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# PROPERTIES OF CEMENT BASED COMPOSITES CONTAINING OIL PALM STEM AS FIBER REINFORCEMENT

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**Abstract:** With the increasing building activities in both developed and developing countries, there has been a growing concern to convert the agricultural and industrial waste to a construction material. Researches since decades ago have shown that the addition of fibers into the cement matrix enhanced the physical and mechanical behavior of mortar and concrete. This paper discusses the properties and usage of oil palm stem fiber as discrete reinforcing material in cement matrix. Cement mortar mixes containing 1 to 4% fiber were made to investigate workability, water absorption and strength of the matrix. Test specimen comprising of cube, cylinder and beam were cast and tested for compressive, tensile and flexural strength respectively following ASTM standards. Laboratory test results reveal that the workability of cement mortar decreases with the increase of oil palm stem fiber. The water absorption capacity on the other hand was found to increase with the increasing amount of fiber content. Regarding strength, the compressive strength has been found to increase up to certain limit of 3% fiber content, beyond which the strength decreased gradually. The tensile and flexural strength of the mortar matrix, however, showed a positive response in terms of fiber content. Results obtained and the observations made in the study suggest that oil palm stem fiber can effectively be used in producing lightweight construction materials.

**Keywords**: *fiber reinforced composites, oil palm stem fiber, water absorption, workability, strength.*

## 1.0 Introduction

Extensive research and development work in understanding and application of fiber concrete materials are still taking place all over the world. These activities include, amongst other things, the development of new, stronger fibers, better fiber reinforced composites and new substitutes for products which have some disadvantages. The use of natural fibers as reinforcing material has been known since mankind started making straw reinforced sunbaked clay or mud bricks. Natural fibers, as a substitute for human made fibers in composites component, have gained interest in last decade. During this century other fibers such as jute, sisal, coconut, ramie, banana, flax, hemp etc. have been used in cement-based products because of their better stiffness per unit weight and lower impact on environment (Gram, 1988). Among the most promising of such materials are cellulose fibers. These are produced mechanically or chemically, either from wood or other vegetable fiber sources. The dimensions of individual fibers vary considerably from type to type and depend on the origin of the fiber source and method of preparation (Fördös, 1988).

The oil palm is a tall-stemmed tree which belongs to palm family *Palmes*. The countries in the equatorial belt that cultivates oil palm are Benin Republic, Colombia, Ecuador, Nigeria, Zaire, Malaysia and Indonesia of which Malaysia is the largest producer of palm oil and palm oil products. It has been estimated that the total solid waste generated by this industry in some two hundred palm oil mills in the country has amounted to about ten million tons a year (Rashid and Rozainee, 1993; Awal and Shehu, 2012).

Oil palm trees are usually felled after the age of 25 years, either due to their decreasing yield or because they have grown too tall which makes harvesting very difficult. For the disposal of oil palm stems, they are normally left to rot or are burnt in the field. However, freshly felled stems with their high moisture content cannot be easily burnt in the field. Leaving the stems in the field without further processing will physically hinder the process of planting new crops as the stern can take about five years to decompose completely (Lim and Gan, 2005).

As a normal practice, oil palm fibers are used for fuel combustion for generation of steam boiler for oil production process. Due to abundances, some of the fibers are discarded and thrown away. However, this by-product has been found to have a good potential in cement based composites (Ahmad *et al*., 2010). Considering the availability and the potential benefits of the palm stem, research works have been initiated at the Universiti Teknologi Malaysia in exploring the full benefits of this waste material in construction. This paper highlights some fresh and hardened properties of cement mortar incorporating oil palm stem fiber as reinforcing material.

## 2.0 Materials and Test Method

### *2.1 Collection and Preparation of Oil Palm Stem Fiber*

The oil palm stem has some sort of unique arrangement of fiber unlike other type of tree trunk. This makes the oil palm stem been chosen as a new reinforcing material. The processes of oil palm stem extraction begin after the oil palm tree is cut into a small piece of log. The process continues where every fiber strands in oil palm stem is extracted out and cut into desired length to around 20-30mm. However, natural fiber cannot be used directly because of poor compatibility between fiber and matrix and due to high moisture sorption (Kalia *et al*., 2009). Chemical treatments are, therefore, considered in modifying the surface properties of fibers.

