APPLICATION OF KRAFT AND ACRYLIC FIBRES TO REPLACE ASBESTOS IN COMPOSITE CEMENT SHEETS

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ABSTRACT

This work presents a characterisation of Kraft and Acrylic fibres in formulations of fibre cement slurries, seeking the replacement for asbestos as fibre in cement-based products. All these materials can be easily provided in Iran and other developing countries which cannot afford the new special cellulose and polymeric technologies exclusive to developed countries. The interest in finding materials that substitute asbestos is due to controversies concerning the use of this material and associated health problems in developing countries.
The chemical, physical and mechanical properties of fibres were determined followed by the flexural strength and modulus of elasticity of fibre cement specimens. The results indicate that the fibre contents and types affect the flexural behaviour and fracture mechanism of composite sheets significantly. The mix design with optimum amount of Kraft and Acrylic fibres found in this investigation satisfies Class 2 classification of the EN 12497 standard and is a feasible alternative for some asbestos cement sheet applications.

KEYWORDS

Kraft fibres; Acrylic fibres; Composite cement products; Cement sheets; Asbestos replacement.

INTRODUCTION

Asbestos is the name given to a group of fibrous hydrous silicates which not only have outstanding mechanical and physical properties but also have excellent durability against environmental conditions, stable in high pH range and high thermal coefficient. Because of its excellent characteristics, it has been used in different applications such as acoustic insulator, thermal insulation, fire proofing and other construction materials (Virta, 2003).

Because of its easy and inexpensive processing as well as other characteristics, during the last century it was used as a building material with various forms and styles to suit different needs. Asbestos Composite Cement Board (ACCB) has been one of the major applications of asbestos fibres in construction, so that at present there are many buildings around the world having ACCB as roofing tiles or wall boards.
Despite the international ban on the usage of asbestos, there are ten Cement Composite Boards factories in Iran and they all use asbestos in their products. The annual amount of asbestos used has increased since 1985 (20,000 tonnes) and is estimated to be 76,000 tonnes in 2003 (Vitra, 2006) and 64,300 tonnes in 2004 (BWI site, 2008). The available statistics show that the production of flat and corrugated cement boards is in excess of 30,000,000 m^2 and 4000 km length of composite cement pipes. Also according to the annual report of the Ministry of Health, the number of deaths due to asbestos related diseases is about 4000 per year.
The design of a durable and low-cost asbestos-free composite cement sheet is a technological challenge in developing countries. As increasing concerns are being associated with chrysotile fibres, new research is now expected for the adaptation of available raw-materials and production systems to fit the consumer requirements at each particular application area (Giannasi, 1997 and Harrison, 1999).

Over the last decades many research studies related to the substitution of asbestos by other raw materials have been published. These works focused on natural cellulose fibres and synthetic fibres, alone or as a mixture. The most important fibres which have been studied are sisal, bamboo, flax, banana, jute, baggasse and Kraft fibres (Coutts, 2005). The latter attracted most attention because of its mechanical and physical characteristics, compatibility with cement matrix, availability and relatively low costs. However it is necessary to undertake suitable treatment on Kraft fibres before using in CCB to prevent decomposition and decay in the alkaline environment of cement (Negro, 2005). Some researchers (Asasutjarit, 2007 & Coutts, 2005) indicate various advantages in the use of natural fibres in cement composites (i.e. increased flexural strength, post-crack load bearing capacity, increased impact toughness and improved bending strength). Natural fibres exhibit many advantageous properties as reinforcement for composites in the Hatschek process (Bilba, 2003, Tolêdo, 2003, and Negro, 2006) but each particular fibre type requires special modification and treatment to improve its vulnerability to chemical decomposition in the alkaline environment of cement (Hachmi, 1990, Miller, 1991 and Roma Jr., 2008). Nowadays, most of the factories which have modified the Hatscheck method use Kraft fibres as primary fibres associated with other synthetic fibres.

Previous research carried out by the authors studied some of the chemical and mechanical properties of fibres such as resistance to alkali, tensile strength, young modulus etc (Khorami 2008a and Khorami 2008b). The effect of fibre length and aspect ratio was also studied. The results showed that Kraft fibres have potential to be used in Cement Composite Boards (CCB). In this research, the application of Kraft and Acrylic fibres has been studied. The research focused on the use of discrete and randomly oriented fibres mixed with cement and water. The effect of different amounts of fibre proportions in the mix design was investigated. The mechanical and physical properties were measured according to relevant standards in the laboratory and the results were compared with the values of control (Kraft only) and reference (no fibres) cement board specimens.

