The Use of Fibre Waste as Complement in Concrete for a Sustainable Environment

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Abstract
One of the many challenges faced in developing world is the issue of waste management. Organic fibres forms major percentage of waste produced from agricultural products and should be of great concern. Fibres have been used to reinforce composites concrete to obtain lighter weight, reduce shrinkage effects which serve to reduce environmental waste. Natural fibre is 100% bio-degradable and recyclable, thereby eliminate pollution, promote biodiversity and conservation of natural resources and thus environmentally friendly.This paper focuses on utilization of some fibres as solid wastes for making economically-friendly and affordable green environment. Three fibres: Jute, Oil palm and Polypropylene fibres were used as complement in concrete and its suitability, durability and influence on the properties of concrete were assessed. The percentages of fibre used were 0.25 and 0.5 of cement content by weight. A total of 84 concrete cube specimens were prepared for standard tests which include compression test, slump test and compaction factor test. The compression test was carried out at concrete ages of 7, 14, 21 and 28 days. As the percentage of the fibre increases, the tendency for fibre to ball up becomes higher in water. The test results showed that for Jute and Oil palm fibres, the optimum fibre content was 0.25% and for Polypropylene fibre, the optimum fibre content was 0.5%. They all yielded increase in strength when compared to the control specimen and has proven to reduce reasonable environmental waste pollution.
Keywords: Environmental Pollution, Fibre, Concrete strength, Jute, Waste reduction

1. Introduction

The development and research of materials and methods in civil engineering is to find result in which three most important aspect are considered; availability, environmental compatibility/preservation and financial constraints. Therefore the selection of construction material should only be made after a complete review of its long-term performance, durability in the structure, and environmental compatibility/preservation. The usage of natural fibres in construction material has taken place since time immemorial, for example the use of straw in sun-dried mud bricks or the strengthening of mortar with horse-hair. In correspondence to that, many studies on natural fibres has taken place for more than twenty years .The benefit from using natural fibres can help to reduce building cost and also help to preserve the environment by optimizing the usage of plant and agricultural waste. Soroushian *et al*. (1992, 1995) proposed the use of magazine wastepaper as reinforcing fibres in thin-sheet cement products. The recycled fibres used were derived from recycling of wastepaper (magazine) by dry mechanical processing. They discovered that optimal composites can be obtained using 8% total fibre mass fraction, 50% substitution level of virgin with recycled fibres, and refinement (beating) of fibres. Aziz *et al.* (1984) reported that coconut coir, sisal, sugarcane bagasse, bamboo, jute and wood cement composites had already been investigated in more than 40 countries all around the globe as complement in concrete. Among the different fibres used for controlling plastic shrinkage cracking, the most promising are synthetic fibres, such as polypropylene fibres. Wang *et al.* (2001), Najm and Balaguru (2002), Banthia *et al*. (1996), Ma *et al*. (2005), Banthia and Yan 2000) studied different types of fibres (PVA, steel, fibrillated polypropylene, polypropylene microfibre, and cellulose, polymeric fibres and Polyolefin fibres. They found that, the total plastic shrinkage crack area was reduced.

Wang *et al.* (2001), Qi (2003) and Wongtanakitcharoen (2005) concluded that fibres introduced a group of large pores at the fibre-matrix interfaces. These large pores provided bleeding channels along the fibres in the mixture, which supplied water to replenish the water lost from the surface. As a result, the capillary stress between the solid particles, and hence the plastic shrinkage cracking potential was reduced. Besides this conclusion, Qi (2003) believed that fibre reinforced mixtures exhibited less plastic settlement than plain mixture, resulting in a reduction in plastic cracking. Boghossian and Wegner (2003) believed that the ability of fibres to reduce cracking must be attributed primarily to its ability to improve the tensile capacity of the fresh mortars and prevent the cracks from growing.

The effect of jute as a natural fibre has not been widely understood. Recent investigation by Sumit *et al.* (2012) deals with the effect of jute as a natural fibre reinforcement on the setting and hydration behavior of cement. This study further investigate the effect of jute fibre, oil palm fibre and polypropylene fibre on concrete properties as a means of waste reduction; and the objectives are: To compare the properties (Workability and strength) of ordinary concrete with the properties of concrete mix containing these fibres and to find the optimum fibre content that minimizes the 'balling effect'.