In this study the fibers were soaked in hot salty water for about 15 minutes to remove all kinds of dirt and to prevent any microbial deterioration thereby improving the quality of fibers. Finally, the fibers were oven dried for 24 hours at a temperature of about 45ºC as to make sure that there is no water in the fiber. Figure 1 shows the treated and cut oil palm stem fibers that are ready to be mixed with mortar. It is generally understood that the bond between a mortar and fiber with rough surface will be stronger than that of the smooth surface (Gram, 1988). Interestingly, the existence of rough surface of palm fiber as illustrated in Figure 2 would be a contributing factor in the development of bond strength of mortar matrix. A flow chart showing the preparation of materials and testing program is illustrated in Figure 3.


Figure 1: Cut and treated oil palm stem fiber.

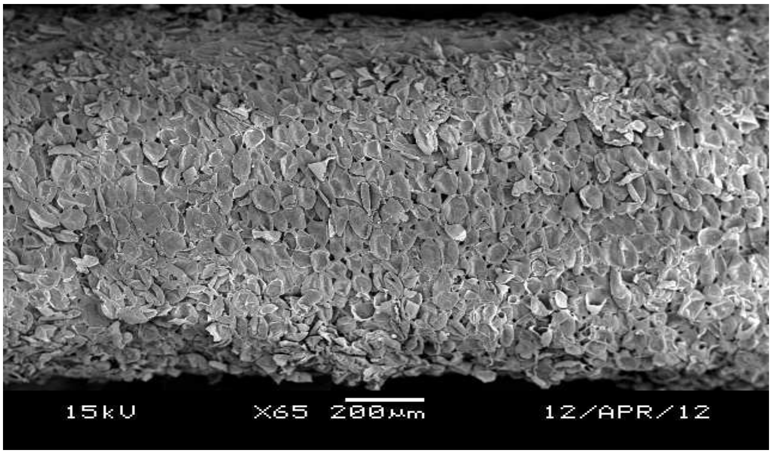


Figure 2: SEM of oil palm stem fiber showing rough surface.

## 2.2 Preparation of Mortar and Test Details

The mortar mix was designed and prepared following ASTM C1329-05 which is type N strength mortar. The proportion of cement: sand: water used in this study is 1: 2.75: 0.6. The fiber content used in this study ranged from 1 to 4% by weight of cement. A total of 75 cubes, 45 cylindrical and 45 prismatic specimens were cast and tested at the age of 3,7,28 and 90 days. Flow table test, following ASTM C1437-07 standard was carried out to measure the workability of mortar. In order to investigate water absorption of specimens, the test was conducted following ASTM C1403-06. For compressive strength of mortar, uniaxial compression test was carried out on 50 mm cube specimen following ASTM C109/C109M-11a. The splitting tensile test was performed on the standard test cylinders measuring 50 x 100 mm conforming ASTM C496/C496M-04. The flexural strength test was, however, conducted on 40 x 40 x 160 mm beams under third-point loading following the ASTM C348-08. All specimens were cured by wrapping the samples by polyethylene sheets in order to prevent loss of moisture from the specimens.