Material Characteristics and experimental procedure

Unbleached Kraft hardwood pulp and lime stone powder were used on a matrix of ASTM Type II cement. The Kraft pulp was made in a paper manufactory and was submerged in the water for 48 hours after beating. The average length of the Kraft fibres used was about 870 µm and the average diameter was about 31 µm. The specific gravity of the Kraft was 1.5. Acrylic fibres of 5mm average length, about 20 µm average diameters, 1.3 specific gravity, 0.4 GPa average tensile strength and 3% elongation at break, were used.

Experiments were performed with twelve different fibre proportions as shown in Table 1. All of the suspensions were made with potable water. The water to cement ratio of 0.3 was used. The suspensions mixture code is as follows:

K: Kraft pulp; **A**: Acrylic ; **L**: Lime stone powder passing 450 Micron sieve.

The proportions given in Table 1 are by weight of cement used. For instance, mixture code K2A0.5L10 represents suspension of 2% (of cement weight) Kraft fibre, 0.5% (of cement weight) Acrylic fibre and 10% lime stone powder.

The Kraft and Acrylic fibres were separated and blended in a mixer with horizontal blades of 15 mm radius for 5 minutes. Cement and water were added to the mixer next and the materials were mixed for further 5 minutes. The suspension was then poured in to the cube mould of 80×180×150 mm. The excess water was pumped out from beneath the suspension mould by a 0.9 bar vacuum pump (Figure 1). A 10 kg weight was placed on top of the suspension during water suction to enhance compaction. Five replicate specimens were prepared for testing (Figure 2). The cement board specimens made were cured in 95% RH and 20°C for 14 days and cured in ambient conditions (50% RH & 25°C) for up to 28 days. The specimens were dried in the 75°C oven for 6 hours before testing. Various tests were carried out according to the relevant BS EN 494:2004 and 12464:2004 standards to determine the physical (density, moisture content, water absorption, thickness swelling, dimensions and tolerance) and mechanical properties (modulus of rupture and flexural strength) of the specimens. Fibred and CCB specimens were also examined using SEM images to investigate the morphology of fibres and microstructure of hardened composite cement sheets.

Table 2 – Mix designs of the cement composite boards made.

Mixture Code	Cement (gr.)	Water (gr.)	fibres		Limestone (gr.)
			Acrylic(gr.)	Kraft(gr.)	
Reference	165	495	0	0	0
Control K2	150	450	0	3	15
Control K4	150	450	0	6	15
Control K6	150	450	0	9	15
K2A0.5L10	150	450	0.75	3	15
K2A1L10	150	450	1.5	3	15
K2A2L10	150	450	3	3	15
K4A0.5L10	150	450	0.75	6	15
K4A1L10	150	450	1.5	6	15
K4A2L10	150	450	3	6	15
K6A0.5L10	150	450	0.75	9	15
K6A1L10	150	450	1.5	9	15
K6A2L10	150	450	3	9	15

Figure 1 – The mould and the vacuum set up used to cast the cement boards.

Figure 2 - The fresh composite cement board specimens after casting.

Experimental testing

Tests for Kraft fibres:

Freeness test

One of the important characteristics of the fibre in cement matrix is the Canadian Standard Freeness (CSF) (Australian/New Zealand standard, 2002) that was designed for measuring the drainage properties of the Kraft -paste. The freeness of pulp is designed to give a measure of the rate at which a dilute suspension of pulp (3 gr. of pulp in 1 litre of water) may be drained. The freeness, or drainage rate has been shown to be related to the surface conditions and swelling of the fibres. Besides these factors, the result is dependent also on conditions under which the test is carried out, such as stock preparation, temperature, and water quality. Fibre freeness is altered through refining. Refining improves the bonding characteristics of the fibres, increasing strength properties such as tensile and burst. However, increased refining also lowers stock freeness and cut fibres.

The results of CSF test depend on many factors, such as the amount of fine particles and small pieces of available wood, fibrillation degree, flexibility of fibres, and the finesse modulus. The procedure for this test is as follows:

1- Specific volume of wood-paste was poured into the cylinders to be drained. Accompanying liquid was brought into the conical case with two orifices, one in the bottom and the other located on the side of the case.

2- Volume of liquid that passes through the hole located on the side of the case was measured and reported as degree of freeness after some corrections on the values of temperature coefficient and pulp.

3- In this research, the cured fibres were examined for freeness test according to CSF.

4- Average measured value for CSF was 500, which was very close to results of other researches (Soroushian, 1994).

