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Experimental Study of Mortar Containing Steel Fibre from Waste Gear Inner Wire

A.G. Ibrahim[a], M.M. Garba, J. Usman, S. Gambo
Department of Building, Faculty of Environment Design, Ahmadu Bello University, Zaria-Nigeria
getsomsc12012@gmail.com

In today's technology, recycling of industrial by product materials has been encouraged as a result of continual accumulation of different wastes. Waste Gear Inner Wire (WGIW) is generated and dumped by mechanic's workshops and their consequent environmental complications due to urbanization; population growth and so on is on the increase. This paper explored the possibility of using WGIW in Fibre Reinforced Mortar (FRM). Different WGIW were obtained from various dumping sites within Kaduna metropolis and their geometry, tensile strength and aspect ratio determined. Based on these physical properties, the WGIW sample with the highest aspect ratio was selected and used in conducting a trial test using different % (0.25, 0.75, 1, & 2). The outcome of the trial showed that 2% gave the best results and was used in the entire research. Two concrete samples (fibred & unfibred one) were then produced and their compressive and tensile strengths determined and compared. Results indicated that fibreed mortar sample has lower flow value than the control by 13.7%. However, the fibred mortar has higher compressive and tensile strengths at 56 days by 19% and 21.1% respectively than the unfibred one. It was concluded that WGIW at 2% volume fraction could be used as fibre in mortar production. The development of FRM using WGIW from local wastes was an interesting approach to solving raw material shortage for the current generation mortar or structural concrete and to reduce waste disposal cost and related environmental issues in Nigeria among others.

Keywords: Aspect Ratio, Mortar, Steel fibre, Suitability, Waste inner wire

Introduction

Portland cement concrete is believed to be a mere brittle material and when such un-reinforced material is subjected to tensile stresses, it is likely to fracture and fail. But when reinforced with steel, it endures the tensile stresses (Rai & Joshi 2014). The ductility of the concrete becomes improved when reinforced with Steel Fibres (SF) in addition to post crack tensile capacity. SF is short, discrete lengths of steel with an aspect ratio (ratio of length to diameter) from about 30 to 150 and with a variety of cross sections and profiles (Rai & Joshi 2014). It is a discontinuous and 3-dimensionally orientated reinforcement when mixed in concrete or mortar. Moreover, some of the factors affecting the performance of SF or any type of fibre according to Kosmatka & Wilson (2012) are shape (straight, hooked, undulated, crimped, twisted, coned), length (6mm to 150mm), diameter (0.05mm to 1.05mm) and tensile strength (1000N/mm^2-2500N/mm^2).

The use of steel fibres in concrete or mortar provides an economic approach which minimizes plastic shrinkage cracks, reduces the severity of thermal cracking, improves the thermal cracking, improves the fatigue, impact resistance, increase overall durability and toughness of the concrete or mortar (Mehrotra, 2009; Behbahani, Nematollahi & Farasatpour 2011; Pereira de Oliveira & Castro-Gomes, 2011). There are a lot of researches across the world on the use of SF on Fibred Reinforced Mortar (FRM).

The effect of hybrid fibres consisting of SF, palm fibre and synthetic fibre on high strength mortar was studied by Dawood &

Ramli (2011). It was observed that hybridization of fibres in the quantities 1.5% SF, 0.25% palm fibres and 0.25% barchip fibres improved the compressive strength and flexural toughness significantly. It also enhanced the splitting tensile strength and flexural strength of the mortar by about 44% and 140% respectively. In 2010, the effects of SF and rubber aggregates incorporated into mortar were investigated by Nguyen, Toumi &Turatsinze. Findings showed that the combination of rubber aggregates and SF has positive synergetic effect on the tensile behaviour of the cement-based mortar.

In concrete or mortar, the volume of SF normally used is between 0.25% and 2% of the total volume of concrete or mortar (ACI 544.3R-10; Kosmatka & Wilson 2012) which slightly improve compressive strength. More than 2% generally reduce workability and dispersion which will require special mix design or concrete placement techniques. But 1.5% by volume of steel fibres can increase the direct tensile strength by up to 40% and the flexural strength of up to 150% in comparison to concrete without steel fibres (Mehrotra, 2009). Also, SF has a relatively high modulus of elasticity and is protected from corrosion by the alkaline environment in the cement matrix (Mehrotra, 2009). SF is used in airport pavements and run way/taxi overlays, bridge deck, industrial floors, highway pavement. It is also used in precast application for improved impact resistance or toughness and used to replace conventional reinforcement in utility boxes and septic tanks. SF is used to minimize crack width, used as primary reinforcement or where high abrasion resistance is required or high impact resistance is a possibility (Nayak & Jain 2012).

