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EVALUATION OF THE BEHAVIOUR OF STRUCTURAL CONCRETE BEARING WASTE WIND-TURBINE BLADE UNDER TENSILE STRESSES

Hurtado-Alonso, Nerea[1]*; López-Ausín, Víctor[2]; Santamaría, Amaia[3]; Skaf, Marta[1]; Fiol, Francisco[1]; Manso, Juan M.[2]

1: Department of Construction, University of Burgos, Burgos, 09001, Spain
e-mail: { nhurtado; mskaf; ffiol }@ubu.es:
2: Department of Civil Engineering, University of Burgos, Burgos, 09001, Spain
e-mail: {vlausin; jmmanso }@ubu.es:
3: Department of Mechanical Engineering, University of the Basque Country, Bilbao, 48013, Spain
e-mail: amaia.santamaria@ehu.eus

ABSTRACT

It is generally acknowledged that it is an urgent task of the concrete industry to find new ways of introducing waste materials in their mixtures in order to increase its sustainability. Wind power industry can play an important role in this challenge, while solving the problem of the recycling of the old wind turbine structures that are reaching the end of their lifecycle, which is currently imperative. Hence, the need for the disposal of Waste Wind-Turbine Blade (WWTB) sets an opportunity to introduce it after crushing as a raw material in concrete, being able to reduce its content of natural aggregates and cement. This research aims to conduct an exhaustive material characterization and analyse the feasibility of adding WWTB in concrete for structural purposes. For this study, five different concrete mixes were produced with variable WWTB volume contents (0.0%, 1.5%, 3.0%, 4.5% and 6.0%). The amount of siliceous aggregate used in all five mixtures remained invariable, as well as the cement content. All the resulting mixtures were characterised in terms of the slump, fresh- and hardened-density tests. Besides, splitting tensile strength and flexural strength allowed evaluating the performance of the concrete mixes under tensile stresses. The results demonstrate that a rise in the WWTB content up to 1.5% can result in a slight increase of the splitting tensile strength, whereas high contents of this waste (6.0%) allow maintaining constant the flexural strength. The values of both properties remain approximately stable when adding WWTB, thus preserving the basic mechanical properties of structural concrete. According to this study, it is feasible to evaluate the addition of WWTB as a method of obtaining structural concrete without compromising any of its tensile-related mechanical properties, simultaneously transform an industry hitherto considered polluting into a more sustainable one.

KEYWORDS: concrete; wind-turbine blade; mechanical properties; tensile stresses.

1. INTRODUCTION

The concrete industry has proven to be one of the largest contributors to climate change, releasing huge amounts of CO_2 into the atmosphere every year [1]. Furthermore, it uses natural resources to produce one of the most widely used materials in construction. Therefore, there is a growing need for changes to transform the industry into a more sustainable one. Recent research suggests that one way to make concrete more sustainable is through the introduction of waste products from other industries as raw materials [2]. Although this leads to a reduction in the use of natural aggregates and cement, it often has significant impact on the mechanical properties of the concrete [3]. Evaluation on the utilize of those waste materials as substitutes in concrete mixes has yet to be profoundly investigated.

From the point of view of the wind energy sector, many wind turbines will be decommissioned in the coming years as they reach the end of their life cycle [4]. The wind energy sector needs to anticipate this development and put in place recycling measures for what is expected to be a challenging task due to the complex composition of the blades. Glass- or carbon-fiber composites, wood, polyurethane, and resins are among their main components [5]. Research to date has shown that the separation of these components is difficult [5], apart from the high economic and energetic costs of the methods used in this task, such as pyrolysis and solvolysis [6]. Some studies have shown that cutting and non-selective crushing wind turbine blades is a rapid and inexpensive method that minimally alter the properties of the components [7]. This method produces a waste material composed of a range of fibers with properties that are ideal for incorporation into concrete mixes, thus enabling the development of more sustainable concrete [7]. This material is labelled by the authors of this study as Waste Wind-Turbine Blade (WWTB).

This study aims to analyse the feasibility of adding WWTB in concrete for structural purposes. In order to achieve this objective, five concrete mixes with different fiber content (0.0%, 1.5%, 3.0%, 4.5% and 6.0% in volume) were produced and various tests were carried out to evaluate their fresh and tensile-mechanical behaviour. Firstly, the characteristics of the materials used in the mix are studied and the manufacturing process of the different concretes is described (Section 2). This is followed by a definition of the fresh and hardened properties and the results achieved (Section 3). Finally, the conclusions are drawn on the basis of the initial objective of the research (Section 4).

