CARD International Journal of Engineering and Emerging Scientific Discovery
ISSN: 2536-7250 (Print): 2536-7269 (Online)
Volume 2, Number 2, June 2017
http://www.casirmediapublishing.com

The Effect of Gum Arabic on Sisal Fibre-Reinforced Concrete: Alternative Material for Prevention of Balling

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ABSTRACT

Fibre has been identified and used in construction, especially in buildings. However, balling, a situation where fibre clumps together discourages its use, especially where the volume fraction of the fibre is greater than 1%. Balling reduces workability which consequently creates voids in concrete leading to reduced compressive strength. In this study, balling in sisal fibre-reinforced concrete was evaluated using gum Arabic, known for increasing the workability of plain concrete. The effect of the dispersed fibre by the action of the gum Arabic on both the fresh and hardened properties of concrete was checked. Performance of two categories of 100 mm concrete cube specimens were considered, comprising control mix of 1:2:4 sisal fibre-reinforced concrete with 3% volume fraction (V_f) of the fibre cut into 30 mm length and gum Arabic of 0.2%, 0.4%, 0.6%, and 0.8% the weight of cement. Water/cement ratio was fixed at 0.6. The concrete cube specimens were cured at 7, 14 and 28 days and the results show that the addition of 3% sisal fibre to the concrete mixture affected the properties of the fresh concrete as it was difficult getting a homogenous mix because of the balling of the fibre. However, addition of gum Arabic into the concrete mix gradually reduced the balling and mixing became much easier and more homogenous. Consequently, there was gradual rise in workability due to the addition of gum Arabic from 0.4% to 0.8%, the weight of cement. Also, the compressive strength of the concrete specimens increased when compared to the control mix (0% gum Arabic). In addition, flexural strength increased at 28 days from 2.7 N/mm^2 for the control mix to 3.54 N/mm^2 with gum Arabic at 0.8%. Thus, the addition of 0.8% gum Arabic by weight of cement to sisal fibre-reinforced concrete improves the workability of concrete mix and increases the strength of the concrete. Therefore, gum Arabic identified as a dispersant of sisal fibres can encourage the increased use of sisal fibre at high percentages and will offer potential for the development of low-cost construction materials.

Keywords: workability, sisal fibre, gum Arabic, balling effect, reinforced concrete

INTRODUCTION

Workability is the property of fresh concrete indicated by the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product (Sinha, 2014). The factors that affect workability are water content in the concrete mix, amount of cement and its properties, aggregate grading (size distribution), nature of aggregate particles (shape, surface texture, porosity, etc.), temperature of the concrete mix, humidity of the environment, mode of compaction, method of placement of concrete, and method of transmission of concrete. These factors mentioned concur with those observed by Gill and Kumar (2015). These are to ensure uniformity and consistency of the concrete product for ease of placement. Consistency and workability of fresh concrete are significant criteria for the concrete mix design proportioning and important properties affecting the placing of fresh concrete on site and the later performance of the hardened state of concrete (Marar and Eren, 2011). However, due to the quest for alternative materials to ensure the sustainability of concrete as a building material and for economy, alternative materials have been sought and found suitable.

These alternative materials although found suitable, have come with their limitations in fulfilling the requirements of suitable concrete. One of these shortcomings is balling in sisal fibre reinforced concrete. Although sisal fibre has been found to be suitable as a replacement for reinforcement in reinforced concrete, it has been found to cause balling, a condition where fibre get hooked to each other causing poor dispersion as a result of large amount of long fibre used in concrete mix. Also, as the percentage of fibre in the concrete increases the workability decreases due to obstruction of flow of concrete. Dispersion of fibre during mixing is a concern in the production of fibre-reinforced concrete.

