USE of GUM Arabic as a Superplasticizer in Self-Compacting Concrete

Caroline M. Athman, Silvester O. Abuodha, Timothy Nyomboi

***Abstract:** In this paper, Gum Arabic (GA) obtained from Acacia Senegal trees found in northern Kenya and most of other semi arid areas in Kenya was used in self compacting concrete as a superplasticizer. The research sought to establish the effect of Gum Arabic on concrete rheology at varying dosages and water-powder ratio. Series of mix design trials were conducted based on European Standard for design of self-compacting concrete (EFNARC). The final optimum mix design ratio applied were: water-powder ratio of 1.1, 1.0, 0.9 and 0.8 and Gum Arabic dosages of 2%, 4%, 6%, 8%, 10% and 12% by weight of cement while the coarse and fine aggregates content applied was 28% and 45% respectively. The resultant mix was tested for passing ability, flow ability and segregation resistance .The results show that Gum Arabic is suitable for use as a superplasticizer in self compacting concrete and a dosage of 8% by weight of cement for water-powder ratio of 1.0, 0.9 and 0.8 by volume and aggregate ratio of 28% coarse and 45% fine is recommended. It is also noted that it has an advantage of being environment friendly.*

***Keywords:** Gum Arabic, Superplasticizer, Spread Flow*

I. INTRODUCTION

Concrete is a widely used construction material and it consists of hard, chemically inert particular substance known as aggregate that is bonded together by cement and water. There are two distinct categories of concrete namely: Normal Concrete (NC) and Special Concrete. Amongst the many types of Special concrete is Self-Compacting concrete (SCC) whose major difference with NC is its ability to flow under its own weight (without being vibrated) completely filling formwork and achieving full compaction even in the presence of congested reinforcement. The concrete de-aerates as it flows and is characterized by low yield stress, high deformability, good segregation resistance and moderate viscosity. Sub-Saharan Africa (SSA) exhibits a number of peculiarities regarding the boundary framework for the casting of concrete (Schmidt, 2014)

Admixtures are often added as part of concrete constituents (cement, aggregates and water) to improve the mechanical and chemical properties of concrete and mortar. Chemical admixtures comprise of plasticizers, super plasticizers, set retarders, accelerators and air entraining agents and alter the concrete properties in various ways such as: reducing water consumption of concrete, reducing bleeding and segregation, reducing slump loss, increasing or decrease setting time among others. The current admixtures being used for SCC are mostly polycarboxylate ether (PCE) based superplasticizers.

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They are crucial for the functioning of SCC. Ideally, no SCC would be possible without use of super plasticizer. With different mix proportions, the optimum dosage of PCE has been found to be 1.6-2.6% (Building Research Institute, 2014). This dosage provides flowable concrete with recommended compressive strength. The concrete is resistant to segregation too. However, the use of PCE may require viscosity modifying agent for stability. Use of viscosity modifying agents further complicates the interactions within the concrete and requires precision in terms of dosage. A slight alteration will lead to peculiar behaviors.

In addition, super plasticizers are expensive and everything that helps minimizing its use or saving costs is economically fundamental Due to the complex interactions between cement and super plasticizers, a large number of problems occur which are often not easy to understand. If the dosage is too high, it may result in segregation, while when the dosage is too low, the flow may stagnate and the scaffolding will not be adequately filled.

The established super plasticizers such as polycarboxylate ethers (PCE) are not easily available in developing countries. There are only a limited number of products available in the market and thus their potential can't be realised. In addition, these products are typically shipped in from Europe, Arabian Peninsula or East Asia which is additionally not really sustainable due to the different climatic conditions between the continents. There is need therefore to use materials tailor made for the African climatic conditions and specifically Sub Saharan Africa (SSA) with economic and environmental value. Gum Arabic is an edible biopolymer obtained as exudates of mature trees of *Acacia Senegal* and *Acacia Seyal*. It has wide range of applications including food processing industries, textiles, ceramics, cosmetics, pharmaceuticals etc.

