USE OF LIGNOCELLULOSIC WASTES FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT

The disposal of lignocellulosic wastes is a major environmental problem. Using them in construction could reduce the magnitude of the problem. However, there are several issues that are limiting their exploitation such as their compatibility with cement, toxicity, and limited strength. This paper reviews the results of recent research into the use of these wastes in making cement-bonded composites. The approaches adopted to overcome aforementioned drawbacks are described. The benefits and limitations regarding the use of such materials are also discussed.

KEYWORDS: Wood, Waste, Cement, Composite, Strength, Lightweight, Environment, Lignocellulosic, Compatibility, and Admixtures.

INTRODUCTION

Large amounts of lignocellulosic wastes are being generated worldwide. In developing countries the rapid rate of industrialisation based on agro-forestry products generates wastes like rice husk, oil palm strands, hazel nuts and saw dust. Whilst in developed countries, in addition to the agro-forestry wastes, a huge quantity of wood waste is available from the demolition of old structures such as buildings, railways, telephone poles, and bridges. Table 1 shows the proliferation of such wastes in some countries. Presently these wastes are either burnt or land filled; these approaches cause various environmental problems like air pollution, emission of green house gases and occupation of useful land. These methods of disposal are certainly wastage of a primary resource. In addition, the biodegradation of wastes, like wood in landfills, emits methane, a green house gas which has 72 times heating effect relative to that of CO_2 (Leliveld and Crutzen, 1992). However, in several cases composting and burning are not possible due to legislation. For instance, wood structures may have been treated for insect and decaying resistance. Many preservatives contain toxic chemicals and therefore the environmental/health regulations limit their use in recycling and disposal options. In view of this situation, it is important to find out some alternative methods of disposal of these wastes.

Construction is a material intensive activity and consumes large amounts of materials. Therefore, the utilisation of such wastes in making cement-bonded construction materials offers an attractive alternative to their disposal.

Wood has been used with inorganic binders like ordinary Portland cement (OPC), gypsum and magnesite since the early part of the twentieth century. However, the production of wood cement composite panels began around 1965, due to the growing public concern about the health hazards associated with the use of asbestos (Coutts, 1988; Moslemi, 1989). Considerable research has been done in this area and wood is used in various forms for making cement-bonded products (Sarja, 1988; Moslemi, 1999). The emphasis was upon the use of 'clean' or virgin wood. More recently attempts have been made to use waste materials in making cement-bonded construction materials. This paper discusses the properties of the cement-bonded composites made using the lignocellulosic wastes, their advantages, limitations and possible applications in construction.

Table 1 : Generation of lignocellulosic wastes in different countries

Country	Source	Type of waste	Quantity per year	Reference
Japan	Construction	Used timber	20 M m^3	Kasai *et al*. (1998)
Malaysia	Oil Palm Industry	Oil palm shells	2.6 M tonnes	Basri *et al*. (1999)
UK	Construction	Used timber	2.5 M tonnes	Magin (2001)
	Pallets (Packaging)	Used timber	1.3 M tonnes	
USA	Construction	CCA treated	8 M m^3	Kamden (2002)
	Railway ties	Creosote treated	1.3 M m^3	
	------	Creosote and Pentachlorophenol treated	2 M m^3	
World (Mainly Portugal)	Cork industry	Cork granules	85 kilo tonnes	Karade *et al*. (2002)

RECENT RESEARCH

During the last decade, several reports on the use of lignocellulosic wastes in making cementitious composites have been published. These include a variety of wastes from different countries. The results of these studies are summarised in Table 2. The studies were supported by the experience with 'clean' wood-cement composites. The earlier studies with 'clean' wood particles indicated that not all wood species are compatible with cement. Several wood species actually inhibit the setting of cement (Simatupang *et al*., 1989). The main cause of inhibition is the presence of chemical compounds like sugar and tannin in the wood particles (Miller and Moslemi (1991). It is, therefore, necessary to either remove these compounds or use accelerators that can offset the retarding effect. The retarding chemicals are removed by washing the wood particles in cold water or in hot water or in an alkaline solution (Irle and Simpson, 1993). Several types of metal salts, such as $CaCl_{2,}$ $FeCl_{3,}$ $SnCl_2$, and $AlCl_3$, can be used to accelerate setting (Zhengtian and Moslemi (1985), but $CaCl_2$ is generally used. An alternative method of accelerating the setting of the wood-cement mix is the injection of CO_2 gas. Geimer *et al*. (1993) found that by the injection of CO_2 into the cement-bonded particleboard, the compaction pressure on the board could be released in 4.5 minutes, whereas the conventional process takes 8 to 24 hours.