2. Methodology

2.1 Sampling

Three types of fibres were investigated as concrete complement as a way of environmental waste reduction in this study. They are jute (natural), oil palm (natural) and polypropylene (synthetic) fibres.

2.1.1 Natural fibre (Jute)

Jute is a natural fibre with golden and silky shine colour, and hence called The Golden Fibre. It is one of the the cheapest vegetable procured from the bast or skin of the plant's stem and the second most important vegetable fibre after cotton, in terms of usage, global consumption, production, and availability. It has high tensile strength, low extensibility, and ensures better breath ability of fabrics. Jute has the ability to be blended with other fibres, both synthetic and natural. Jute leaves are consumed as food in many countries. It is a popular vegetable in West Africa, the Yoruba of Nigeria call it "ewedu" and the Songhay of Mali call it "fakohoy." It is also a popular dish in the northern provinces of the Philippines, also known as saluyot.
The jute plants (ewedu) were purchased from the local market in Ogbomoso. The leaves were removed and stalks tied into bundles. The bundles are then taken for steeping in water. The tied bundles of jute stalks were taken to a slow running stream which is free from pollution as possible for retting. The bundles were steeped in water at least 60 to 90cm in depth and left for 10 days (usually between 5-15 days. The optimum water temperature for retting was 26.0^{o}C. When the barks separate out easily from the stick retting was completed. When the retting was complete, fibres were ready for extraction. Fibre were extracted (stripping) as quickly as possible otherwise the quality will suffer. Finally, the extracted fibre were washed in clean water and hung on bamboo railings for drying which takes 2-3 days before they were used in this research. Plate 1 shows the dried jute fibre after steeping and retting.
Jute fibre is 100% bio-degradable and recyclable and thus environmentally friendly with moisture content of 12.6%. Food and Agricultural Organization of the United Nations (FAO, 2012) asserted that it is one of the most versatile natural fibres that have been used in raw materials for packaging, textiles, non-textile, construction, and agricultural sectors. It helps to make best quality industrial yarn, fabric, net, and sacks.

Plate 1: Dried Jute fibres used

2.1.2 Natural fibre (Oil Palm fibre)

Palm oil fibre has a moisture content of 10.4%. In Nigeria the oil palm tree is referred to as the tree of money because of its usefulness and the economic values - production of palm oil, palm wine etc one cannot disregard this wonderful tree. The oil palm produces annually over 7 million tonnes of crude palm oil (CPO), making Nigeria one of the world's leading producer of the oil.
The palm oil fibres used in this research were gotten from the empty fruit branch of oil palm tree. After oil extraction process, the fruits or nuts were stripped from fruit bunches, leaving behind the empty – fruit bunches as waste. The valuable fibre was obtained from the oil palm empty fruit branches after it had been washed and dried as shown in Plate 2. CPO and its economic co-products - palm oil kernel cake (PKC), constitute only 10% of the crop, leaving the rest of the biomass to waste. The biomass includes the oil palm trunks (OPT) and fronds (OPF), kernel shell, pressed fruit fibre (PFF) and palm oil mill effluent (POME). At present, these products are not only underutilized but frequently the causes of pollution. Moreover the expansion of plantation in Nigeria has generated enormous amounts of vegetable waste, creating problems in replanting operations and tremendous environmental concerns, when left on the plantation floor, these materials create great environmental problems.