Physical tests

Prepared fibres were poured into the test tubes and de-fibred. After full separation, length and diameter of fibres as well as the diameters of cellulose pores were measured with projectina optical microscope with 30 repeats. The diameter of the cell wall thickness is calculated as half-difference between fibre diameter and bottom orifice diameter.

Table 2 – Physical characteristics of fibres

Physical characteristics	Average (Microns)
Length	870
Diameter	31
Cell wall thickness	4

Test for Acrylic fibres:

Tensile tests were carried out using Textechna Vibromat M. The results are shown in Figure 3A. For resistance to cement alkaline condition the fibres were placed in a solution of NaOH with pH of 12 for 28 days and then the tensile testing was carried out. The results for this are shown in Figure 3B. The results indicate not much change in the tensile strength of the Acrylic fibres before and after submerging in alkaline solution. This confirms its suitability for application in this work.

Cement Boards tests:

In this research, the strength of specimens was tested in flexural loads. The flexural samples were flat rectangular and tested with a point load system according to the EN12467:2004 standard procedure. This standard suggests 5 classes for flexural strength as shown in Table 3.

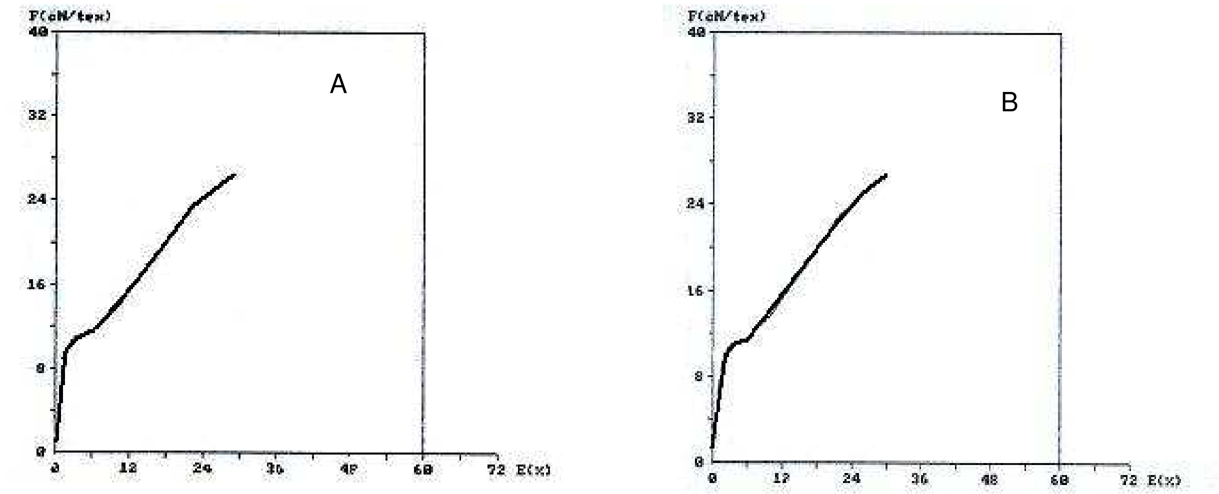


Figure 3 – Tensile test results for Acrylic fibre before (A) and after (B) submerging in alkaline solution.

Table 3 – Minimum modulus of rupture (MOR) according to EN12467.

Minimum *MOR* in the wet condition Mpa		**Minimum *MOR* in the ambient condition** Mpa	
Classes	Category A and B	Classes	Category C
1	4	1	4
2	7	2	7
3	13	3	10
4	18	4	16
5	24	5	22
NOTE 1: Where manufacturers state minimum product MOR this shall be at the 4% acceptable quality level (AQL). NOTE 2: For textured sheets the MOR cannot be used for calculating mechanical performance.			

Results and discussion

The results of the bending loads against the deflection for all the specimens are shown in Figures 4 to 9. The results of the specimens with constant Acrylic fibre amount but variable Kraft fibre percentage (i.e. 2%, 4% and 6% by weight of the cement) are given in Figures 4 to 6. The results for the specimens with constant Kraft fibre amount but variable Acrylic percentage (i.e. 0.5%, 1% and 2% by weight of the cement) are given in Figures 7 to 9.

Figures 4 to 9 show that the stress of all specimens (except reference specimens) increased uniformly with deflection up to 0.1 MPa following with a sharp change between 0.1 to 0.2 MPa. To make this clearer further this section of Figure 8 is enlarged in Figure 10. The initial increase in stress can be due to hair line cracks occurring in the cementitious matrix and load transfer to fibres in the matrix. The greater stress increase in samples containing fibres implies that fibres are stressed and part of the load is carried by fibres after this point. From Figures 4 to 9 it can be observed that the stress-strain relationship remains linear elastic up to the maximum flexural strength of the specimens. The slope of the line is interpreted as modules of elasticity which is affected by behaviour of different fibres in the specimens. The stiffness of the specimens increases as the slope of the line increases. In other words the deflection of the specimens is also affected by type of fibres and its proportions used.

