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RECYCLING TEXTILE RESIDUES INTO CEMENT COMPOSITES

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Abstract

Changing wastes into raw materials is one of the most favored options for waste management, as it diverts wastes from landfill and saves resources. Fibers, either vegetable (cellulosic) or synthetic, may be added to cement pastes in order improve the properties of concrete or mortar by reinforcement. At the same time, if the source of fibers is wastes, then such processes make ways for recycling. In the work described here we studied the compatibility of residues from the nonwoven textile industry with Portland cement, with the aim of manufacturing reinforced fiber-cement composites. The methodology was based on the monitoring of the temperature of cement setting, and when fiber or other materials were added to cement pastes. Results showed that the textile waste from needling machines investigated here is not compatible with cement. The reason is ascribed to a higher cotton content (65%), which enables cation exchange to occur in cement suspensions, and that disturbs cement setting reactions. On the other hand, however, synthetic fibers do not seem to hinder cement setting.

Key words: cement, compatibility, recycling, textile, waste

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1. Introduction

Fibers or wood chips can be added to cement pastes in order to enhance the properties of concrete or to make construction materials. Namely, wood-cement panels are in the market of materials for pre-fabricated construction. Fibers, of any kind, may improve the concrete properties by reinforcement (Summerscales et al., 2010).

Wood-concrete is lighter than a regular concrete. A typical value for the density of wood-cement panels is 1.5, hence approximately half that of a common concrete. Wood-cement composites are easier to work, because they can be sawn with a common saw, shaped, drilled, nailed and sanded readily. On the other hand, wood-cement composites are better in some ways other than wood-composites. They present a higher resistance to biodeterioration, to fire and to moisture, and they have no binder that may emit free formaldehyde. Also, wood residues and fiber residues may be used in wood-cement composites, giving a possibility for a more appropriate way of waste disposal, which is recycling.

Coconut husk particles have been used in cement composites with calcium chloride ($CaCl_2$) as a compatibility enhancer (Olorunnisola, 2009), and also eucalypt and poplar wood wool (Ashori et al., 2011). It has been possible to manufacture wood-cement particleboards to compete with gypsum boards, with the same average density (0.7) and with better bending and screw-withdrawal properties (Tittelein et al., 2012). Furthermore, Pinto et al. (2011) and Paiva et al. (2012) have proposed corn cob particle boards as possible alternative for thermal insulation panels.

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Also, Pinto et al. (2012a) have focused on characterizing corn cob as a possible building material, taking into account that this organic product is taken as an agricultural waste. Also, for corn cob recycling purposes, Pinto et al. (2012b) suggested the application of corn cob as a sustainable aggregate for lightweight concrete manufacturing. In addition, Binici et al. have explored the possibilities of the application of agricultural wastes in inorganic matrix composites (Binici et al., 2012, 2014; Binici and Yardim, 2012; Binici and Aksoğan, 2015).

Bleached and unbleached eucalypt pulp fibers both have their own advantages for the reinforcement of cement-based composites (Tonoli et al., 2010a). The effect of the length of vegetable reinforcing fibers in engineered cement composites has been assessed, using eucalyptus fiber, as a hardwood short fiber, and pine fiber, as a softwood long fiber (Tonoli et al., 2010b). Characteristics of vegetable fibers, like fiber shape and morphology, that are irregular along fiber length, as opposite to synthetic fibers, play an important role in the bond strength (Silva et al., 2011).

There is already research going on that is focused on the development of possible building applications for textile materials and wastes. For instance, Marques et al. (2010) proposed a textile based reinforcement of lightweight concrete elements. Meanwhile, Paiva et al. (2011) studied the potential of textile waste as an insulation material for double external brick masonry walls. Peixoto et al. (2012) studied the advantages of reinforcing cement-based coating mortars with the incorporation of textile threads waste. Binici et al. (2013) have investigated the addition of carbon and acrylic fibres in the reinforcement of mortars. Also, Sen and Jagannatha Reddy have studied jute (Sen and Jagannatha Reddy, 2013; 2014a), and sisal and artificial carbon and glass fabric (Sen and Jagannatha Reddy, 2014b) in reinforced concrete beams. Furthermore, Abdullah et al. (2011) have applied SEM – Scanning Electronic Microscopy to obtain information on the fracture behaviour of coconut fiber reinforced cement composite.