Table 2. Properties of some cement-bonded composites incorporating lignocellulosic wastes

Organic aggregate	Source	Particle:cement ratio (wt.)	Admixture (% of cement wt.)	Density, kg/m^3	Comp. Strength, MPa	Flexural strength, MPa	Reference
Pine wood	Construction waste	1.0:2.0	$CaCl_2$ (4)	800-1220	1.10-6.64	0.57-1.65	Wolfe & Gjinoli (1999)
Conifer (Cedar, Cypress and Pine)	Construction waste	30 to 60% wood of total volume	Water reducing admixtures (1-1.5)	920-1250	5.00-8.00	4.00 -7.00	Kasai *et al.* (1998)
Hazelnut shell		0.02:1.00 - 0.10:1.00	Sand		26.50-43.70	4.40-7.00	Demirbas and Aslan (1998)
Oil Palm shells	Oil Palm industry		Sand and fly ash	1801-1856	15.00-20.00		Basri *et al.* (1999)
Oil Palm frond	Oil Palm industry	1.0:2.2 - 1.0:2.7	$MgCl_2$ (0-15)	1200		5.00-23.00	Hermawan *et al.* (2001)
Cork granules	Cork industry	0.1:1.0 - 3.33:1.0	--				Karade *et al.* (2002)
Bark of Japanese Cedar	Forestry waste	1.0:2.2	$MgCl_2$ and Na_2SiO_3	1200	10.00-22.00	2.00-8.00	Eusebio *et al.* (1996)
Rattan (Palmae)	Cane Furniture	1.0:2.5-1.0:3.25	$CaCl_2$ (2.5-3.5)	1050-1200		0.50-1.60	Olorunnisola and Adefisan (2002)

These concepts have been applied by various researchers to the use of lignocellulosic wastes from different sources (Table 2). Kasai *et al.* (1998) used wood particles from construction waste in Japan for making wood-chip concrete. They made concrete with a density range of 920 to 1250 kg/m^3. They found the flexural strength of the product in the range of 4 to 7 MPa and compressive strength 5 to 8 MPa. The ratio between flexural strength and compressive strength was 0.5 to 0.9, greater than that for normal concrete. This indicates the reinforcing effect of wood particles. They further reduced the density to about 780 kg/m^3 by adding artificial lightweight aggregates. This resulted in comparatively lower bending and compressive strength values at 2.05 and 2.2 MPa, respectively.

Wolfe and Gjinolli (1999) carried out a pilot study on the use of southern pine wood particles derived from construction waste for making cement-wood composites (CWC). They used copper chromium arsenate (CCA)- treated wood particles for making lightweight panels. The properties of their product are given in Table 2. They found that the toughness index (I_5), which is used to compare the energy absorption capacity during failure of a material, was greater than 5.5 whereas the average value of I_5 for other fibre reinforced concrete products is 5. Therefore, they achieved a better toughness index. They concluded that there were no compatibility problems between CCA-treated wood and cement. In another study on the use of CCA- and chromic acid-treated pine, it was found that the treated pine was more compatible than untreated pine. This was based upon an increased resistance to withdrawal of sticks embedded in cement and the increased flexural toughness of wood-cement composites (Schmidt *et al*. 1994). The results from these studies demonstrate that the manufacture of wood-cement composites could be a viable method of disposal for CCA-treated wood waste.

The effects of ground hazelnut shell, spruce and beech woods, and tea waste upon the mechanical properties of cement were investigated by Demirbas and Aslan (1998). They illustrated that an increase in these lignocellulosic content in the mix leads to lower compressive and flexural strengths for the cementitious composite. Mixes of ground hazelnut with cement showed the smallest relative decrease whereas the effect of tea waste was very severe. No clear reason was reported for this behaviour. However, it could be due to the presence of tannin in the tea waste. They concluded that ground hazelnut shell and beech wood could be used as an additive material in making cementitious composites.

Basri *et al.* (1999) investigated the use of oil palm shells (OPS) as coarse aggregate for making lightweight concrete. Their results indicated that OPS concrete had a 28-day air dry density of 1801 to 1856 kg/m^3 in comparison to 2301 kg/m^3 for the control concrete. They reported that the strength was within the normal range for structural lightweight concrete. Hermawan *et al*. (2001) showed that oil palm frond retards cement setting. However, the addition of $MgCl_2$ accelerated cement setting and also improved the strength properties of the composite.

Waste cork granules are very lightweight waste obtained from cork-producing industries for which bottle stoppers are the main product. The cork granules have a cellular structure, as can be seen in Figure 1. A research study is underway to use these cork granules for making lightweight concrete that has versatile applications (Karade *et al.* 2002). The results indicate that the addition of cork considerably reduces the density of the composite and enhances failure strain. These properties of the composite are attributed to the cellular structure of cork (Karade *et al.*, 2001). Furthermore, a good bonding between cork and cement paste was observed.

