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Derleme Makale / Review Paper

A Study on the Production Process and Properties of Cement-Based Wood Composite Materials

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ABSTRACT

Due to the growing environmental concern, lignocellulosic materials have become a common substitute for the conventional reinforcement element in composite strcutures. However, these natural sources are preferred to cost efficient and to increase mechanical performances. In a cement bonded composites, wood is incorporated as an aggregate in the mineral matrix (as fibres, sawdust, shavings or particles), and cement acts as a binder. These are employed due to their ease of production, and the enhanced biodegradability, leading to applications for sustainable purposes in construction applications. Wood-cement composites are considerably better performance on high fire, weathering and bio-deterioration risk applications to which solid wood and resin bonded composites are vulnerable. However, the vast of literature on cement-wood bonded composites has already been reviewed and pointed by a number of researchers. Many valuable fundamental informations have already established for utilizing wood for these products. A comprehensive results was to investigate some wood species that are abundant resources in many countries, for their suitability for manufacturing such composites.

Keywords: Cement, wood, composites, mechanical properties

Çimento Esaslı Odun Kompozit Malzemelerin Üretim Prosesi ve Özellikleri Üzerine Bir Çalışma

ÖZ

Çevre ve doğayı korumaya olan ilginin giderek artması sonucu, lignoselüloik esaslı kaynakların kompozit malzemelerin yapısında güçlendirici eleman olarak kullanımına olan ilginin artmasına neden olmuştur. Zira bu doğal kaynaklar, daha düşük maliyetlidirler ve yeterli direnç özelliklerin sahiptirler. Çimento ile yapıştırılmış odun esaslı kompozit malzemelerde tipik olarak çimento ile odun veya türevleri (talaş, yonga, lif vb.) mineral matris yapıda çimento ile bağ yaparak çimentonun bağlayıcılığında bir arada bulunurlar. Bu malzemeler, kolay üretime imkan sağlamaları yanında gelişmiş biyobozunma sağlamaları ve sürdürülebilir kaynaklardan üretilmelerinden dolayı yapı ve konstrüksiyon işleri

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için uygundurlar. Odun-çimento esaslı kompozit malzemeler, sentetik reçine ile üretilmiş kompozitlere göre daha yüksek yangına, dış atmosferik şartlara ve biyolojik bozunmalara dayanım gösterieler. Günümüzde, çimento esaslı kompoztler çok sayıda literatür bilgileri mevcuttur. Birçok araştırmacı tarafından çimento-esaslı kompozit malzemelerin üzerine çalışmalar yapılmış ve bulgular rapor edilmiştir. Birçok önemli ve değerli bilgiler bu çalışmalardan sağlanabilir. Farklı odun türleri için dünyanın bazı bölgelerinde karşılaştırmalı çalışmalar yapılmış ve çimentolu üretime uygunlukları uygunluğu konusunda bazı öneriler bulunmaktadır.

Anahtar Kelimeler: Çimento, odun, kompozitler, mekanik özellikler

INTRODUCTION

In general, cement-bonded composites are made by blending proportionate amounts of wood (fiber, particle or flake) with a Portland cement binder in the presence of water. However, this special preparation, allowing the woods to embedded in a matrix withbinder to make a rigid material. In this matrix system, wood could serve as a low-cost filler and/or reinforcing material that improves the stiffness, toughness, strength-to-weight ratio, thermal and acoustic properties of concrete when incorporated into matrix strcuture with cement.

Typically, these products contain between 10 to 70% wood (by weight) and conversely 90 to 30% cement (by weight) as binder, depending on the material (Youngquist, 1999). However, the properties of final productsare significantly influenced by the amount and nature of both the cement binder and the woody material (Simatupang and Geimer, 1990; Jorge et al., 2004).

It has already well established that cement-bonded compositesemit no hazardous elements during manufacture that generally health risks associated with the synthetic resin bonded composites. However, these are also very resistant to deterioration, particularly byinsects, fungi, moisture and fire. Moreover, acceptable properties of aproduct could be obtained when the particles are fully encased, and the binder is a continuous matrix. In this sense, it differs considerably from conventional wood-based composites, where fibers or particles are ‘spot welded’by organic based synthetic resins that applied as a finely distributed spray. Therefore, the cement binders have usually higher density than thermosetting resins; that the required amount of binder (cement) per unit volume of composite material is much higher than that of synthetic resin-bonded wood composites (Van Elten, 1996; Jorge et al., 2004; Frybort et al., 2008).

