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Comparing flexural behaviour of Fibre - Cement Composites reinforced bagasse, wheat and eucalyptus

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Abstract

In this paper the applications of Agricultural-Waste Fibres (AWF) are considered in producing the Fibre Cement Boards (FCB). Three different AWFs including bagasse, wheat and eucalyptus fibres as 2 and 4% by the weight of Portland cement, were used to produce FCB. Moreover, the effect of silica fume on flexural behaviour characteristics of FCB has been studied. The results show that the flexural behaviour of the FCBs depends on the type, length, diameter, aspect ratio and texture of fibres. Also for all groups with increasing fibre content from 2 to 4 percent of cement weight, maximum flexural strength increases. Moreover, silica fume could improve the flexural strength for all the groups.

Keywords: Fibre cement board, Flexural behaviour, Bagasse fibre, Wheat fibre and Eucalyptus fibre.

1. Introduction

During the last two decades, the application of fibres in cement-based composites have been gaining momentum and been applied to enhance the properties of these construction materials. One of the most important cement composites is Fibre Cement Board (FCB) that is used in flat or corrugated shape and is manufactured by Hatscheck process. They can be used as a material for roofing, internal/external wall and facade. The most important ingredients to produce FCB are fibres, cement and water.

After banning asbestos fibres due to its hazardous effects on human health, finding alternatives fibres has drawn the researcher's attention. The investigations for a replacement of asbestos fibres resulted in many synthetic and natural fibres being examined in numerous laboratories around the globe. At CSIRO (Commonwealth Scientific and Industrial Research Organization) a wide range of natural fibres (wood, bamboo, banana, flax, etc.), prepared by different pulping methods (chemical, mechanical and various combinations) were studied in various matrix systems (cements, mortars, etc.). According to this research, replacing asbestos fibres with synthetic fibres solely is too difficult because Synthetic fibres are effectively an order of magnitude greater in diameter than wood fibres and thus cannot by themselves form films and trap the cement particles. They are more likely to settle out in the Hatscheck machine.[1]

Several studies have shown cellulose fibres can be considered as one of the most important candidates for asbestos fibre in FCB manufactured by the Hatscheck process because of the individual characteristics, availability and economic aspects.[2-4]

Much effort has been devoted to wood fibres because they possess many advantages such as availability, lower cost, simple production processes for making cementitious composites of various shapes, renewability and recyclability, non-hazardous nature, and biodegradability. [5]

Cellulose fibres have a wide range of physical and mechanical properties that is related to the original source it comes from, diameter, length, specific gravity, methods of processing, treatment etc. Also, the properties for each type of cellulose fibres such as bagasse or eucalyptus can be different in each country depending on the weather; type of soil, type of fertilizing etc. So the results of each research may be exclusive and cannot be generalized to other research. In this regards, the results of some pieces of research have been brought to as follows.

In 2010 Karade, S et al [6] depicted that cellulose fibres have many advantages such as low cost, availability, chemical stability, environmentally friendly and reinforcing characteristics but their durability shortcomings have to be remedied. They tried to use lignocellulosic wastes fibres to manufacture FCB. However, in this effort there are various restraints like compatibility of these wastes with cement, and limited composite strength.

Some pieces of research [7,8] have portrayed that treated bagasse fibres (diameter: 0.4 - 1 mm) demonstrate many advantages such as; it is eco-friendly, cheap and has a suitable thermal conductivity.

Native fibre named fique fibre or Cabuya was investigated in connection with cementitious matrixes by Delvasto, S [9]. In this research an appropriate low scale production technology for manufacturing corrugated sheets which can be used for roofing were developed. However, the result of this experience showed that it is necessary to do some adjustments in order to overcome problems related to the parameters of the process and the type and volume fraction of the ingredients of mix.

In 2010, Tonoli, G. et al [10] evaluated the advantages of using hardwood short fibre pulp (eucalyptus fibres) as an alternative to softwood long fibre pulp (pinus) and polymer fibres, traditionally used in reinforcement of cement based materials. The effects of cellulose fibre length on microstructure and on mechanical performance of fibre–cement composites were evaluated before and after accelerated ageing cycles. They found out, Hardwood pulp fibres were better dispersed in the cement matrix and provided higher number of fibres per unitary weight or volume, in relation to softwood long fibre pulp. The short reinforcing elements lead to an effective crack bridging of the fragile matrix, which contributes to the improvement of the mechanical performance of the composite after ageing.