Figures 4to 6 show the effect of Kraft fibres on stress-deflection relationship of the specimens. The slope of linear part of the graph changes with the increase in the percentage of fibres within the specimens. As the ultimate modules of elasticity of a composite depends on the lowest modules of ingredient materials, the decrease in slope is due to the lower modules of elasticity of fibres compared to the cementitious matrix.

As expected the maximum flexural strength of the composite cement sheets is increased by using fibres. The optimum percentage of Kraft fibres for use in cement sheets depends not only on the amount of Kraft fibres but also the amount of Acrylic fibres used. In general samples with low percentage of Kraft fibres with blended Acrylic fibres showed the best results. Figures 4 to 6 show that although specimens did not break at maximum load applied, i.e. increased ductility, the highest energy absorption was achieved in specimens containing 2% Acrylic fibres. This indicates the more plastic behaviour of these mixes.

The effect of Acrylic fibres on flexural behaviour of cement Kraft fibre sheets is shown in figures 7 to 9. When acrylic fibres content is over 1%, the slope of the elastic part of stress-deflection relationship curve decreases with increase in fibre content. Mixes containing 0.5% and 1% Acrylic fibres showed the highest elasticity modules. From Figure 8 it can be seen that Acrylic fibres have no significant effect on flexural strength of the high content Kraft fibre specimens. Figures 7 to 9 also reveal that the Acrylic fibres are most effective with lower content of Kraft fibres in the cement composite sheet.

Figures 7 to 9 depict the effect of Kraft fibres on flexural strength of specimens. The greater the amount of Kraft fibre used in the Kraft fibre only specimens, the significantly higher the flexural strength. Figure 7 shows about 100% increase in flexural strength of Kraft fibre only specimen while Figures 8 and 9 show 50 and 10% increase respectively. However, the post crack behaviour of specimens in Figures 8 and 9 is highly affected by the amount of fibres in the mix. It can be observed from figures 4 to 9 that the area below the stress-strain curve is increased with increase in the percentage of fibres. In other words, fibres are effective after the composite sheet reaches its maximum strength as fibres act as ties between two fractures interfaces of the cement matrix and prevent the sudden failure of the samples.

The results of maximum flexural strength of the specimens are shown in Figure 11. The magnitude of increase in flexural strength varies with amount of fibre in the mix. Figure 11 shows that fibre contents affect the flexural behaviour and fracture mechanism of composite sheets significantly. In specimens containing 2% Kraft fibres, increase of Acrylic fibres from 1 to 2% results in slight decrease in flexural strength. This is due to floatation of Acrylic fibres in the mix and therefore accumulation of these synthetic fibres on the surface of the specimens. This will prevent the uniform distribution of fibres in the mix and therefore being ineffective to improve the flexural strength of cement composite sheet. Figure 11 also shows that use of 4% Kraft blended with Acrylic fibres results in 6% and 8.5% decrease in flexural strength of specimens containing 1% and 2% fibres compared to those containing 0.5% Acrylic fibre respectively. Based on above results 1% Acrylic fibres blended with 2% Kraft fibres gives the optimum blended amount for these fibres. Also it seems that with same amount of Kraft fibre, the distribution of fibres in the mix tends to become non-uniform as the Acrylic fibres content increases. This was confirmed by visual observation of samples in the laboratory. This may be the reason for the decrease of flexural strength with increase amounts of synthetic fibres. With respect to visual observation, this group of specimens was smooth on surface with fibres uniformly distributed in the fractured sections. This is also confirmed by the SEM image as shown in Figure 12.

