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PROPERTIES OF MORTAR REINFORCED WITH NATURAL HORSE HAIR AND KENAF FIBRES

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Abstract: Cement based materials such as concrete and mortar are widely used in construction industry. One of the drawbacks of concrete or mortar is its low tensile strength that will affect cracking. Thus, enhancing its tensile strength using short fibres is beneficial in reducing problems caused by cracks. This study highlights the effects of natural horse hair and kenaf fibres with different curing conditions on the properties of mortar. Three different curing conditions were employed namely, water curing, air curing and 7-days in water and thereafter dry curing. The mortar samples, cubes and prisms, were tested in compression and flexure at the ages of 3, 7 and 28 days. In addition, the water absorption, fibre surface and mode of failure of the samples were also recorded and analysed. The experimental results show that the inclusion of horse hair and kenaf fibres enhanced the flexural strength but reducing the workability of the mortar. The horse hair mortar recorded higher flexural and compressive strengths compared to kenaf fibre mortar. However, the effect of fibres on the compressive strength was not significant in which the control sample recorded higher compressive strength compared to horse hair and kenaf fibre mortars. In addition, the water absorption for kenaf fibre was higher than horse hair due to its porous microstructure. It was recorded also that the samples with natural horse hair and kenaf fibres failed in a ductile manner compared to control sample due to the bridging effect of the fibres that able to hold the matrix together.

Keywords: *Fiber reinforced mortar, horse hair, kenaf fibre, compressive strength, flexural strength, ductile.*

1.0 Introduction

Concrete or mortar if designed properly will have a good compressive strength and durability. However, one of the setbacks for concrete or mortar is it can easily crack once hardened due to its low tensile strength properties (Neville, 1995). Many studies have been conducted to improve the engineering properties of mortar including its tensile strength by adding short organic or inorganic fibres. Fibre reinforced cement composite can be defined as concrete or mortar incorporating relatively short, discrete, and discontinuous fibers (Mindess *et al*., 2003). The inclusion of short fibers in concrete or mortar at optimum percentage will generally improve the properties of mortar including tensile strength, flexural strength, impact strength, toughness and the failure mode compared to control sample (Choo, 2003; Mazaheripour *et al*., 2010; Umoh and Bassey, 2015). Study on the use of glass fibre in self compacting concrete showed an improvement on the tensile strength of the sample (Mohd.Sam *et al*., 2014). The main role of fibers in the mix is to control cracking by bridging across the cracks and subsequently provide post-cracking ductility to the concrete or mortar (Mindess *et al*., 2003). Nowadays, there are many types of short fibers used with different properties and characteristics. The types of fibers that can be used including steel fibers, glass fibers, polypropylene fibers, carbon fibers, and natural fibers. Normally for structural application a high tensile strength fibre such as steel fibre is preferred and low tensile strength natural fibres can be used for non-structural application. Although the strength of the member is of the main target but the durability aspect especially the natural fibres in the mix should not be neglected (Aziz *et al*., 1984). Horse hair is one of the fibres that is strong, lustrous and resilient, and low in density. Generally the hair taken from the mane is softest and ranges from 50 to 150 µm in diameter. On the other hand, hair from the tail is coarser and stronger with the diameter in the range of 75 to 280 µm (Encyclopaedia Britannica).

Reinforcing mortar with low cost natural fibre is beneficial in an attempt to enhance the tensile properties of the mortar. As mention earlier, cracking is one of the major problems that can occur at earlier or later stages of the hardened mortar. The cracks can be caused by one or a combination of many factors such as drying shrinkage, thermal effects and also the applied load. The obvious effect of short fiber in the mix is the conversion of brittle nature of concrete or mortar into more ductile properties (Ding *et al*., 2009). In this study, the effects of natural horse hair fibre on the properties of mortar are investigated. As for comparison, an organic kenaf fibre was also used in the manufacture of mortar samples. Thus, the main objectives of this study are as follows:

i. To determine the physical characteristics of natural horse hair and kenaf fibres.

ii. To investigate the effects of different curing conditions on strength properties of mortar reinforced with natural horse hair and kenaf fibres.

iii. To evaluate the effects of natural horse hair and kenaf fibres on the strength performance of mortar.

