Research Letter

Mechanical Properties and Decay Resistance of Hornbeam Cement Bonded Particleboards

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Cement bonded particleboards were manufactured from hornbeam (*Carpinus betulus* L.) wood particles. Hydration tests were carried out to determine the inhibitory index in order to characterise wood-cement compatibility. The results revealed that the mixture of hornbeam-cement can be classified as moderate inhibition. Two wood: cement ratios were applied in this study, namely, 1 : 3 and 1 : 4, for the board manufacture. It was found that an increase of cement-wood ratio resulted in an improvement in all properties examined, except MOR. All properties of the boards made from 1 : 4 wood: cement ratio surpassed the minimum requirements set forth by the building type HZ code. Boards were exposed to brown and white rot fungi, *Coniophora puteana*, and *Trametes versicolor*, respectively. Overall, both fungi failed to attack the cement-bonded boards.

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1. INTRODUCTION

Cement-bonded particleboard has been manufactured using conventional technology, where the boards are kept under pressure for consolidation for several hours. The pressure is necessary because the hydration of the cement is a slow process. The cement hardening is usually completed in three to four weeks. The characteristics that make such type of boards desirable to various construction applications are decay and fire resistance and good dimensional stability.

A significant problem however, when these products are manufactured, is the compatibility of wood with cement. The term compatibility, when applied in the area of wood-cement composites, refers to the degree of cement setting after mixing with water and with a given wood in fragmented form. Generally, if the chemical process of cement hardening is undisturbed by the presence of wood, it is considered that cement and wood are compatible. On the other hand, if cement hardening is impaired by the presence of wood, then cement and wood are referred as incompatible [1]. The latter is commonly expressed by a lowering of the physical and mechanical properties of the final product. Weatherwax and Tarkow [2] described a method to quantify differences among species by using the term inhibitory index, which

compares the extension of wood-cement inhibition based on the percentage increase in setting time. Hofstrand et al. [3] incorporated maximum temperature and the maximum slope of the temperature time curve of the wood-cement mixture and neat cement, respectively, into the inhibitory index calculations. The inhibitory index of any species can be computed from the values of maximum temperature of hydration, the maximum slope of the exothermic curve and the hydration time needed to reach maximum temperature of the inhibited cement when compared, respectively, with the values of the uninhibited cement. The lower the inhibitory index, the higher the compatibility between cement and wood. Objective of this communication was to manufacture wood cement particleboards using particles of hornbeam, a less utilised wood species in Greece, and to evaluate the mechanical properties and decay resistance of the boards.

2. MATERIALS AND METHODS

2.1. Hydration test

The hydration tests were carried out as previously described [4]. To calculate the inhibitory index (I) of the species, the

following equation was used:

$$I = 100 \left[\left(\frac{t_2 - t'_2}{t'_2} \right) * \left(\frac{T'_2 - T_2}{T'_2} \right) * \left(\frac{S'_2 - S_2}{S'_2} \right) \right], \quad (1)$$

where t_2 : time to reach maximum temperature of the inhibited cement in seconds (wood-cement-water mixture), t'_2 : time to reach maximum temperature of the uninhibited cement in seconds (cement-water mixture), T_2 : maximum hydration temperature of the inhibited cement in °C (wood-cement-water mixture), T'_2 : maximum hydration temperature of the uninhibited cement °C (cement-water mixture), S_2 : maximum temperature-time slope of inhibited cement °C (wood-cement-water mixture), S'_2 : maximum temperature-time slope of uninhibited cement °C (cement-water mixture).

2.2. Board manufacture

Hornbeam particles that previously passed the 1×1 mm sieve were the raw material used in this study. The bonding agent employed was commercial grade Portland cement, type I. The wood: cement ratios applied in this study were 1 : 3 and 1 : 4, based on the oven dry weight. Calcium chloride (CaCl_2 -3% based on weight of cement) was introduced into cement slurry to accelerate cement set during hydration. The boards manufactured according to methodology described in Okino et al. [5] and Fuwape [6]. A predetermined amount of air-dried wood particles and a CaCl_2 distilled water solution were thoroughly blended. Cement was subsequently added and the constituents were mixed until the cement paste was completely hydrated. The quantity of distilled water added was calculated using a relationship applied by other researchers as well [6–8]. In his formulation, the water requirement was determined as follows:

$$\text{water (litres)} = 0.35C + (0.30 - MC)W, \quad (2)$$

where C = cement weight (Kg), MC (%) = wood strands moisture content (oven-dry basis), W = oven-dry wood strand weight (Kg).

After 15 minutes of manual mixing, the cement-wood water mixture was screened onto to a caul. The mat was evenly distributed to provide as uniform a density as possible and prepressed to a thickness of approximately 50 mm. Cold pressing took place under an initial pressure of 5 MPa, to a 15 mm thickness, after which the board was retained in compression for 24 hours. Target board density was 1200 Kg/m³. A total of six boards were made, each measuring 40 × 40 cm. To minimise cement capillary desiccation and enhance hydration, boards were misted with distilled water, then wrapped in cellophane before storing for curing at 20°C and 65% relative humidity for a month. After manufacturing, the boards were conditioned at 20°C and 60% relative humidity and tested for IB (internal bond, sample size 50×50 mm), MOR-MOE (moduli of rupture and elasticity, sample size 300 × 50 mm), TS (thickness swelling, after 24 hours immersion in water, sample size 50 × 50 mm) according to procedures defined in the European Union standards EN 310, EN 317, and EN 319.

TABLE 1: Inhibitory index of hornbeam wood species used in this study. (Standard deviations in parentheses.)

Wood species	Inhibitory index (%)	
	Without additive	With additive (3% CaCl_2)
Hornbeam	39.15 ^(a) (4.3)	−0.92 (0.08)

^(a) Each value represents the mean of four replicates.