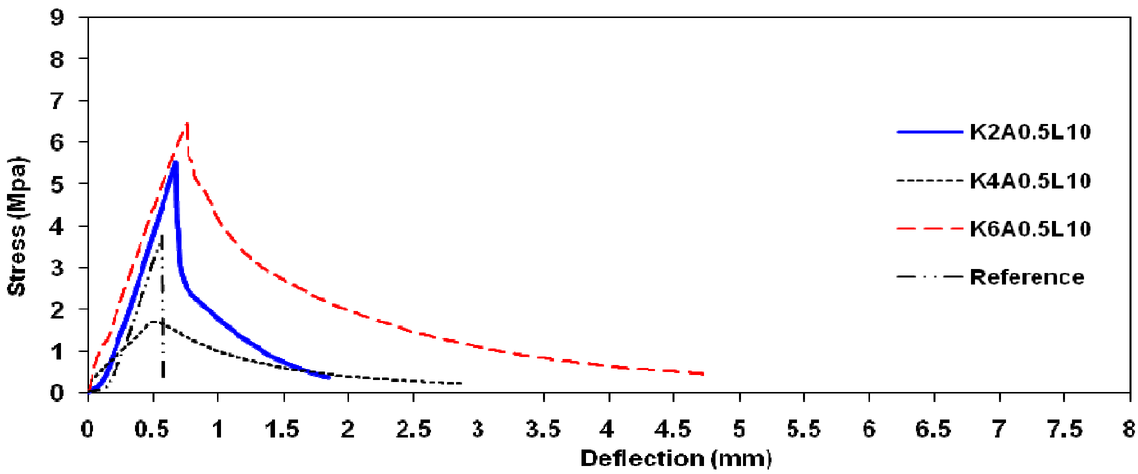


Figure 4 - Stress vs. deflection for specimens with 0.5% Acrylic fibres.

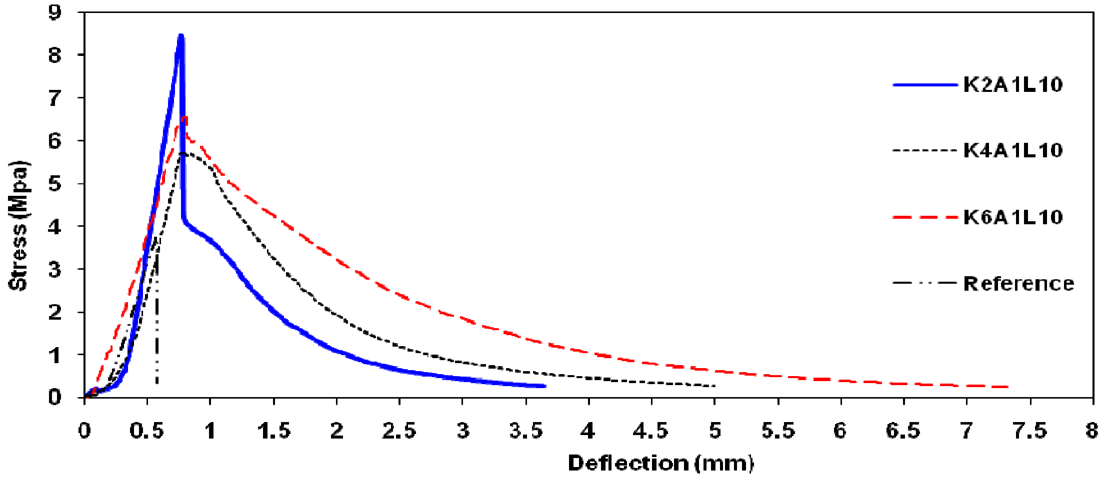


Figure 5 - Stress vs. deflection for specimens with 1% Acrylic fibres.

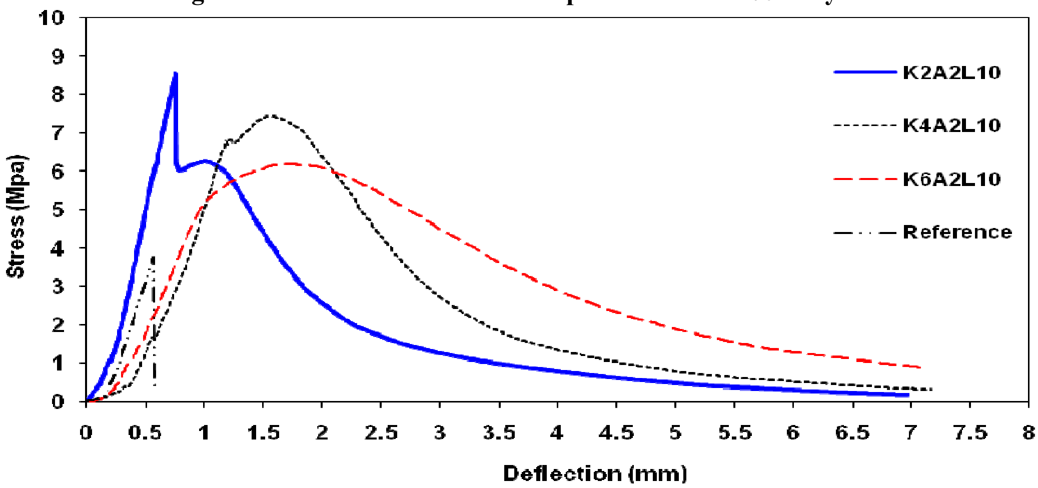


Figure 6 - Stress vs. deflection for specimens with 2% Acrylic fibres.