2. MATERIALS AND METHODOLOGY

2.1. Materials

In the preparation of the five concrete mixes, standardized CEM II/A-L 42.5 R (EN 197-1 [8]) was used. Added water was obtained from the supply network of Burgos (Spain), the location where this research was carried out. In order to ensure adequate workability, two superplasticisers, Plastizicer Type 1 (SIKA5920) and Plastiziser Type 2 (SIKA20 HE), were added. As for the natural aggregate, siliceous crushed aggregate divided into different fractions was used: sand 0/2 mm, fine gravel 2/6 mm, and coarse gravel 6/22 mm. Particle size gradation of each fraction of aggregates is shown in Figure 1.

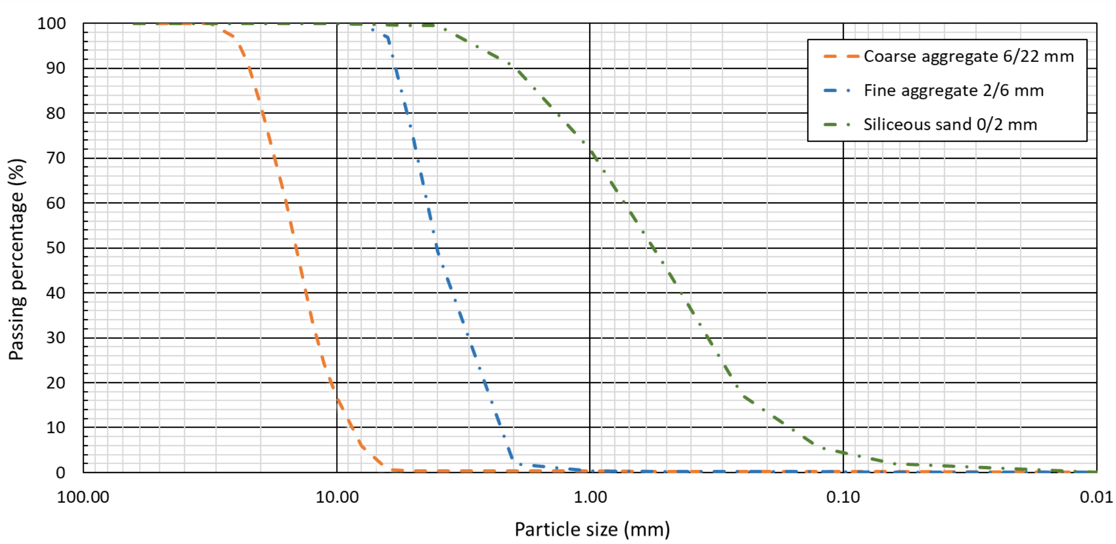

Figure 1: Particle gradation of aggregates.

An exhaustive characterization of the aggregates was performed in order to determine their physical properties in accordance with EN 933-1 [8]. Densities obtained were 2620 kg/m^3, 2580 kg/m^3 and 2590 kg/m^3 respectively, with little variation between the different aggregate fractions. Regarding water absorption values after 24 hours, both fine gravel (1.83 % wt.) and coarse gravel (1.66 % wt.) had substantially higher values than the siliceous sand (0.52 % wt.).

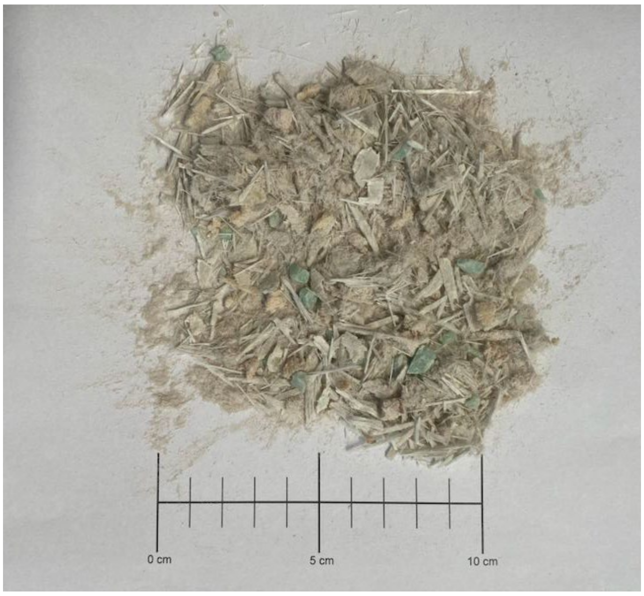

Figure 2: WWTB material.

