ASSESSMENT OF THE COMPATIBILITY OF WOOD AND PLASTIC WITH CEMENT FOR THEIR RECYCLING IN CEMENT COMPOSITES

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ABSTRACT

The compatibility between maritime pine wood and cement, and between plastic (LDPE) and cement, was assessed for the recycling of wood and plastic in cement composites. Temperature vs. time profiles of cement setting were registered and compatibility indices were calculated. Results indicate that recycling of plastics in plastic-cement composites does not pose any questions regarding chemical compatibility. However, maritime pine hinders cement setting in some extent. So, in order to manufacture wood-cement composites with recycled wood, physico-mechanical properties of composites must be assessed, too.

KEYWORDS

wood, plastic, cement, composites, recycling

RESUMO

Foi avaliada a compatibilidade entre a madeira de pinho bravo e o cimento, e entre plástico (LDPE) e cimento, com vista à sua reciclagem na forma de aglomerados com cimento como ligante. Obtiveram-se perfis de temperatura versus tempo da presa do cimento, e calcularam-se índices de compatibilidade. O plástico não tem problemas de compatibilidade com o cimento, e, como tal, a reciclagem de plásticos nesta forma será possível. No caso do pinho, a madeira de facto retarda a presa do cimento em certa extensão. Portanto, as propriedades físico-mecânicas de aglomerados cimento-madeira também deverão ser testadas se se pretender reciclar madeira desta forma.

PALAVRAS-CHAVE

madeira, plástico, cimento, compósitos, reciclagem

1. INTRODUCTION

Cement composites offer a possibility for the recycling of several wastes, namely wood and plastic residues. Beyond the environmental and economical benefit of turning a waste into a raw material, thus avoiding the disposal of waste, with the concomitant costs and use of landfill space, wood- or plastic-cement composites may have enhanced properties. Comminuted wood or plastics can work as reinforcing agents and as a filler to lower the density of concrete. Also, wood-cement composites have several advantages when compared to solid wood: they are generally more resistant to biodeterioration, to moisture and to fire.

But, for recycling of wood or plastic in cement composites, these composites must have the desired levels for physico-mechanical properties. Examples of such properties are modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), thickness swelling (TS), density (D), etc.

If we are adding materials to the cement chemical system we may disturb the hydration reactions that lead to cement setting. With wood-cement composites there has been active research for the assessment of their physico-mechanical properties, in which degree such properties can become lowered because of cement setting hindrance, and about the mechanisms of the disturbance of cement setting reactions.

For a long time, extractives have been pointed out as the wood chemicals that are responsible for cement setting hindrance (Hachmi and Moslemi, "Effect of Wood"; "Correlation"). These studies correlate the amount of extractives in several wood species with the degree of incompatibility, as assessed by physico-mechanical testing. But other studies went into detail enough as to identify extractive chemicals. For example, in *Acacia mangium* Wild., teracacidin with a 7,8-dihydroxyl group in a leucoanthocyanidin structure, was found to have a strong inhibitory effect (Tachi et al.). As another example, in the heartwood of sugi (*Cryptomeria japonica* D. Don), sequirin-C and pinitol were found to be the main inhibitory components (Yasuda et al.). Latter, Pereira et al. ("Extractive Contents" and "Adsorption of Cations") have shown that the known ability of wood to act as a cation-exchanger material may also contribute for cement setting hindrance. Cations, like Ca^{2+}, which has an essential role in cement setting reactions, are removed partially from solution by adsorption, with a concomitant release of H^+ ions.

The assessment of the compatibility between any reinforcing material and cement can be carried out by making use of methods that belong to two wide groups: physico-mechanical testing (as already mentioned) and calorimetry. In the scope of the first group of tests, properties like MOR (modulus of rupture), MOE (modulus of elasticity), when manufacturing panels (Wei et al.), or compression of cylindrical samples (Lee and Hong), have been assessed.

