Table of Contents

Sisal Fibre Bundle Composites—A Review of Properties in Relation to Microstructure. ................................................. 435
M. P. ANSELL

Biodegradable Composites Reinforced with Cellulose Nanofiber Extracted from Waste Paper Pulp ........................................ 448
H. TAKAGI, A. N. NAKAGAITO, M. S. A. BISTAMAM and J. K. PANDEY

Mechanical Properties of Recycled PP Reinforced with Microcrystalline Cellulose: Effect of MAPP Content ....................... 451
N. SAMAT, N. I. ZULKIFLI and H. ANUAR

Studies on Mechanical Properties and Thermal Analysis of New Polymer Foam Composites Originated from Coconut Trunk Fiber/Polyypropylene/High Density Polyethylene Composites .... 457
H. OSMAN, T. Y. HOW, D. N. U. LAN and Z. M. ARIFF

Mechanical Performance of Cement Mortar Composites Reinforced with Cellulose Fibres ............................................... 477
J. CLARAMUNT, M. ARDANUY, F. PARES and H. VENTURA

Tension Fatigue Behavior of the Laminates Jute/Epoxy .................. 485
A. MIR, C. ARIBI and B. BEZZAZI

SESSION 11: HYBRID COMPOSITES

Toughening of Carbon Fibre Composites By Hybridisation with Self-Reinforced Polypropylene ............................................. 495
Y. SWOLFS, L. GORBATIKH, P. J. HINE, I. M. WARD and I. VERPOEST

Hybridization of Ductile Steel Fibre and Self-Reinforced Composites ................................................................. 503
M. G. CALLENS, P. DE CUYPER, Y. SWOLFS, L. GORBATIKH and I. VERPOEST

Behavior of Hybrid Metal Matrix Composites Reinforced with Continuous and Discontinuous Fibers ...................... 511
J. A. DIBELKA and S. W. CASE

SESSION 12: IMPACT AND DYNAMIC RESPONSE

Ballistic Impact Analysis on the Advanced Combat Helmet (ACH)—Testing and Simulation .................. 523
L. B. TAN, K. M. TSE, H. P. LEE and V. B. C. TAN

Impact Behavior of Polypropylene/Glass Fiber Fabric Composites .... 545
G. SIMEOLI, D. ACIerno, L. SORRENTINO, S. IANNACE and P. RUSSO

Effect of Incorporating Foam Based Flexible Blunt Trauma Pads on the Shock Wave Protective Performance of Flexible Body Armour 554
A. HARIS, H. P. LEE, T. E. TAY, B. C. KHOO and V. B. C. TAN
Mechanical Performance of Cement Mortar Composites Reinforced with Cellulose Fibres

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ABSTRACT

The aim of this work is to evaluate the mechanical performance of cement mortar composites reinforced with various percentages of cellulose fibres. Results indicated that for low content of fibres there is a high adhesion between the cement matrix and the fibres and, consequently, the fracture of the composite under flexural stress occurs by rupture of the matrix and the fibres. However, for higher fibre content, the collapse of the material occurs by a progressive rupture of the matrix which is dispersed in a dense network of fibres and which disintegrates, releasing the fibres. These results could be interesting for modelling the mechanical performance of vegetable fibre reinforced cement mortar composites.

INTRODUCTION

The use of vegetable fibres to reinforce brittle matrices such as cement mortar or concrete constitutes an interesting possibility that offers many advantages with respect to other fibres or reinforcements. On the one hand, due to their mechanical properties, vegetable fibres can improve the ductility, flexibility and crack resistance of the resulting material. On the other hand, from the environmental point of view, it is worthy of mention the great effort that has been made in the civil engineering field with the aim of improving the materials and techniques commonly used. With regard to materials, the use of waste and renewable sources as raw materials together with the use of more environmentally friendly materials has notably increased over the last few years. Consequently, a number of researchers have been involved in investigating the exploitation of natural fibres as load bearing constituents in cement mortar composite materials [1-9].

The mechanical performance of vegetable fibre reinforced cement mortar composites (VFRCMC) depends on different factors. Once established the manufacture process, the main parameters that will determine the mechanical properties of the composites will be the intrinsic resistance of the matrix –defined basically by the cement content- and the percentage of the fibre.

From a general point of view, cellulosic vegetable fibres have similar mechanical characteristics and therefore, with similar treatments and content, the
resultant properties of the composites are similar. Various authors justify this statement due to when the composite breaks, the fibres tend to debonding and pull-out without rupture [10]. This phenomenon is the responsible of the increase of the toughness [11-16].

Coultts and other authors [12-14] use the following equation for the calculation of the modulus of elasticity and the flexural strength of the composites, known as the rule of mixtures (Equation 1):

\[ X_c = X_m \ast v_m + \eta_1 \ast \eta_2 \ast X_f \ast v_f \]  

(1)

Where \( X_m \) and \( v_m \) are the modulus of elasticity or the strength and the volume of the matrix respectively; \( X_f \) and \( v_f \) are the modulus of elasticity or the strength and the volume of the fibre respectively; \( \eta_1 \) and \( \eta_2 \) are factors which depend on the orientation and the critical length of the fibre respectively. This equation has been questioned by various authors and Laws [17] considered that for the calculation of the flexural strength, it is not necessary to include the term corresponding to the matrix. In this case \( \eta_2 \) is calculated as:

\[ \eta_2 = \frac{l}{2l} \text{ if } l < l_c \]
\[ \eta_2 = 1 - \frac{l_c}{2l} \text{ if } l > l_c \]  

(2)

Where \( l \) is the length of the fibre and \( l_c \) the critical length of the fibre defined as the length that establishes the limit between the pull-out and the rupture. The critical length is difficult to calculate. In any case, this equation takes into account that during the fracture of the brittle matrix there is only one crack that becomes higher until the fracture or pull-out of the fibres. This model can be applicable for low fibre contents but can be wrong for high contents.