The physical properties of WWTB, which is shown in Figure 2, were analysed with the objective to define the feasibility of this waste material for concrete production. Its real density was approximately 1600 kg/m^3, which was similar to the value of a lightweight aggregate [9]. The residue contained a high percentage of fibers, representing 66.8% of the total weight, which makes this material suitable to use as reinforcing fibers in concrete. Moreover, the average length of the fibers was around 13 mm, values that are similar to those that are currently commercialise for concrete production.

2.2. Mix design and dosage

In the present study, the effect of WWTB dosage on concrete performance was analyzed. Therefore, the WWTB dosage, expressed as a volume fraction of the concrete mix, was the only variable analysed. Five concrete groups with five different WWTB volume fractions (0%, 1.5%, 3.0%, 4.5% and 6.0%), which were labelled M0.0, M1.5, M3.0, M4.5 and M6.0, respectively. The concrete mixture containing no WWTB was initially designed as the control mixture for comparative purposes.

Labelled with the name M0.0, the reference mix had standard design values: 320 kg/m^3 of cement CEM II/A-L 42.5 R [8], a water-to-cement ratio of 0.40, and plasticizer content of 1% of the cement mass. The remaining mix volume was formed by aggregates. For each aggregate fraction, the optimum setting of the Fuller's curve was determined by adjusting the different contents of each of the fractions to obtain a compact curve, thus the proportion of each fraction being defined. Adjustment resulted in a quantity of 500 kg/m^3 sand 0/2 mm, 600 kg/m^3 fine gravel 2/6 mm and 900 kg/m^3 coarse gravel 6/22 mm for each mix.

WWTB content was added as a global addition to the total volume of the mixture in the percentage corresponding to its proportion. As the percentage of WWTB increased, workability decreased with water/cement ratio increasing to values of 0.42 for M1.5, 0.43 for

M3.0, 0.44 for M4.5 and 0.46 for M6.0. In addition, the amount of plasticizers added to the mixtures had to be adjusted to a maximum of 1.82% wt for the mixture with higher WWTB content.

2.3. Mixing process

The mixes were produced using a five-stage mixing process that enables the addition of WWTB material to the final mix without altering the water quantity required for a homogenous mixture. First, the aggregates of the three fractions are added simultaneously with 30% of the water. After three minutes have passed, the cement and the remaining water are added. Prior to the addition of the WWTB material determined for each type of mixture, first half of the plastizer is mixed for two minutes. Second half of the plastizer is added right after the WWTB to balance workability. After the last stage, the mixture is blended for another five minutes.

2.4. Experimental tests

2.4.1. Fresh properties of concretes

At the end of the mixing process, the properties of the fresh concrete were evaluated. The methodology of the test consisted in the execution of the Abrams cone test (EN 12350-2 [8]) in order to measure the slump of the mixture. Then, fresh density (EN 12350-2 [8]) of each mix was measured for later comparison with the hardened density.

2.4.2. Hardened properties of concretes

A total of nine samples were prepared for testing purposes. Three 100x100x100 mm cubic specimens were prepared to measure hardened density (EN 12390-7 [8]) by weight difference after immersion in water; six prismatic specimens of 75×75×225 mm were manufactured to carry out flexural strength test (EN 12390-5 [8]) both at 7 and after 28 days. Finally, for the evaluation of the splitting tensile strength test (EN 12390-6 [8]), also after 7 and 28 days, six cylindrical specimens of 100 mm diameter and 200 mm were prepared.

3. RESULTS AND DISCUSSION

3.1. Slump flow

Results obtained for the five mixtures showed slump values between 100 mm and 150 mm, all of them classified as S3 according to EN 206 [8]. It can therefore be concluded that higher levels of WWTB did not reduce the workability of the mixture. For mix M4.5 a slump value of 135 mm was obtained, which was the highest of all the mixes tested. WWTB dosages above 4.5% showed a 20% decrease in workability compared to the reference mix. This is due to the high specific surface area of the WWTB material, which requires a higher amount of water and plastiziser [10,11] to keep the workability approximately constant, although a decrease in workability cannot sometimes be avoided.

3.2. Fresh density

There was a decrease in the fresh density of the mixes to values of 2280 kg/m^3 for all mixes as the amount of recycled material increased [12]; all values were slightly lower in comparison to M0.0, the reference concrete, which had a fresh density of 2430 kg/m^3. This drop of up to 6% compared to the reference mix is due to the increasing addition of water in the mixtures [13] and the low density of WWTB. Figure 3 shows fresh density values for each mix percentage.

