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RECYCLING OF TEXTILE FIBERS FOR THE PRODUCTION OF FIBRE-REINFORCED CEMENT*

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Abstract

This research analyzes the possible recovery of waste textile fibers as reinforcements for components made of cement. The study showed how the use of waste textile fibers for the reinforcement of components produced with cement paste represents an advantageous and feasible possibility for building applications. In detail, we used waste fibers produced during the finishing of fabrics, sampled at a textile company in Carpi. The fibers were characterized whit IR techniques, optical and electronic microscopic analysis, and subjected to pre-processing to increase their workability. With these fibers, joists were prepared in both cement paste and mortar. After maturation, the samples were characterized by bending test, optical microscopy analysis and withdrawal characterization. The results showed that the fibers used as reinforcement led to an increase in the mechanical properties of the samples with an increase in their percentage. In addition to the increase in bending load, a marked increase in toughness was observed, which is significantly higher in samples with fibers than in the reference white. The workability loss observed is relatively limited and in any case can be compensated with the addition of fluidizers. Ultimately, the possible use of waste textile fibers for the production of fiber-reinforced cement or mortar was demonstrated.

Keywords: recycling, textile fibers, cements, fiber-based

1. Introduction

Every year tons of waste produced by the fashion system are disposed of in landfills, although there are several studies that have highlighted the possibility of recycling and reuse, which would allow reducing the quantities of material disposed in the landfill. The ISPRA data (Special Waste Reports, 2017) identify that 37.4% of non-hazardous waste produced by

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the Italian manufacturing sector comes from the textile, clothing and industrial tanning sector. In fact, the economic model that has spread in recent decades is of the "linear" type, focusing on mass production and continuous growth in the market, without taking into account the quantities of waste produced.

Textile waste can be divided into two types: from clothing (clothes at the end of life) and from processed textile fibers (products from the textile industry). As for the waste from processed textile fibers, these are composed of fabrics, scrap pieces, waste yarn, waste fibers from processing, such as shearing, teaseling, finisching, and sampling. For the year 2015 the waste from textile industry in Italy is about 342 thousand tons (Special Waste Reports, 2017).

In our research we used fiber processing waste, in particular we used the waste produced by the finishing of fabrics. Recycled textile fibers, used for experimental research, are produced in the factory of the textile finishing company Stellatex (Carpi, Italy). In particular, raising and shearing machines present in the Stellatex factory are responsible for the production of waste fibers. The raising machine is used to form a fluff on the treated fabric, this treatment is done to increase heat insulation and to improve aesthetics. The shearing is used to cut the fluff from the fabric at a defined and adjustable height. During the shearing process suspensions of fibrous material in the air is generated. This fibrous material is aspirated with a special suction tube system, this conduit continues to the outside of the building where the suction pump and filtering air systems are located.

The recovered waste material is formed by microfibers of various types and sizes depending on the type of fabric being worked. A company like Stellatex produces 35 tons / year of this waste, depending on the quantity of fabrics processed during the year. It is estimated that in Italy the quantities produced by the entire finishing sector can be at least 5.000 tons / year.

The main purpose of this study is to analyze the possible recycling of waste microfibers produced in the finishing of fabrics in the production of fiber-reinforced cement components. In particular, the influence of microfibers on the mechanical properties, on the workability of the cement pastes produced and on the thermal properties of the manufactured articles were analyzed. The use of fibers for the production of cementitious matrix composites (fiber-reinforced cements, FRC) is consolidated over time (Aziz and Ansell, 2004; Shah and Rangan, 1971). The use of fibers improves the ductility of the cement conglomerate in the phase following the beginning of the cracking phenomenon, this take to a reduction of the brittle behavior of the cement matrix. The presence of fibers increases the toughness, prevents the propagation of the cracks, which are due to the onset of tensile stresses and at doses higher than 2% the fibers improve the bending load, tensile load, and shear strength (Andersons et all., 2006; Marchetti and Cutolo, 1991). Other strengths of fiber-reinforced cement mixtures are greater resistance to fatigue, greater impact resistance, greater resistance to thermal stress, and decrease of post-hardening linear shrinkage. This fiber behavior is linked to the "stitching" effect that the fibers develop in the cement matrix, increasing its resistance. The addition of fibers carry out to a reduction in the workability of the cement mix. The fibers normally used, are in steel, polypropylene, aramid, and glass, in recent years, research has been carried out on the use of natural fibers in particular hemp and cotton (Bledzki and Gassan, 1999; Sgriccia et al., 2008). The textile fibers have a structure similar to natural fibers, which suggested the possibility of using them for the production of FRC composites. With the use of textile fibers an improvement in the mechanical properties can be expected, in particular in the flexural modulus and in the breaking strength. However, given the structural difference between textile fibers and commercial fibers, we do not expect values similar to those of a FRC for structural use. Another interesting parameter is thermal conductivity, by inserting textile fibers that have low thermal conductivity in the cement, an overall reduction in conductivity of FRC is likely.