Since it has begun to use in construction industry in 1970s, there has been growing interest on cement bonded wood composite manufacturing in worldwide. However, a significant portion of recent literature on those products have focused on woody materials with the goal of determining effects of variables on panel products. However, the composition of the cements are also very important because of their unusual properties. Therefore, it is important to monitor the chemical and physical properties of both cement and woods for better manufacturing process.

CHEMICAL PROPERTIES OF PORTLAND CEMENTS

The cements, which have various specific chemical proportions in various types could considered to be used with woody materials that may exhebit exceptional end use properties. In this sense, the general properties of cements and their chemical composition are summarized in below.

It has well known that Portland cement gets its properties from chemical reactions between the cement and water that known as ‘hydration or crystalization’ (Lea, 1970; Malhotra, 2013). Because of the complex nature and chemical reactions, for simplicity, the shorthands form is used to denote the chemical compunds in typical portlant cement as seen in Table 1.The typical Portland cement composition is given in Table 2.

The American Society for Testing and Materials (ASTM) has designated five types of portland cement (Type I-V). However, these cement types differ primarily in their chemical content and in their properties. The general characteristics of these types are listed in Table 3.

Table 1. The chemical compounds in typical portland cement (Lea, 1970;Taylor, 1997)

Compound	Formula	Shorthand form
Calcium oxide (lime)	Ca0	C
Silicon dioxide (silica)	SiO_2	S
Aluminum oxide (alumina)	Al_2O_3	A
Iron oxide	Fe_2O_3	F
Water	H_2O	H

Sulfate	SO_3	S

Table 2. The typical Portland cement clinker composition* (Lea, 1970; Taylor, 1997; Malhotra, 2013)

Compound	Short-hand form	% (by weight)	Effects
Tricalcium aluminate **($Ca_3Al_2O_6$)**	C_3A	10	It liberates heat during the early stages of hydration, but has little strength contribution. Cement low in C_3A is sulfate resistant.
Tetracalcium aluminoferrite **($Ca_4Al_2Fe_2O_{10}$)**	C_4AF	8	This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln. It hydrates rapidly, but does not contribute much to strength of the cement.
Dicalcium silicate **(Ca_2SiO_5)**	C_2S	20	It hydrates and hardens slowly. It is largely responsible for strength gain after one week.
Tricalcium silicate **(Ca_3SiO_4)**	C_3S	55	This compound hydrates and hardens rapidly. It is largely responsible for portland cement's initial set and early strength gain.
Sodium oxide **(Na_2O)**	N	< 2.0	
Potassium oxide **(K_2O)**	K	< 2.0	
Gypsum **($CaSO_4.2H_2O$)**	CSH_2	5	It slows down the hydration rate of C_3A.

*Actual weight varies with type of cement

Table 3. General features of the main types of Portland cement (ASTM; Taylor 1997; Malhotra, 2013)

Type	**Classification**	**Characteristics**	**Applications**
I	General purpose	Fairly high C_3S content for early strength development	General construction (most buildings, bridges, pavements, etc)
II	Moderate sulfate resistance	Low C_3A content (<8%)	Structures exposed to soil or water containing sulfate ions
III	High early strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
IV	Low heat of hydration (slow reacting)	Low content of C_3S (<50%) and C_3A	Massive structures (i.e. dams)
V	High sulfate resistance	Very low C_3A content (<5%)	Structures exposed to high levels of sulfate ions
White	White color	No C_4AF, low MgO	Decorative (otherwise has properties similar to Type I)