The methods used for research and for manufacture of wood-cement composites can be adapted to a diversity of raw materials, which may include fibrous wastes like textile fibers. In order to assess the feasibility of reinforcing concrete or manufacturing cement panels with textile residues, and at the same time looking for a recycling technique, we have investigated waste fibers from the production of nonwoven fabrics. Cement pastes were prepared with these fibers, or with 100%-cotton fiber or with plastic particles, these latter for comparison purposes. With each experimental condition, the cement setting process was monitored by registering the temperature. The comparison of the temperature profiles, together with thermal parameters taken from temperature data, gave information on the extent of cement hardening and, hence, on the compatibility, and/or suitability, of recycling textile residues by incorporating them in cement composites.

2. Material and methods

The fiber residue used in this study was provided by a manufacturer of nonwoven fabrics. The raw material used by that company is actually waste from fabric and cloth manufacturing. That is saying, they recycle wastes of those industries in nonwoven fabrics. The rags they receive are cut mechanically with knifes, then torn and, finally, shredded to fiber. Then these fibers are spread into a mattress and enter into a needling machine. This mattress is pressed and the fast up-and-down movement of a transverse steel beam where numerous needles are attached makes the interlocking of the fibers, which in turn makes a thick fabric. The main fibrous residue of such nonwoven fabrics, which is investigated in this work, is the thin and short fibers that drop from the needling machine. We were informed that this residue should contain about 60% of cotton and the remaining being mostly polyester. The company has no way so far of recycling this residue.

The cement used was provided by a Portuguese cement manufacturer. Because we need a strong exothermic cement setting, so that a temperature profile can be obtained, cement Portland Class I 42.5 R of CIMPOR was used. The fiber residue and the cement were stored in plastic bags for a maximum of 3 months.

Fiber moisture content was measured by placing duplicate samples of it, of about 15 g in weight, in an oven where the temperature was set at 105 ± 3ºC for an overnight period. Wet and dry weights, rigorous up to 0.0001 g, were used to calculate moisture content on a dry basis.

The cotton percentage in the fiber residue was determined by adapting the Klason lignin method. This method is commonly used to analyze the content of lignin in a given wood or pulp sample (TAPPI T222 om-88, 2006), and is based on the total hydrolysis of polysaccharides by strong acid leaving the condensed lignin as a solid residue. In our case, the cotton fraction of the residue was totally hydrolyzed, leaving synthetic fibers as an insoluble residue. The procedure applied is as described in the following. To a fiber sample, with a weight of about 1.0 g, but weighted to 0.0001 g, it was added 15 mL of 72% sulfuric acid (H_2SO_4) and this mixture was left to react with stirring for 24 hours at room temperature. After that, the mixture was transferred to a 1 L-round bottomed flask and to it was added 560 mL of distilled water to lower the concentration of the acid to a value of 3%. It was then refluxed for 4 hours. After cooling, the mixture was filtered. The filter, with the remaining fiber, was dried at 105 ± 3ºC for 2 hours. Dry weights of the fiber sample before and after this hydrolysis procedure were used to calculate the percentage of cotton in the fiber residue. Cotton percentage determination was done in duplicate.

The apparatus for cement setting monitoring involved the use of a thermally isolated plastic flask (thermo flask) and a thermocouple that was connected to a data logger OMEGA OM-PLTC, which was linked to a desktop computer. Temperature data were acquired with software provided by the data logger manufacturer. Temperature was registered every 10 minutes and each total test took 24 hours.

Cement pastes were produced as a mixture of cement, water and fiber residue. For comparison purposes, we have also included in the experiments small pieces (about 5 x 5 mm) of LDPE (low-density polyethylene) and 100%-cotton fiber. The 100%-cotton fiber we have used is the one used by the nonwoven fabrics company for their products, and is known commercially as "cotton seeds". It is a sub product of the cotton production and processing industry. So, it was not bleached.