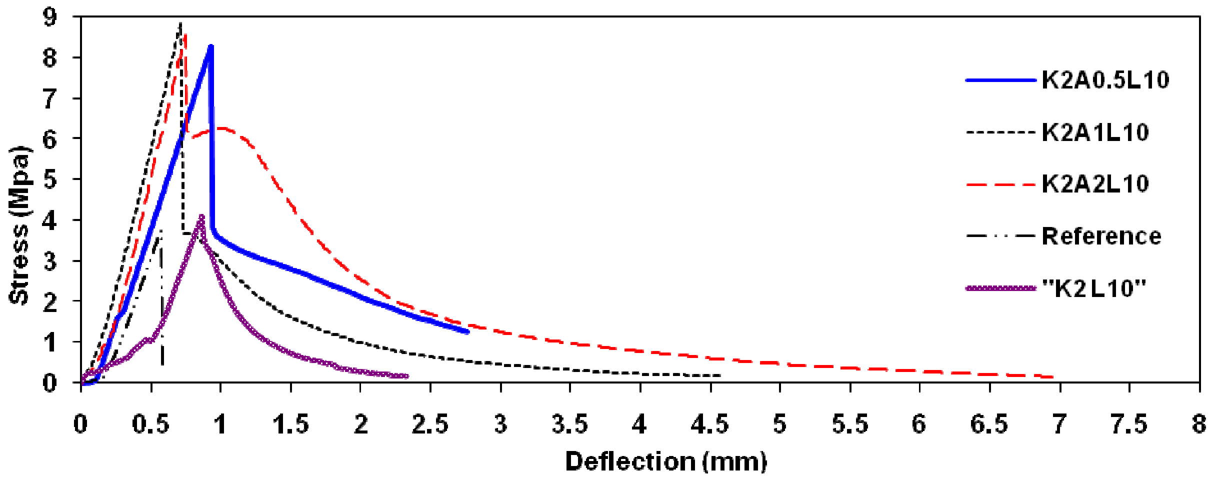


Figure 7 - Stress vs. deflection for specimens with 2% Kraft fibres.

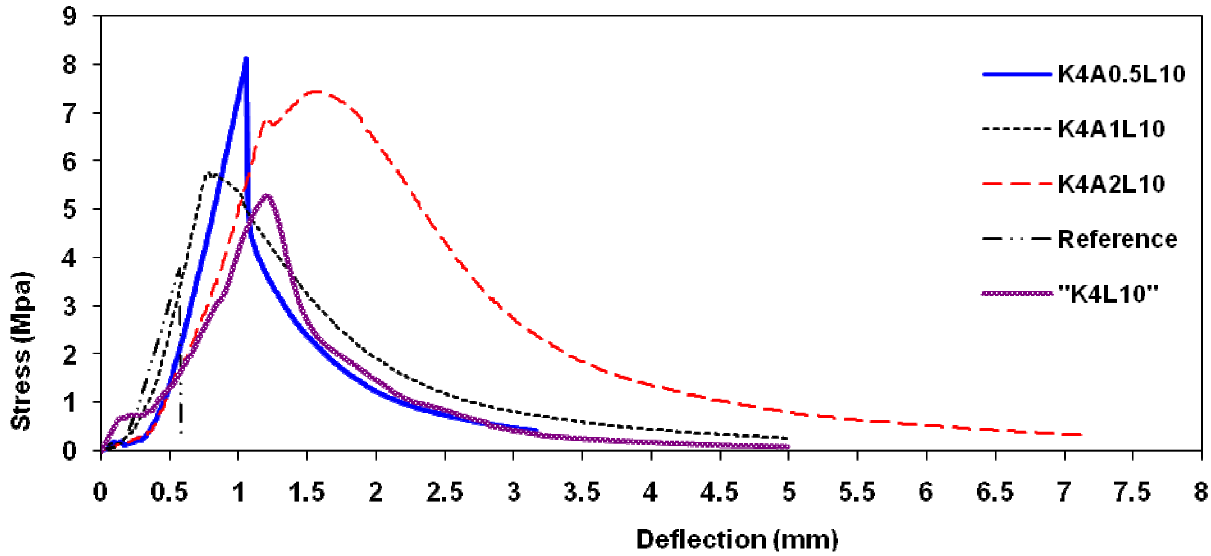


Figure 8 - Stress vs. deflection for specimens with 4% Kraft fibres.