The differences between these cement types are rather subtle and all those five types contain about 75wt Calcium silicates (Ca3SiO4 andCa2SiO5) and 18 wt% Calcium Aluminate minerals (Ca3Al2O6 and Ca4Al2Fe2O10) and the properties of cured concretes made with all five are quite similar (Lea, 1970; Taylor, 1997). Type I and Type II cement are quite similar and it is common to put cements meeting both designations labeled as Type I/II (Lea, 1970; Taylor, 1997). However, the types II and V are designed to be resistant to sulfate deteriation which is an important phenomenon that can cause severe damage to concrete structures. In sulfate reaction, the hydration products of C3A and sulfate ions that enter the concrete from the outside environment. Hence, type II and type V cement focus on keeping the C3A content low while the hydration products of C4AF are similar to those of C3A, but they are less vulnerable to expansion. It is important to note that the most effective approach to prevent sulfate deteriation is to keep the sulfate ions from entering the concrete in the first place. This could be done by using mix designs that give a low permeability (mainly by keeping the water/cement ratio low) and, if practical, by putting physical barriers such as sheets of plastic between the concrete and the soil (Lea, 1970; Malhotra, 2013). Type III cement is designed to develop early strength development more quickly than a type I cement. This is very useful and important for maintaining a rapid construction practice, since it allows cast-in-place concrete to bear loads sooner and it reduces the time that precast concrete elements must remain in their forms. However, these issues are particularly important in cold weather, which significantly reduces the rate of hydration of all Portland cements. The downsides of rapid-reacting cements are a shorter period of workability, greater heat of hydration, and a slightly lower ultimate strength (Malhotra, 2013). Type IV cement is designed to release heat more slowly than a type I, meaning that it also get strength more slowly. A slower rate of heat release limits the increase in the core temperature of a concrete element. The maximum temperature scales with the size of the structure, and type III concrete was developed due to excessive temperature rise in the interior of very large concrete structures such as; dams (Taylor, 1997; Malhotra, 2013). On the other hand, white Portland cement (WPC) is made with raw ingredients that are low in iron and magnesium, the elements that give cement its greyish color. It tends to be significantly more expensive than Portland cement, however, so it is typically confined to architectural applications.

CEMENT-BONDED WOOD COMPOSITE MANUFACTURING PROCESS

The cement bonded particleboard also known as *Wood-Cement Board* (WCB) was first commercially manufactured in early 1970s, Switzerland. Typically, it was a mixture of wood particles and Portland cement together with some additives that suspended in a matrix system called *wood-reinforced cement bonded board*, in which the proportion of wood elements should be appopriate proportion. Its density had around 1100-1350 kg/m3 but it can be decreased at 850 kg/m3 with using various wood strands and called *Oriented Wood Cement Boards* (OWCB).

Since 1940, the wood wool called *Excelsiorboards* (WWCB) manufacture has commonly used in Europe and Asia (Wolfe and Gijnolli, 1997). However, the composition and properties of the WWCB are various, having an apparent density in the range of 300–500 kg/cm3, a wood/cement ratio between 0.4 and 0.6 (Ashori et al., 2011; Dudart de la Gree et al., 2013).

A general flowchart for the production of cement-bonded wood-based composites is shown in Figure 1. The process, similar to that used for fabricating panels bonded with thermosetting resin, could be divided into several groups including:

- Wood particle or fiber preparation,
- Mat formation,
- Pressing,
- Curing and drying.

However, the mat formation and pressing could be either continuous or discontinuous. The moisture content of wood (particles, fibers or strands) are depends on whether the blending and forming operations are wet or dry. Because the process requires water of hydration particle moisture content, even for the dry methods, is usually higher than that employed in making panels with thermosetting resins (Simatupang and Geimer 1990; Buchmayer, 1999).