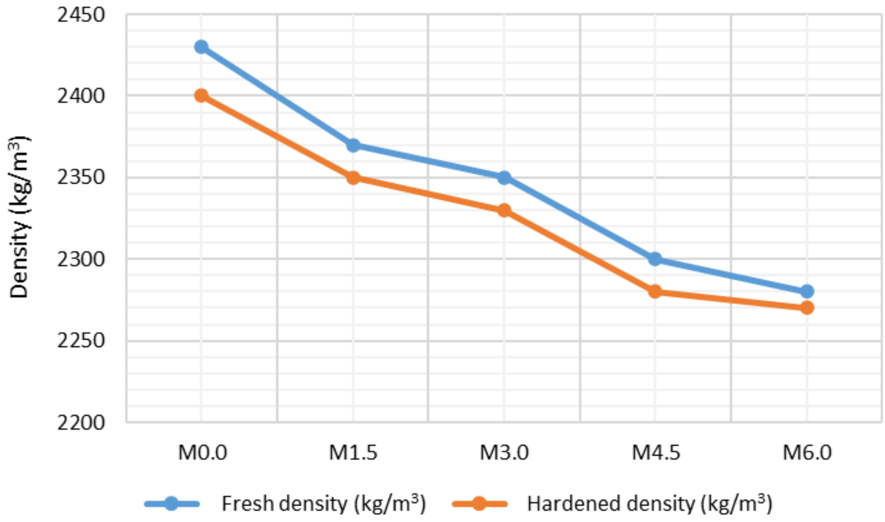

Figure 3: Fresh density and hardened density values for the five different mixtures.

3.3. Hardened density

For the hardened density measurement, values higher than 2250 kg/m^3 were obtained for all the mixtures with different percentages of WWTB. The decreasing trend continues as the amount of WWTB increases [14], as with the property described above. Testing results showed the highest result 2400 kg/m^3 for M0.0 and the lowest 2270 kg/m^3 for M6.0.

Figure 3 shows the comparison of the different fresh and hardened density values for each mix percentage. As the curing process progressed, concrete mix lost water by evaporation [15,16]. Thus, the hardened density values for all mixes were slightly lower than the fresh density values. The variation was less than 1%, and was therefore considered negligible.

3.4. Flexural strength

The results obtained for flexural strength at 7 and 28 days are presented in Figure 4. At a fiber content of 1.5 %, a value for the flexural strength was obtained that was only slightly different from that of the reference concrete (M0.0).

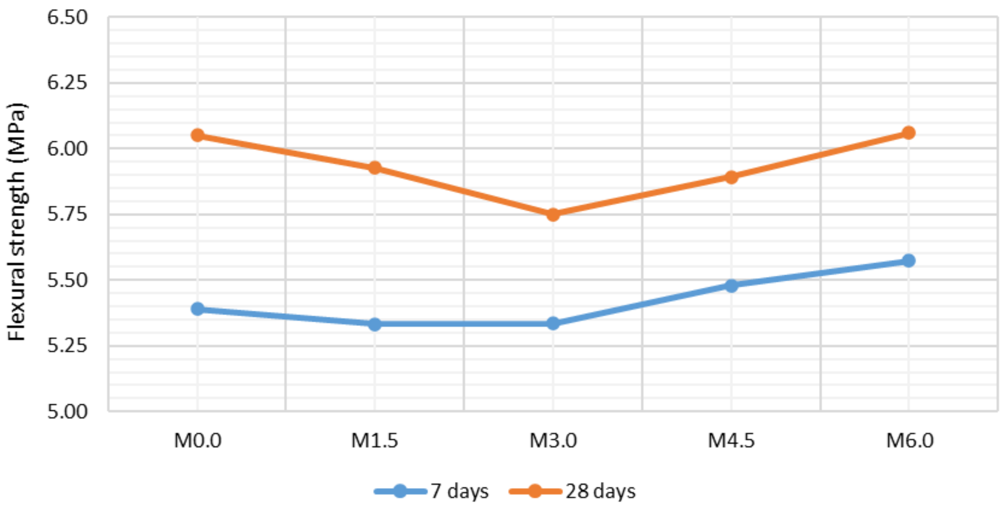

Figure 4: Flexural strength of the mixes at 7 days and 28 days.

For low WWTB contents, the wood and polyurethane particles had a negative effect, reducing the flexural strength values by up to 5%. It is only at 4.5% that WWTB content is sufficient to partially counteract some of the negative effect on flexural strength. The minor increase in strength above 3.0% is attributable to the stitching effect of the fibres [17], but is not noticeable at higher percentages as it serves to counteract the increase in the w/c ratio.