Biopolymers bear the image of being environmentally more acceptable than synthetic polymers produced in a chemical plant, and although this point can be argued it does influence the choice of materials used especially for interior home building (Zakka P.W, Olorunmeye F. Job, 2015). Gum Arabic has a complex effect on the rheology of self compacting concrete. It is both at the same time a thickener and a plasticizer. This seems to depend much on the dosage and the solid volume fraction of the paste. According to Kamal H. Khayat, 1998 GA is an organic admixture just like tragacanth gum. There are four varieties of Acacia Senegal namely A.*senegal,var.senegal*, *var.kerensis, var.rostrata* and *var.leiorhanchis* . In Kenya, Gum Arabic is collected from both *Acacia Senegal* and *Acacia Seyal:*

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However the most commonly occurring species in is *A.senegal var.Kerensis* and forms the basis of the international export market (Vellema, Mujawamariya, & Haese, 2014).Gum Arabic is actively collected and marketed in Mandera, Marsabit, Turkana and Samburu counties

Research by Benjamin, Peter, & Benjamin, 2015 showed that, an increase in Gum Arabic dosage reduces the slump (mm) when used in normal concrete at dosages ranging between 0.2-0.6% by weight of cement. This is characterized by the degree of workability which changes from high to medium for the maximum water/ (cement+GA) ratio.

At the dosages of 1,2 and 3% by weight of cement Gum Arabic Karroo was found to be a good water reducing admixture in normal concrete (Mbugua, Wanjala, & Ndambuki, 2015). Modified Gum Arabic in its liquid state, (i.e., reducing the water-cement) ratio, showed a clear and significant change in fresh (slump) and hardened (compressive strength) properties of normal concrete at dosages of 0.4%, 0.6% and 0.8% (Abdeljaleel & Hassaballa, 2012)

Research by Zakka P.W, Olorunmeye F. Job, 2015 whose conceptual framework was built on production of ecological self-compacting concrete showed that Gum Arabic is a viable ecological plasticizer.

As a follow up to the above researches on the use of Gum Arabic in concrete, this research was conducted with a view of finding its effect on rheology of self-compacting concrete.

II. MATERIALS

The materials applied in this experimental study were:

Cement

Ordinary portland cement (CEM1 42.5N Bamburi power plus) was purchased from Bamburi cement manufacturing company in Kenya. It had a specific gravity of 3.09, water demand of 45% and bulk density of 1300.

Limestone Filler

Limestone filler was purchased from Mineral Enterprises Limited located in Athi river, kenya. It had 85% calcium carbonate, water demand of 38% and bulk density of 1381

Gum Arabic

Gum Arabic for this study was obtained from farms in Isiolo, Northern Kenya.

Chemical Superplasticizer

Chemical superplasticizer used as control was MC Powerflow 5101 purchased from MC-Bauchemie Muller GmbH & C0. KG Construction Chemicals Company. It had steam pressure of 23 hPa at 20^0 and dendity of 1.04

Fine Aggregates

Naturally occuring river sand of maximum size 4.75mm was used as fine aggregate. Its specific gravity was determined as stipulated in BS 882, 1992 and was found to be 2.39. Its water absorption was 4.71% bulk density of 1610

Coarse Aggregates

Crushed stone of nominal size 10mm size was used as coarse aggregates for all concrete mixes. Its specific gravity was determined to be 2.55, water absorption of 5.56%, cleanliness of 1.95% and bulk density of 1420

Water

Portable tap water fit for drinking was used for all the concrete mixes

III. METHODS AND RESULTS

Two concrete mixes with different types of superplasticizers were used. MC Power flow 5101 served as control while Gum Arabic was the subject of study at varying water-powder ratio and dosages by weight of cement. Trial mixes were prepared based on European Standards for Testing Self Compacting concrete (EFNARC). Air content was assumed to be 2% of the total volume of concrete. A fixed proportion of 28% of the total volume of the mix was used. Fine aggregates were varied between 43 and 45 %by volume of mortar. Water-powder ratio by volume was varied between 0.65-0.8. Limestone filler was used as a substitute for cement at a ratio of 40:60 respectively. This ratio was chosen from results of water demand for the two powders.

Aggregates were first dry mixed before adding combination of the powders. 80% of the mixing water was added and further mixed before adding MC power flow 5101 together with the remaining 20% of the mixing water. Based on the results from the trial mixes, trial no. 7 was chosen for further studies since it didn't exhibit any bleeding behavior. Both coarse and fine aggregate ratios were maintained constant as so recommended by Okamura & Ouchi, 2003 while water-powder ratio and superplasticizer dosages were varied. The concrete was tested for viscosity using V funnel and passing ability using L-box.