This work is divided in four main parts:

a) Sampling and characterization of recycled fibers, sampling was carried out by taking fiber fractions every week for a period of 6 months. This activity was necessary to obtain a representative sample of the microfibers produced in the Stellatex activity;

b) Preliminary treatment of the fibers;

c) Realization of the FRC samples using different percentages of fibers;

d) Physical-mechanical characterization of the samples produced and analysis of the data obtained.

2. Materials and methods

The fiber used is a mixture of microfibers obtained from the air purification plant of the Stellatex company. The material was characterized by IR analysis, and electron microscopy to obtain the fiber composition and their morphology. For IR analysis a FTIR Thermo-Nicolet Nexus has been used. In addition to these parameters, the fibers were analyzed to determine the water content and its water absorption. The importance of these parameters is due to the FRC sample preparation method. The preparation involves the dispersion of the powdered cement and of the fibers in water therefore, it is essential to know the behavior of the fibers in the presence of water. The absorption of water by the fibers would determine the variation of the water/cement ratio fundamental for the development of the final mechanical properties of the sample. The results obtained showed that the recycled fibers are dry, while immersed in water they absorb four times their weight. Using these data, research was carried out using both untreated and water-saturated fibers to verify the influence of the two conditions on the final properties of the samples. The saturated fibers are obtained by immersion in water at 25°C for 3 hours, filtered and left in the air at 25°C for 1 hour to remove the excess water.

In addition to the saturation treatment, part of the fibers was treated with NaOH in a 5% solution in water. This treatment was suggested by various studies, which show how the pretreatment of natural fibers with NaOH improves the adhesion properties between fiber and matrix and improve the mechanical properties of the fibers. In the treatment with NaOH the fibers are immersed in a 5% solution of NaOH for 30 minutes, then the fibers are washed in distilled water up to neutral pH. Finally, we proceed with drying the fibers in the oven at 80°C for 24 hours. The result of the treatment on the fibers is shown in the photo of Fig.1, where the increase in volume in the material after treatment is observed.