2.0 Materials and Methods

2.1 Material

The raw materials used to produce mortar mixes were cement, fine aggregate, water, together with horse hair and kenaf fibres. The ordinary Portland cement (OPC) was used throughout the study that conforming to BS EN 197-1: 2000. The fine aggregates used was normal crushed sand. The horse hair fibre was obtained from the UTM Equine Park. The average length of the horse hair fibres used in the mortar mix was 40 mm. The estimated density of the horse hair was 1100 kg/m^3 with the average diameter of 140 µm. The kenaf fibre that has the density of 1400 kg/m^3 was obtained from the Structures and Materials Laboratory. The original length of kenaf fibre in a bundle form was in the range of 500 to 1000 mm. It was cut to a 40 mm in length so that the fibre length used in the mortar mix is consistent with the length of horse hair fibre. Figure 1 shows the picture of horse hair and kenaf fibres used in the study.

Figure 1: Horse hair and kenaf fibres

The mixing water for the mortar mix was obtained from the fresh tap water available in the laboratory. All the experimental works and preparation of the mortar samples were conducted in the Structures and Materials Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM).

2.2 Mix Proportions

The mortar used in this study was designed with the mix proportions of one part of cement to three parts of fine aggregate (1:3). The water-cement ratio used in the mix was 0.45. The optimum fibre content included in the mix was determined using flexural strength test from the trial mixes using 40x40x160 mm prism sample tested according to BS EN 1015-11:1999. Three different percentages of fibre content by volume were used in the trial mixes i.e. 0.5%, 1.0% and 1.5%. The results from the trial mixes show that the sample with 1.0% fibre recorded the highest flexural strength and was used in the preparation of the mortar samples throughout the study.

2.3 Sample Preparation

The mortar samples were prepared, cured and tested at the ages of 3, 7, and 28 days. For the control mortar, three cubes and prisms were prepared for each test age. The standard steel moulds used in this study were cube moulds of 70x70x70 mm and prism moulds of 40x40x160 mm. Before casting the interior surfaces of the moulds were coated with a layer of oil before placing the fresh mortar to make it easier to demould the samples. The mortar was mixed using a mechanical bowl mixer. The fresh mortar mix was poured into the steel mould and compacted using vibrating table. After 24 hours, the samples were demoulded and cured in the designated curing regimes.

3.0 Laboratory Testing

3.1 Fresh Mortar

The level of workability of different type of fresh mortar mixes was observed and recorded during mixing and pouring the mortar into the moulds. In addition the level of difficulties during compaction using vibrating table was also observed as an indication of the mortar workability.

3.2 Hardened Mortar Testing

3.2.1 Density

All the cube mortar samples were weighed using weighing machine after achieving the specified testing age for all type of curing conditions. The density of the different mortar samples was then calculated to determine the effects of fibre inclusion and curing conditions.

3.2.2 Compressive Strength Test

Compressive strength test was conducted using compression testing machine. The mortar cube was loaded incrementally to failure in compression as shown in Figure 2. The maximum load sustained by the cube sample was recorded and the compressive strength of the sample was calculated. The test was conducted in accordance to BS EN 1015-11:1999. The ultimate load and failure mode of the mortar cube were recorded to determine the effect of horse hair and kenaf fibres on the mortar samples

Figure 2: Compression test of mortar cube

3.2.3 Flexural Strength Test

Flexural strength test was conducted for all type of mortar prisms. The testing procedures used in the study are as stated in BS EN 1015-11:1999. The test performed is known as three-point loading test. Flexural strength test of mortar prisms was conducted using the flexural strength testing machine. Figure 3 shows the sample of mortar prism tested under flexure. The ultimate load at failure was recorded and the flexural strength was then calculated. The mode of failure of the prism samples was also observed and recorded. This was done to study the effect of horse hair and kenaf fibres on the strength and mode of failure of the samples.