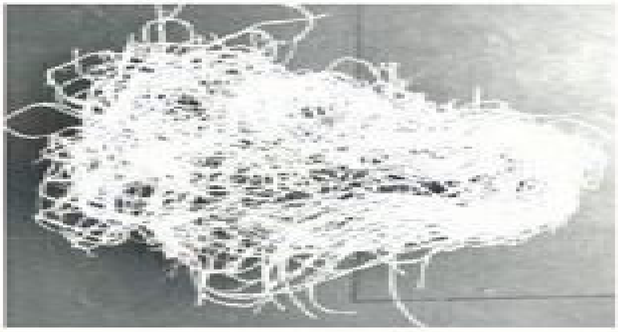

Plate 2: Oil palm fibres

2.1.3 Synthetic fibre (Polypropylene)

The synthetic fibre polypropylene (Plate 3) used for the purpose of this project were supplied by Sulachem Nig Ltd. Polypropylene (PP) is a thermoplastic polymer made by the chemical industry and used in a wide variety of applications, including packaging, textiles, stationery, plastic parts, automotive components, and polymer banknotes. Most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of low density polyethylene (LDPE) and high density polyethylene (HDPE). PP is normally tough and flexible, especially when copolymerised with ethylene. This allows polypropylene to be used as an engineering plastic. Polypropylene is reasonably economical, and can be made translucent when uncolored but is not as readily made transparent as polystyrene, acrylic or certain other plastics. It is often opaque and/or coloured using pigments. Polypropylene has good resistance to fatigue.

The emergence of polypropylene fibres has introduced to the world the possibility of having a high-performance and more cost-effective product in the market place. Polypropylene fibres possess better durability, as it does not rust. It also contributes to the ease in handling as it weights about one-fifth of an equivalent steel short-fibre. It is usually mixed with fresh concrete which are used in thin-walled, pre-cast elements of a building. It is also used in some non- structural elements

Plate 3: Polypropylene Fibres

2.2 Concrete make up

Concrete cube size of 150 x 150 x 150 mm was used to conduct the compressive test. The specimens were differentiated with respect to the type of fibre used and the fibre content by weight of cement. Specimens which contain zero percentage of fibre were used as control specimen. A total of 84 test cubes were prepared. Crushed stone from quarry (nominal maximum size 10 mm) in accordance to BS 882, 1992 were used and river sand passing 600 µm sieve which was air dried to obtain saturated surface dry condition to ensure the water cement ratio is not affected. Ordinary Portland cement was used in all mixes. Clean water from the laboratory was used to prepare all specimens in this test.

2.2.1 Mixing and Curing Process

The batching was by weight. In order to achieve uniformity consistency throughout the process, conventional mixing method was adopted. It should be noted that fibres tends to clump together and form series of fibre balls (balling effect) when the fibre length increases. Therefore in order to prevent this, certain content of fibre is to be used to get minimum balling effects. The fibre content chosen was 0.25% and 0.5% of cement weight. After mixing and pouring into the mould, the specimens were cured in water in curing tank before testing for 7, 14, 21 and 28 days. The following notations were used to differentiate the fibre type and percentage used:

P_0=Control mix

P_{J1}=0.25% Jute fibre

P_{J2}=0.5% Jute fibre

P_{O1}=0.25% Palm oil fibre
P_{O2}=0.5% Palm oil fibre
P_{P1}=0.25% Polypropylene fibre
P_{P2}=0.5% Polypropylene fibre

3.0 Experimental Tests

The experimental tests were carried out in the structural section of the new civil engineering laboratory of the Ladoke Akintola University of Technology Ogbomoso, Oyo State.

3.1 Tests on Fresh Concrete

3.1.1 Slump and compacting factor tests

Slump test and compacting factor tests were carried out on fresh concrete following the procedures described in BS1881 part 102, 103. The slump test cone and the compacting test apparatus were used to determine the workability of the concrete with 0.25% and 0.50% replacement. The Compacting factor was evaluated using equation (1).

$$Compacting\ factor = \frac{mass\ of\ test\ sample}{mass\ of\ fully\ compacted\ sample} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.2 Testing of Hardened Concrete

After the fresh concrete had been tested it was mixed properly and poured into the concrete cube mould to dry after which they were removed from the mould and place in the curing tank for testing.