Cement pastes were a mixture of 200 g of cement, and 70 g (or mL) of water, and given quantities of waste fibers (or 100%-cotton or plastic (LDPE)) to achieve several cement to fiber residue weight ratios, as follows: neat cement; cement:fibre residue 10:1; cement:fibre residue 5:1; cement:plastic 10:1; cement:plastic 5:1; cement:100%-cotton 10:1; and cement:100%-cotton 5:1. Calcium chloride ($CaCl_2$), a common cement setting accelerator, was used as cement-fiber compatibility enhancer. It was added to cement:fibre residue 10:1 pastes at a rate of 4% of cement, therefore 8 g of $CaCl_2$ for each batch, and it was diluted in the water prior to paste formation. Only this condition was experimented with $CaCl_2$.

Pastes were worked out for 5 min, they were then wrapped in aluminum foil and transferred to the thermo flask. The thermocouple wire was inserted in the paste and the remaining empty volume of the flask was filled with pieces of Styrofoam. The flask was then closed and the software for temperature data acquisition was activated.

3. Results and discussion

The stock of fiber residue from the needling machines used in the current research had 0% moisture content, and no correction in weight was needed when weighing fiber portions for cement pastes. The percentage of cotton in this residue as measured by the "Klason lignin" method was 65%. The remaining must be almost all polyester.

Fig. 1 shows the average temperature profiles obtained with the conditions indicated before for cement setting. Actually, to make easier the reading of such figure some conditions are omitted. Because the conditions "Plastic 10:1" and "Plastic 5:1" gave similar thermograms, only the latest is shown because, if it was the case, this was the condition where the plastic would give the highest interference due to the lowest cement proportion. We want to demonstrate that plastic does not hinder significantly the cement hardening. Also omitted is "Fiber residue 10:1". Here we are concerned about demonstrating that the fiber residue hinders a lot, even if cement is in the highest proportion. The condition "Fiber residue 10:1" gives only a relatively higher peak than "Fiber residue 5:1", around 700 minutes. The thermograms with 100%-cotton could almost be superimposed. So, only the condition "100%-cotton 10:1" is shown.

As shown by the pronounced decrease in the peak temperature (T_{max}) relatively to the neat cement, and by a lengthen in the time to reach that temperature, the fiber residue interferes considerably with the cement hardening. Such interference is so drastic that even using $CaCl_2$ dissolved in the water for the cement pastes, it did not have a significant rise in T_{max}; only t_{max} was shortened because of $CaCl_2$, but not much.