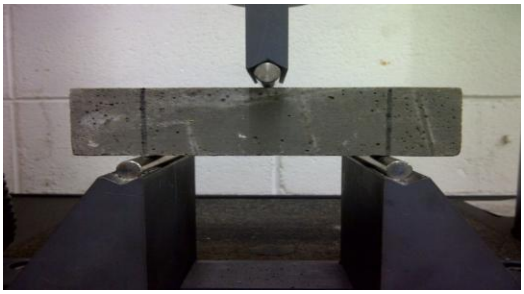

Figure 3: Flexural test of mortar prism

4.0 Results and Discussions

4.1 Surface Texture

The surface texture of horse hair and kenaf fibres is shown in Figure 4. It can be seen that the surface of horse hair is slightly rougher than kenaf fibre. Most likely this will produced better bonding between mortar matrix and the fibre. As a result it improves the strength of the horse hair mortar samples as indicated from the results of compressive and flexural strengths. Generally, the compressive and flexural strengths of the horse hair mortar was found to be higher than the kenaf fibre mortar as discussed in the following sections.

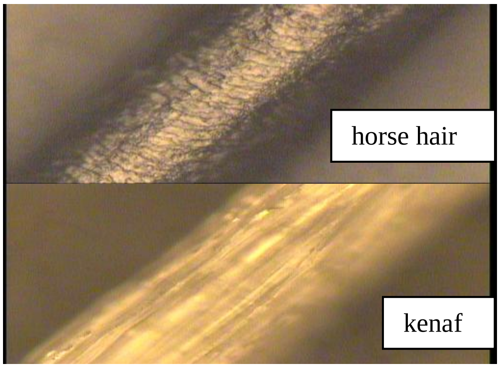

Figure 4: Surface texture of horse hair and kenaf fibres

4.2 Workability

Through the observation during mixing and casting, the workability of mortar was found to decrease by the inclusion of short fibres. Mortar mix with kenaf fibre was found to have the lowest workability followed by mortar with horse hair fibre and control mortar. This probably due to the properties of kenaf fibre that tend to absorb water added in the mix more than horse hair fibre. Thus, it will reduce the water content in the mix resulting in lower workability. The percentage of water absorption from the experimental work for horse hair and kenaf fibre was found to be 63% and 74%, respectively.

4.3 Density of Mortar Cubes

The mass of all mortar cube samples were determined after achieving the specific curing age and the density of the mortar sample was then calculated. Table 1 shows the density results of all mortar samples cured in different curing conditions. Generally, it can be said that there is no significant differences in the density for control mortar, horse hair mortar and kenaf mortar cubes since the main mortar ingredients are the same. The total weight of horse hair and kenaf fibres added is relatively low and hence does not influence much on the density of the hardened mortar.

Table 1: Density of samples in different curing regimes

Type of sample / Curing condition	*Density (kg/m^3)*		
	water	*air*	*7d water + air*
Control mortar	2361	2128	2332
	2405	2244	2317
	2419	2215	2376
Horse hair mortar	2346	2317	2274
	2303	2274	2215
	2274	2244	2303
Kenaf fibre mortar	2405	2230	2259
	2390	2259	2215
	2361	2215	2259

The experimental results show that the range of density recorded for control samples in water curing, air curing and 7days water + air curing was between 2361 and 2419 kg/m^3, 2128 and 2244 kg/m^3, 2317 and 2376 kg/m^3, respectively. For the horse hair mortar the densities in water curing, air curing and 7d water + air curing were in the range of 2274 to 2346 kg/m^3, 2244 to 2317 kg/m^3 and 2215 to 2303 kg/m^3, respectively. On the other hand, in similar curing conditions the kenaf fibre mortars recorded densities in the range of 2361 to 2405 kg/m^3, 2215 to 2259 kg/m^3 and 2215 to 2259 kg/m^3.