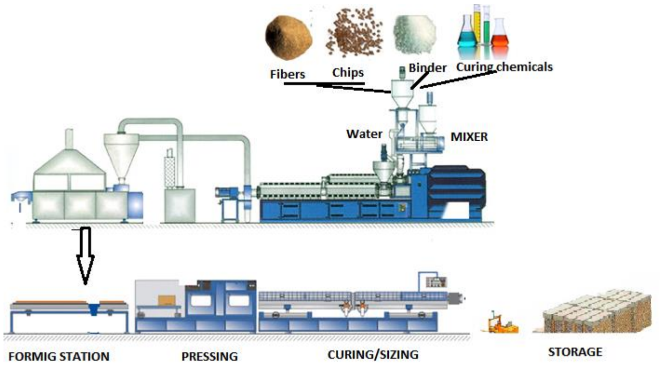

Figure 1. A typical cement-based wood composite manufacturing process

However, one of the major difference in the processing of cement-based compared to synthetic-bonded composites is the very long hardening time (up to 4 weeks) required. Whereas the rate of strength development in hot pressed thermosetting resin bonded boards allows the release of compression forces in a just few minutes. Moreover, cement-bonded panel products usually cured at ambient conditions, may require up to 8 hours of press time. This is usually accomplished by pressing and clamping stacks of boards which are then set aside to harden. Following the release of the clamping forces, most cement binders need additional time to develop full strength (Wolfe and Gijnolli, 1997; Youngquist, 1999; Buchmayer, 1999). On the other hand, manufacturing methods are dishguished by the amount of water present in the furnishby their water-binder ratio and basically divided into three categories (Kuroki et al., 1993);

- The wet process,
- The semi dry process,
- The dry process

The wet process is usually preferred to manufacture corrugated boards and molded products. In this process, a dilute slurry (with water) made of wood fibers, binder, aggregates, and additives is formed into a mat and dewatered on a screen equipped with a vacuum chamber. Moreover, the water in the furnish dissolves part of the cement component forming a saturated solution. In this regard, tricalcium silicate hydrolyzes and forms small amounts of calcium hydroxide that crystallizes from the solution as hexagonal particles. In further reactions, the portions of the tricalcium aluminate and calcium sulfate (a minor but important ingredient of portland cement) go into solution and form trisulfate (Lea, 1970; Simatupang and Geimer, 1990; Taylor, 1997; Malhotra, 2013).

Although the wood-cement boards are manufactured using many different methods, the Hatschek process is one of the most common and is considered the state-of the-art process at present (FCM, 1998). However, the Hatschek process starts with wood chips that are broken down and mixed with water and cement. The additives are added to form a pulp-like system. This slurry is fed into a sieve cylinder sheeting machine. The rotating cylinder skims off a small volume of the slurry and deposits it in a thin layer onto a production surface that is placed on the forming roller. Further layers are added until the desired mat thickness is achieved, at which point the mat are cut to size and sent to a chamber where they are pressed to remove water. The panels then enter a bath of 60 oC and at 90-95% humidity environment for 8 h where the cement is further hydrated. At this point, the panels are pressed, if necessary, and air-cured or autoclaved. Air curing involves stacking the panels and storing at ambient conditions for 3 to 4 weeks. Moreover, autoclaving cures the panels with high-pressure steam. Typically the products are cured for 12 h in an autoclave at 175 oC and 1.0 to 1.2 MPa pressure (FCM, 1998; Buchmayer, 1999; Van Elten, 2006; Moslemi and Begum 2017). A general process chart for Hatschek process is shown in Figure 2.

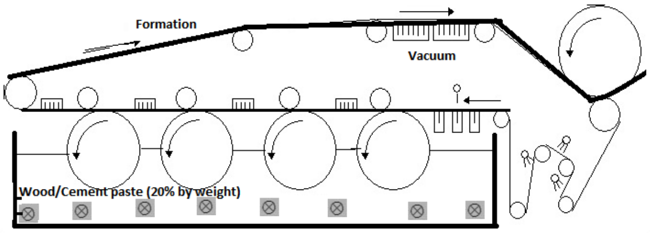

Figure 2. A typical Hatschek process chart

In the the semi dryprocess, the water/cement ratio is about 0.5 to 0.8. Following mat formation in molds by mechanical devices, the highly viscous mixture is compacted by vibration or a light pressure. However, wood wool boards (Excelcior) made with the the semi dry process (casting process) require sustained pressure following compaction.

In the dry process where the moisture released from the wood particles during pressing makes up a portion of the necessary water of hydration.

However, wood cement boards made of shavings do not require prolonged compaction pressure (Simatupang and Geimer 1990).Compared to particles or flakes, the spring back forces in boards made with refined wood fibers are negligible after pressing. Therefore fiberboards couldbe hardened without sustained compression. The general hardening procedure of cement- based materials is summarized in Figure 3.