Gum Arabic was hand cleaned to remove any visible impurities, ground to relatively small particles, dissolved in water, sieved through a kitchen sieve, dried in the oven until a slime formed before being ground to fine particles. For use in cocnrete, the solid Gum Arabic was weighed, dissolved in 30% of mixing water 10 minutes before use. Shear yield stress was calculated using the following equaiton derived by Roussel, Stefani, & Leroy, 2005.

$$\tau o = (225\rho g v\verb|^|2)/128\pi^2 R^5$$

Where τ_0 – shear yield stress

ρ – desnity of the sample

v-volume of sample

r-radius of spread flow

The results were as shown below

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Table 1: Test Results for Trial Mixes

Trial No	Coarse aggregates (%)	Fine aggregates (%)	w-p ratio	superplasticizer	Spread flow (mm)	Observation
1	28	45	0.8	1.5	>800	Excessive bleeding
2	28	43	0.7	1.5	680	Bleeding
3	28	43	0.65	1.5	693	Bleeding
4	28	45	0.6	1.5	400	High viscosity
5	28	43	0.6	2.1	>800	Excessive bleeding
6	28	45	0.7	2	600	Bleeding
7	28	45	0.65	1.8	677	No bleeding

Table2: Test results for Fresh Properties of Self Compacting Concrete

Component	Units	Value
Visocity	sec	15
Passing ability	-	1

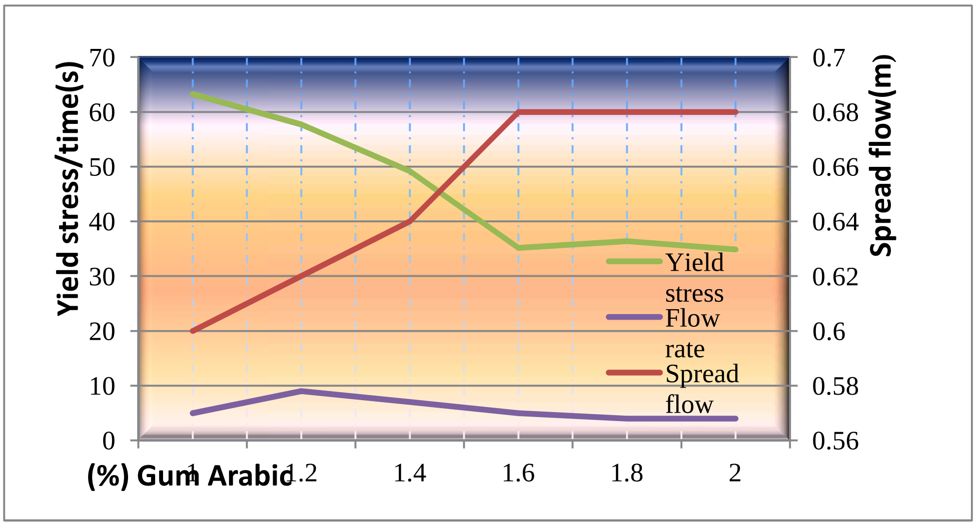

Fig 1: Relationship between MC Power flow 5101 dosage at w-p 0.65 and spread flow