The average density of samples in different curing conditions is shown in Figure 5. It can be seen from the figure that the air curing resulted in lower density of the samples compared to other curing conditions. This can be attributed to the loss of water from the sample due to evaporation upon drying. In contrast, samples cured in water showed the highest density compared to samples subjected to air curing and 7d water + air curing.

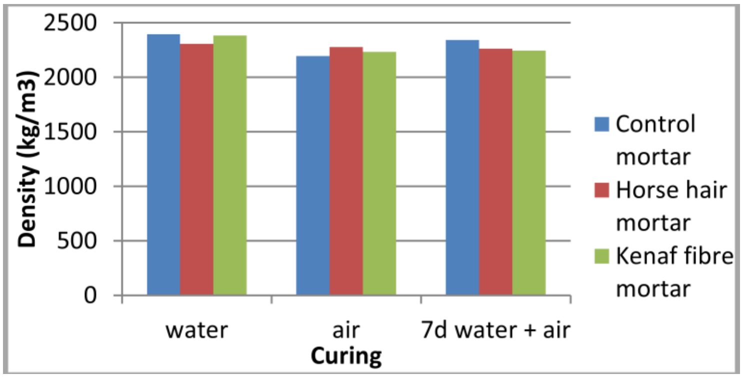

Figure 5: Average density of samples in different curing conditions

4.4 Compressive Strength

The compressive strength results of all mortar mixes at the age of 28 days for different curing conditions are presented in Table 2. The results show that to some extent the different curing conditions affect the compressive strength of the mortar samples. However, the effect of various curing conditions was only slightly different between the control mortar, horse hair mortar and kenaf fibre mortar. For the control mortar samples, the water curing and 7days water + air curing recorded higher compressive strength compared to samples subjected to air curing. Similarly for horse hair mortar and kenaf fibre mortar samples subjected to air curing recorded the lowest compressive strength compared to the other curing conditions. It was most likely due to the lower hydration process of the cement as a result of less water in the sample because of water loss upon drying. In contrast to control mortar, samples of horse hair and kenaf fibre mortars subjected to the 7 days water + air curing produced higher compressive strength than water curing. This was probably due to better bonding between mortar matrix and horse hair and also kenaf fibres once the mortar drying out after 7 days in water as compared to samples that are continuously cured in water.

The experimental results also indicated that the inclusion of horse hair and kenaf fibres was found to slightly reduce the compressive strength for all curing conditions compared to the control mortars. The percentage difference compared to control mortar was about 4.7% and 10.0% for horse hair mortar and kenaf fibre mortar, respectively, in water curing. However, for air curing condition the horse hair mortar had 2.0% higher compressive strength than the control mortar. As for the kenaf fibre mortar the strength was 6.2% lower than control mortar under air curing condition. Finally, under 7 days water + air curing the strength of horse hair mortar and kenaf fibre mortar was 2.3% and 6.2% lower than the control mortar, respectively. The experimental results show that the

7 days water + air curing was found to be better for horse hair mortar and kenaf fibre mortar compared to the water and air curing conditions.

The effect of curing conditions at different ages on compressive strength of all samples is shown in Figures 6 to 8. It can be seen from the figures that the difference in compressive strength at the ages of 3 and 7 days in all curing conditions for control mortar, horse hair mortar and kenaf fibre mortar is significant. However, at the age of 28 days the difference started to decrease and the strength was relatively comparable among all types of mortar sample. Figure 9 shows the effect of different curing conditions on the compressive strength of the samples at the age of 28 days. The results indicated that the 7 days water + air curing condition produced better strength performance for horse hair and kenaf fibres mortar compared to water and air curing. This was most likely due to the enhancement of the bonding between the mortar matrix and the fibres.