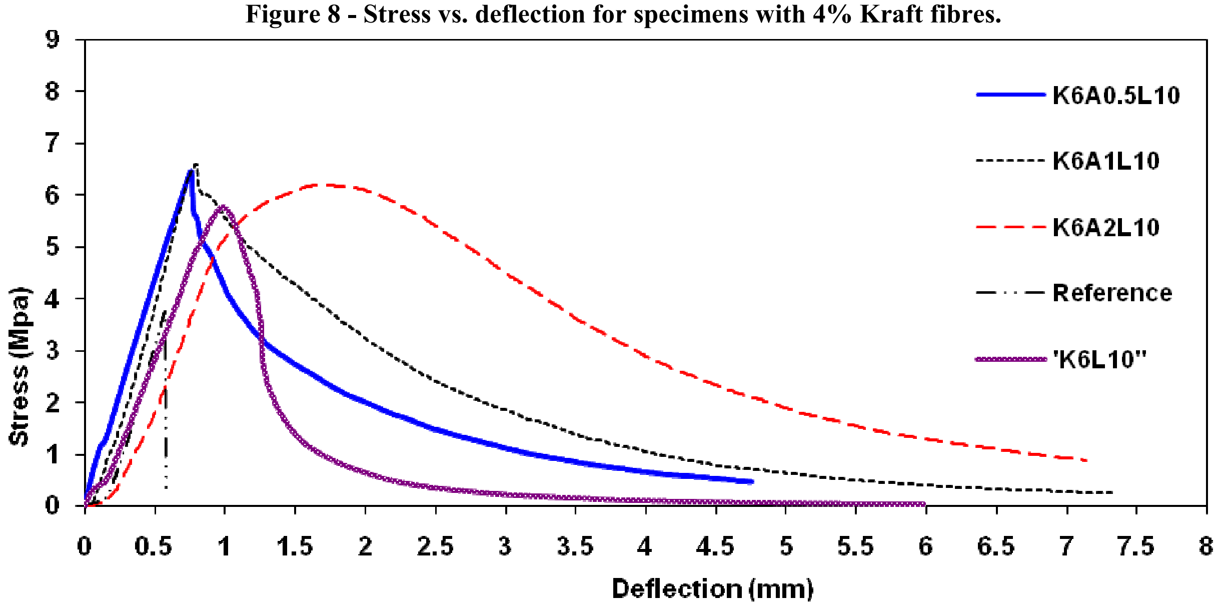
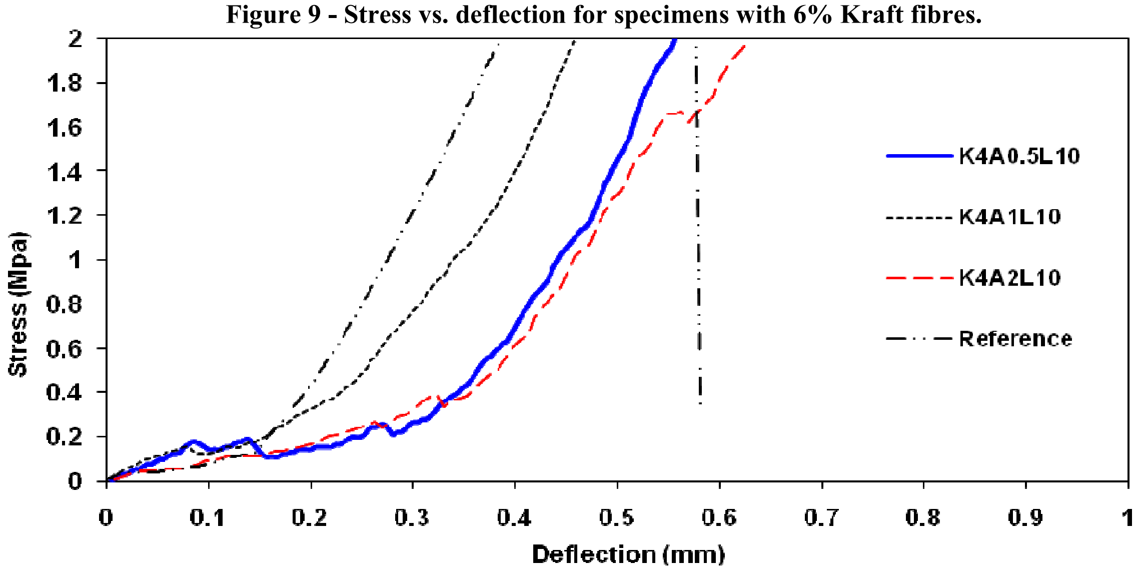


Figure 9 - Stress vs. deflection for specimens with 6% Kraft fibres.