Calorimetric methods are based on the exothermic nature of cement setting reactions. Thus, hindrance of cement setting can be studied either by measuring the amount of heat evolved or by registering the evolution of temperature along time. The lower the amount of heat evolved in comparison to a cement-only paste, the more incompatible is a given wood species (Hachmi and Moslemi "Correlation"). With temperature profiles, the higher the slope of the initial part of the temperature vs. time plot, or the higher the temperature reached in the process, or the shorter the time to reach the maximum of temperature, the less incompatible is the wood species being studied (Pereira et al. "Characterisation of the Setting").

The research work presented here aims at studying the compatibility between maritime pine wood and cement, and also between plastic and cement, as a first assessment to recycle wood and plastic in the form of cement composites. The methodology is based on the registration of temperature vs. time profiles, and the calculation of compatibility indices with thermal parameters obtained from the plots. This is because only if they are compatible with cement can wood- or plastic-cement composites be manufactured with the desired levels for physico-mechanical properties.

2. MATERIALS AND METHODS

Wood was provided by a particleboard plant. The company is a manufacturer of wood-based panels. Such panels have the inner layer made of coarse particles and the faces made of MDF fibre. For this research work is was used only wood particles that are applied for the inner layer. The company recycles a lot of wood for the industrial process input. Therefore, truly, the furnish is a mix of wood species, that includes some tropical hardwoods. However, the most part is comprised of maritime pine (*Pinus pinaster* Ait.), and the wood particles used in this work were supposed to be made of maritime pine only. Wood particles were applied as received, and were not processed further. Storage was made in a plastic bag.

Because of its similarity to pine wood in terms of specific heat, LDPE (low-density polyethylene) was chosen as the kind of plastic to be used in this research project. Distilled water 5-litter bottles made of LDPE were first cut with a scissor in pieces about 2.5 x 2.5 cm. Then, cuts were ground in a common kitchen mini chopper to a size of about 5 x 5 mm.

Cement was provided by a cement manufacturer. In order to have strong exothermic cement settings, it was used the cement brand Portland Class I 42,5 R of CIMPOR. Storage was made in plastic bags for about 8 weeks.

Given the range of 0.55 – 0.70 kcal kg^{-1} K^{-1} for the heat capacity of LDPE, and of 0.6 – 0.67 kcal kg^{-1} K^{-1} for pine wood, as found in the scientific literature, it were taken the averages of these range limits as specific heats for calculation purposes; i.e., 0.625 kcal kg^{-1} K^{-1} for LDPE, and 0.635 kcal kg^{-1} K^{-1} for pine wood.

The amounts of LDPE and wood applied for cement pastes were such that the heat capacity of either pastes were the same. Therefore, to have a cement:wood ratio of 13:1 (in mass), pastes were prepared by mixing thoroughly 200 g of cement, 70 mL of water and 15 g of wood, or 15.24 g of LDPE. The paste for reference comprised only 200 g of cement and 70 mL of water. Pastes were worked out for about 5 minutes.

Just after being prepared, pastes were wrapped in aluminium foil and transferred to a thermos flask as a tentative adiabatic reactor. After that, a thermocouple was inserted and the thermos flask was closed. The thermocouple was connected to a data logger, OMEGA OM-PLTC. Temperature was then registered each 10 minutes, and stored in a personal computer with the software provided by the data logger manufacturer. Cement pastes were left to set, and temperature was registered, for 24 h.

Cement set runnings were made in triplicate; when at least one of the temperature vs. time profiles was not close to the other two, a fourth running was made. Then, temperature vs.

time profiles were drawn. In the plots, each point is the average of the difference between cement and room temperatures obtained at the given time.

3. RESULTS AND DISCUSSION

Figures 1 to 3 show the temperature profiles for the setting of cement-only, cement plus wood and cement plus plastic. The 3 temperature profiles for cement only were fairly reproducible; those for cement plus plastic were quite reproducible; however, those for cement plus wood were far from being reproducible. That is why 4 runs were made in this case. The natural inherent variability of wood must play here its role.