Mechanical, physical and thermal performance of the roofing tiles produced with several formulations of cement-based matrices reinforced with sisal and eucalyptus fibres has been investigated by Tonoli, G.et al

[11]. The results showed that the physical properties of the tiles were more influenced by the fibre content of the composite than by the type of reinforcement. According to the results of this study, after approximately four months of age under external weathering the toughness of the vegetable FCB fell to 53– 68% of the initial toughness at 28 days of age.

Karade, S et al [6] concentrated on lignocellulosic wastes which are generated worldwide from various sources such as agriculture, construction, wood and furniture to make cement-bonded construction materials. They faced various restraints like compatibility of these wastes with cement, their toxicity, and limited composite strength. To overcome these drawbacks, they had to take some requirements such as pre-treatments, use of chemical admixtures and modified manufacturing process.

An investigation has been performed into the addition of chemicals such as calcium sulphoaluminate, metakaolin or silica fume to reduce the concentration of hydroxyl ion in the pore solution, thus producing a less aggressive environment for the cellulose fibres . [12]

It has been reported that cement based composites containing 10% of silica fume were found to have improved compressive strength, lower water absorption, lower coefficient of chloride ion diffusion, lower penetration of chloride ions and higher polarization resistance than those of control specimens. Mostly, Pozzolanic materials not only act as a filler but also are useful to create a cementitious binder that contribute to improve the matrix strength within the cement composites .[13]

Many fibre cement composite products that are used in construction are required for use externally or in aggressive environments such as roofing and cladding. Investigations into the use of silica fume in non-asbestos fibre cement composites has shown that it can enhance bending strength and density, while it reduces porosity and water absorption. These qualities could make fibre cement composites containing silica fume significantly more resistant to freeze-thaw effects.[14]. The use of Pozzolanic materials as a partial weight replacement for cement has also been investigated in order to reduce the alkalinity of the cement matrix as well as refining the pore structure of the matrix. Silica fume, used at relatively large amounts (i.e., 30% or greater replacement of cement by weight) appears to significantly minimize composite degradation due to wet/ dry cycles.[14]

Composites containing fibres and silica fume were reported to further increase polarization resistance and compressive strength. Studies have shown that the addition of silica fume further improves the permeability of fibre cement composites due to the positive effect from Pozzolanic reactions, which produces denser and more homogeneous structures and bonding within the matrix. [13].

It seems, agricultural waste fibres, which are broadly accessible in most developing countries, can be used as convenient materials for brittle cement matrix reinforcement. Taking into account the fibres mechanical properties, with a suitable mix design, it is probable to develop a material with appropriate properties for building purposes. So in this research, to assess the applicability of the waste natural-sourced fibres like wheat fibre (WF), bagasse fibre (BF) and eucalyptus fibre (EF), an experimental study was established to investigate flexural characteristics of the cement boards produced from these agricultural waste fibres.

2. Experimental procedure

2.1. Materials

Cement: Ordinary Portland cement Type I.

Fibres: The fibres were prepared from different sources of the agricultural wastes. Three types of fibres were used. They included: Bagasse fibre (BF), Wheat Fibre (WF) and Eucalyptus Fibre (EF). Bagasse is the solid cellulosic fibres residue left after extraction of juice from the sugar cane stalk. In the same way, wheat and eucalyptus fibres are obtained from the stalk of wheat and eucalyptus respectively. Fibres were initially refined to improve their mechanical properties. To achieve this; damp fibres were fibrillated by passing the suspension of pulp fibres through a relatively narrow gap between a revolving rotor and a stationary stator. All types of fibres were cured in water for 24 hours before entering the mixer.

Water: Potable water was used for preparation of the specimens.

Silica fume: In some specimens, amorphous - micron powder of silica fume were replaced for 5% of cement weight. Specifications of the used silica fume have been presented in table-1

Table-1 Properties of used silica fume

Colour	Gray

Specific Gravity	2.35
Solubility	Insoluble
Bulk Density	625 kg/m^3
Silicon Dioxide (SiO2) %	93 %
Moisture Content %	1.5 %
Oversize percent retained on 45-µm (325 sieve)	3.2 %
7 day Pozzolanic strength activity index	112 %
Specific Surface	20 m^2/g

The result of particle size analysing test for silica fume has been depicted in fig -1

As it can be seen, the majority part of micro silica has a smaller size than cement particles (75 micron) and approximately continuous grading can be observed in this diagram.