3.2.1 Compressive Strength

The compression test was conducted using compressive test machine in accordance with BS 1881-Part 11. Concrete cubes of 150x150 x150mm were used to determine the compressive strength using equation 2. The samples were demoulded 24 hours after casting and cured in water until the testing ages. The compressive strengths of concretes are determined at the ages of 7, 14, 21 and 28 days

An increasing compressive load was applied to the specimen until failure occurred to obtain the maximum compressive load. The concrete dimensions were taken down before testing.

$$Compressive\ strength = P/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

P: Ultimate compressive load of concrete (kN)

A: Surface area in contact with the platens (mm^2)

4.0 Result and Discussion

4.1 Slump Test Result

Slump Test result as shown in Figure 1 revealed that average slump ranges between 5 and 16 mm, which are within true slump values. It can be deduced from the value of the slump that as the percentage of each fibre increases, the workability also decreases. Therefore the concrete mix will require more water to obtain better workability as the percentage of each fibre increases for better strength. It should also be noted from the result that 0.25% Oil palm fibre gave the greatest slump.

The workability is high at compacting factor of 0.95. From Figure 2, specimen P_{J1}, P_{P1}, P_{O1} and P_{O2} all gave high workability while P_{J2} and P_{P2} gave medium workability. It should be noted that when higher percentage of fibre is used, the compacting factor become less resulting in low workability. This may be due to the distribution of fibre that interrupts the movement of the concrete particles.