Table 2: Compressive strength of mortar at 28 days

Type of sample / Curing condition	**Comp. Strength (N/mm^2)**		
	water	**air**	**7d water + air**
Control mortar	37.4	34.2	38.6
	37.8	33.8	38.3
	38.8	34.6	38.9
Horse hair mortar	34.9	35.5	37.0
	35.8	34.8	38.5
	37.8	34.9	37.5
Kenaf fibre mortar	33.9	31.9	37.4
	34.1	31.7	36.2
	34.7	33.8	35.0

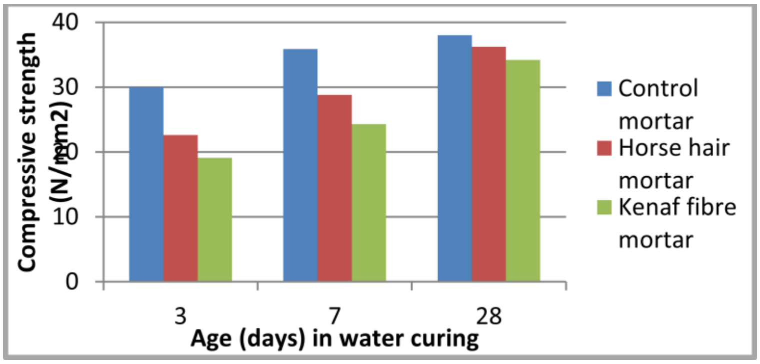

Figure 6: Effect of water curing on compressive strength

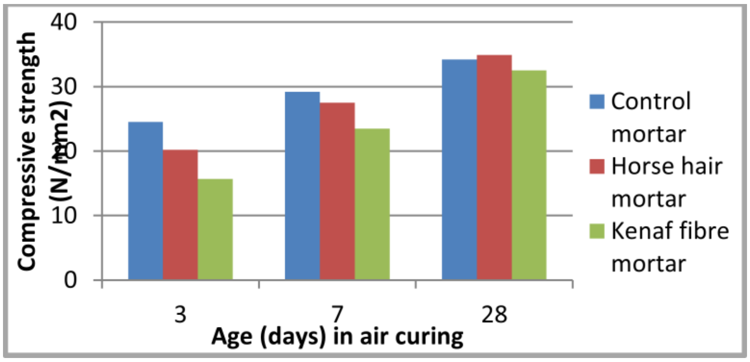

Figure 7: Effect of air curing on compressive strength

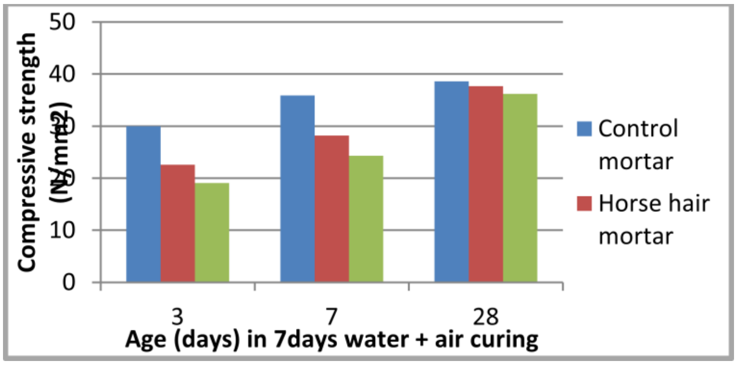

Figure 8: Effect of 7 days water + air curing on compressive strength

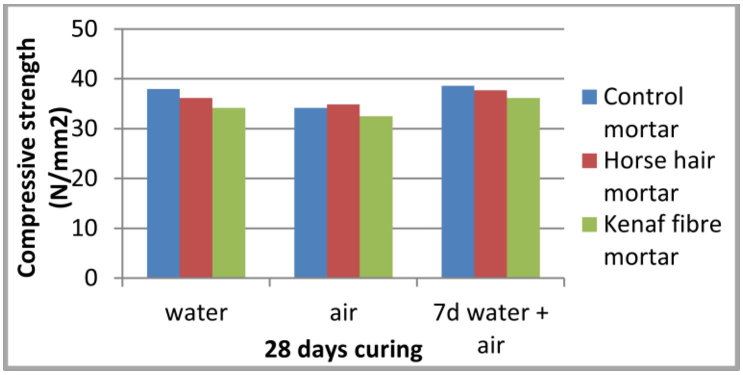

Figure 9: Effect of curing conditions on compressive strength at 28 days

4.5 Flexural Strength

The results of the flexural strength test of all mortar mixes at the age of 28 days for different curing conditions are shown in Table 3. The results show that the horse hair mortar prism was found to produce higher flexural strength compared to kenaf fibre and control mortars for all curing conditions. This can be seen as the effectiveness of horse hair in enhancing the flexural properties of mortar. The highest flexural strength was recorded for horse hair mortar prism with 7 days water + air curing condition. The flexural strength of the horse hair mortar was about 15.0% and 14.4% higher than the control mortar and kenaf fibre mortar, respectively. On the other hand, the flexural strength of the kenaf fibre mortar was only 0.6% higher compared to the control mortar. This again shows the effectiveness of the horse hair fibre compared to kenaf fibre in improving the flexural strength of the mortar.

Table 3: Flexural strength of mortar at 28 days