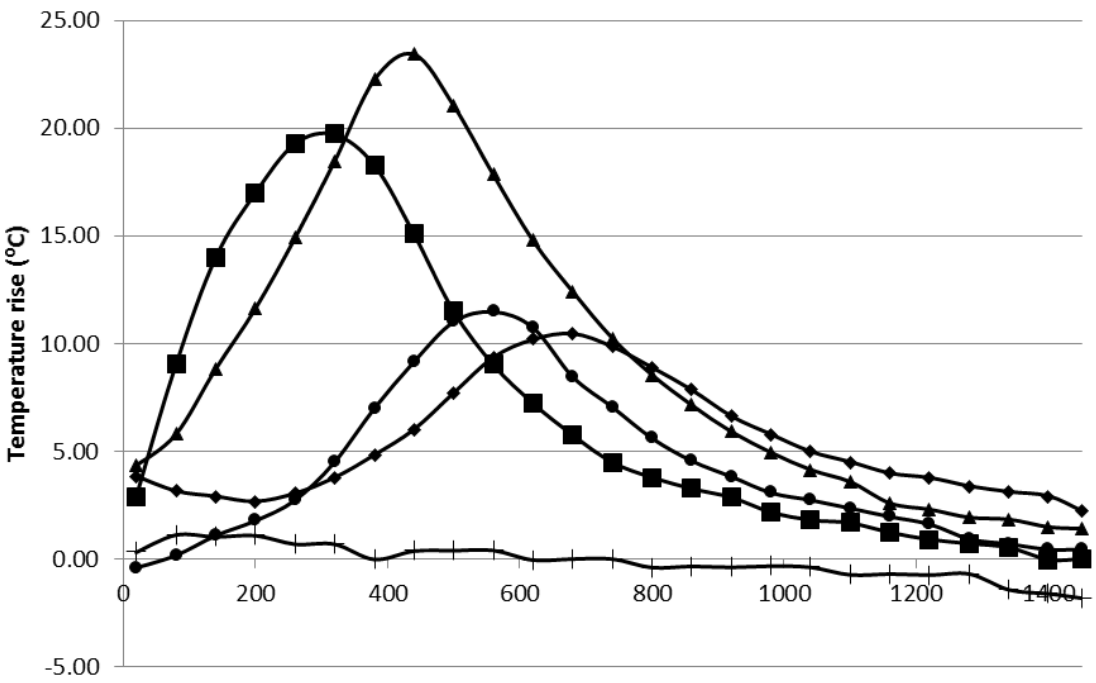

Fig. 1. Temperature profiles of cement setting obtained in the different conditions experimented

In order to demonstrate that cotton is the component of the fiber residue that hinders cement setting, we have used plastic (LDPE) mixed with cement. Plastic, probably because it is an inert material, in terms of the chemical and surface interaction, it does not seem to hinder cement setting in a significant extent. Its thermogram shows only a small decrease in the peak temperature, but nevertheless, cement hardening was somewhat faster. Because of this, we do not assign to the polyester fraction of the residue the interference in cement setting shown by the fiber residue as a whole.

On the other hand, we have used also 100%-cotton mixed with cement. The main result showed by the thermogram is basically that heat is not generated and, hence, cement did not set. This could be seen during the experiments by the total lack of integrity of the pastes after temperature recordings. Because of this, we assign to the cotton component the origin of the hindrance in cement setting showed by the fiber residue.

These qualitative considerations can be expressed in quantitative terms, as explained next. From each thermogram of cement setting, the following three measures were obtained:

T_{max} – highest temperature reached in the process;

S_{max} – maximum slope of the T vs. t curve, usually observed in the pronounced temperature rise that precedes T_{max}; and,

t_{max} – time interval between the beginning of the test and T_{max}.

Also, with these raw data several compatibility indices may be calculated. What we call "simple indices" are defined as (Eqs. 1-3):

$$I_T = \frac{T_{max}(s)}{T_{max}(c)} \times 100 \quad (1)$$

$$I_S = \frac{S_{max}(s)}{S_{max}(c)} \times 100 \quad (2)$$

$$I_S = \frac{t_{max}(c)}{t_{max}(s)} \times 100 \quad (3)$$

where: "c" refers to the reference condition of only cement and water (neat cement); "s" refers to the experimental condition of a paste of cement, water and something else.

If each of these indices compares alone the reference condition and the experimental condition in terms of T_{max}, S_{max} or t_{max}, we can also define "composed indices" that combine the three basic indices indicated above. That is, composed indices compare the reference condition and the experimental condition involving at the same time T_{max}, and S_{max}, and t_{max}. Among many possibilities, here we use the arithmetic and the geometric averages of I_T, I_S and I_t (Eqs. 4 and 5):

$$I^{+} = \frac{I_T + I_S + I_t}{3} \quad (4)$$

$$I^{\times} = \sqrt[3]{I_T \times I_S \times I_t} \quad (5)$$

Table 1 shows the values of the raw parameters, as taken from all experimental conditions of cement setting, and the values of the indices calculated with them.