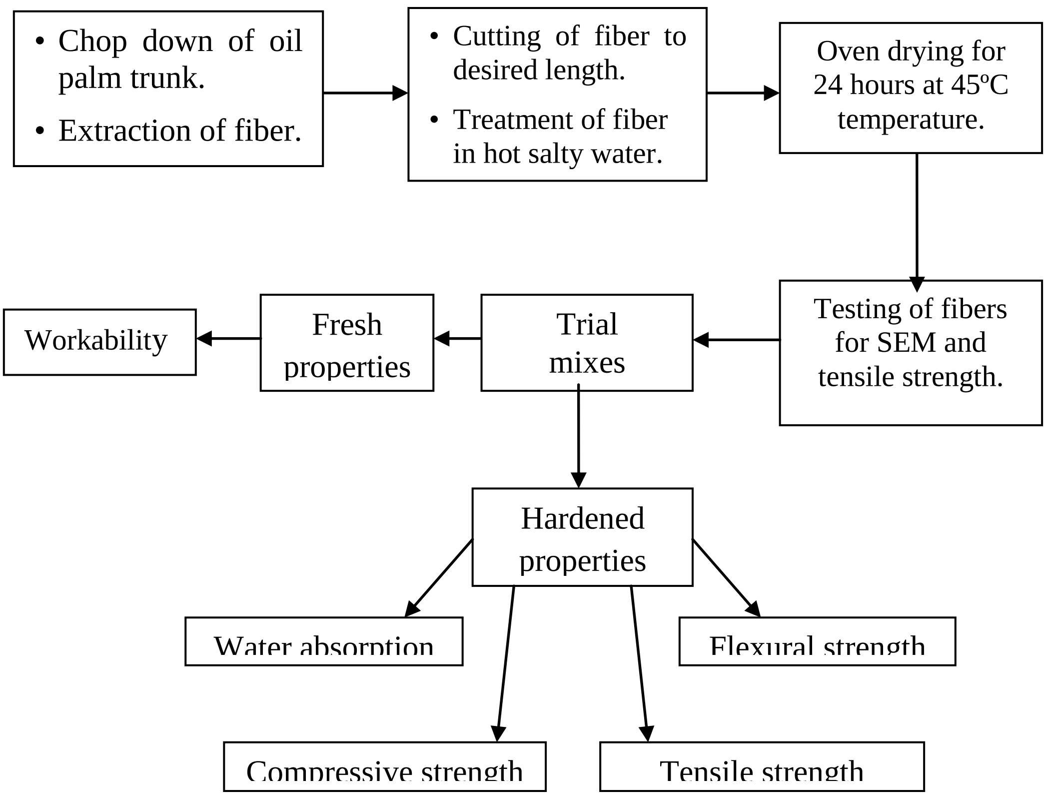


Figure 3: Flow chart showing preparation of materials and test program.

## 3.0 Result and Discussion

### *3.1 Workability of Mortar Matrix*

In this study flow table test was used to determine the workability of mortar. The flow values of mortar mixes having various amounts of fibers are illustrated in Figure 4. Data presented in the figure reveals that workability in terms of flow gradually decreased with the increase in fiber content. This is to note that all the values ranged between 6 to 12%, which are within the limiting values (4-11%) for mortar with god flow level, as stipulated in ASTM1437-07. According to Rehsi (1988), the fresh mortar matrix shows a certain amount of stiffening and reduction in workability when chopped fibers are added to it. The fiber may interlock and form balls if to long fiber is used. Unlike metallic fibers, the length of the chopped natural fibers added does not influence the additional water requirement to any significant extent. Water-soluble constituent in the fibers cause retardation in the setting and hydration of the cement. Consequently, the strength of the fiber reinforced mortar is likely to affect.