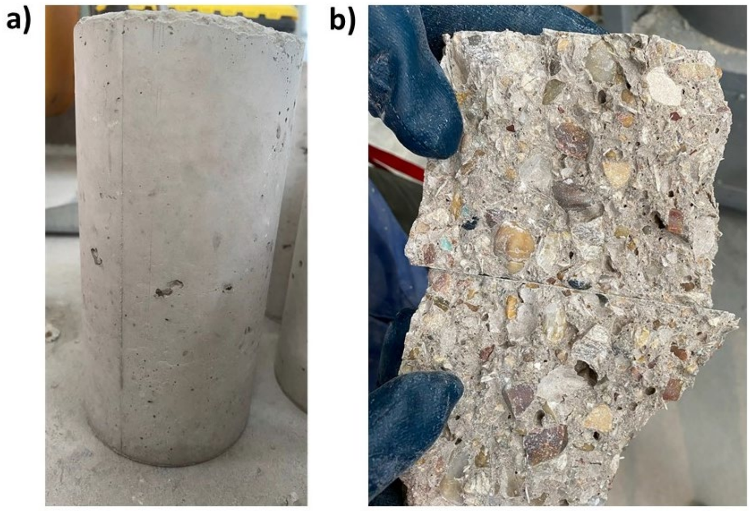

Figure 5: Splitting tensile strength test: (a) untested sample; (b) Sample fragment after test.

3.5. Splitting tensile strength

It can be seen graphically in Figure 6 results of 7-day and 28-day testing for splitting tensile strength. A visual assessment of the specimen before and after the test, is also shown in Figure 5. The results showed a slight improvement for M1.5 in the 7-day test and an increase of 3.43% in the 28-day test. These results decreased with the addition of WWTB at contents above 3.0% vol, due to the poorer bonding of the wood particles [18] and polyurethane compared to the natural aggregate. The difference between the splitting tensile strength obtained by the mixes in the 7 and 28 day tests was greater as the content of WWTB increased, reaching a value of 10% for M1.5. However, at higher percentages of fibre content, and with the decrease in strength, this difference does not reach a value of 1%.

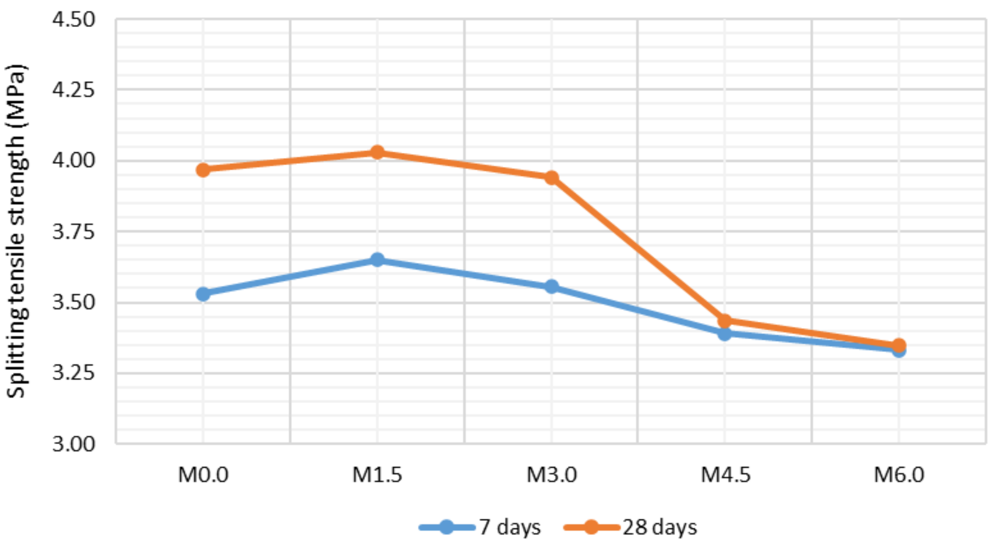

Figure 6: Splitting tensile strength of the mixes at 7 days and 28 days.

4. CONCLUSIONS

The following conclusions can be drawn from the aspects discussed:

- Due to the low density of WWTB residue, the introduction of WWTB residue into the concrete mix results in a decrease in fresh density. The same behaviour is found regarding the hardened density.

- In terms of flexural strength, a higher addition of WWTB fiber over 3.0% results in an increased flexural strength value due to the stitching effect they provide to the concrete matrix.

- In terms of splitting tensile strength, the addition of a high percentage of residue, up to 3%, considerably maintained the strength values at both 7 and 28 days.

A preliminary evaluation of tensile stresses of concrete containing waste wind-turbine blade is presented in this paper. The data obtained in this study are encouraging to continue investigating the behaviour and importance of the addition of this type of fiber in concrete mixture.

5. ACKNOWLEDGEMENTS

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