T_{max} was highest for neat cement, but followed closely by plastic. The fiber residue performed poorly, and the addition of $CaCl_2$ showed only a small improvement. Because no thermogram was obtained with 100%-cotton, no thermal parameters could be derived. As seen by S_{max}, the conditions with plastic were somewhat better than for neat cement. The fiber residue showed poor performance, but we can distinguish clearly among the experiments with the fiber residue. Fiber residue 10:1 was better than fiber residue 5:1, due to the higher cement proportion, and the influence of calcium chloride is seen, but fiber residue 10:1-thermogram is still far from neat cement.

Concerning t_{max}, pastes with plastic were somewhat more reactive than neat cement. The fiber residue hindered cement setting a lot. Calcium chloride, although it made some improvement, could not bring the setting of pastes with the fiber residue to near that of neat cement.

Composed indices show that plastic 10:1 was better, followed closely by plastic 5:1. Fiber residue 5:1 showed to be the worst condition, apart from 100%-cotton, followed by fiber residue 10:1, and then by calcium chloride in the fiber residue, all far short of the neat cement even though a setting accelerator was used.

Because many species of wood are known to hinder cement setting when wood-cement composites manufacturing is attempted, and that such interference can be so big that ultimately materials have no physical integrity, as a first approach we ascribe to the high cotton content of the fiber residue the reason why cement does not set in a reasonable extent. Also, evidence is presented here that 100%-cotton, or cellulose fiber, hinders substantially cement setting.

The traditional explanation for this phenomenon has been lying on lignocellulosic material extractives, i.e. organic compounds of low molecular weight that enter into solution when lignocellulosics are soaked in water, in solvents or in chemical solutions (Hachmi and Moslemi, 1989). Some studies have identified the molecules of the interfering extractives (Tachi et al., 1989).

However, as cotton used in textile blends has been bleached before, it should contain no extractives. Even though, we can still ascribe to cotton the cause of such interference.

Pereira et al. (2003) demonstrated that when lignocellulosic materials are soaked into cement suspensions, cation exchange occurs. Lignocellulosics readily adsorb cations like calcium and release hydrogen ions (Pereira et al., 2005). Such cation exchange is likely to disturb cement setting reactions, where calcium plays a key role.

Table 1. Values of raw parameters taken from temperature profiles, and of compatibility indices calculated with them

Experimental Condition	T_{max} (ºC)	S_{max} (ºC/min)	t_{max} (min)	I_T	I_S	I_t	I^+	$I^\times$
Neat cement	23.55	0.0553	430	-	-	-	-	-
Fiber residue 10:1	10.48	0.0272	650	44.5	49.2	66.2	53.3	55.8
Fiber residue 5:1	8.09	0.0096	670	34.4	17.4	64.2	38.6	35.0
$CaCl_2$	11.38	0.0426	550	48.3	77.0	78.2	67.8	74.2
Plastic 10:1	21.34	0.0613	330	90.6	110.8	130.3	110.6	116.9
Plastic 5:1	19.72	0.0548	330	83.7	99.1	130.3	104.4	110.5
100%-cotton 10:1	-	-	-	-	-	-	-	-
100%-cotton 5:1	-	-	-	-	-	-	-	-

As suggestions for further research, if these results show that the fiber residue interferes considerably with cement setting, as seen from the thermal behavior of cement setting, it could be assessed how far this interference is reflected in concrete and mortar properties. Future research will focus on tests on concrete and mortar samples to assess mechanical properties (e.g. compression and flexure strength), workability, durability, permeability, among others.

The microstructure and the elemental composition, identified by performing analysis by Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS), will also complement the research reported here, in the same way as it was carried out by Pinto et al. (2013).

4. Conclusions

The experimental results reported in this paper indicate that a fiber residue from the nonwoven textile industry with a high cotton content (65%), being the remaining synthetic fiber (polyester), is not compatible with cement. Cement does not set in a full extent, as seen by temperature monitoring.

The reason for this drawback is ascribed to the higher cotton content of the textile residue, by means of a cation exchange phenomenon that occurs on cotton fiber surface when it is added to cement pastes, and that will disturb cement setting reactions. On the other hand, synthetic fibers do not seem to hinder cement setting, which makes them promising for concrete or mortar reinforcement.

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