Type of sample / Curing condition	*Flexural Strength (N/mm^2)*		
	water	*air*	*7d water + air*
Control mortar	7.1	6.0	7.2
	7.0	5.9	7.3
	6.8	6.0	6.9
Horse hair mortar	7.1	7.1	8.3
	7.4	6.9	8.2
	7.1	7.3	8.1
Kenaf fibre mortar	7.2	6.4	7.2
	5.4	7.1	7.1
	6.8	6.6	7.2

Figure 10 shows the average value of flexural strength of all mortar prism samples at 28 days under different curing conditions. It can be seen from the figure that the horse hair mortar had better performance compared to control mortar and kenaf fibre mortar for all curing conditions. The effect of short fibres, horse hair and kenaf, in enhancing the flexural strength of mortar is clearly shown by the result under air curing condition where both samples recorded higher strength compared to the control sample. However, mortars with horse hair and kenaf fibres developed the highest strength in 7 days water + air curing condition due to better bonding between fibres and mortar.

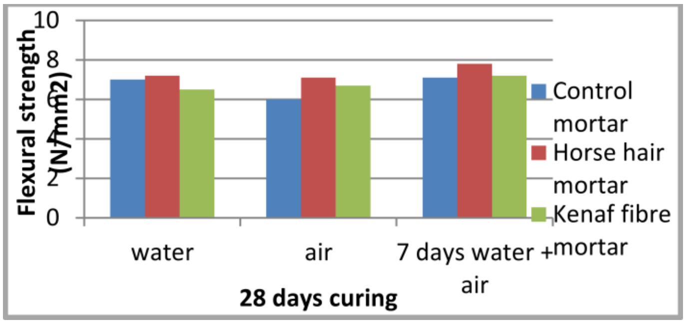

Figure 10: Effect of curing conditions on flexural strength at 28 days

4.6 Mode of Failure

The general mode of failure of cubes sample under compression for all type of mortars is shown in Figure 11. It can be seen from the figure that the failure of cube samples containing horse hair and kenaf fibres is seen to be less brittle compared to the control sample. The shape of the horse hair mortar dan kenaf fibre mortar cubes was still intact even after reaching their ultimate load. This can be attributed to the bridging effect of the fibres that hold the matrix together. As for the control sample, after failure part of the mortar surface was found to spall off as shown in the Figure 11. Thus, the use of horse hair and kenaf fibres is seen beneficial in improving the performance of mortar.