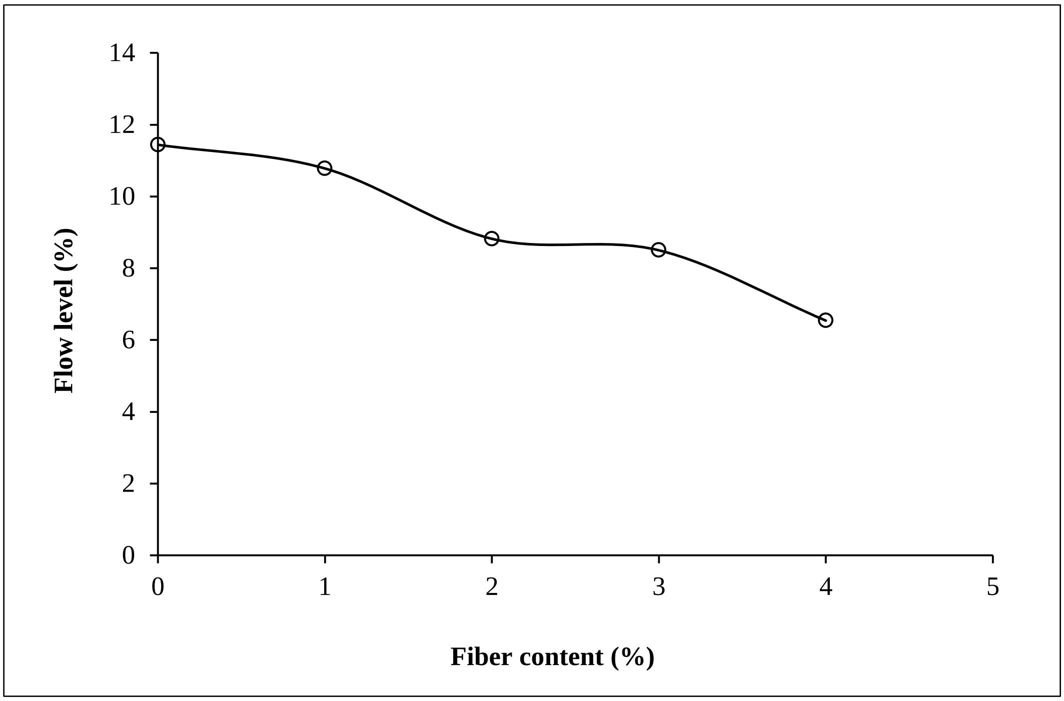


Figure 4: Effect of fiber content on workability of mortar.

### *3.2 Properties of Hardened Mortar Matrix*

#### *3.2.1 Density and Water Absorption*

In Table 1, it can be seen that higher the fiber content in the mortar mix higher was the water absorption rate of the specimens. The specimens having high fiber-cement ratio showed higher percentage of moisture content and water absorption than those of low fiber-cement ratios due to the high fiber content. As shown in Table 1, the density and water absorption of control specimen i.e. with 0% fiber were 2160 kg/m$^3$ and 6.97% respectively. The corresponding values, for example, for the specimens with 3% fiber were 2240 kg/m$^3$ and 12.19%. This is to be expected because the water has been absorbed by the fiber on the surface of the specimens that penetrated via the void of the specimens. The water absorption rate of the specimens are higher not only because of the water absorption of natural fiber itself, but also due to the fact that the water-cement ratio employed in the mix design was slightly higher which created more void than usual.

Table 1: Physical properties of cement mortar with various fiber contents.

| Fiber content, by weight of cement (%) | Density (kg/m$^3$) | Water absorption (%) |
|---|---|---|
| 0 | 2160 | 6.97 |
| 1 | 2190 | 9.83 |
| 2 | 2200 | 10.25 |
| 3 | 2240 | 12.19 |
| 4 | 2320 | 13.54 |

#### *3.2.2 Compressive Strength*

Figure 5 summarizes the compressive strength data of mortar at the age of 3, 7, 28 and 90 days. Obviously, longer the curing period higher was the compressive strength development in all mixes. Strength data shown in the figure, however, reveal that mortar specimens containing oil palm fiber were relatively weaker at early ages. With time, an increase in the development in strength has been noticed particularly for the mortar specimens with up to 3% fiber. A similar observation has been made by Awal *et al.* (2011) who found that the strength of fiber reinforced mortar increase linearly with the increase in fiber volume up to a certain limit.

Although the compressive strength of fiber reinforced mortar was much affected by the presence of fiber, the failure mode, however, exhibited a considerable change from fragile to a ductile state. Due to bridging effect of the fiber, the cube specimens did not crush into pieces rather holds their integrity up to the end of the test. At typical failure mode of the 50mm cube specimen under compressive strength test is illustrated in Figure 6.