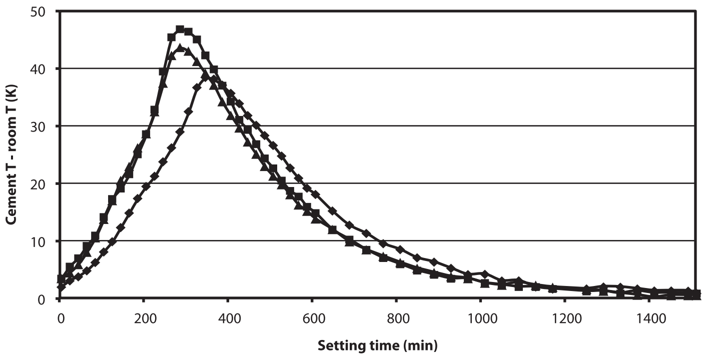

Figure 1. Temperature vs. time profiles for the setting of cement only pastes.

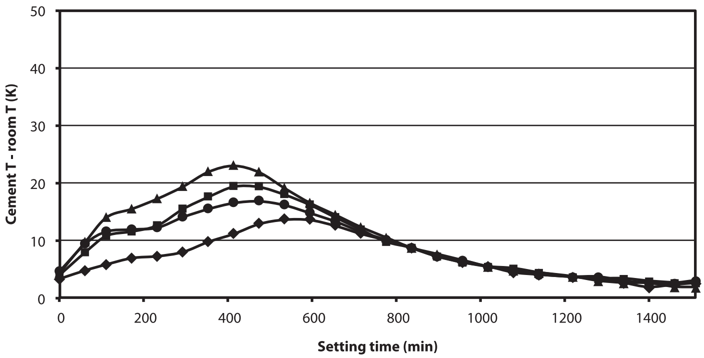

Figure 2. Temperature vs. time profiles for the setting of cement plus wood pastes.

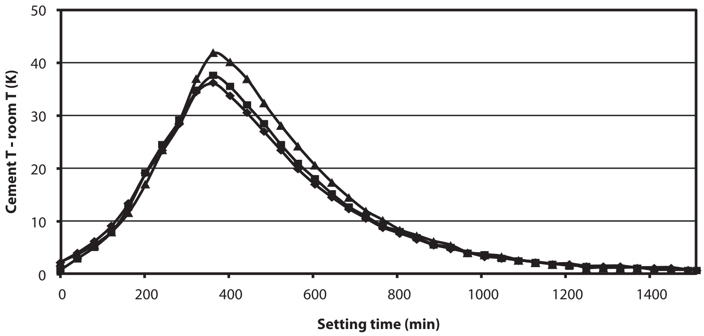

Figure 3. Temperature vs. time profiles for the setting of cement plus plastic pastes.

Figure 4 compares the average temperature profiles of cement-only paste, with that of cement plus wood and that of cement plus LDPE. LDPE does not interfere with cement setting in a great extent. However, on the other hand, wood imparts a significant degree of hindrance on cement setting.

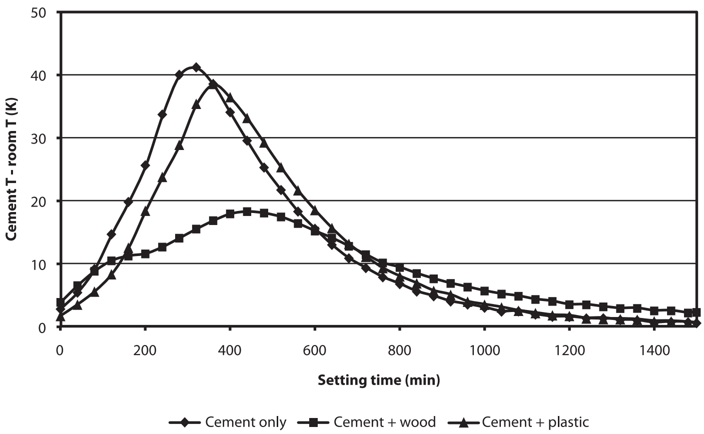

Figure 4. Average temperature vs. time profiles for the setting of cement-only paste, cement plus wood and cement plus plastic.