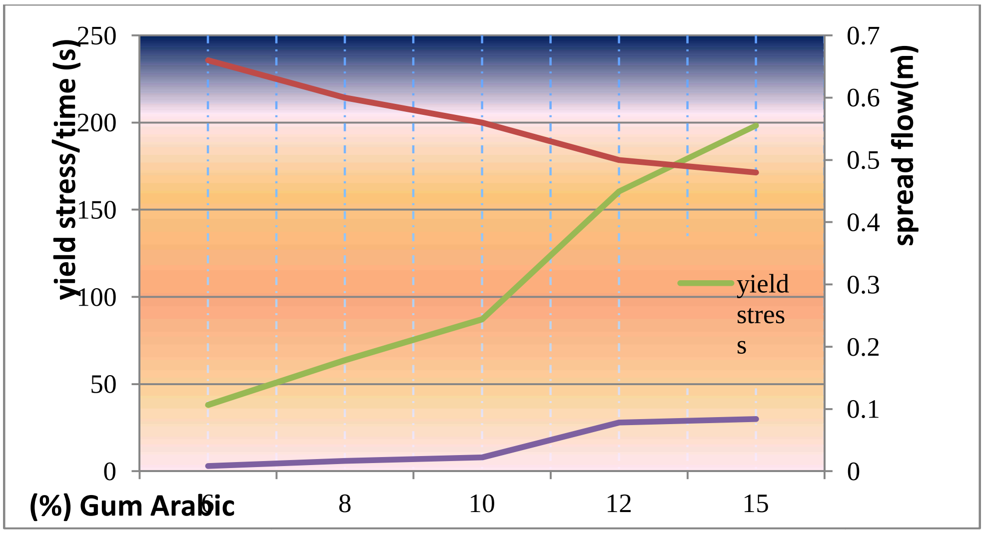

Fig 2: Relationship between Gum Arabic dosage at w-p ratio 1.1 and spread flow

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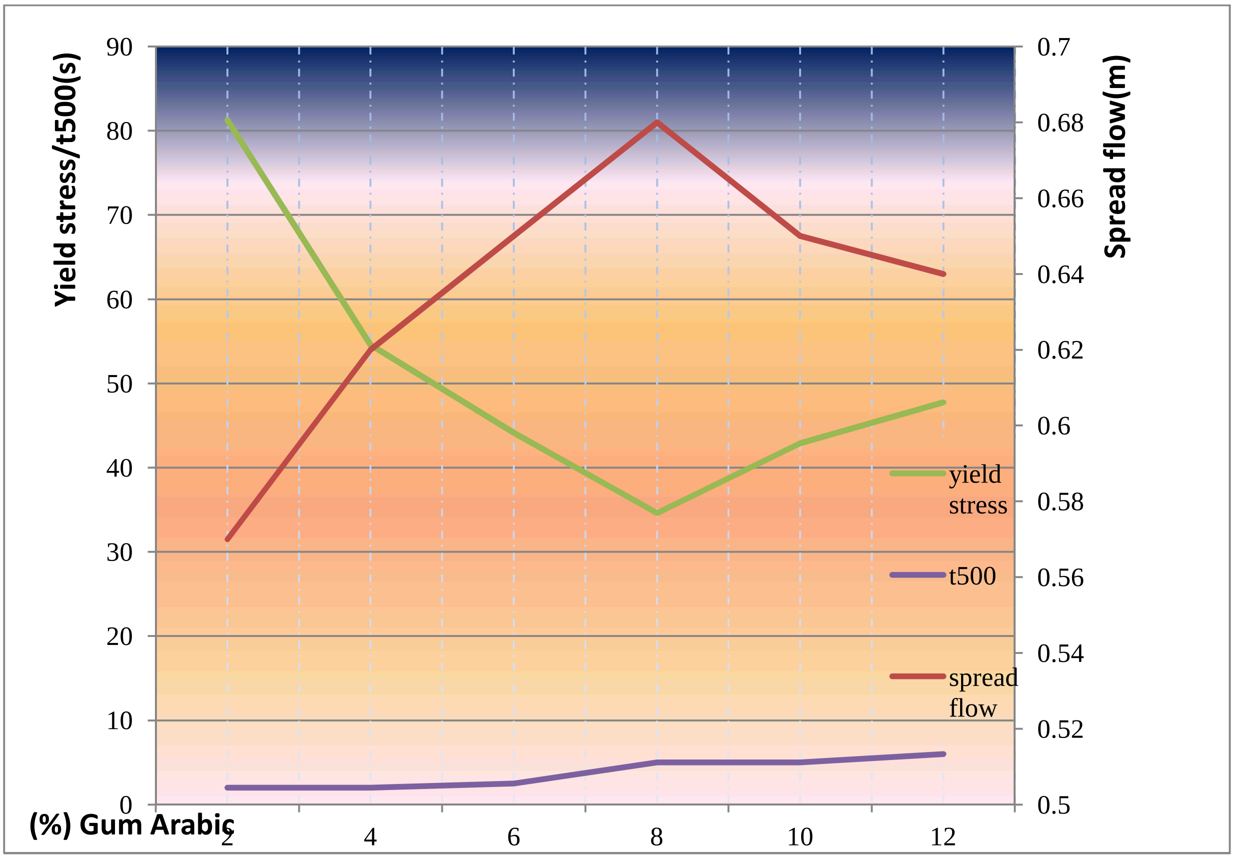