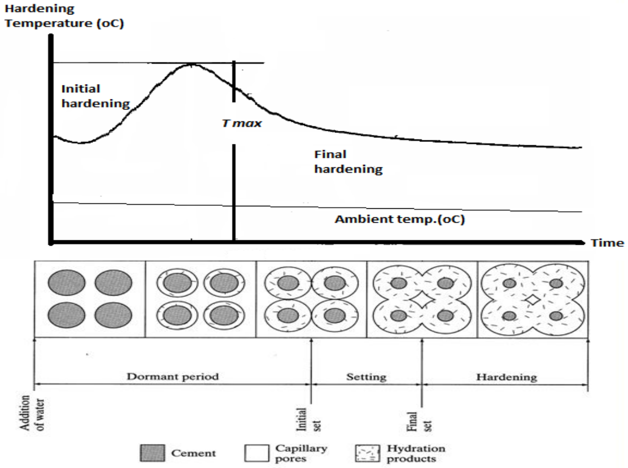

Figure 3. Hardening procedure of cement-bonded materials

CEMENT-WOOD CHEMİCAL BONDING MECHANİSMS

The wood-cement interactions based on recent literature findings have been reviewed and valuable informations presented in below. However, the literarture findings could be used based on the simple chemical properties of wood and cement. Moreover, in evaluating the bonding of wood which has been various chemical constituents even in the similar families, the different mechanism must control the final products properties. In addition, the presence of some additives could also effects either incease or reduce the hydration (curing) of cement, which in turn leads to further complex reactions.

As mention above sections, typically, an Portland cement is mostly made up of Calcium silicate-$Ca2SiO4$ and Calcium aluminate-$Ca3\ (AlO3)2$. Hence, these groups have interacted with main wood chemical constituents of cellulose, lignin, hemicellullose and extractives.

It has already well established that the noncellulosic polysaccharides (hemicelluloses, starch, pectins, etc.) could be easly soluble in alkali environments. In this sense, the acetyl groups may be cleaved by alkali in those structures. However, the ester linkages in hydrolyzable tannins, sugar residues (usually D-glucose) with one or more polyphenol carboxylic acids could be hydrolyzed by alkalines while some hemicellulose groups might be soluble in water (Fengel and Wegener, 1984; Sjostrom, 1993). With having these informations, it is reasonable to suggest that, although wood-cement interactions have many complex phenemons and multiple reactions could be occur at the same time, the formation of hydrogen bridges between cement and wood are primarily effect on bonding. The plausible mechanism for the formation of bonds between hydrated cement products with the wood and cellulose are presented in Figure 4. Moreover, the reaction patways presented in this study go some way in helping to substantiate the validity of the wood-cement bonding reaction within the matrix system (Li et al., 2005; Kruger et al., 2009; Jo and Chakraborty, 2015; Doudart de la Grée et al., 2015a and 2015b).