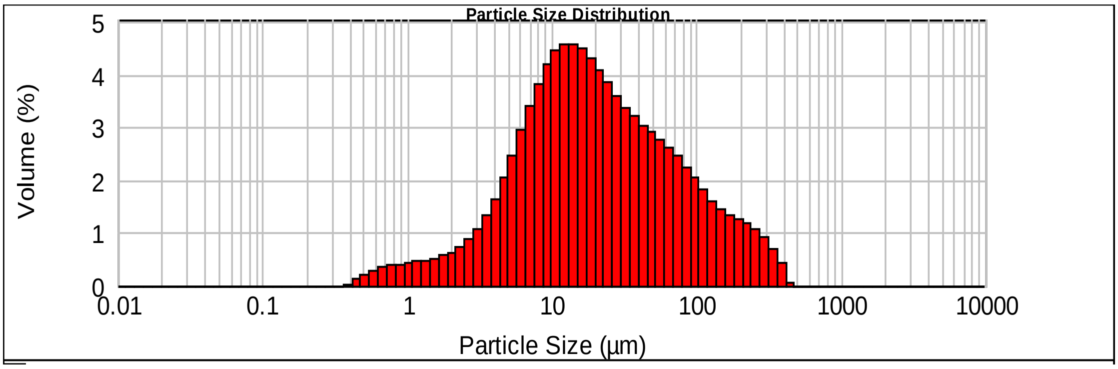


Fig. 1: The result of particle size analyzing test for silica fume

2.2. Mix design and specimen preparation

The mix proportions of fibre-cement slurry were designed in order to investigate the effect of type and percentage of fibres on flexural behaviour of FCB. Different percentage of natural fibres (Eucalyptus, Bagasse and Wheat fibres), were mixed with cement and water to form an aqueous slurry of a cementitious binder. Silica Fume (SF) was also replaced for 5 percent of cement weight in some groups of mixes to study its effect on properties of FCB.

Ten different mixes were designed by equal amounts of water-cement (binder) ratio and varying percentage of different fibres. A control mix with neat cement was also prepared to compare the results. Table 2 shows a mix proportion of specimens and correspondence codes used in this research. For each group, six replicates were carried out for flexural behaviour test.

TABLE 2- MIX PROPORTION OF THE SPECIMENS

Mix Design Code	Cement (g)	Water (g)	Silica fume (g)	Fibre (g)	Proportion
Reference (Control)	150	450	-	-	No fibre used (reference)
(B2)	150	450	-	3	2% BF
* (B4)	150	450	-	6	4% BF
* (B4M5)	142.5	450	7.5	6	4% BF+5% SF
(W2)	150	450	-	3	2% WF
(W4)	150	450	-	6	4%WF
(w4M5)	142.5	450	7.5	6	4% WF+%5SF
(E2)	150	450	-	3	2% EF
(E4)	150	450	-	6	4%EF
(E4M5)	142.5	450	7.5	6	4% EF+%5SF

*Note: to simplify the code of each mix (group), Fibre Cement Board (FCB) made out of each type of fibre is considered with abbreviation name of the ingredients. For instance B4 means, FCB reinforced by 4%

Bagasse fibre and similarly B4M5 means, FCB reinforced by 4% Bagasse fibre and 5% Microsilica (Silica Fume) were replaced for the cement.

2.3. Test procedure

Water-cement (binder) ratios of 3 were used to prepare the primary slurry for making the specimens. A rotary mixer with horizontal blades was used. Before adding fibres in composite, to unravel fibres from each other and better dispersion in cement paste, they were subjected to a specific mixer for 5 minutes. Then the cement, water and fibres (after unravelling) were added to the mix and stirred for another 5 minutes. The well-mixed slurry was poured into the moulds to form the sheet 18×8×0.8 cm for all mixing proportions. Fig.2 shows a laboratory set up system to make the specimens and some of the specimens which were made according to the EN12467: 2004 test method,

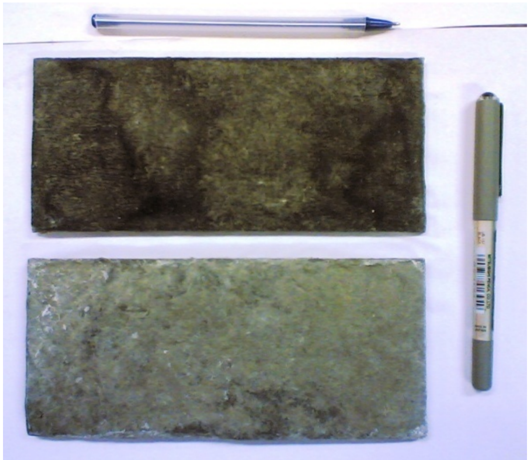


Figure 2- Some specimens and equipments for producing the specimens

Excessive water was sucked from the specimens using a vacuum pump (1 bar power). The weight of sucked water was measured until the water/cement(binder) ratio for specimens become 0.3. During this procedure, a 10 kg weight was applied to the specimens to aid drainage and level off the surface of the specimens. Then, the specimens were demoulded, exposed for 1 hour in ambient conditions and then were put in a curing chamber (RH=95% and temperature 21 degrees of Celsius) for 28 days. After curing, the specimens were ready for flexural test.