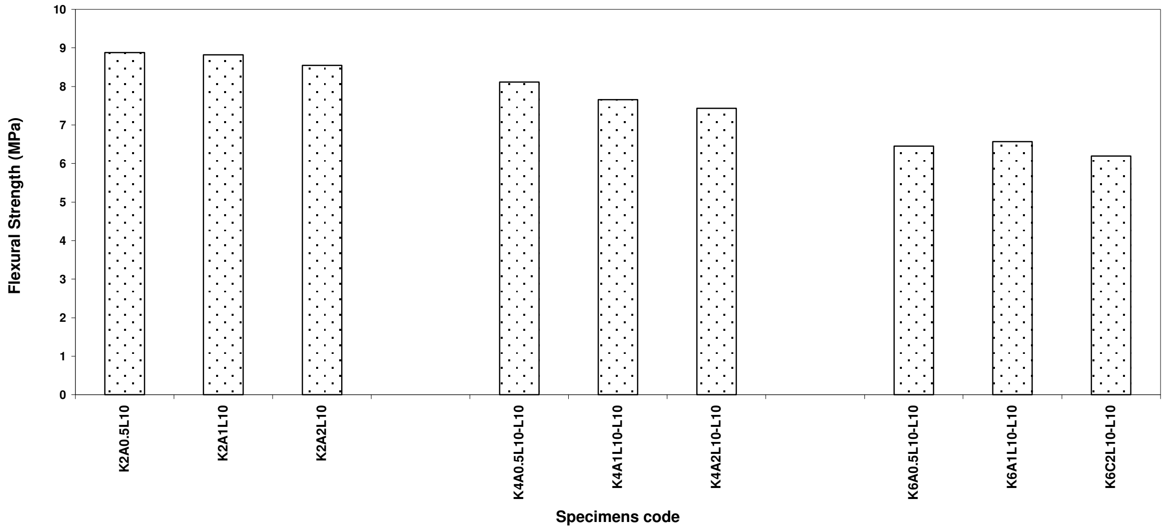


Figure 11 – Maximum flexural strength of the blended fibres cement composite sheets.

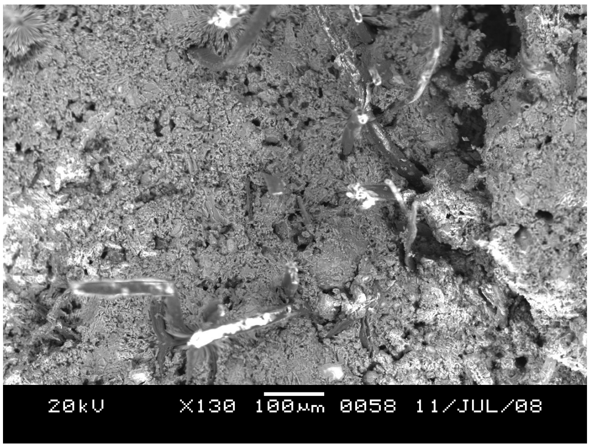


Figure 12 – Smooth surface and uniformly distributed fibres in the fractured surface of the K2A1L10.

CONCLUSION

Based on the results and discussion presented, the following conclusions were drawn:

1. A blend of Kraft and Acrylic fibres in cement composite can lead to a substitute for asbestos in cement composite boards. The mix with optimum amount of Kraft and Acrylic fibres found in this investigation satisfies Class 2 classification of the EN 12497 standard.
2. 1% Acrylic fibres blended with 2% Kraft fibres give the optimum blended amount for the fibres studied.
3. The optimum blended fibre doubles up the MOR of the Kraft fibre only specimens and improves the flexural behaviour of the specimens.
4. There is an interaction between Kraft and Acrylic fibres in the cement composite sheet so that with increasing Kraft fibre amounts and constant Acrylic amount, the flexural strength decreases. The optimum percentage of Kraft fibres for use in cement sheets depends on not only the amount of Kraft fibres but also the amount of Acrylic fibres used.
5. The Acrylic fibres are more effective with lower content of Kraft fibres in the cement composite sheets.
6. The fibre contents and types affect the flexural behaviour and fracture mechanism of composite sheets significantly. Increasing the Acrylic fibre content by more than 1% not only reduces the flexural strength

slightly but also causes the flotation of Acrylic fibres in the mixture and therefore accumulation of these fibres on the surface of the specimens. This will prevent the uniform distribution of fibres in the mixture and therefore being ineffective to improve the flexural strength of cement composite sheet.

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