However, non-availability of these materials in developing countries like Nigeria is hindering the growth of concrete technology. But there are other ways that such countries can benefit through conversion of waste to wealth. Recently, some researchers like Foti (2013) studied concrete specimens reinforced with fibres made from waste polyethylene terephthalate (PET) bottles. It was observed that there was adherence between PET and concrete material, suggesting a possible use of this material in the form of flat or round bars, or networks for structural reinforcement. Jalal (2012) used waste SF recovered from milling and machining in concrete production and the results indicated improvement of the fragile matrix, mostly in terms of toughness, energy absorption and post-cracking behaviour. The influence of adding Lathe Machines waste material as fibres at the dosage of 5% to 30% by weight of cement was studied by Ashish & Rinku (2012). The results showed strength increase of up to 20 % when cement was replaced with 20 % SF. But strength decreased when 25 % and 30 % cement was replaced by SF. Strength reduced due to decreasing quantity of cement. On the other hand, adding SF in place of cement did not act as a binding material which affected the bond strength of concrete, hence reducing strength of concrete. Study on the influence of adding waste materials like lathe waste, soft drink bottle caps, empty waste tins, waste steel powder from workshop at a dosage of 1% of total weight of concrete as fibres was undertaken by Murali *et al.*, (2012). These materials were deformed into rectangular strips of 3mm width and 10mm length. Results showed that a concrete block incorporated with steel powder has increase in compressive strength by 41.25% and tensile strength by 40.81%. Concrete made with soft drink bottle caps exhibited an increase in flexural strength by 25.88%.

Moreover, the effect of polyethylene terephthalate (PET) as fibre using different volume (0%, 0.5%, 1.0% and 1.5%) in mortar production was investigated by Pereira de Oliveira & Castro-Gomes (2011). Results indicated that the incorporation of PET fibres significantly improves the flexural strength and toughness of mortars, so also, 1.5% was regarded as optimum for desired workability. However, there is limited literature in Nigeria that showed the use of waste materials as an alternative to SF in the production of FRM or concrete. Therefore, this research focused on assessing the suitability of WGIW as fibre in the production of FRM with a view to availing Nigeria with an alternative fibre material as well as converting environmental pollution resulting from dumping of this material.

Materials and Methods

Materials

Dangote blended cement of 43.5 grades that complied with the requirements of BS EN 197-1:2011 was used throughout the experiment. The chemical composition of the cement is presented in table 1. Naturally occurring river sand with maximum particles size 4.75mm and retained on 150µm was used. Prior to use, the sand was sieved to reduced impurities, silt content and large particles in accordance with BS EN 12620:203 and used in the experiment. Some of the physical properties of the sand used are shown in Table 2

Preparation of Steel Fibre from Waste Gear Inner Wire (WGIW)

WGIW used in this research were obtained from the dumping sites of different mechanic workshops in Kaduna metropolis. The WGIW was successfully separated from dirt and oil by washing using petrol before determining their tensile strength using tensor meter (shown in Figure 2) and finally chopping them to the required length (averagely 12mm). The WGIW in Figure 1 are characterized by different diameters of 0.28mm, 0.32mm and 0.39mm which was determined using digital Vernier calliper, as can be seen in Figure 1. The geometry of the various sourced WGIW is presented in Table 3. Therefore, the WGIW with highest aspect ratio (43) was selected and used in the entire experiment. The higher the aspect ratio of a fibre, the more the compressive and tensile strengths of concrete will be (Sable & Rathi, 2012). It is on this basis that the selection was made.