2.3.1.Fibre tests

Freeness test

One of the main characteristics of the fibres within cement matrix is pulp freeness. This test has been designed to measure the drainage properties of wood paste. The result of this test depends on many variables such as the amount of fine particles and morphology of fibres, type of fibres, fibrillation degree, flexibility of fibres, and the finesse modulus.

In this study, the freeness test was carried out according to the AS/NZS 1301.206s:2002 standard. The freeness is commonly called Canadian Standard Freeness (CSF) because it has been based on the test developed by the Canadian Pulp and Paper Research Institute. For the current study CSF=450-550 were gained for all types used fibres.

Physical properties

Some of the most important physical and mechanical properties of the fibres were tested and summarized in Table 3.

Table -3 Test results of physical characteristics of fibres

Fibre type	Bagasse	Eucalyptus	Wheat
*Average length (mm)	1.303	1.12	1.238
*Average diameter (mm)	0.348	0.480	0.345
**Average tensile strength (MPa)	30.947	19.440	6.093
Aspect ratio	3.744	2.3	3.588

*: Average length and diameter obtained from 50 fibres of each type.

**: Average tensile strength obtained from 10 fibres of each type.

In order to measure tensile strength of these fibres, 10 longer fibres (length ≈ 4mm) were selected and put in special jaws (named TG32 Fine Wire Grip with Spring Action Clamp) using delicate load cell (resolution= 0.0001N)as are depicted in figure 3.

Figure 3- measuring the tensile strength of fibres using Fine Wire Grip

2.3.2.Cement board tests

Flexural strength

Flexural behaviour of the specimens under three points load system according to BS EN12467:2004 was investigated. This standard suggests 5 classes for flexural strength as shown in Table 4.

Table 4- Minimum failure load for various classes according to the EN12467:2004

Class	Minimum flexural strength (MPa)
1	4
2	7
3	10
4	16
5	22

3. Experimental results and discussion

For each group, six specimens were reproduced. In some cases, one or two specimens had a difference of more than 10% compared with the average of other members of the group, so those specimens were omitted. Consequently only the results with less than 10% difference compared with the average strength and the standards deviation less than 0.6 MPa were selected for analysing.

3.1. Flexural behaviour

According to BS EN 12467, the results of flexural strength test (or MOR: Modulus of Rapture) should be interpreted by calculating flexural stress as follows:

$$\sigma = \frac{3PL}{2BH^2} \qquad (1)$$

Where

σ is flexural stress/ modulus of rapture (MPa)

P is the breaking load (N)

L is the span of the simple supports (mm)

B is the width of the specimen. (mm)

H is the thickness of the specimen. (mm)

In each group, the flexural behaviour of a specimen being nearest to the average of the flexural strength (with the difference less than 10% through the mean and standard deviation less than 0.6 MPa) was selected as a representative of that group. Fig 4a and 4b are associated with different groups and compare the flexural behaviour of the representative for each group with other groups.

In theses graphs, central point deflection of the specimen against flexural stress calculating with the above mention formula has been drawn.

In fig 4.a flexural behaviour of FCB for all groups with 2% fibre content has been attested. As it is observed, adding 2 percent fibres leads to some changes in maximum flexural strength, however the ductility of specimens is almost similar to each other and also they are brittle as was the control specimen. Maximum flexural strength for the control specimen is 3.7 MPa and for the specimens include EFCCB2, BFCCB2 and WFCCB2 are 3.9, 5 and 2.9 MPa respectively. Except WFCCB2, other specimens, particularly BFCCB2 has an increase in flexural strength.