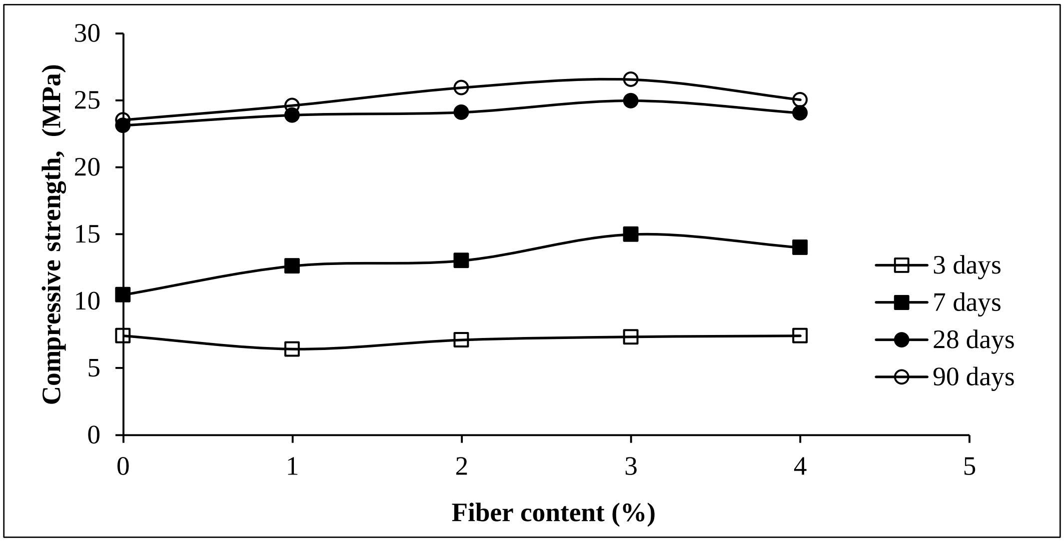


Figure 5: Compressive strength of mortar containing oil palm stem fiber.

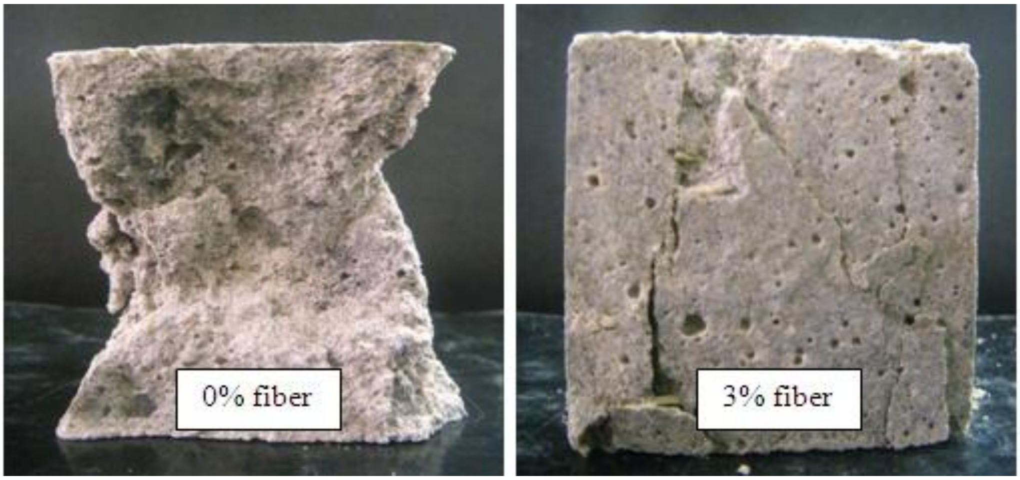


Figure 6: Failure mode of mortar cube under compressive load.

### *3.2.3 Splitting Tensile Strength*

The tensile strength of mortar containing oil palm stem fiber was carried out at the age of 3, 7 and 28 days. It has been found that like compressive strength, the tensile strength of mortar specimens increased with increasing amount of fiber. Figure 7 shows that at all ages the splitting tensile strength of mortar containing oil palm stem fiber was higher than that of control mixture. However, unlike in compression, there has been a sharp development of strength in tension with the increase in the fiber content of the specimens.