Table 1: Chemical composition of cement

Material	Chemical composition (%)						
	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	TiO_2	LOI
Cement	71.297	17.519	4.74	0	2.768	0.105	3.492

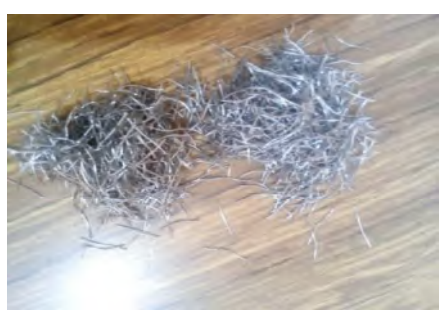
Table 2: Physical Properties Fine Aggregate

Material	Location	Absorption capacity (%)	Specific Gravity	Fineness Modulus
Fine sand	ABU Dam	6	2.65	3.1

Table 3: Physical Properties of WGIW

S/No.	Diameter (mm)	Length (mm)	Aspect Ratio (L/D)	Tensile Strength (N/mm^2)
1.	0.28	12	43	1623
2.	0.32	12	38	1888
3.	0.39	12	31	1657

WGIW before Cutting



WGIW after Cutting

Figure 1: Sample of WGIG

Figure 2: Tensor Meter

Mortar Mix and Preparation of Specimens for Testing

The mortar was produced using the guidelines of ASTM 150-07 where trial test was carried out to determine the most appropriate w/c ratio. Also, another trial test was conducted in order to determine fibre content (in terms of % of the weight of concrete) that will give optimum workability, compressive and tensile strength. Result of the trial indicated that 2% fibre is the optimum and was used for the research. Mixture proportions used in this test program are summarized in Table 4. The first mix was cast without steel fibre content while the second was cast using steel fibres content at 2% of the concrete material.

The process of mortar mixing was performed using a small mortar mixer of 7 litres capacity. The compaction process was performed manually by means of tamping rod where each mould was filled in two layers and each was tamped 25 times. After the compaction process, the excess concrete was removed and the surface finished.

After the production, the mortar samples (cube size 50×50×50mm& cylinder size 100×50mm) were allowed to set. The specimens were de-moulded on the next day after casting (24 hours). Specimens were then immersed in water, cured and their strengths determined at 7, 14, 28 and 56 days.

Tests on Fresh and Hardened Mortar Samples

The fresh property (flow) of the two mortar samples was assessed in accordance with BS EN 12350. In order to determine the compressive strength of the mortar, uniaxial compression test was carried out on the 50 mm cube specimen in accordance with BS EN 12390-3:2002. The split tensile test was performed on test cylinders measuring 50x100mm conforming to ASTM C496. Figure 3 shows the sample of the concrete specimens.

Table 4: Materials Composition Requirement (Kg)

Sample	Cement	Sand	Fibre	Water	W/C
Control	5.64	14.4	0	3.7	0.5
Fibred	5.64	14.4	1.4	3.7	0.5

50x50x50mm cube specimen

50x100mm cylinder specimen

Figure 3: Concrete Specimens

Results and Discussion

Tests results are presented below:

Table 3 indicated the physical properties of the available WGIW sourced. These properties are the diameter, length and tensile strength. Kosmatka and Wilson (2012) stated the average physical properties of a typical steel fibre as length (6mm to 150mm), diameter (0.05mm to 1.05mm) and tensile strength (1000N/mm^2-2500N/mm^2). The results obtained are within the range stated by Kosmatka & Wilson (2012). Also, Sable and Rathi (2012) stated that the higher the aspect ratio of a fibre, the more the compressive and tensile strengths of the concrete will be. Moreover, the performance of fibre increases with increasing fibre length and decreasing the diameter. It is based on this that the fibre with the highest aspect ratio (43) was selected and used in the entire experiment.

Figure 4 shows the fresh (flow value) property of the two mortar samples (control and fibred) which was measured in accordance with BS EN 12350:5. It can be seen that the control is more workable (flow) than the fibred sample by about 13.7%. The presence of the high % of fibre and that the WGIW is not a standard fibre could be the likely reasons for the low flow value in the fibred sample. This negated the statement by ACI 544.3R-10 which states that more than 2% of SF generally reduces workability and dispersion. So, at 2%, WGIW when used as fibre in mortar production could reduce workability.