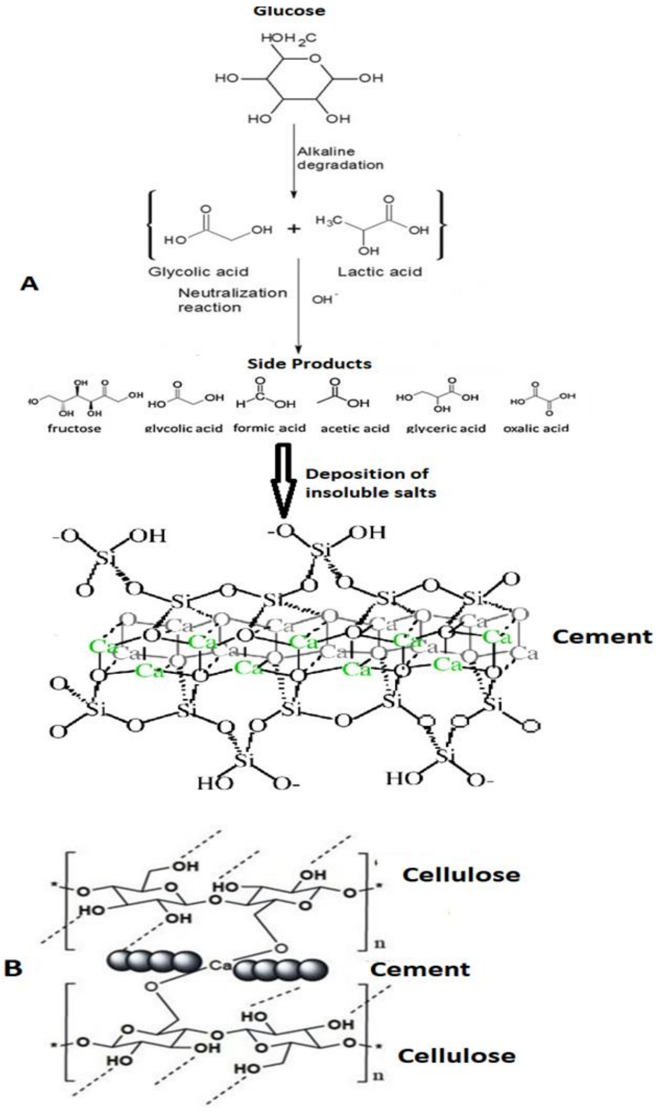

Figure 4. Suggestion mechanism for the formation of of bonds between hydrated cement products with the wood constituents *(a: Formation of bonds between cement and glucose side products, b: Formation of bonds between cement and cellulose)* (Li et al. 2005; Kruger et al. 2009; Jo and Chakraborty 2015; Doudart de la Grée et al. 2015a).

WOOD-MATRIX INTERFACE AND BONDING STRENGTHS

In genaral, wood bonding, with either synthetic or mineral binder (cement), usually occurs fibre surface and the binder matrix (Coutts and Knightly, 1984). However, due to numerous hydroxyl groups in wood structure, the strengths of composite matrix islargely dependent on hydrogen bonding potential. Moreover, these hydrophilic hydroxyl groups could be hinder effective reaction with hydrophobic matrix elements. In synthetic adhesive based bonding process, the presence of waxes, pectins and related hydrophobic compunds in the cell wall prevents the interlocking with the matrix by covering the reactive functional groups of the fibres. In mineral based bonding process, the chemical constituents of cell wall particularly sugar content mainly effects inhabiting the interlocking with the matrix by changing crystalization (hydration) reactions. These are clearly effects inaccessibility to reaction sites resulting a low adhesion across the phase boundary and a resultant weak dispersion of force and poor strength properties (Kabir et al., 2012; Pickering et al., 2016). However, within a fibre-matrix system, it is also possible to tailor the interfacial bonding practically by developing interfaces from matrix-fibre reaction and the modification of fibres that are incorporated into the cement. However, to improve the interfacial bonding between fibre and matrix, some fibre surface modification techniques have already been suggested many researchers. The detailed information on wood-cement compatibility and improvement techniques could be found elsewehere (Semple and Evans, 2004; Fan et al., 2012; Doudart de la Grée et al., 2015b). So far, four important interfacial bonding mechanisms have alreday hypothesized for natural and synthetic adhesive bonding mechanisms that also case for mineral bonding (i.e. cement) process. These are;

- Mechanical interlocking,
- Electrostatic interactions,
- Chemical bonding,
- Inter-diffusion bonding.

However, different types of bonding could be occur at the same interface at the same time (Semple and Evans, 2004). It has already well presented that mechanical interlocking occurs when the fibre surface is rough. These increases the interfacial shear strength but has less influence on the tensile strength (Pickering et al., 2016). Moreover, the electrostatic interactionsmight be achieved when a coupling agent is used as a bridge between the fibre and matrix that are particularly significant in metallic interfaces. Moreover, the chemical bonding occurs when there are chemical groups in the phase boundary that could react to form chemical bonds. Those chemical interfacial strengths depend on the type and density of the bonds (Semple and Evans, 2004; Pickering et al. 2016). Inter-diffusion bonding occurs when atoms and molecules of the fibre and matrix interact at the interface.