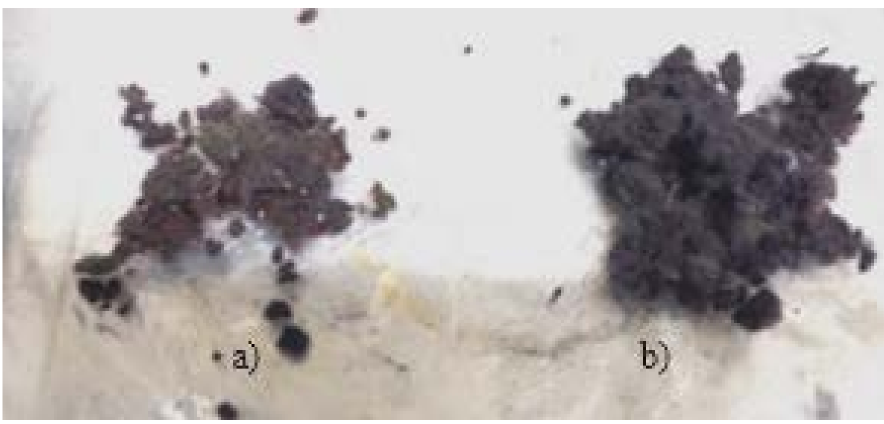

Fig. 1. Photograph of fibers a) untreated; b) treated with NaOH

For mechanical tests 5x3.5x30 cm joists were made by pouring in a wooden formwork, a Portland 42.5 R was used as cement. The joists were produced in cement paste using different percentages of fibers according to the compositions shown in table 1. The percentage of fibers is calculated as a percentage of the weight of the cement used and the fibers are considered dry. For each composition, five joists were made to obtain statistically comparable data. The samples produced were compared with reference beams produced with only cement and water with a 0.42 ratio. In the case of joists made with saturated fibers, the 0.42 water-cement ratio was obtained by decreasing the amount of water used. In practice it has been calculated the theoretical amount of water that the saturated fibers tend to yield to the mixture and subtracting it from the total of water used.

Table 1. Compositions of sample

Type of fibre	***% fibre***	***water-cement ratio***
Untreated	1; 2; 3; 4	0.42
Water-saturated	1; 2; 3; 4	0.42
NaOH treated	1; 2; 3; 4	0.42

As mentioned above, the joists are produced by casting in wooden formwork, at the end of each casting the formwork was vibrated to obtain maximum compaction; the joists are removed from the formwork after 72 hours. For a complete maturation and hardening of cement matrix, the joists ware placed in a climatic chamber at 23°C and 95% humidity until the 28th day after casting. After 28 day, the specimens were subjected a three-point bending test using the Instron 5567 testing machine using the UNI EN 12390-5 standard as a reference.

In addition to the mechanical properties, the linear shrinkage is measured to verify the effect of the fibers on this parameter, in fact one of the most delicate aspects of the cement mixtures is the hydraulic shrinkage, which leads to the formation of real cracks and fractures that already develop during laying and hardening of the material. The addition of fibers usually reduces this shrinkage, preserving the cement matrix from fractures.

To analyze the thermal conductivity of the FRC products, they were made of 30x30x3 cm concrete blocks. These blocks were made with casting in formwork using untreated fibers and cement, the water-cement ratio was 0.42 while the percentage of fibers used was 2%, 3%, and 4% percentage calculated relative to the weight of the cement. For the analysis of thermal conductivity, Netzsch HFM Lambda conductivity analysis system was used.

3. Results and discussion

The analyzes carried out on the recycled fibers used for the experimental part showed that these are composed of 60% pure cotton, 30% of cotton blend and 10% of synthetic material (Nylon, Viscose, Polyester). This result is obtained using IR analysis and electron microscopy, the IR spectrum of the fibers is shown in Fig. 2, while in Fig. 3 shows an image obtained by SEM. From the images, SEM emerges the impossibility to be able to measure the average length of the fibers given the strong intertwining of the threads, while the thickness can be evaluated on the order of 10 microns. As regards the measurement of linear shrinkage, the data obtained showed a reduction of up to 80% with the introduction of fibers (Table 2). In all cases, the shrinkage reduction is maximum when the fiber percentage exceeds 2%.

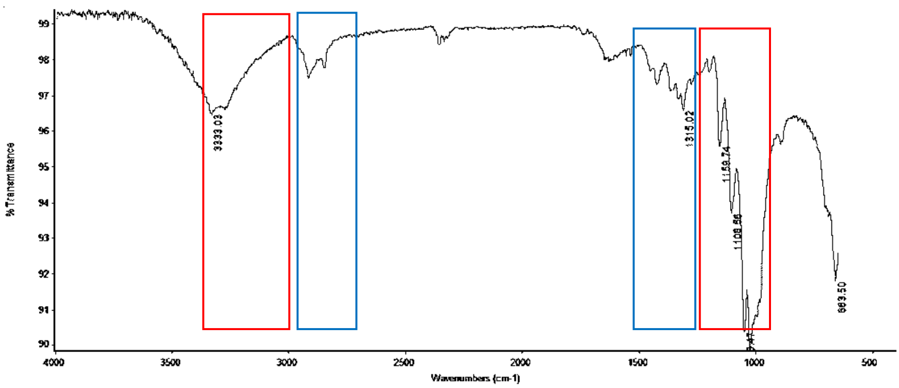

Fig. 2. Spectrum FT-IR of nontracted fiber. The red rectangles identify the peaks attributable to cotton, the blue rectangles identify peaks attributable to nylon and viscose fibers.

