REUSE OF NATURAL FIBER REINFORCED ECO-COMPOSITES INTO POLYMER MORTARS FOR LOW-COST CONSTRUCTION SECTOR

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ABSTRACT

During the last few years the potential of natural fiber-based polymer composites has received considerable attention, due to their promising specific properties and for both economic and environmental benefits in global trend toward sustainability. However, one of the biggest problems facing mankind recently is the environmental pollution resulting from industrial wastes and waste living materials. So, the reuse of waste materials, including polymer based composites, especially thermoplastics-based ones, for different fields of application, is being widely encouraged from the viewpoints of environmental protection and resources exploitation [1].

In the framework of the ECO-PCCM project, development and design of recycling-reuse facilities for transformation of solid–polymer composite waste into polymer mortars and concrete structures for the low-cost building industry was performed [2]. Thermoplastic polymer matrix based composites reinforced with natural fibers (rice straw and kenaf fibers) have been recycled and reused as reinforcement of polymer mortars based on PES resin. The obtained materials have been analysed with standard test methods such as mechanical tests, TGA, DMTA, DSC and SEM.

1. INTRODUCTION

Last decades, polymer mortars (PM's) and concretes have become one of the competitive materials in the construction industry. In general, the PM's were used for finishing work in cost-in-place applications. Prof. Ohama has reviewed the recent developments in PM's [1] and PM's have been examined from the viewpoint of environmental protection and resources exploitation. Recycling industrial wastes as filler components and/or aggregates in polymer mortars makes these materials very interesting from an ecological point of view [2]. In addition, the resulting materials have useful physical and mechanical properties. Four recycled fillers (powdered rubber, tyre rubbers, micronized tyre fibers and milled electrical cable wastes) have been used by Bignozzi *et al*. in order to formulate new polymer mortars [3]. The comparison of their mechanical properties and microstructure with those of a plain polymer mortars indicates that the presence of recycled waste affects the physical-mechanical behavior. The use of silane coupling agent has been also considered and its effect in leading to more compact materials has been reported and discussed. Keiji *et al.* have studied the strength in concrete reinforced with recycled and crushed carbon fiber reinforced plastic (CFRP) pieces [4]. Mechanical properties such as compressive and flexural strength of CFRP reinforce concrete have been evaluated and its fracture behavior as well as the adhesion at the interface were characterized [5,6].

2. EXPERIMENTS

Polymer mortars (PM's) with unsaturated Polyester resin (commercially available orthophthalic liquid DISTITRON 3584, with 35 % monomer content) as binder have been prepared by mixing foundry sand and milled recycled eco-composites (milled size of 0,050 mm) in mix proportions of 40/20/40 $^{\%}/_{\%}$ wt. Normal silica sand with size of 0,020-0,070 mm was used as a base inorganic aggregate. Several types of eco-composites based on Polylactide matrix with kenaf fibers and rice straw (Kenaf fibers by KEFI-Italy, Rice straw-RS by Kocani-Macedonia, PLA-Kenaf and PLA-RS are project eco-composite samples [2]) were used as recycled organic fillers.

The obtained polymer mortars have been characterized with flexural tests, thermogravimetry (TGA), dynamic-mechanical analysis (DMTA), differential scanning calorimtery (DSC) and scanning electron microscopy (SEM). The flexural tests were performed on unnotched samples (60x10x2mm), with a Universal Instron Machine (Model 4301) using three-point test. The tests were performed at crosshead speed of 2 mm/min, span 48 mm, at room temperature. Morphology of fracture surfaces of composites after the flexural test was analysed using a JEOL SEM (vacuum Au/Pd alloy deposition of the samples in a Polaron Sputtering apparatus was performed previously). Dynamo-mechanical measurements were carried out using a dynamic thermal analyzer (DMTA PE-Diamond system), operating in bending mode at a frequency of 1 Hz. The samples were investigated in the temperature range from -100 to 160 ^{o}C at a heating rate of 2 ^{o}C/min. The thermal stability of the samples was measured using a Perkin Elmer Pyris Diamond Thermogravimetric/Differential Thermal Analyzer. About 12 mg of the composite samples were heated from 40 ^{o}C to 800 ^{o}C at a heating rate of 20 ^{o}C/min in nitrogen atmosphere. DSC analysis have been done by DSC-7 Perkin Elmer at heating rate of 20 k/min under the nitrogen.

3. EXPERIMENTAL RESULTS

3.1. Mechanical behavior

Mechanical properties of the studied polymer mortars are reported in Table 1 for flexural test measurements and in Table 2 for impact resistance.