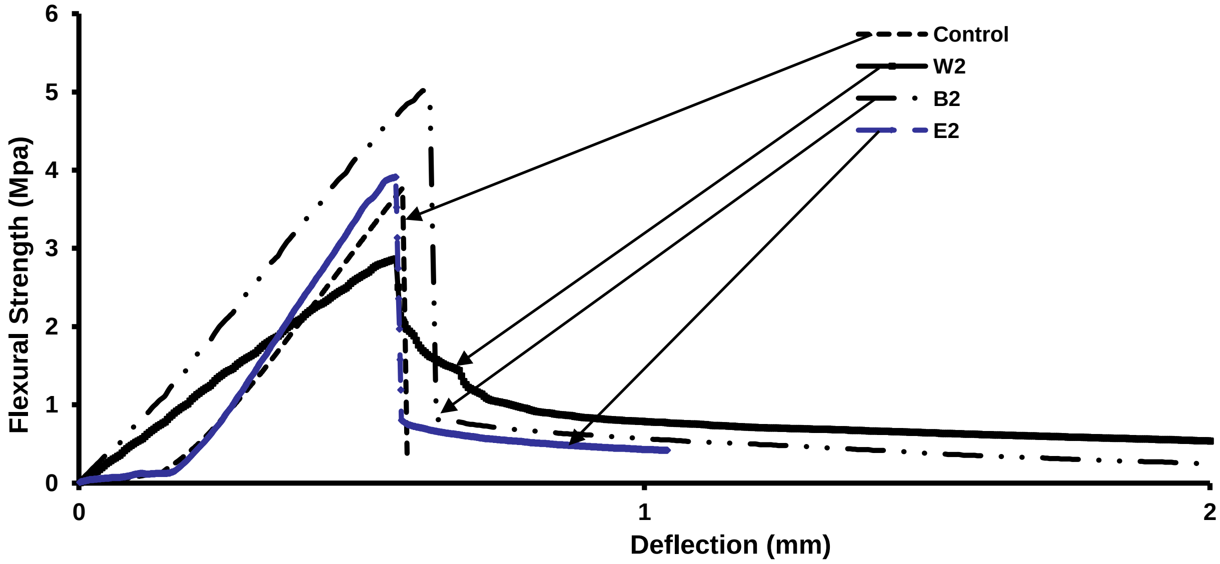


Fig 4.a Flexural behaviour of FCB with 2% fibres and compare with control specimen

In order to identify the effect of increasing the content of fibre on flexural behaviour characteristics, the graphs for the specimens with 4 percent fibres have been drawn in fig 4.b

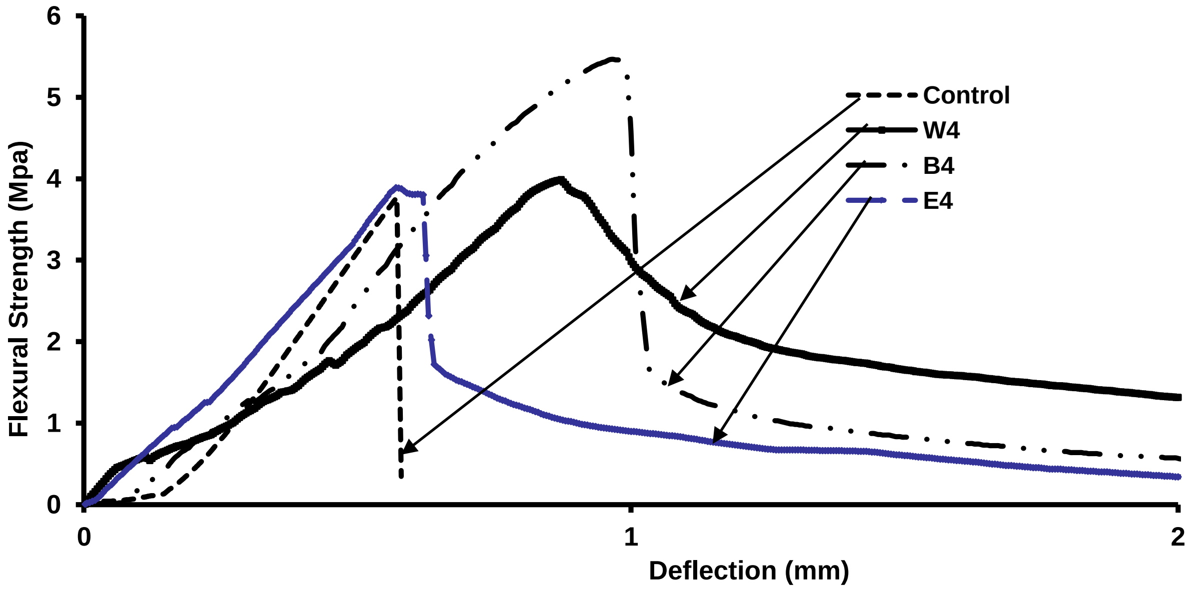


Fig. 4.b Flexural behaviour of FCB with 4% fibres and compare with control specimen

Increasing 4 percent fibres to specimens changed the flexural behaviour considerably. Not only do all the groups have the maximum flexural strength more than the control ones but also their ductility has been improved.