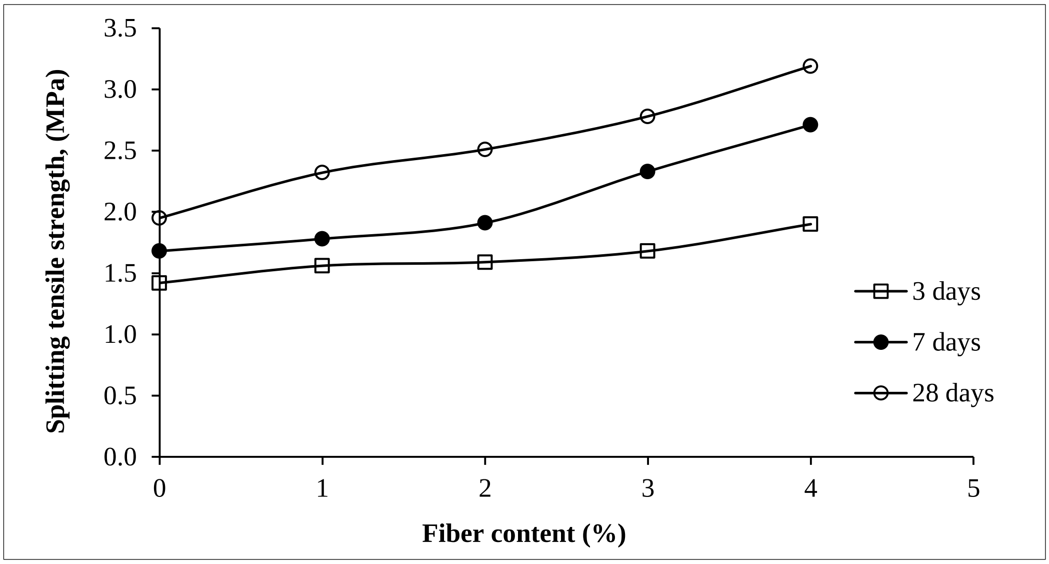


Figure 7: Splitting tensile strength of mortar containing oil palm stem fiber.

It is interesting to note that like other fibers, the oil palm stem fibers appeared to control the cracking of mortar and alter the post cracking behavior. The oil palm stem fibers seem to provide a load redistribution mechanism after initial cracking. Unlike in normal mortar, it was difficult to separate the fractured specimens because of the bridging effect that kept the two mortar parts together as shown in Figure 8.

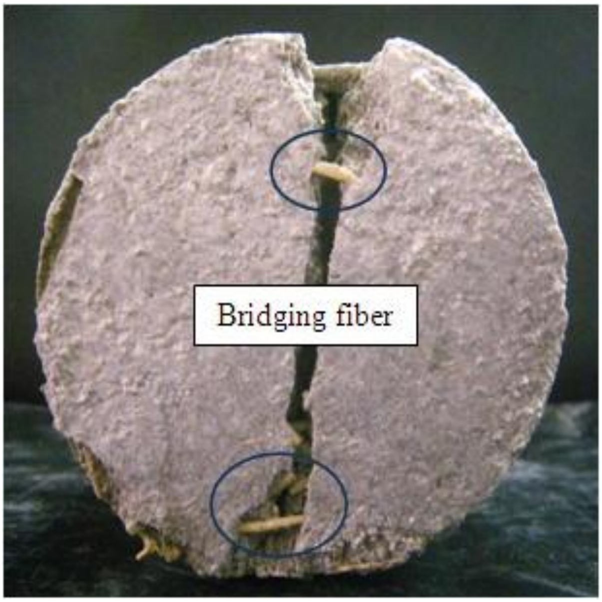


Figure 8: A typical fractured specimens under tensile load showing the oil palm fibers acting as bridging agent.

