to the other substances; especially asbestos. The researcher has conducted the experiment taking the volume fractions of coir fibres as 2%, 3%, 4%, and 5% from the whole amount of the mixture with 25mm, 38mm, and 12.5mm lengthy fibres, The thermal conductivity each sample was in between the range of 0.61 to 0.68 W/m°K when the hazardous materials like asbestos also having 0.65 W/m°K.

In addition to that, research analysis of Cook et al.,1978 (cited from [7]) has investigated the coir fibre reinforced cement composites for roofing sheets with the fibre volume fractions of 2.5, 5, 7.5, 10 and 15% and the fibre lengths of 2.5, 3.75 and 6.35 cm. The investigations carried out for the bending, impact, shrinkage, water absorption, permeability and fire resistance has shown that, the best results can be obtained through the fibre volume fraction of 7.5% and the length of 3.75 cm.

5. PROPERTY ENHANCING CHEMICAL TREATMENTS

Coir fibres are naturally available, biodegradable materials which easily catch fire. With the time, it can be degraded due to photochemical (UV) degradation, biodeterioration, fibre mineralization, and exposing to hot water [10] and therefore inherent properties also get dissipated due to the natural process of degradation. Generally coir fibres are taken for a retting process before compositing with other materials to de-husk and remove the pithy material from the fibrous mesocarp [5]. However, in addition to that, the coir fibres should be subjected for several chemical treatments in order to overcome the above-mentioned disadvantages. The major goals of fibre chemical treatment are to remove lignin, hemicellulose, silica, and pith from the fibre in order to improve impregnation between fibre and matrix and improve fibre surface roughness in order to improve interaction. The ideal mechanical qualities are ensured by a good balance of time and focus throughout the treatment [14].

5.1 Chemical coupling methods

Purpose: Surface modification

Coir fibres are treated with a chemical compound to produce a strong bonding between fibre and matrix on the surface. The most commonly used chemicals compounding methods are, Graft polymerisation with methyl metha acrylate, Graft polymerisation with acrylonitrile, Treatment with iso-cyanates, Esterification with malic anhydride, treatment with silane coupling agents, treatment with triazine coupling agent and treatment with silane [14].

5.2 Alkaline treatment

Purpose: Increase bonding strength, increase surface roughness, increase Mechanical properties

The treatment is performed by immersing coir fibres in the water for a given period of time. The concentration and the time of soaking vary from 0.5 % to 20 % and time of soaking ranging from 15 minutes to 96 hours [25]. It disrupts the hydrogen bonding in the chemical structure and improve the surface roughness. However, higher alkali concentration causes to deteriorate the strength of the fibre and make damages on it ([26] , [14]).

5.4 Acetylation

Purpose: Minimize the hygroscopic nature, improve the dimensional stability, improve tensile properties, flexural properties and interfacial shear strength properties.

Acetic anhydride is added to fibres and place in the chamber at a temperature of 100 °C to 120 °C for 3 hours [14]. Acetylated coir fibres are recognized as more effective in acetylated natural fiber-reinforced polyester composites, which ensures minimum tensile strength losses and higher bio resistance compared to silane treated fibres [11].

5.5 De-waxing

Purpose: Increasing bonding strength

De-waxing is used to remove wax from the surface of untreated raw fibres. The most popular method for natural fibres like coir fibre is soaking coir fibres in acetone and then hot detergents. Soaking in hot water and detergents are found to be excellent for improving flexural properties. In addition to that, 'Soxhlet extraction' in acetone, followed by distilled water cleaning, and ethanol benzene extraction also used as a natural fibre dewaxing technique [14].

5.6 Application of fire retardants

Purpose: Improve fire resisitivity

The retardant agent applied on the coir fibre surfaces using conventional textile finishing methods including washing, bleaching, dyeing and coating [27]. Most frequently used fire retardants for natural fibres are ammonium phosphates, such as mono-or diammonium phosphates (DAP), ammonium bromide (where allowed), borax and boric acid, ammonium sulphamate, and sulphates [9].

6. CONCLUSION

Coir fibres are abundantly available, natural, cheap, non-toxic and light weight material, which is able utilized as reinforcement in concrete to gain high tensile strengths. But the studies on the properties of natural coir fibres and their applications have shown that there is a likelihood of using coir fibres for ceiling tiles as well. The review has been done referring number of research articles which are about coir fibres and its intrinsic properties. Gypsum is one of the most frequently used ceiling materials in both commercial and public buildings due to its prominent features like low thermal conductivity, fire resistivity, appearance, etc. However, gypsums are not susceptible to water and fungal growth and weight is comparably high. Cement-fibre ceiling tiles are also becoming popular products in most of public and residential buildings. However, most of the current market available cement-fibre ceiling tiles are manufactured using glass fibres and other synthetic fibres. As a solution for all the issues engaged with gypsum tiles and as an economical and sustainable replacement for cement-fibre ceiling tiles, the suitability of coir fibres is analysed using other experimental studies about coir fibres. After referring related studies, it is able to explicate that, coir fibres are excellent in properties like low thermal conductivity, acoustic insulation, moisture resistivity and strength and enhance the mechanical and flexural properties after making composite with both gypsum and cement separately. When exploring the existing studies, it was able to attain that, to acquire the desired properties, the volume fractions and lengths of fibres have significant influence. According to the previous studies, the best performance of the coir fibre – gypsum composite has been given when coir fibres are mixed with gypsum at a rate of 30% of the total weight of the mixture. After considering the fibre-cement composites, the best volume fraction for coir fibres can be recommended as 4% to 10% of the total weight of the mixture and the most suitable length of coir fibre lays between 2.5 cm to 5 cm. The main disadvantage of coir fibre is its weakness to resist the fire. In addition to that, natural degradation, fibre mineralization is also should be taken into the account before using them as a composite with other materials. In order to avoid such weakness and of course to enhance the existing properties different chemical treatments such as alkaline treatment, chemical compound treatment, Acetylation, applying fire retardants and de-waxing can be performed.

7. REFERENCES

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