The aim of this work is to evaluate the effect of the fibre content on the mechanical performance and on the microstructure of cement composites reinforced with cellulose fibres for low and high content. For this purpose various series of composites with 0%; 2%; 4%; 6%; 8% and 10% of cellulosic fibres have been prepared and characterized with flexural tests.

MATERIALS AND EXPERIMENTAL PROCEDURES

UNE-EN 197-1:2000 Type I cement supplied by CEMEX (Spain) was used for the present research work. Silica fume has been used to replace a 10 wt.% of the cement. Sand used, “quartz flour”, with similar particle size distribution to the cement, was supplied by Sibelco. Sika Visocrete-3425 fluidizer, obtained from Sika S.A.U., was used at a maximum dosage rate of 40 g/1000 g of cement to aid workability.

Unbleached softwood kraft pulp (Pinus insignis), supplied by Smurfit Kappa Nervión, S.A. (Spain), was used as reinforcement.

The specimens were prepared following the UNE-EN 196-1:2005 standard and cured in a chamber for 28 days at 20° C and relative humidity higher than 90%. The wt. % of fibres was 0%; 2%; 4%; 6%; 8% and 10%. The final water / cement ratio varied depending on the fibre content. The compacting pressure was maintained constant for all the samples.
The mechanical characterization of the composites was performed via flexural with a three-point bending configuration using an Incotecnic press equipped with a 2kN load cell.

RESULTS AND DISCUSSION

Mechanical properties

Figure 1 shows the typical stress-deflection curves for the composites analyzed under flexural tests. As shown, the curves of the specimens without fibres or with very low percentage present a linear portion followed by a sudden fracture. For middle contents on fibres the curves are characterized by a strain softening behaviour, with a decrease of the flexural strength of the composite after the first crack formation. Finally, for the specimens with high content on fibres the curves are typical of strain hardening behaviour, it is to say, there is an increase of the flexural strength after the first crack formation.

![Figure 1. Typical stress-deflection curves of the cement compared with the composites with wood fibres.](image)

The average values of the maximum flexural strength measured before (contribution of the cement matrix) and after the first crack (contribution of the fibres), are shown in Figure 2. As could be seen there is a decrease of the maximum strength of the matrix with the increase of the fibre content until 4 wt.%. For higher content of fibres the strength of the matrix is maintained around of the 50% of the maximum achieved. At the same time, the increase of the fibre content generates a post-cracking reinforcement with values of maximum flexural strength around 4 and 12% higher than the strength of the matrix.
Figure 2. Maximum flexural strength provided by the matrix and the fibres to the composites.

On the other hand, the values of modulus of elasticity (Figure 3) calculated for low (0 to 50\% of maximum achieved) and high strength (50 to 90\% of maximum achieved) decreased linearly with the increase of the fibre content.

Figure 3. Modulus of elasticity calculated from 0-50 \% and 50-90 \% of maximum achieved with respect to the fibre content.

On the other hand, as shown in Figure 4, the toughness or energy absorbed during the flexural test of fibres, increased linearly with the fibre content.
Finally, as is shown in Figure 5, as is expected, there is a decrease of the density of the composite with the percentage of fibres.

**Microstructure**

Figures 6 to 8 show SEM micrographs of the fracture surface of the composites. For the specimen with 2 wt.% it could be seen at low magnifications (Figure 6a) a general view of the dispersed fibres in the matrix. For higher magnifications (Figure 6b,c,d) it could be observed how most of these fibres have been fractured without
debonding and pull-out. This kind of fracture could be also observed for the samples with 4 and 6 wt.% of fibres (Figure 7). However, for these samples, there are also fibres debonded from the matrix by pull-out without fracture. This type of failure is observed in more fibres with increasing the content in the matrix.

Figure 6. SEM micrographs of the fracture surface of the composites with 2 wt.% of fibres.

Figure 7. SEM micrographs of the fracture surface of the composites with 4-6 wt.% of fibres.
Figure 8. SEM micrographs of the fracture surface of the composites with 10 wt.% of fibres.

On the other hand, for the composites with high content of fibres the behaviour of the material is very different (Figure 8). In this case it is possible to observe fragments of matrix surrounded by fibres and separated from the fracture section.

From these observations it can be concluded that the fracture behaviour of the composites is very different depending on the fibre content. So, for low fibre content the fracture behaviour of the material can be described as a brittle matrix surrounding the fibres where the reinforcement of the fibres is done by fracture or debonding and pull-out. However, for high fibre content this behaviour of the material can be described as fragments of matrix surrounded by a network of fibres where there is a mixture of effects of debonding, rupture and mechanical friction of the fibres.

CONCLUSIONS

The properties of cement mortar composites reinforced with fibres depend considerably on their content.

With respect to the mechanical performance, the increase of fibre content decreases the strength of the matrix which is stabilized for content of around 4 wt.%. At the same time there is an increase of the strength of the reinforcement which also tends to stabilize at a similar value or slightly greater than that of the matrix for contents of around 4 wt.% on fibres. The modulus of elasticity decreases linearly with the fibre content meanwhile the toughness of the material increases.

For low content of fibres the stress is transferred from the matrix by rupture or pull-out. However when the content increases is due to the fibres tend to reinforce by pull-out rather than rupture contributing to an increase of the toughness. For high
content as 10 wt.% of fibres the mechanism of fracture of the material is related with a multi-cracking of the matrix inside a network of fibres.

ACKNOWLEDGMENTS

The authors would like to acknowledge MICINN (Government of Spain) for the financial support of the project BIA2011-26288.

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