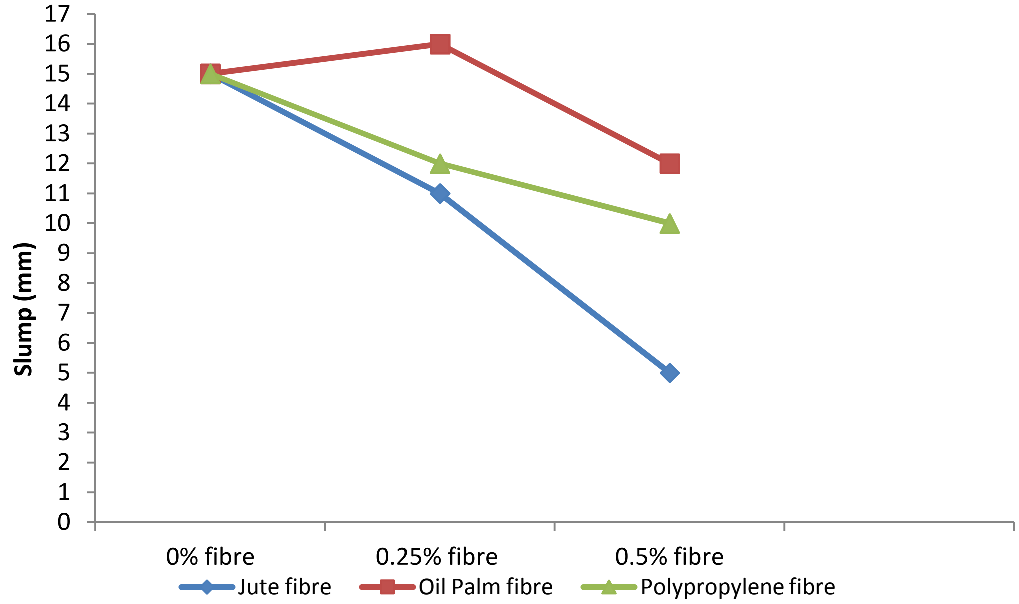

Figure 1: Slump test results

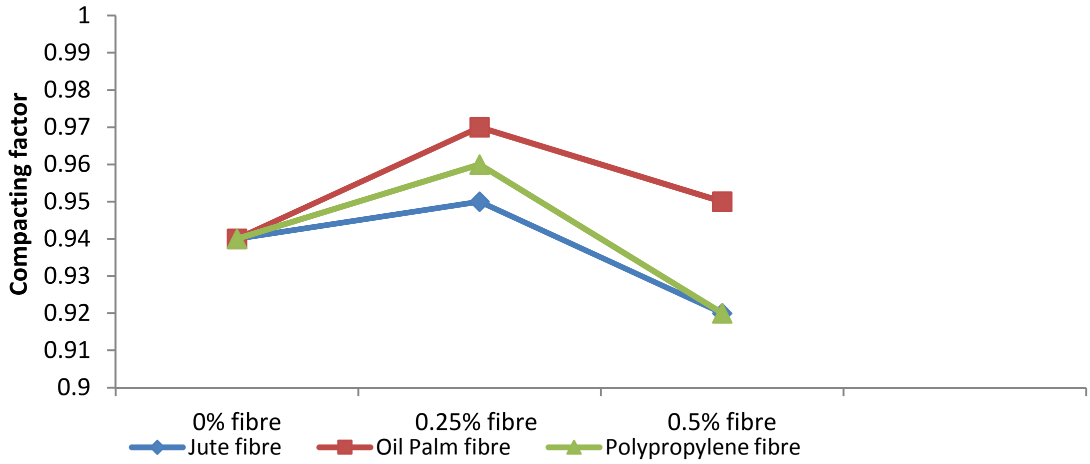

Figure 2: Result of compacting factor test

4.2.1 Influence of Fibre on Concrete Strength Development

The effect of Jute, oil palm and polypropylene fibre on compressive strength of the concrete at various periods is shown in Figure 3 using 0.25 % fibre content. The result shows that with the addition of Jute, oil palm and Polypropylene fibres, the compressive strength increases greatly from the 7th- 28th day compared to the control mix P_0. It should also be noted that specimen P_{O1} (0.25% Palm oil fibre reinforced concrete) gave the highest compressive strength of 20.80 N/mm^2 after 28 days of curing. However there is an exception for this at the 7 and 14 day of curing for Polypropylene fibre.

The effect of 0.5% fibre content of Jute, oil palm and Polypropylene fibres on compressive strength of concrete at various periods is shown in Figure 4. The result shows that with the addition of Jute fibre, the compressive strength is lesser between 7-28 days compared to the control mix P_0. With the addition of oil palm fibre the compressive strength was lesser than that of control mix P_0 during between 7- 21 days of curing but on 28th day of curing it gave the highest compressive strength of 17.42 N/mm^2. However, with the addition of 0.5% Polypropylene fibre addition, the compressive strength was greater compared to that of the control mix.

It can be deduced that the usage of different fibre and different fibre content, the strength of concrete can be improved. With material such as concrete, which contains void spaces of various sizes and shape in the matrix and micro-cracks at the transition zone between the matrix and coarse aggregate, by adding fibre the failure mode under the compression stress is very complex and vary with the type of fibre and fibre content.

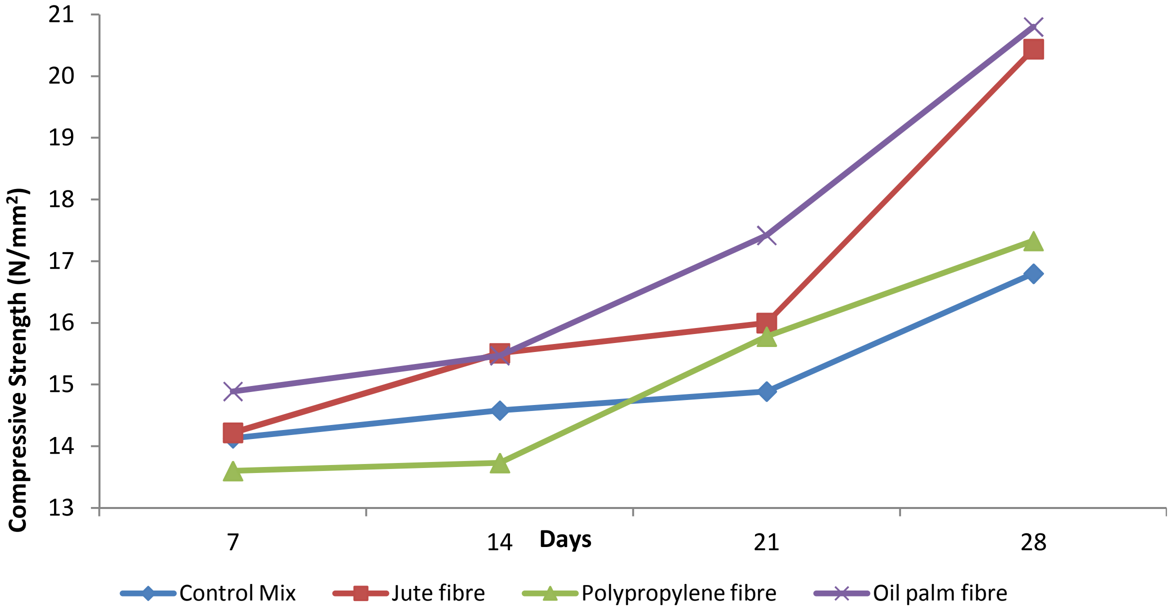

Figure 3: Influence of 0.25% Jute, oil palm and Polypropylene fibres on Concrete strength development