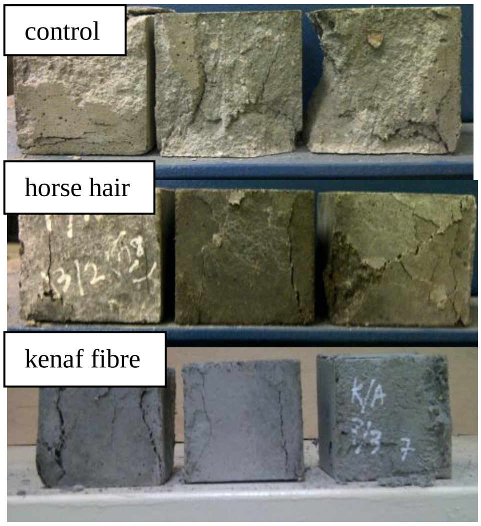

Figure 11: Failure mode of different types of mortar cubes

Similar effect of short fibre on the mode of failure of the prisms also can be seen in Figure 12. The experimental results show that upon failure the control mortar prism was separated into two halves whereas for the horse hair mortar and kenaf fibre mortar prisms the samples were still intact. This also an indication the effectiveness of fibres causing the bridging effects on the tested sample by changing the mode of failure from brittle type of failure to a more ductile failure. The results showed the benefit of including short fibres, horse hair and kenaf, in the mortar mix in improving its tensile and flexural strength properties.

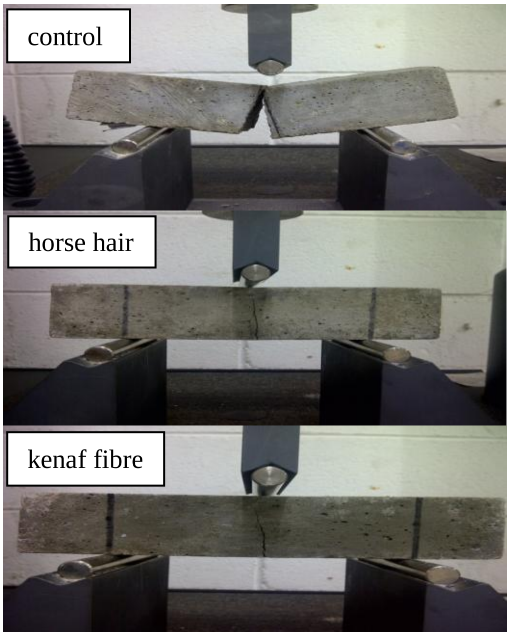

Figure 12: Failure mode of different types of mortar prisms

5.0 Conclusions

The following conclusions can be drawn on the basis of test results obtained from the experimental study.

(i). The workability of the mortar decreases by the inclusion of horse hair and kenaf fibres. Kenaf fibre affects workability more than horse hair fibre due to its surface texture and higher level of water absorption.

(ii). The effect of horse hair and kenaf fibres on the density of the mortar samples was not significant due to the low density of the fibres.

(iii). The surface texture of the horse hair was found to be rougher than kenaf fibre. This affects the bonding between the mortar matrix and the fibre that consequently resulting in higher compressive and flexural strengths of the samples compared to kenaf fibre mortar.

(iv). The 7 days water + air curing condition was found to produce better compressive and flexural strengths for all types of mortar samples compared to water and air curing conditions. This may indicates that a minimum of 7 days water curing is sufficient to produce an optimum strength of the mortar samples.

(v). The horse hair mortar prism samples recorded the highest flexural strength compared to kenaf fibre mortar and control mortar for all curing conditions. It shows the effectiveness of the horse hair fibre in enhancing the tensile properties of the mortar.

(vi). The inclusion of short fibres, horse hair and kenaf, resulted in a more ductile failure of the mortar cube and prism samples as compared to mortar without fibre.

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