Table 1. Flexural data for the polymer mortars with recycled eco-composites

Sample	Flexural tests (un-notched samples)	
	Modulus [MPa]	Stress at maximum load [MPa]
PES	2710 ± 120	58.4 ± 3.1
PES/RS/Sand	4610 ± 290	23.7 ± 1.6
PES/PLA-RS/Sand	3470 ± 280	17.2 ± 1.3
PES/Kenaf/Sand	4190 ± 220	26.6 ± 0.9
PES/PLA-K/Sand	3960 ± 260	21.5 ± 1.5

Table 2. Impact resistance of the polymer mortars with recycled eco-composites

Sample	Impact tests (V-notched samples)	
	KC [MN m-3/2]	Resilience [KJ/m^2]
PES	0.59 ± 0.06	0.13 ± 0.03
PES/RS/Sand	1.35 ± 0.14	0.41 ± 0.08
PES/PLA-RS/Sand	0.84 ± 0.07	0.22 ± 0.05
PES/Kenaf/Sand	1.48 ± 0.19	0.98 ± 0.11
PES/PLA-K/Sand	0.93 ± 0.04	0.27 ± 0.03

Evidently, higher flexural modulus (up to 40%) have been obtained for all the studied PMs, while the flexural strength decreased. Impact resistance tests have shown that higher values for KC and impact resilience were measured for all the preprared PM's compared to the neat PES resin. Both mechanical tests have shown that higher values were measured for the PM's only with recycled natural filler (Kenaf, Rice straw) compared with the PM's with recycled PLA-composites, which indicate on some compatibility problem among thermoplastic-thermosetting polymer matrix.
For the studied PM systems, also higher storage (*E'*) and loss (*E"*) modulus were measured by DMTA. Characteristic DMTA thermograms for the storage modulus (for rice straw based system) is reported on Fig. 1.

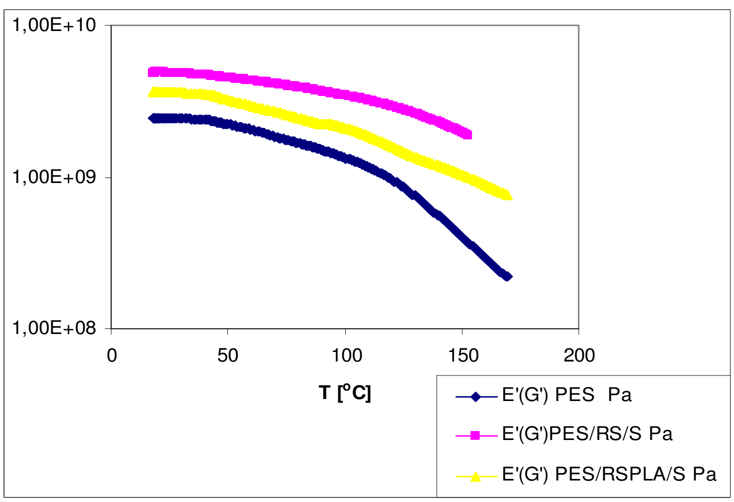


Fig. 1. DMTA curves of the storage modulus for PM's with rice straw

3.2. Thermal properties of the Polymer mortars

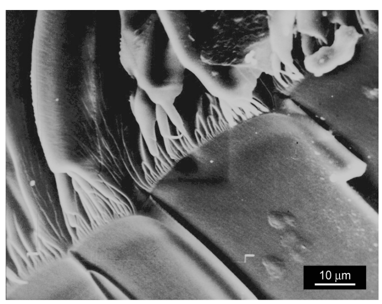
Thermal properties have been followed by DSC and TGA and the obtained parameters are presented in Table 3. DSC analysis has shown that T_g of the studied PM's has been shifted to higher values which indicate changes in the elastic behavior of the studied systems. TGA has confirmed that all the prepared polymer mortars have shown higher thermal stability compared to the neat PES matrix.