### *3.2.4 Flexural Strength*

Figure 9 illustrates the flexural behavior of mortar containing oil palm stem fiber in three different ages of 3, 7 and 28 days. The higher the percentage of oil palm stem fiber added, better was the performance of concrete in flexure. Although the flexural strength kept increasing with the increase of fiber content, the development of strength was prominent for to up a certain limit of 3% fiber content.

An important aspect that can be outlined from the experimental results is the ductility and tenacity of mortar containing oil palm stem fiber when fiber content volume is increased. This phenomenon could be due to the higher deformability and energy absorption of the mortar during the cracking phase. Interestingly the mortar containing oil palm stem fiber showed a higher bending stiffness and a different cracking pattern than the normal mortar. Most cracks showed a reduced width appearing from casting surface due to the presence of oil palm stem fiber, which tend to move to the lower portion of the specimen.

A similar observation has been demonstrated by Wang and Belarbi (2005) who explained the flexural behavior of normal mortar failure to be more brittle and explosive in nature. Once it reached a certain limit, the mortar crushed, and the load eventually dropped suddenly and violently. Unlike that of normal mortar, fiber reinforced mortar composites in this study failed in a more ductile manner with a gradual drop of loading capacity.

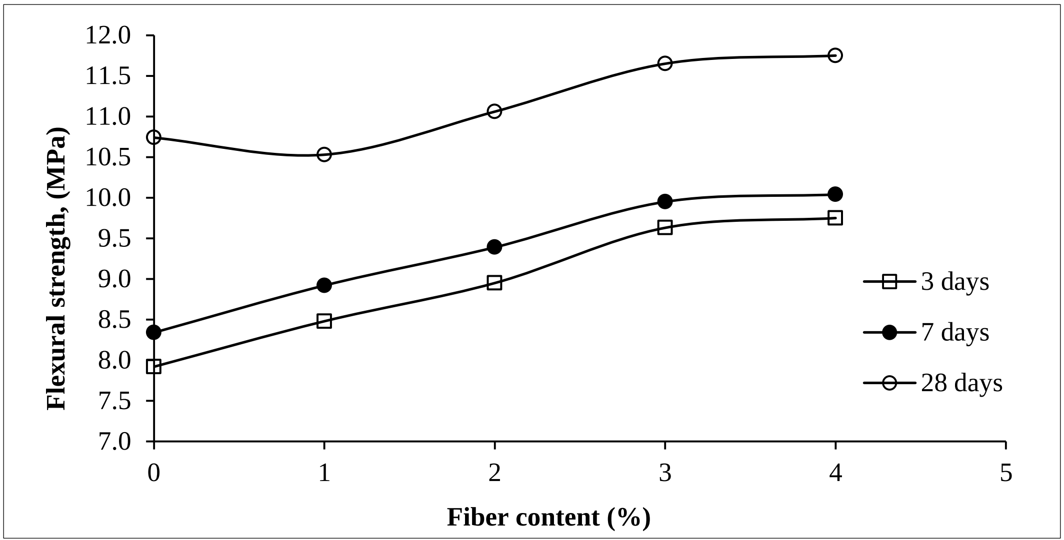


Figure 9: Flexural strength of mortar containing oil palm stem fiber.

## 4.0 Conclusion

The experimental works carried out in this research draw some conclusions. These are:

1) The inclusion of oil palm stem fiber affected the workability of mortar. It has been found that the workability of mortar mixes decreased with the increase of fiber content.

2) Palm oil stem fiber has been found to improve the overall strength of mortar to a certain limit. This improvement has been shown to be prominent in case of splitting tensile and flexural strength as compared to that of compressive strength. Generally, higher the *l/d* ratio and fiber content, higher was the strength development.

3) The results obtained and the observations made in the preliminary study suggest that the palm stem fiber has good potential as a reinforcing material. Long-term research work including deformation behavior and durability aspects, however, has been put forward for future study to obtain better understanding of this material in mortar and concrete mixes.

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