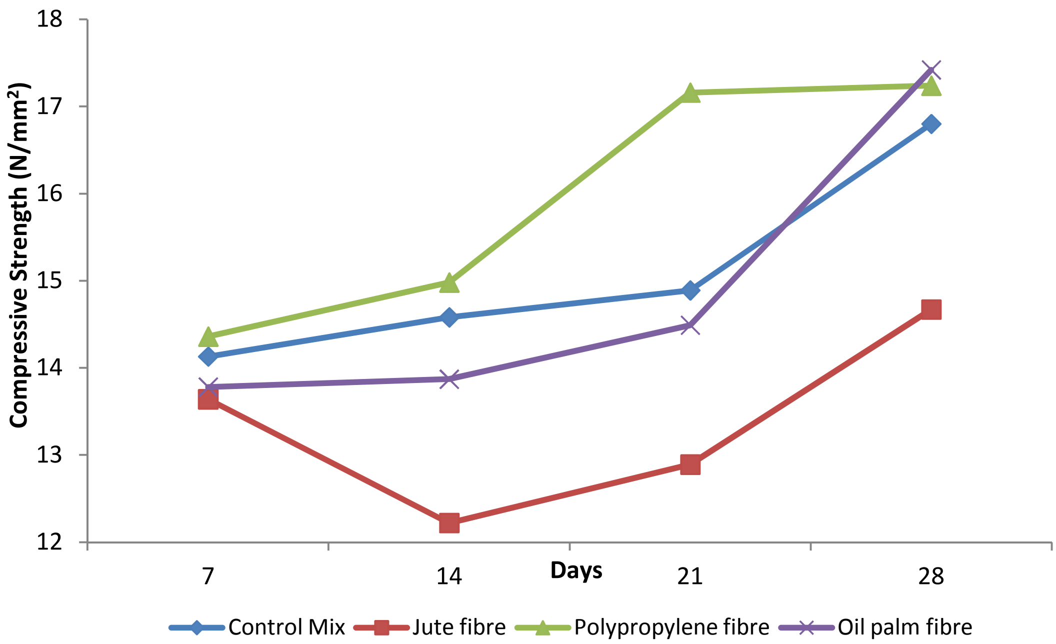

Figure 4: Influence of 0.5% Jute, oil palm and Polypropylene fibres on Concrete strength development

5.0 Conclusion and Recommendation

Various types and percentages of fibre can be used as complement in concrete to improve the strength and workability of concrete which can serve to reduce environmental waste, thereby preventing environmental pollution. Not necessary the more the fibre the higher the strength, but when the fibre is added in certain amount it has good effect on the concrete. Throughout the test, as the fibre content increases, the cracks visibility is lesser. This shows good bonding can be develop with the addition of fibre. Fibre in concrete can be said to play important role in concrete by providing good fibre-matrix bonding, and able to interrupt the distribution of compressive stress that result in multi cracking in concrete.

5.1 Conclusion

- Fibres are cheap and readily available for use as fibre reinforced concrete compared with ordinary concrete because lesser cement is used in the former.

- When the fibre used is 0.25% and 0.5%, the balling effect reduced dramatically; resulting in uniformly distribution of fibres in concrete
- The optimum fibre content when added to concrete is 0.25% for jute and Palm oil fibre. On the other hand, when polypropylene fibre is used, the optimum fibre content was 0.5%.

5.2 Recommendation

From this study the possibility of using both natural and synthetic fibre as an engineering material is high based on the increase in strength development with respect to age of concrete. For better assessment of the effects of these fibres as complement in concrete, compressive strength test checked at 56 and 90 days was recommended. Other research area of great importance is fibre reinforced concrete as an acoustic building material.

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