Table 3. DSC data for the polymer mortars with recycled eco-composites

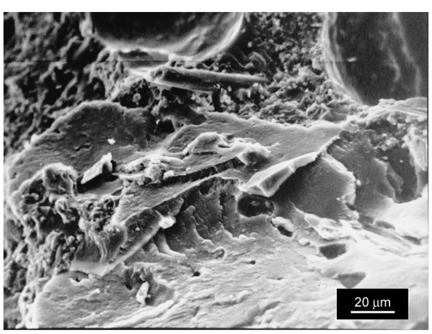
Sample	TGA data		DSC Data	
	T_d [°C] *[wl=0,5%]*	T_d [°C] *[wl=40%]*	T_g [°C]	ΔC_p [J/g°C]
PES	200	384	48,1	0,2
PES/RS/Sand	324	410	52,3	0,6
PES/PLA-RS/Sand	339	413	46,1	0,5
PES/Kenaf/Sand	338	412	55,8	1,1
PES/PLA-K/Sand	339	405	50,3	0,5

3.2. Fracture morphology

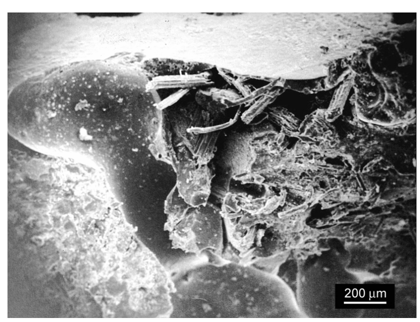
Some of the SEM microphotographs with the characteristic morphology obtained at the fracture place during the flexural test of the studied PM's are presented on Fig. 3. Fig. 2.a. represents the fracture of the neat PES matrix with characteristic " river" markings. Fracture place of the polymer mortar PES/PLA-K/S has inhomogeneous place with some voids which contribute for lower mechanical parameters. The clean fiber surface of the kenaf indicates that the adhesion between the fiber filler and polymer matrix is very weak. The same phenomena are evident and in the other studied PM's with PLA-Rice straw. Fracture surface of the PES/RS/S polymer mortar exhibits characteristic cellular structure typical for the RS presence.



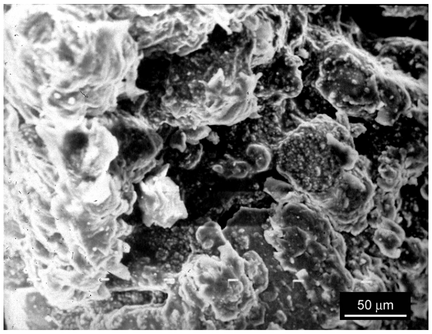
a) PES (x750)



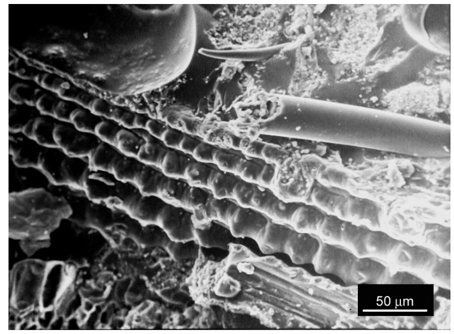
b) PES/PLA-K/S (x350)



c) PES/Kenaf/S (x35)



d) PES/PLA-RS/S (x200)



e) PES/RS/S (x200)

Fig. 2. SEM microphotgraphs of the studied polymer mortars
a) PES (x750); b) PES/PLA-K/S (x350); c) PES/Kenaf/S (x35);
d) PES/PLA-RS/S (x200); e) PES/RS/S (x200).

4. CONCLUSIONS

Several types of polymer mortars reinforced with recycled eco-composites have been prepared and characterized. Characterization protocol includes mechanical tests, DMTA, TGA and DSC, as well as SEM analysis. Flexural test measurements have shown that higher flexural modulus have been obtained for all the studied PMs, while the flexural strength decreased. Using the DMTA, also higher storage (*E'*) and loss (*E"*) modulus were measured.

Thermal analysis has shown that T_g of the studied PM's, as well as the decomposition temperatures, T_d, were shifted to higher values which indicate changes in the elastic behavior and higher thermal stability respectively, compared to the neat PES matrix.

ACKNOWLEDGEMENTS

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REFERENCES

1- Ohama, Y. "Recent progress in concrete-polymer composites", *Advanced cement Based Materials*, 1997; 5, 31-40
2- ECO-PCCM, FP6-INCO-CT-2004-509185
3- Bignozzi, M.C., Saccani, A., Sandrolini, F., "New polymer mortars containing polymeric wastes. P.2. Dynamic mechanical and dielectric behavior", *Composites P.A*, 2002; 33, 205-211
4- Keiji, O., Tomoyuki, S., Makoto, M., " Strength in concrete reinforced with recycled CFRP pieces", *Composites P.A*, 2005; 36, 893-902
5- Davies, G.A.O. and Olsson, R., "Impact on composite structures", *The Aeronautical Journal of the Royal Aeronautical Society*, November 2004:541-563.
6- Olsson R., "Analytical prediction of large mass impact damage in composite laminates", *Composites: Part A*, 2001;32:1207-1215.