As it can be seen, the flexural strength and the ductility of BFCCB are more than other groups. After bagasse, the best flexural behaviour is related to WFCCB and EFCCB respectively.

Increasing bagasse fibre content from 2 up to 4 percent enhanced the maximum flexural strength of the control sample 37 and 44 percent respectively. Increasing fibres content more than 4 percent creates disruption. The low specific gravity of the bagasse fibres causes fibres to float on top of the slurry and it creates a lack of homogenous mixture in the composite so that the top surface of the composite fills with accumulated fibres. Therefore, making specimens with an excess of 4% fibre content was stopped.

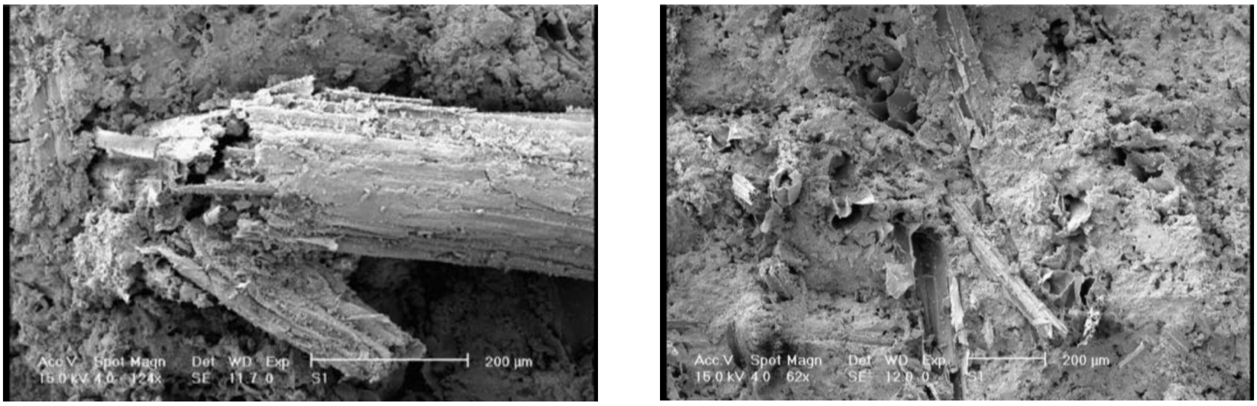
Better performance of the bagasse fibre can be attributed to the high tensile strength and the high aspect ratio of the bagasse fibre rather than the wheat and the eucalyptus fibres. High aspect ratio of the fibre leads to an increase the lateral surface area of the fibres contacting with the cement, hence bonding between the cement and the fibres increases. Also, the high tensile strength of the fibres causes a change in the mechanism of rupture from breaking fibres to pulling up the fibre from the matrix. This means that the bonding strength between the cement and the fibres controls the mechanism.

Flexural behaviour of the composite containing the wheat fibres has also been illustrated in Fig 4.a and 4.b.

As it can be seen, adding 2 % of the fibres causes a reduction in the flexural strength compared to the control specimen, while increasing 4 % of these fibres enhance the flexural strength a bit more than the control specimen. After analyzing the broken pieces of the specimens, it was observed that some parts of the wheat fibres couldn't distribute uniformly in the matrix and a quantity of these fibres clamped together and was placed in some points of the specimen. It means some areas of the specimens were without fibres. This could lead to grow the initial cracks in these areas. When the amount of the fibres reached up to 4 percent, the fibres covered the whole of the composite however, the "balling effect" was still observed in some points of the composite. This means, a minimum amount of the fibres have been distributed in the whole of the composite.

Another point than can be deduced from Fig 4.b is that applying 4% fibre content of the wheat or eucalyptus fibres causes an insignificant raise in maximum flexural strength compared to the control specimen. However, its effect on energy dissipation (and ductility) is considerable. It seems, there is an important difference between the behaviour of wheat and eucalyptus fibres in cement matrix. These different behaviours are demonstrated in figure 4c.

The average and minimum tensile strength of the wheat fibres are 6 and 4 MPa respectively (Table-3). As it can be observed in fig4.b, while the maximum flexural strength of WFCCB approaches 4 MPa, the specimens start gently breaking. This can be due to some weak fibres with minimum tensile strength (4MPa) , being placed in the matrix and reaching the maximum tensile bearing capacity, they then break and the initial cracks appear in the specimens. Once, some parts of the specimens are encountered by cracks, the applied stress for the remainder of the specimen increases. Since there are some strong fibres in the specimen, loading can continue and breaking would occur softly. Observation of the broken specimens shows (Fig 4.c) that most of the wheat fibres had been broken rather than pulled up from the matrix. This type of behaviour for wheat fibres can also lead to more ductility as shown in fig4.b because breaking fibres come about gradually and it will increase the ductility of the specimens.