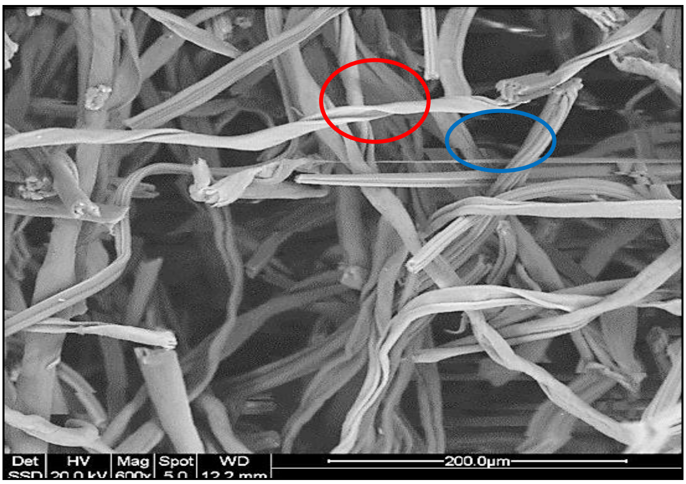

Fig. 3. Micrograph SEM of untreated fiber. The red circle indicates a cotton fiber; the blue circle indicates nylon and viscose fibers

The result obtained is in line with expectations given that the introduction of fibers has the consequence of reducing the linear shrinkage. The bending tests showed a significant increase in the value of the maximum bending load, as shown in the graph in Fig. 4, with values that quadruples with 4% of the fibers with respect to the reference sample data. The bending tests showed a significant increase of the maximum load value to bending as shown in the graph of Fig. 3 where it shows the average value of the maximum load measured. From the data in the graph, we can see how the samples produced with saturated fibers show an increase in the bending load up to 3% of added fibers, while the value of the load begins to decrease to 4% of added fibers. The data obtained, are probably related to the preparation of the sample because the amount of water used is reduced to compensate for the release of water from the saturated fibers. In practice, the samples have a real water-cement ratio of less than 0.42, which, as known, leads to an increase in the mechanical properties of cement products.

Table 2. Decreased percentage of linear shrinkage

% fiber	*Untreated, Δ%*	*Water-saturated, Δ%*	*NaOH treated, Δ%*
1	20	41	58
2	43	57	61
3	76	78	80
4	80	80	80