One way analysis of variance (ANOVA) at 5% level of significance was used to compare the properties of the panels between different wood cement ratios.

2.3. Decay tests

60 samples, measuring 50 × 50 × 15, were packed in an argon atmosphere and sterilised by irradiation (2.5 Mrad.) prior to decay tests, using the methods described in DD ENV 12038: 1996. Laboratory pure strains of the brown rot fungi *Coniophora puteana* (No FPRL 11E) and white rot fungi *Trametes versicolor* (CTB 863A) were used, grown on malt agar. 48 blocks (24 for each fungi) were planted on sterile specimen supports placed on the cultures of the test fungus actively growing on 5% malt agar in 500 mL capacity jars. An additional set of 12 sterile control samples was used to assess operational control losses. The closed jars were incubated for 16 weeks, at 22 ± 1°C and 75 ± 5% relative humidity to evaluate the efficacy of the treatments. After incubation, the samples were removed from the jars, cleaned, weighed, conditioned to constant weight as above, and reweighed. Weight loss (WL) was expressed as a percentage of the initial weight of the sample. Weight losses from sterile controls were subtracted from the decay results to give corrected data.

3. RESULTS AND DISCUSSION

3.1. Hydration test

The results obtained from the hydration test are shown in Table 1. From this, it can be seen that the mixture of hornbeam-cement was classified as moderate inhibition. When CaCl_2 was incorporated, the mixture was graded as low inhibition. The value of inhibitory index is negative, probably due to the capacity of the CaCl_2 to buffer or minimise the adverse effect of the soluble sugars and extractives and also to accelerate the cement hardening and setting.

3.2. Mechanical and physical properties

The mechanical properties of the boards are presented in Table 2. Table 2 shows that an increase of cement-wood ratio resulted in improvement in MOE, IN, and TS properties, and this improvement is significant at 5% level of significance. However, the MOR value was significantly decreased, as the cement-wood ratio increased. This is in line with the observations made by Moslemi and Pfister [7] and Papadopoulos et al. [9]. They found that the modulus of elasticity, internal bond strength, and thickness swell increased linearly with greater cement-wood ratio. The

TABLE 2: Mechanical and physical properties of cement-bonded hornbeam boards. (Standard deviations in parentheses.)

Wood: cement	Density ^(a) (Kg/m ³)	MOR ^(b) (N/mm ²)	MOE ^(b) (N/mm ²)	IB ^(a) (N/mm ²)	TS ^(a) (%)
1 : 3	1270 (0.18)	12.68 (0.5)	6009.6 (32.1)	0.35 (0.07)	1.75 (0.6)
1 : 4	1280 (0.12)	10.56 (0.8)	7056.4 (199.3)	0.56 (0.04)	0.67 (0.1)
BISON type HZ	1.20	9.0	3000	0.40	1.2–1.8

^(a) Each value represents the mean of twelve replicates.

^(b) Each value represents the mean of eight replicates.

TABLE 3: Weight loss (WL) of cement-bonded hornbeam boards. (Standard deviations in parentheses.)

Wood: cement	Brown rot WL ^(a) (%)	White rot WL ^(a) (%)
1 : 3	0.85 (0.07)	−1.88 (0.40)
1 : 4	−2.92 (0.20)	−1.45 (0.66)

^(a) Each value represents the mean of twelve replicates.

relationship between cement-wood ratio and MOR values is considerably different from that of MOE or IB or TS. The MOR decreased with an increase of cement-wood ratio since higher proportion of wood in the board may enhance the flexural property of the board. When wood occupies more volume in the board, the areas of stress concentration around the component particles are more diffused, resulting in increased applied stresses [6]. The results reported here are in conformity with those made by other workers [7–9] regarding the use of cement in particleboard, flakeboard, and OSB manufacture. All properties of the boards, if we exclude the IB value of boards made from 1 : 3 wood: cement ratio, surpassed the minimum requirements set forth by the building type HZ code, as shown in the last line of Table 2. This is in line with the results published by Okino et al. [10]. They manufactured cement-bonded boards with 1 : 3 wood: cement ratio and used cypress particles.

3.3. Decay resistance

The results obtained after a 16-week incubation period are presented in Table 3. Overall, both fungi failed to attack the cement-bonded boards. Visual examination revealed a slight presence of mycelium in the surface of the tested samples. Boards showed weight gain instead of weight loss. This according to Okino et al. [5, 10] was a consequence of the final curing process of the cement, at this high cement: wood ratios. Research in durability of cement-bonded panels is not very common in the literature. Tests conducted by Dinwoodeie and Paxton [11] and Pirie et al. [12] suggested that conventionally made cement-bonded particleboards are very resistant to the attack of the white rot fungus *Pleurotus ostreatus* and to the brown rot fungus *Coniophora puteana*. Similar results were also reported by Okino et al. [10] in cement-bonded boards made from cypress particles. The present study was the first study, as far as the author is aware, that examined the decay resistance of oriented strand board using cement as a binder.

4. CONCLUSIONS

The aim of this paper was to manufacture wood cement particleboards using particles of hornbeam and to evaluate the mechanical properties and decay resistance of the boards. Based on hydration tests, it was found that the mixture of maple-cement can be classified as moderate inhibition. Two wood: cement ratios were applied in this study, namely, 1 : 3 and 1 : 4, for the board manufacture. It was found that an increase of cement-wood ratio resulted in an improvement in all properties examined, except for MOR. All properties of the boards made from 1 : 4 wood: cement ratio surpassed the minimum requirements set forth by the building-type HZ code. Boards were exposed to brown and white rot fungi, *Coniophora puteana* and *Trametes versicolor*, respectively. Overall, both fungi failed to attack the cement-bonded boards.

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