According to Shah and Daniel (1999), fibre balling can even occur before the fibres get into the mixture: Adding fibres first to the mixer will cause the fibres to fall on each other and form balls since there is nothing to keep them apart. Once the fibres get into the mixture ball-

free, they nearly always stay ball-free. Adding fibres too fast to a mixture which is not workable to enable the fibres to get mixed in fast enough can cause their piling up in the mixer. Using a mixer with worn-out mixing blades is yet another cause of fibre balling. Balling will also occur when the critical fibre content is surpassed. The most common causes of wet fibre balls are over-mixing and using mixtures with too much coarse aggregate (more than 55% of the total combined aggregate by absolute volume) (Shah and Daniel, 1999). Clumping or "balling" of fibres can be a problem at high fibre contents, but does not appear to be a major problem at additions below 1.0 percent (Ludirdja and Young, 1992). Ludidja and Young (1992) further show that synthetic fibres seem to perform better than glass or steel fibres in this respect. Wafa (1990) conclude that straight fibres produce balling at high fibre content and will require special handling procedures. Also, Nwankwo and Achuenu (2014) observe that the inclusion of 3% volume fraction of sisal fibres as reinforcing agent in concrete cause a reduction in the workability of the fresh concrete mix.

Workability being an important property of any fresh concrete, therefore, with respect to balling, it is necessary that it is enhanced. Incorporating a super-plasticizer is essential to achieve medium to high level workability (Labib and Eden, 2017). This is evident in the works of Rahuman and Yeshika (2015) where sisal fibre reinforced concrete with different mix proportions and different percentage of fibre addition is considered. However, the need for cost effective and local concrete materials has focus attention on natural plasticizers for this purpose. Some natural plasticizers found suitable for concreting purposes include natural rubber latex (Shobha, 2014), palm liquor (Otoko and Ephraim, 2014), gum Arabic (Abdeljaleel *et al;* 2012) and rain tree pod solution (Ravindra *et al;* 2016). According to Mohamed *et al* (2016), workability always increases with increase in percentage of Arabic gum biopolymer. Thus, to a larger extent, this suggests that gum Arabic has the tendency to counter the balling effect evident in sisal fibre reinforced concrete. The properties of hardened concrete which are affected by sisal fibre are of major significance. Since large amounts of sisal fibres result in increased compressive strength in

concrete, elimination of balling effects is a necessity if workability must be enhanced. Consequently, the need to explore gum Arabic and determine its effect in sisal fibre reinforced concrete with respect to balling.

LITERATURE REVIEW

Previous studies have shown that balling is a phenomenon commonly associated with sisal fibre reinforced concrete. Vajje and Murthy (2013) observe that there is more bulging in concrete with added fibres than in plain concrete. Also, the failure is not sudden and with increase in fibre-cement ratio, the cracks at failure load are observed to be very less. Again, from their study it is discovered that fibre-reinforced concrete show more increase in strength than plain concrete for 0.5% fibre-cement ratio. There is little increase than plain concrete for 1% fibre-cement ratio and further increase in fibre-cement ratio to 1.5%, the strength is decreased further than plain concrete although sudden failure is resisted. They conclude that the decrease in strength could be due to decrease in slump and increase of fibre in concrete which leads to voids. Hence, the use of proper dispersing agent which does not affect other properties except workability is recommended for higher fibre-cement ratios. According to Balaguru and Shah (1992), fibres that are long and at higher volume fractions ball during mixing process. Also, Yaseen (2013) shows that fibres which are too long tend to 'ball' in the mix and create workability problems. Consequently, Yaseen (2013) recommends that an equivalent ideal aspect ratio should be found through trial mixes to find the percentage ratio ranges that can be tested, and limits the Volume fraction (V_f) of fibres to 1% of volume fraction because further increase of the fibres leads to balling and results in non-workable mortar.

To address balling, Abdeljaleel *et al;* (2012) establish that gum Arabic has a significant effect on the properties of fresh and hardened concrete. The increase in gum Arabic liquid at all ages, the compressive strength values decrease and slump values increase. Also, the compressive strength and slump values increase with increase in the ratios of gum Arabic modified liquid, from which there

is significant change in the properties of fresh and hardened concrete when adding ratios 0.4%, 0.6% and 0.8% of gum Arabic modified-liquid and reducing water cement ratio at all ages. Thus, it is concluded that, the significant effect of gum Arabic liquid occurs at a ratio of 0.4% of the additive.

According to Ashraf (2001), the effect of gum Arabic liquid in concrete mixes show high compressive strength and good workability, achieved at gum Arabic liquid ratios between 0.2% and 0.8% of cement content. In effect, gum Arabic liquid ratios of 0.6% and 0.8% resulted in high compressive strength and good workability. Wong (2014) also used gum Arabic to deal with dispersion in nanotechnology, particularly in carbon nano-reinforcements, due to their inherent self-attraction and hydrophobicity, which show increase in young modulus (rigidity) of the concrete.