In a typical matrix system, like cement-bonded wood composites, the bonding between fibre and matrix determines the mechanical properties materials. However, during stress transfer between matrix and fibres, well interfacial bonding allows the composites to carry load to a higher strain limit, although strong interface enables crack propagation which ultimately reduces toughness and strength (Semple and Evans, 2004). Moreover, one of the significant property improvement in fibre reinforced composites is that of fracture toughness. Toughness is quantified in terms of the energy absorbed per unit crack extension and thus any process that absorbs energy at the crack tip could give rise to an increase in toughness. It was hypotheses for steel fibres effects on concrete that a large amount of pores in the matrix decreases its original compressive strength, but randomly spread fibres across the micro cracks bridge them together and, therefore, also increase their resistance to concentrate into macro cracks. In this sense, depending on the mixture proportions and additive properties, the tensile and compressive strength may be changed (increased or decreased). Hence, dimensions and fibre types are very important for the cracking behavior of concrete material (Antona and Johanson, 2011).

For a continuous fibre (wood) matrix system (i.e. cement-based wood composites), it is not all the fibres pulled out from the matrix since the fibres often fracture. However, due to the nature of the defect distribution, not all fibres could break in the plane of the crack. Thereby, if the bonding between the fibre and matrix is weak then the fibres are carrying the bulk of the stress at the crack tip. Thereby, there could be a greater poisson's contraction in the fibre than in the matrix and these tensile stress may develop perpendicular to the interface between the fibre, which is contracting and the matrix, which is not. However, the stress could fracture on the weak fibre matrix interface that the crack is forced to run up, down and around the fibres. In order for the crack to proceed past the fibre, the fibre must break. Nevertheless, this only occurs when the stress in the debonded fibre is raised to the fracture strength of that fibre. This stress may be less the maximum value of fracture strength (αf). In this sense, it requires an additional amount of elastic strain energy to be input into the debonded region of the fibre at the crack tip-energy which is released as heat and noise as the fibre fractures. Since the fibres are linearly elastic, the elastic strain energy per-unit volume of fibre is:

$$G_{\varepsilon} = \frac{\sigma^2{}_f}{2E_f} \tag{1}$$

Where, G_ε: elastic strain energy per-unit volume, σ: stress, f: fibre fracture energy, σ_f: fracture strength of the fibre, E_f: elastic modulus of the fibre.

The total additional energy required is the product of the number of fibres per unit area, the additional strain energy per unit volume of fibre and the volume of debonded fibre:

$$G_{\varepsilon} = f\,\frac{4}{\pi d^2}\,x\,\frac{\pi d^2}{4}\,x1x\,\frac{{\sigma_f}^2}{2E_f} = \frac{f{\sigma_f}^2}{2E_f} \tag{2}$$

If we further assume that the crack running along the interface is limited to a length no shorter than the critical fibre length:

$$l_c = d\,\frac{\sigma_f}{\sigma_m} \tag{3}$$

Then

$$G_{\varepsilon} = \frac{fd\sigma_3^f}{2E\sigma_m} \tag{4}$$

Where, l_c: critical fibre length, d: width of the cross-section. The additional surface area of the fibre-matrix debond mutliplied by the surface energy (x2 for the two new surfaces created).

$$G_{\varepsilon} = \frac{f4}{\mu d^2}\,x\,\pi dlx2y = 8f\,\frac{1}{d^{\gamma}} \tag{5}$$

$$G = f\left(\frac{d\sigma_f^3}{2E\sigma_m} + \frac{8\sigma_f\gamma}{\sigma_m}\right) \tag{6}$$

The formulas are given in above (eq. 1 to 6) are useful for determining a general debond strengths of compostie materials and could be also useful for mineral bonded composite strengths such as; cement-bonded wood composites.

PROPERTIES OF CEMENT-BONDED WOOD COMPOSITE (CBWC)

In general, acceptable properties of a cement bonded board are dependent on both the nature of the binder and on the wood properties. However, wood-cement composites have been taken as very stable dimensionally when subjected to water interactions, as compared to conventional organic synthetic binder wood composites, like fiberboard. In addition, the water absorption and residual water absorption are much less (Lee, 1984).

However, water transfers between wood particles and cement matrix could be reduced by pulverization of the particles with hydrophobic components. Moreover, the behaviour of cement paste under constant and varying relative humidity conditions could be monitered closely (Fan et al., 1999). It has been found that polyethyleneglycol, bitumen and some petroleum residues could be useful for improving dimensional stability of cement-wood matrix structure (Mougel et al., 1995).