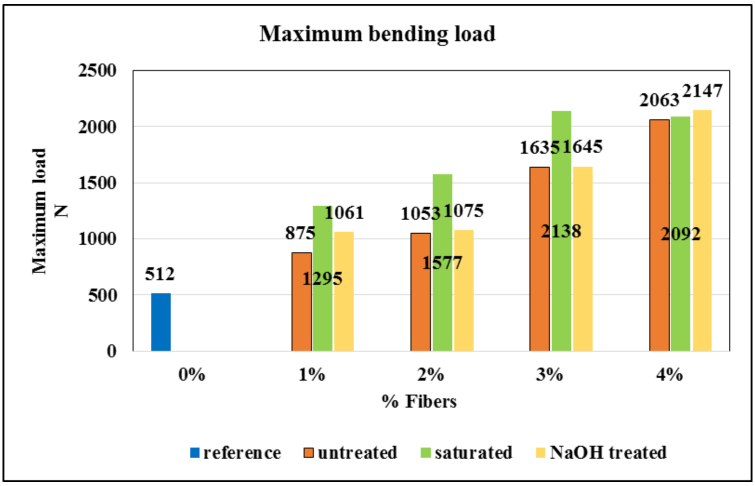

Fig. 4. Average value of the maximum bending load for FCR samples

With the saturated fibers was hypothesized that through the release of water would increase the amount of water in the water / cement / fiber mixture by returning the water to cement ratio of 0.42 reference value. In reality, from the data obtained it emerges that the release of water assumed by the fibers is not able to supply the quantity of water missing. Only with an addition of 4% fibers results come back in line with the other samples. The data obtained for the samples produced with untreated fibers and treated fibers with NaOH, have similar values, therefore the treatment with NaOH does not seem to improve the bending properties. It therefore appears that the fibers treated with NaOH do not determine better flexural properties in the FCRs than the use of untreated fibers. The specimen breaking sections were analyzed with Optika SZN 6 optical stereomicroscope to verify the dispersion of the fibers inside the cement matrix. The first information obtained is that the fibers inside the matrix have a high dispersion. Another information that emerged is the presence of accumulations of fibers that tend to increase with the increase in the percentage of fibers used (Fig. 5).

From the images of Fig. 6, we note how the action of the fibers appears after the cracking of the concrete, to the formation of the first cracks in the cement matrix the fibers are activated assuming a sewing effect of the openings creating a bridge (crack-bridging) between flaps of cracks. This involves a reduction in the width of the cracks and the fiber guarantees the concrete a residual resistance even in the post-cracked phase, this phenomenon is indicated as tensionsoftening. For the measurement of the thermal conductivity of the composites, as already mentioned, 30x30x3 cm concrete blocks were created, with 2% 3% and 4% fibers (Fig. 7). For each composition, three samples were made and four samples were taken on each sample.

Fig. 5. Images of the rupture surface of samples with: A) 1% of untreated fibers,
B) 4% nontreated fibers

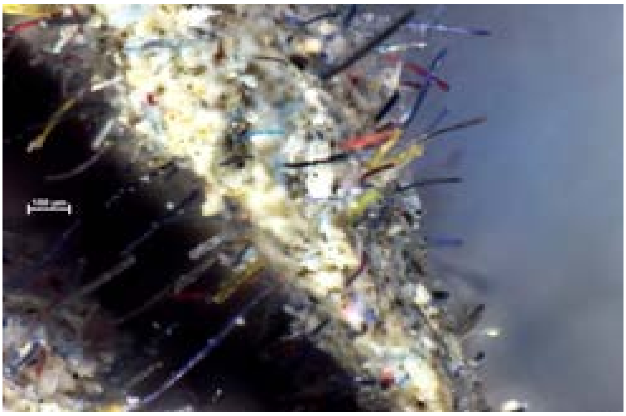

Fig. 6. Images of crack-bridging

Fig.7. Images of blocks of cement for analysis of thermal conductivity

Table 3 shows the averages of the thermal conductivity obtained. The results show the decrease in thermal conductivity with increasing percentage of fiber, with the value of Λ that was almost halved, it can therefore be inferred that the insulating power of the sheet is doubled.

Table 3. Thermal conductivity data

Fibers, %	*Thermal conductivity (W/(m·K)*
0	0.41
2	0.397
3	0.315
4	0.237

6. Conclusion

From the data obtained, the recycling of textile fibers in cement products can be an interesting option. Specifically, we can conclude with the following observations:

- The insertion of the recycled fibers inside the cement paste has led to a reduction in the hydraulic shrinkage, this figure improves with the increase in the percentage of inserted fibers.
- The results of flexural tests performed on the specimens show an increase in flexural strength, considering the different formulations, the best bending behavior was obtained using saturated fibers.
- Treatment of the fibers with NaOH does not increase the bending strength of the material, therefore the best solution is to introduce the fibers without any surface treatment or at most introduce them to the saturated state.
- The introduction of the fibers cannot exceed 4% by weight on the cement due to the loss of workability.
- As the percentage of fibers increases, the value of the thermal conductivity has almost halved and therefore the insulating power has doubled.

From the data observed, surely the introduction of recycled fibers is feasible to increase the insulating power of plaster and improve the shrinkage resistance of concrete floors. To continue the research activity, it will be interesting to study the use of superplasticizers in order to increase the dispersion of the fibers, improve the workability and increase the percentage of dispersed fibers.

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