Fibres breaking in the WFCCB specimens

Fibres pulling out in the EFCCB specimens

Fig 4.c Different mechanism of rupture in the WFCCB and the EFCCB specimens

Breaking the EFCCB specimens seems not to be related to the weak tensile strength of the eucalyptus fibres. As it can be seen (fig 4.a and 4.b), applying 2 or 4 percent fibres, doesn’t have any important affects on flexural behaviour of the composites. In other words, maximum flexural strength and ductility for the both groups are similar to each other. The reason can be attributed to the aspect ratio of these fibres. The aspect ratio for the eucalyptus fibres is 2.3 while for the wheat and the bagasse fibres are 3.5 and 3.7 respectively. This means, the little amount of lateral surface area of the eucalyptus affect the bonding within the cement and the fibres. Observation of the broken specimens (Fig 4.c) shows that most of the eucalyptus fibres were slipped and pulled out rather than breaking. The sliding of the fibres occurs suddenly and rapidly so it is not expected for these specimens to show great ductility or energy dissipation. Fig 4.a , 4.b and observation of broken samples prove this declaration.

Effect of silica fume

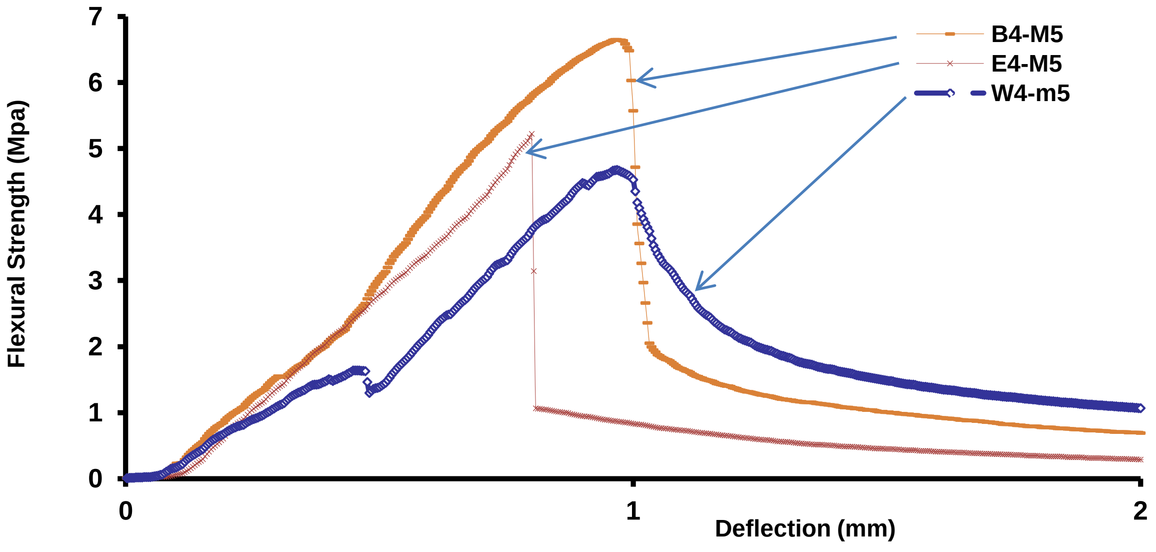


Fig-4.d effect of replacing 5% micro silicate for cement for all groups

Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2), with individual particles being extremely small. Due to these fine particles, large surface area and the high SiO_2 content, silica fume is a very reactive Pozzolanic.

Figure 4.d compares the flexural behaviour of the specimens containing silica fume for each group. As it can be observed (by comparing Fig. 4.b and 4.d), replacing 5 percent by weight silica fume for the cement, the flexural strength increases around 20 percent compared to the specimens without silica fume.. This increase can be attributed to the silica fume particles being extremely small compared to that of the cement particles (approximately 2 times smaller). The silica fume particles act as filler materials within the cement matrix, reducing the porosity of the composite as voids containing air and moisture are filled. Also due to the Pozzolanic reaction of silica fume, calcium silicate hydrate can be formed which aids in giving higher strength. Application of silica fume in cement composite boards which are reinforcing by cellulose fibres causes an increase on the flexural strength because these very fine Pozzolanic materials decrease the alkaline environment of cement matrix. Indeed, Kraft cellulose fibres have little lignin which can be attacked by alkaline cement; hence it leads to degradation in strength of composite. It seems, use of these Pozzolanic

materials leads to reduction in alkaline matrix. And immersion of fibres in slurred silica fume can be useful for durability properties of the fibre cement boards.