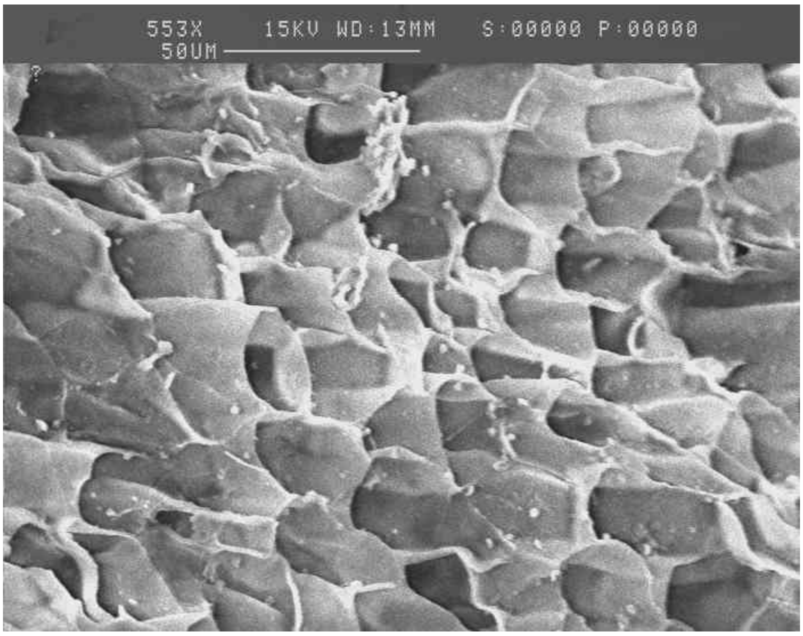

Figure 1: SEM micrograph of cork showing cellular structure of cork

An investigation to use Japanese cedar bark material in making cementitious composites was conducted by Eusebio *et al.* (1996). They found that bark retards the setting of cement. However, the addition of $MgCl_2$ and Na_2SiO_3 improved the hydration behaviour of the composite with a negligible change in compressive strength.

Olurunnisola and Adefisan (2002) investigated the use of rattan (cane) furniture waste in Nigeria for the manufacture of cement-bonded particleboard. They applied hot-water extraction as a pre-treatment of the chopped strands and added $CaCl_2$ as an accelerator. Their results (Table 2) describe a product with low flexural strength that is suitable only for use in low-stressed building applications.

DISCUSSION

It appears that, like wood, all types of lignocellulosic wastes are not compatible with cement. Before using them, it is therefore important to assess their compatibility with cement. Accordingly, it may be necessary to use a suitable pre-treatment method or a suitable dose of accelerator. The problem with extraction is that it takes considerable time, which can reduce productivity. Moreover accelerators like $CaCl_2$ may corrode steel in contact with the composite. Alternatively, CO_2 can be injected but obtaining a uniform gas distribution throughout the product could be a potential technical problem. Consequently more research is required in this direction. Curing at higher temperature is another possibility. Nevertheless, the results of these studies indicate that lightweight composites with moderate strengths can be produced. The advantages associated with the use of these composites are that they are lightweight, tough, water-resistant, fire resistant, durable, machinable (cutting), and cost effective. They can also be nailed. The problems in making such composites are inconsistent quality of raw material (wood waste), unreliable dimensional stability and lower strength of the composite in comparison to the normal strength concrete. Despite these disadvantages, the composites have sufficient strength for several non-structural applications like partition, sound absorption, thermal insulation and low cost housing. When compared to resin-bonded products, the cement-bonded products are better in all respects, with exception of density.

The strength properties of these composites can be further enhanced by the incorporation of fibres such as jute, sisal, alkali-resistant glass fibre, normal glass fibre and mineral wool. For example, a significant improvement in the strength and dimensional stability properties was achieved by using inorganic fibres in a study conducted by Wei and Tomita (2001).

If these wastes can replace the use of virgin wood in making cement-bonded wood composites, it will be very beneficial from an environmental point of view, since recycling of these wastes can reduce the level of timber harvesting and thus the rate of deforestation. It can also help in reducing landfill areas, which in turn will save large useful land areas for more productive uses. However, recycling of these wastes is not easy due to health concerns.

CONCLUSION AND RECOMMENDATIONS

The large amount of lignocellulosic wastes is causing various environmental problems. The results of recent studies on the use of these wastes indicate that these wastes can be used in making versatile cementitious composite building materials. However, in a few cases pre-treatment of these wastes or the use of chemical accelerators is required. These composites are lighter than the normal weight concrete and as a result they are not equally strong. Thus, more research is required to enhance the strength of such composites without losing the benefit of lower density. Further research on the health and safety aspects relating to the use of preservative treated wood and on the improvement of the compatibility between waste and cement will reveal more applications for such composites. This in turn will help in the effective use of wastes and the saving of natural resources like forest and land.

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