Generally, the use of super-plasticizers in sisal fibre reinforced concrete improve workability as shown by Ritesh and Gopi (2017) where 2% plasticizer was used to compare the physical properties of conventional concrete and sisal fibre reinforced concrete. It is therefore evident that gum Arabic has, to some extent, proved to be a suitable alternative in addressing workability issues in concrete, but with this regard to sisal fibre-reinforced concrete, it is yet to be ascertained.

MATERIALS AND METHODS

Materials

The materials used in this study include ordinary Portland cement, fine aggregates, coarse aggregate, water, Sisal fibre and gum Arabic.

Cement

Dangote brand of Ordinary Portland Cement which conforms to BS 12 (1991, 1996) was used. Standard consistency test, initial/final setting time tests, specific gravity test, bulk density test and compressive strength tests were carried out on the cement to

determine its suitability for the study. The resulting physical properties of the cement are detailed in Table 1 below.

Table 1: Physical Properties of Dangote Ordinary Portland Cement

Test	Result	BS 12 (1991, 1996) requirements
Standard consistency (%)	28.9	26.0 - 33.0
Initial setting time (Minutes)	87	Minimum of 45
Final setting time	210	Maximum of 600
Specific gravity	3.15	-
Bulk density (kg/m^3)	1440	-
Compressive strength at 3 days (N/mm^2)	20	Not less than 15.0 (≥ 15.0)
Compressive strength at 7 days (N/mm^2)	25	Not less than 23.0 (≥ 23.0)
Compressive strength at 28 days (N/mm^2)	29.5	Not less than 32.5 (≥ 32.5)

Aggregates

Normal weight aggregates conforming to BS 882 (1992) were used. The fine aggregate used was clean river sand and the coarse aggregate was quarry sourced. The nominal coarse aggregate size was generally limited to 12mm. Sieve analysis, bulk density, specific gravity, moisture absorption and free moisture content tests were conducted in accordance to BS 882 (1992) to determine the physical properties on the aggregates. The results of the tests on the fine aggregates revealed a fineness modulus of 1.61, bulk density of 1420kg/m^3, 5.3% voids, specific gravity of 2.62, 0.29% moisture content and average water absorption of 18.79%. Results for coarse aggregate revealed a bulk density of 1344kg/m^3, 7.8% voids, specific gravity of 2.56, 0.19% moisture content and average water absorption of 1.18%.

Sisal Fibres

The sisal fibres, which were factory processed and dry, have specific gravity and water absorption of 1.2 and 231 respectively.

Water

The water used for this work was obtained from public supply system and met BS 3148 (1980) recommendations.

Gum Arabic

The gum Arabic was ground into powdered and weighed to required quantity. Abdeljaleel *et al;* (2012) establish that the best result is obtained when gum Arabic is used as a liquid additive with percentages ranging from 0.20% to 0.80% the weight of cement.

METHODS

Mix ratio of 1:2:4 with water/cement ratio of 0.6 was adopted for this study. The materials were mixed manually to reflect common practice adopted by low income developers. The gum Arabic was dissolved in water before being applied in the batched materials and mixed thoroughly until a uniform mix of good and appreciable consistency was achieved. Both slump and compacting factor tests, in accordance with BS 1881-122 (2011) were conducted to measure the workability of the fresh mix. The concrete was produced for the following percentages of gum Arabic

i. C-specimen containing 3% volume fraction of sisal fibre and 0.00% gum Arabic.
ii. A-specimen containing 3% volume fraction of sisal fibre and 0.20% gum Arabic.
iii. B-specimen containing 3% volume fraction of sisal fibre and 0.40% gum Arabic.
iv. D-specimen containing 3% volume fraction of sisal fibre and 0.60% gum Arabic.
v. E-specimen containing 3% volume fraction of sisal fibre and 0.80% gum Arabic.

RESULTS AND DISCUSSION

In the study, 3% volume fraction (V_f) of sisal fibre with diameter of 0.18mm which gave an aspect ratio, l/d of 166.66 were used. Results of slump and compacting factor tests are obtained and shown in Table 2 below.