Compatibility indices enable people to make quantitative comparisons of temperature profiles. Table 1 shows several compatibility indices calculated after the temperature profiles, which definition is as follows:

$I(T) = T_{max}(s)/T_{max}(c)*100$

$I(S) = S_{max}(s)/S_{max}(c)*100$

$I(t) = t_{max}(c)/t_{max}(s)*100$

$I+ = [I(T) + I(S) + I(t)]/3$

$Ix = [I(T) * I(S) * I(t)]^{(1/3)}$

where:

T_{max} means maximum temperature reached during cement setting

S_{max} means average slope of temperature vs. time plot, from the beginning until T_{max} is reached

t_{max} means time elapsed since the beginning of cement setting until T_{max} is reached

"c" refers to neat cement paste as reference

"s" refers to paste made of cement plus wood or plus LDPE

Table 1. Thermal parameters obtained after cement setting runs, and thermal indices calculated with them.

Paste	T_{max} (K)	S_{max} (K(min)	t_{max} (min)	I(T)	I(S)	I(t)	I+	Ix
Cement only	42.0	0.197	319	-	-	-	-	-
Cement + wood	19.0	0.033	460	45	17	69	44	38
Cement + plastic	39.5	0.129	357	94	65	89	83	82

The thermal parameter where the interference of wood or LDPE is more pronounced is S_{max}, as among the 3 thermal parameters, it was in that one where lowest values were obtained. This means that setting speed of cement was lowered by adding wood, and in a lower extent by adding LDPE. Then it comes T_{max} of cement plus wood in terms of lowering degree; in these terms, LDPE affected almost nothing cement setting.

Indices I+ and Ix combine the 3 indices referred above. They show that both wood and LDPE affect cement setting. However, wood a lot and LDPE a little.

This research work aimed also at checking if just the presence of wood or LDPE would affect cement setting by absorbing heat. Such an effect would lower T_{max}. Indices show that this is not the case. The absorption of heat, because of the heat capacity of LDPE, did not affect significantly T_{max}, if it had any influence. Because the heat capacity of LDPE in cement pastes is the same as that of wood, one may conclude that heat absorption does not play a significant role in cement setting hindrance.

The same conclusion can be obtained by calculation. Cement has a specific heat of 0.20 kcal Kg^{-1} K^{-1}. Thus, a neat cement paste (200g cement + 70 g water) has a heat capacity of 110 cal K^{-1}. On the other hand, cement plus wood paste (200 g cement + 70 g water + 15 g wood) and cement plus LDPE paste (200 g + 70 g water + 15.24 g LDPE) have the same heat capacity. That is 120 cal K^{-1}. Therefore, the addition of pine wood or LDPE into the cement paste only increases the heat capacity by 9%. Which is a very small increase.

As a conclusion one can say that recycling of plastics in plastic-cement composites does not pose any questions regarding chemical compatibility between plastic and cement. Plastic--cement composites should not present physico-mechanical properties lowered in a significant extent because of the inclusion of plastic.

In the case of wood, however, the manufacture of wood-cement composites with recycled wood must be undertaken with care. The compatibility of wood with cement must be assessed. Such assessment can be carried out first by calorimetry. Temperature profiles obtained with cement plus wood pastes may be compared with those obtained with cement only pastes, as reference. Another way of applying calorimetry is by the measurement of the heat evolved during cement setting.

Calorimetric assessment must be complemented by physico-mechanical testing. This is because, eventhough wood usually hinders cement setting, with many wood species it is possible to obtain cement composites with physical and mechanical properties that accomplish with the relevant industrial standards. It is the case of maritime pine (Pereira et al. "Characterization of Cement-Bonded").

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