In Fig 4.d the highest flexural strength belongs to the specimens containing bagasse, eucalyptus, and wheat fibres, respectively. For the supplement of 5% silica fume, the flexural strength of the specimens containing bagasse fibres has been enhanced reaching strength of just under 7MPa.

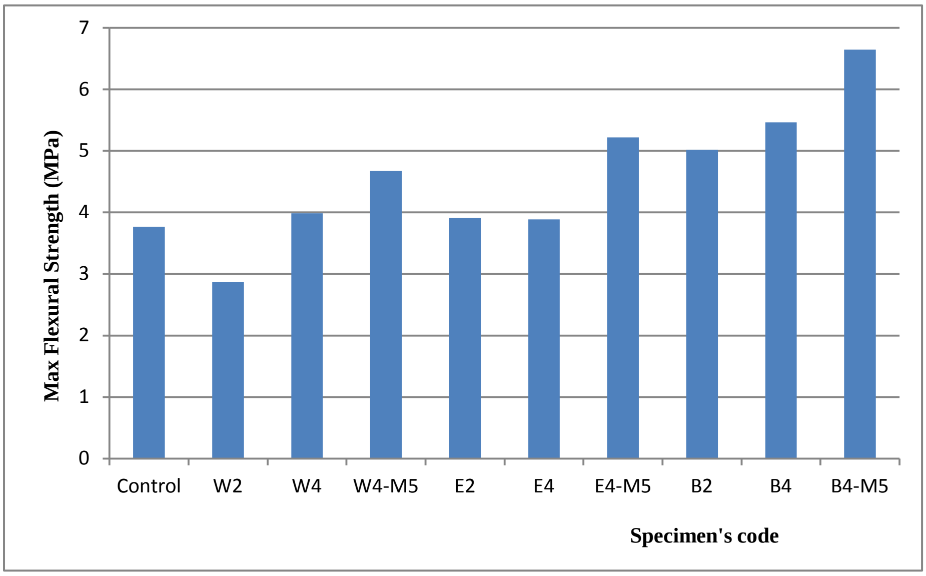


Fig 4.e Maximum flexural strength for different groups

Maximum flexural strength for different groups compared to the control specimen has been shown in Fig. 4.e. As it can be observed, except specimen W2, other specimens have strength higher than the control specimen. Only specimens containing eucalyptus fibres have not been changed with different amounts of fibre content and other groups showed an increase in flexural strength when the amount of fibre content was raised from 2 to 4 percent and this was due to particular characteristics of used eucalyptus fibres. Replacing 5 percent of cement weight by silica fume led to an approximate 20 percent increase in flexural strength for all groups, this was because of Pozzolanic and filler effects of these very fine materials. The highest flexural strength belongs to specimens reinforced by bagasse fibres that can be attributed to high tensile strength and high aspect ratio of these fibres.

4. Conclusions

The large amount of waste agricultural materials produced in many areas is causing various environmental problems. The results of this study on the use of these waste materials indicates that some of the waste materials may be used in making versatile cementitious composites which could be used in the construction industry. However, other specifications of the products related to waste material such as durability should be considered in future research. From the results of the above experiments on performance of bagasse, wheat and eucalyptus fibres in cement composite boards, the following conclusions can be drawn:

1. The agricultural waste fibres (i.e. bagasse, eucalyptus and wheat fibres) showed a satisfactory consistency with cement paste.

2. Flexural behaviour characteristics of FCB using bagasse fibre (BF) enhance considerably compare to the wheat and eucalyptus fibres. This may be due to mechanical and physical properties of bagasse fibres.

3. The maximum amount of fibres to be used in FCB depends on the physical, mechanical properties of fibres and manufacturing process. With considering the conditions of this study, maximum fibre's content in FCB in laboratorial scale could be 4% by the weight of cement.

4. All groups of specimens reinforced by bagasse and only some groups of specimens reinforced by eucalyptus and wheat fibres, including silica fume, have flexural strength greater than the grade 2 strength required by BS EN12467 standard.

5. The best result is related to the bagasse fibres when it uses 4% by the weight of cement and it increases maximum flexural up to 6 MPa, this is about 50% more than the control specimens and it can increase to 6.6 MPa when 5 percent by the weight of silica fume is replaced for cement.

6. Addition of the silica fume could improve the mechanical property of the FCB and causes an increase approximately 20 percent in flexural strength of the FCB.

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