Table 2: Slump and Compacting Factor Tests Results

Mix code	Gum Arabic (%)	Sisal Fibre (%)	Slump (mm)	Compacting factor
C (control)	0	3	30	0.83
A	0.20	3	30	0.83
B	0.40	3	40	0.85
D	0.60	3	46	0.87
E	0.80	3	50	0.88

Slump

From Table 2 above, the slump at the control mix is 30 mm. When 0.20% gum Arabic was mixed with the recommended water/cement ratio of 0.6, there was no change in slump value. This agrees with Abdeljaleel *et al;* (2012) and Abdulabbas (2013) that, not until at 0.40% gum Arabic, there is no significant change in the workability of concrete. However, at 0.4% gum Arabic, an increase in slump from 30 mm to 40 mm was recorded, which is 33.33% increase in slump value. At 0.60% gum Arabic, the slump increased to 46 mm, while at 0.80% gum Arabic, slump recorded was 50 mm, thus indicating increase of 53.33% and 66.67% respectively when compared to the slump of the control mix.

Compacting Factor

At the control mix, compacting factor of 0.83 was obtained and it was observed that fibres stuck to the hoppers and had to be tampered gently to ease them from the hoppers. Appreciable reduction in the workability of the concrete mix was also observed and balling of fibres was visibly obvious during mixing. As the gum Arabic concentration increased, the compaction factor increased a little compared to the value at the control mix. The compaction factor for gum Arabic at

0.8% gave a value of 0.88 which indicates an increase of 6.02% when compared to the compaction factor result at 0% gum Arabic. Note that in these tests, the mixes with 0.4% - 0.8% gum Arabic content showed no sticking to any hoppers and the concrete material required no easing gently by poking with tamping rod compared to before the addition of gum Arabic at that percentage.

As recommended by European Ready Mixed Concrete Organisation, ERMCO (2012), gum Arabic was used as an admixture to aid workability. It was noticed that the balling of fibre while mixing gradually reduced. Also, the clumping of fibres gradually decreased as the quantity of gum Arabic increased in the concrete. According to ERMCO (2012), fibres can be made to have coating - a thin surface layer to provide special properties in order to avoid balling of fibres. For instance, steel fibres are coated with water-soluble glue which minimize the risk of balling and promote homogeneous mixing in concrete. Thus, the effect of gum Arabic on the sisal fibre reinforced concrete increased the slump and compaction factor values.

Adjusting mix proportion to compensate for reduced workability entails likely, either an increase in the cement content or increase in water/cement ratio. Increasing the cement content is expensive as it increases the cost of construction thus making sisal fibre reinforced concrete uninteresting. Increasing the water/cement ratio above 0.6 reduces the strength of concrete as well, because the limit for water/cement ratio according to Shah and Daniel (1998) should be within 0.4 - 0.6. This leaves only the option of using an admixture as the possible solution to balling.

From the analysis above, the following findings were made:
1. Gum Arabic has a low viscosity and thus alters the viscosity of water and improves the workability of concrete.
2. The sisal fibre reinforced concrete made with a gum Arabic quantity of 0.2% shows no significant change in both the fresh and hardened concrete characteristics.

3. Clumping of fibres in the concrete started to disperse noticeably from 0.4% - 0.8%.
4. The suitable quantity of gum Arabic from this study was found to be 0.8% the weight of cement.

CONCLUSION

The study has found gum Arabic as a suitable additive plasticizer for preventing balling, which is a characteristic of sisal fibre-reinforced concrete. However, the most suitable gum Arabic content at which balling is prevented was found to be 0.8% the weight of cement at water/cement ratio of 0.6. It is worthy to mention also that at 0.2% gum Arabic addition there was no change in the slump and compaction readings. As such, the use of gum Arabic as a plasticizer in sisal fibre-reinforced concrete does not only prevents balling but also enhances workability. Thus, mixing sisal fibre-reinforced concrete with gum Arabic as additive can aid achieving desired workability and mechanical strength characteristics. In order to avoid balling of sisal fibre-reinforced concrete, which avoids strength reduction of composite, gum Arabic between 0.6% and 0.8% can be used to achieve uniform dispersal of sisal fibre throughout the mix. Therefore, the identification of gum Arabic as a dispersant of sisal fibre will encourage increase in the use of sisal fibre at higher percentages and will offer potential for the development of low-cost construction materials.

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