Fig 3: Relationship between Gum Arabic dosage at w-p ratio 1.0 and spread flow

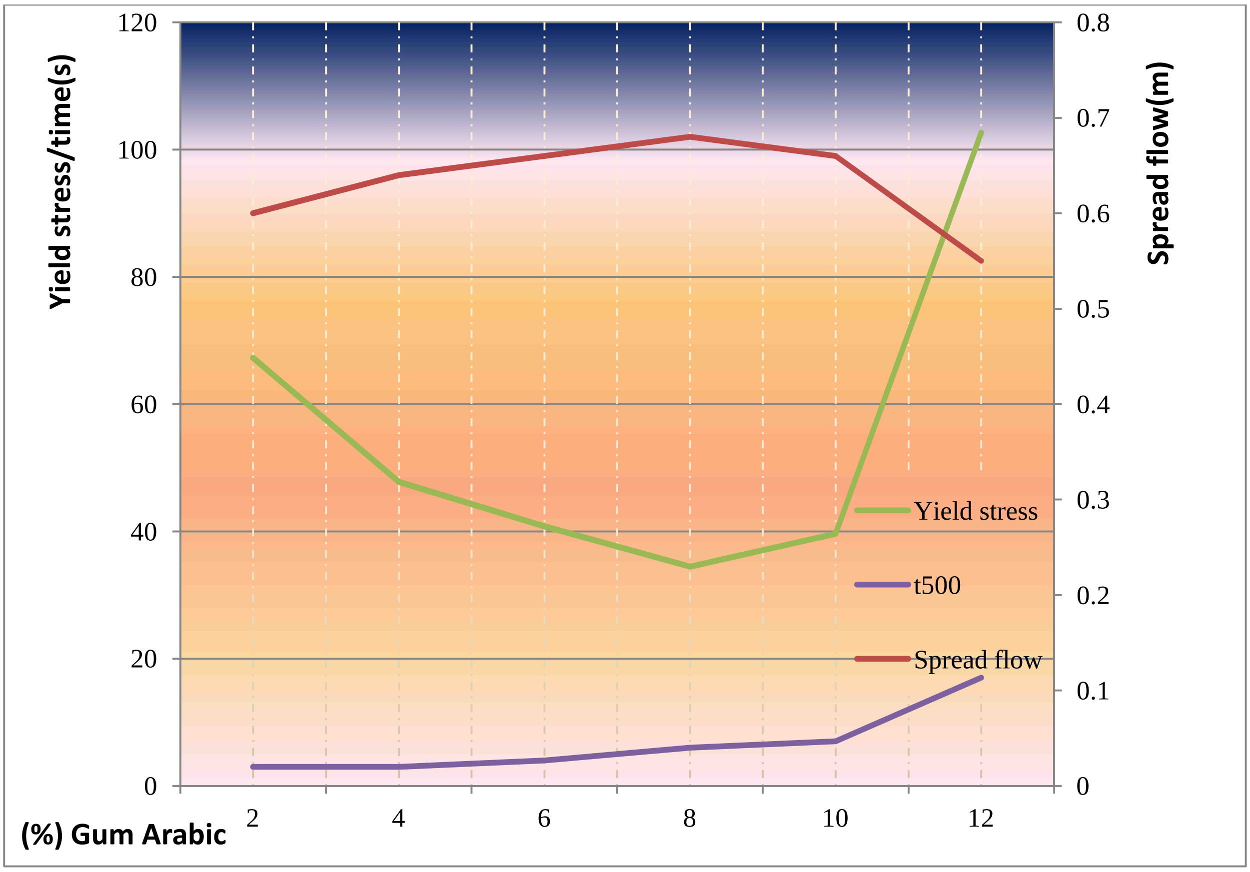

Fig 4: Relationship between Gum Arabic dosage at w-p ratio 0.9 and spread flow

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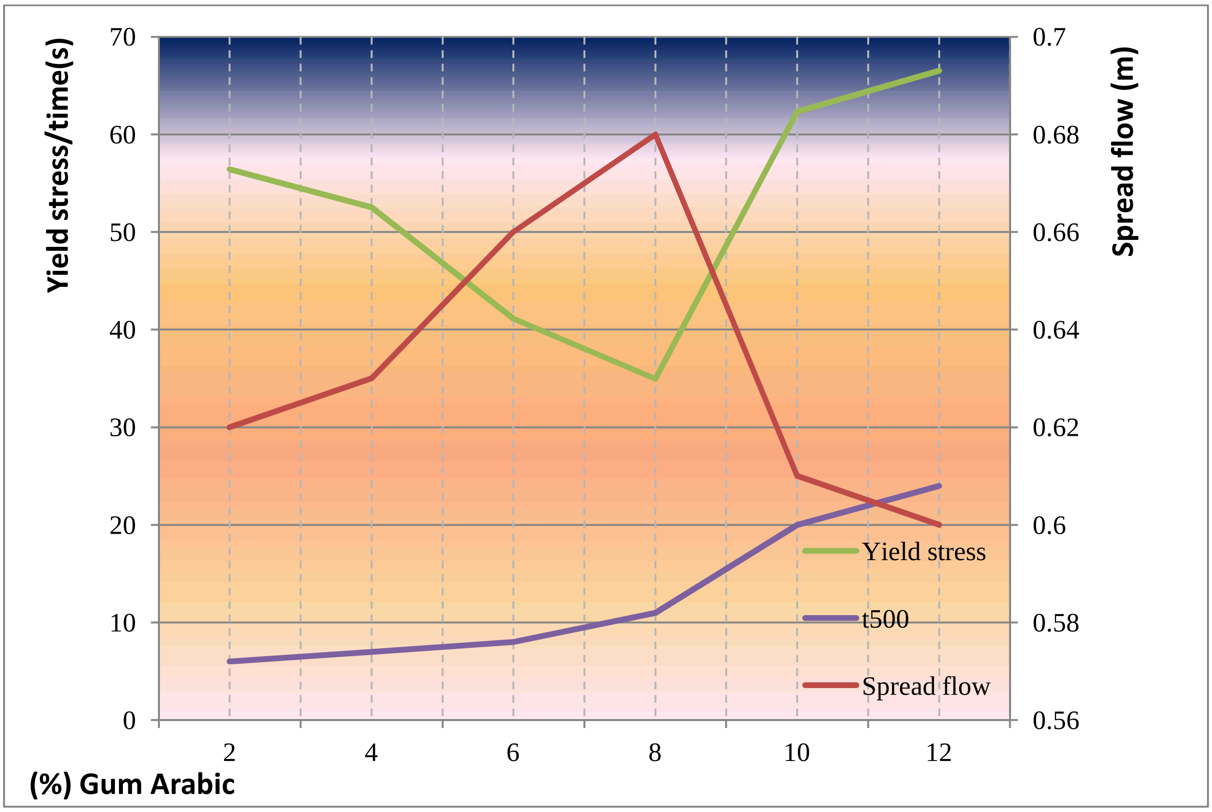

Fig 5: Relationship between Gum Arabic dosage at w-p ratio of 0.8 and spread flow

IV. DISCUSSION

As the dosage of the control (MC Power flow 5110) increases from 1% by weight of cement, the spread flow was seen to increase while yield stress was decreasing at a similar rate. The target spread flow was ranging between 660-750mm which is falls under SF2 flow class according to EFNARC, 2002; suitable for many normal applications. At the dosage of 1.5% a spread flow of 660 mm was achieved. At 1.8%, the optimum spread flow was achieved (680mm). The lowest yield stress was achieved at 2% of 34.8N/m^2. Beyond 2%, the concrete started bleeding and/or segregating.

Except for w-p ratio of 1.1 with Gum Arabic as the superplasticizer, the rest of the w-p ratios exhibited a similar behavior in terms of dosage and spread flow relationship. The spread flow was seen to increase with increasing dosages of Gum Arabic up to a dosage of 8% by weight of cement beyond which it would start to decrease gradually. Yield stress in the other hand, was decreasing at increasing dosages. For w-p ratio of 0.9, the concrete viscosity was observed to be increasing with the increasing dosages of Gum Arabic. Although at w-p ratio of 0.9 the target spread flow was achieved at two dosages, 6% and 10%, the concrete was observed to be more stable at the latter dosage.
At w-p ratio of 1.1, a different trend was observed. As the Gum Arabic dosage was increasing, the spread flow was decreasing while yield stress was increasing. This is not recommendable since for self compacting concrete, yield stress is always low; below 50N/m^2. The target spread flow was achieved at the dosage of 6%; however, the concrete exhibited bleeding.

V. CONCLUSION AND RECOMMENDATION

Gum Arabic reacts faster with cement after being further processed (as discussed above) rather than in fresh state. At a water-powder ratio between 1.0 and 0.8, Gum Arabic exhibits a good spread flow behavior. Beyond 1.0, the concrete ceases to exhibit self compacting behavior and but rather normal concrete with respect to yield stress. Below w-p 0.8, the concrete was highly viscous.
From the results obtained in this study, it can recommended that, Gum Arabic is suitable for use as a superplasticizer at a dosage of 8% by weight of cement being the optimum for w-p of 1.0-0.8. The yield stress for w-p 1.1 and 0.9 was relatively lower than that of the control further affirming that Gum Arabic is a suitable superplasticizer.
Gum Arabic being a biopolymer is less harmful to the environment as compared to the superplasticizers that are produced using petro fuels. The process of preparation is rather mechanical and doesn't require high tech machineries which are not readily available in developing countries.

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