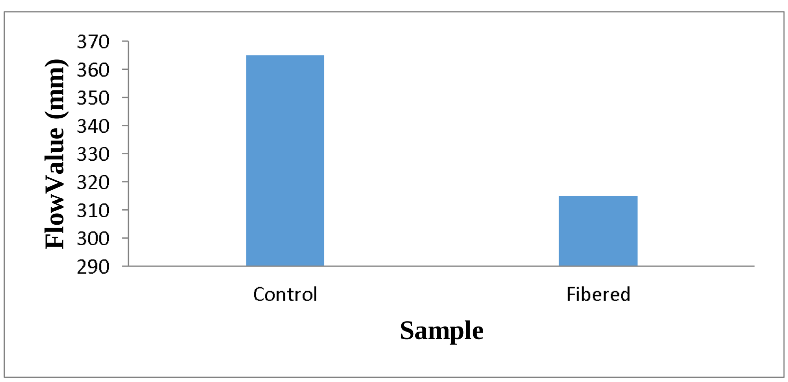


Figure 4. Flow value of the two different mortar samples

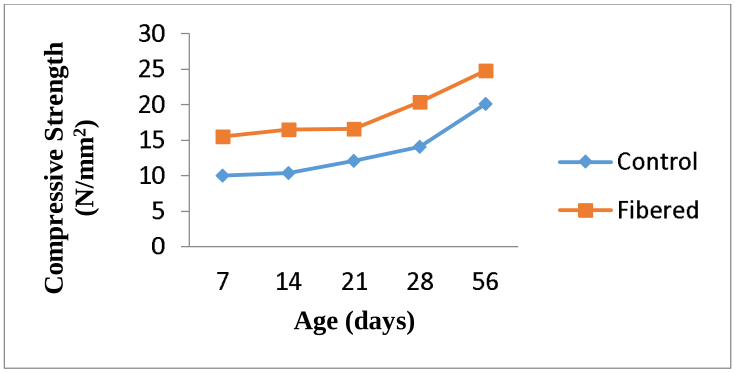


Figure 5. Compressive strength of Mortar Samples

Compressive strength of the two specimens as shown in Fig. 5 was determined at 7, 14, 28- and 56- days curing age. Fibred specimens appeared to have higher compressive strength than the control sample throughout the curing period. The strength of the fibred specimen is 35.5%, 30.9% and 19% higher than the control at 7, 28 and 56 days respectively. The improvement in the strength is even higher than what Kosmatka and Wilson (2012) stated in their report.

Figure 6 depicts the tensile strengths of the two specimens. Results revealed that the tensile strength of the fibred sample is higher than the control sample; 32%, 20% and 21.1% higher at 7, 28 and 56 days respectively. The increase in tensile strength of the fibred sample at 28 & days is 20% & 21.1% respectively which is below the % increase stated by Murali *et al.* (2012), Dawood and Ramli (2011) and Mehrotra (2009). But the percentage of the fibre in the specimen is more than 1.5% by volume. This could be the likely reason why the direct tensile strength is not up to 40% as claimed by Mehrotra, (2009).

Conclusions

The development of FRM using WGIW from local wastes was an interesting approach to solving raw material shortage for the current generation structural mortar or concrete and to reduce waste disposal cost and related environmental issues in Nigeria among others. Mortar sample produced with WGIW has improved compressive and tensile strengths as compared to control. WGIW can also be used in enhancing the properties of mortar in terms compressive and tensile strength as well as reducing environmental problems associated with dumping of these materials. It was, therefore, concluded that WGIW at 2% could be used as fibre in mortar production.

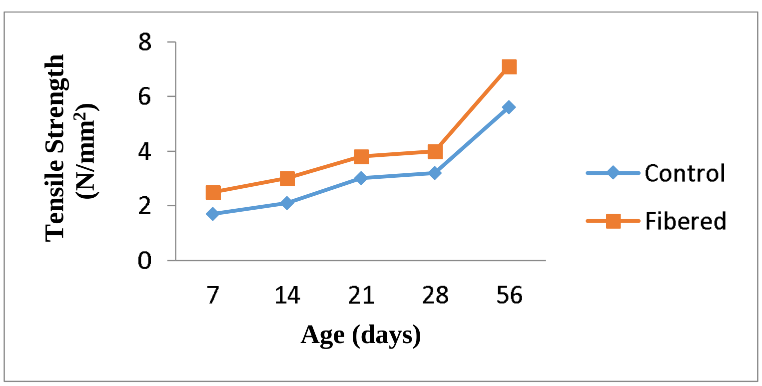


Figure 6. Tensile strength of Mortar Samples

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