In general, wood-cement composites present a high durability against natural weathering or aging. Beside a high dimensional stability, and high resistances against biodegradation (fungi and insects attack), it is also fire resistance and some level sound insulation properties as well (Fan, 1997; Fanet al., 2006; Plekhanova et al., 2007; Kruger et al., 2009). However, Portland cement-based composites may be also considered non-toxic yet and commonly referred to as being virtually incombustible. This is attributed to the lower content of organic matter and the crystal water in the binder.

It is important to notice that the wood cement composites are usually heavier than conventional wood-based composites but they are lighter than concrete. However, it has higher stiffness compared with concrete, and may reduce material cost and improve performance of conventional concrete panels while preserving its mechanical qualities. Therefore, they could be replace concrete in construction, specifically in applications that are not subjected to heavy loads, like walls. They were also used for interior paneling in several other buildings. Moreover, an added advantage over massive concrete panels is their ability to withstand larger deformations before failure.

Beside, high in density and the appropriate strength in construction industry, an important advantage of wood-cement composites to engineering applications appears to lie in their ability to absorb and dissipate mechanical energy (Wolf and Gjinolli, 1997 and 1999). This, as well as good sound dissipation and absorption properties, has attracted research and development of wood-cement composites as very practical and cost-effective sound barriers (Wolf and Gjinolli, 1999; Lan and Huang, 2000; Boothby et al., 2001). Some general properties of cement bonded wood composites are given in Table 4.

Although their obvious benefits compared with other types of wood panels, there are several factors thathave prevented wood-cement composites from becoming more widespread (Moslemi, 1989 and 1993). One of the important issue of these is the long initial and post-press curing time of the portland cement binder, whichleads to reduced production capacity and a requirement for a large inventory of boards during curing (Lipinsky, 1989). However, the high weight-to-strength ratio and machine wear of productscompared with resin bonded particleboards has also reduced their popularity (Lee and Short, 1989), despite the higher toughness and durability. Some important adventagenous and non-adventagenous properties of these products over other conventional wood-based materials, briefly summarized in Table 5.

Table 4. Some properties of cement bonded composites

Property	**Cement-bonded fiberboards**	**Cement-bonded particleboards**
Density (kg/m^3)	1300	1250
Moisture (%)	< 10	< 10
MOE (N/mm^2)	6000	3000
MOR (N/mm^2)	12.0	9.0
IB ((N/mm^2)	2.0	0.4
Fire resistance	A1	B1
Heat resistance (W/mK)	0.18	0.12
pH	11-13	12-13

Table 5. Important properties of cement bonded composites (Fan, 1997; Plekhanova et al., 2007; Kruger et al., 2009; and Fan et. al., 2012)

Advantages	**Disadvantages**
High water resistance	Low bending strength
High fungal/termite/mold/vermin resistance (Due to its high alkalinity, pH: 11)	High energy use during manufacturing process
High fire resistance	Long curing time (21 to 28 days)
Well insulation and acoustic performance	Manufacturing process is more complex and time consuming
High freeze-thaw resistance	The machine wear problems during cutting
Can be used in both exterior and interior purposes	Need more labor and transportation cost
No volatile organic compound release as is the case with resin-bonded boards	Needed extra care and attention in hydration process of cement
Low cost and ease of manufacture	It can notused in light constructions like furniture
Easy of workability	High density and heavy material
Low production investment and simple technology required	

CONCLUSIONS

The cement bonded wood composite manufacturing become importance where the technology and materials for manufacturing conventional resin-bonded wood composites are expensive or unavailable. Because of strong competition from other lignocellulosic materials, utulization of cement-bonded compostes have not been in great demand. However, efficient utilization may create a new industry by making a valuable asset out of a costly material. Moreover, many wood resources are significantly under utilized in construction due to the lack of basic understanding of the mechanisms and technologies involved in the bonding of cement. One of the major obstacle to further successful development of wood-cement composite industries is variation in wood compatibility with cement. There is extreme variation in inhibiting effects among both hardwoods and softwoods with Portland cement resulting in strong species specificity among potential raw materials for wood-cement composite manufacturing industries.

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