Preliminary investigation and SWOT analysis of sustainable mortar utilizing Arabic Gum

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Abstract. Modern concrete technology requires commercial chemical additives or admixtures - synthetic in nature which are considered as non-ecological construction practice. Conversely, Arabic Gum (AG) is also known to alter the properties of the concrete without compromising the techno-economic and environmental merits when adequately incorporated. This research explores the potency of AG in the development of ordinary Portland cement (OPC) mortar. Four types of mixes were prepared after admixing the dosage of AG in the range of 0% to 1.5% at an interval of 0.5% by weight of the OPC. The specimens were tested by evaluating representative fresh and mechanical properties, such as visual inspection, flow, and compressive strength. The findings were also correlated with the scanning electron microscopy. The results indicated that workability was linearly enhanced by the inclusion of the AG. On the other hand, the strength progressed up to 1% dosage of AG afterwards insignificant development was noticed attributed to bleeding phenomenon leading to a non-cohesive matrix. Therefore, 1%-admixed AG mixture was considered as optimum mix yielding a maximum flow of 250 mm and a 28-day compressive strength of 47.4 MPa. These values were 47% and 22% higher than that in the AG-free mix, respectively. It is postulated that the AG acts like a superplasticizer and contribute to enhance the workability of the mixture, whereas optimum dose provide microstructural densification resulting in higher strength. Hence, up to 1% of AG can be beneficially admixed depending on the flow and strength requirements. The SWOT analysis indicated that the usage of AG in production of construction products might expand the market for the farmers, cut-short the material cost and contribute to the circular economy.

1. Introduction

Chemical admixture plays vital role in modern construction applications and help control the water demand, setting times, air entrainment, corrosion, and shrinkage characteristics when admixed at suitable dosage to the fresh mix. The worldly demand of the admixtures has grown to approximately $18 billion in 2020 [1] and continuously escalating due to increase in rate of population and urbanization. However, the existing commercial admixtures are synthesized using oil-based polymers which are known to be non-renewable, the direct exposure of them to human and the environment is considered as hazardous, they may also behave unpredictable sometimes resulting in abnormal fresh and hardened properties of concrete, they may also require more than 10% of the total construction cost, and need to be stored at favorable temperature having a shelf life of not more than one year [2].

The problems associated with the chemical admixtures have directed the attention of researchers to propose sustainable and viable solutions. One of the options to replace the traditional admixtures is to incorporate the supplementary cementitious materials (SCMs) which includes the by-products of various agricultural (rice husk ash, date palm ash, palm oil fuel ash, etc.), industrial (fly ash, slag, silica fume, etc.), and natural minerals (natural pozzolan, metakaolin, clay, etc.) [3,4]. A few studies reported that Arabic gum (AG) – a water-soluble material obtained from the tall Acacia trees exist in Arabian Peninsula – has potential to be used as an admixture. The typical AG tree is depicted in Figure 1.

Fig. 1 Typical Arabic gum tree, its secretion from branches, and collected fruit.

According to the review of literature, Satti and Ahmed [5] observed that a 0.8% dosage of the AG by weight of cement was beneficial in minimizing the water content of up to 11.5% without impairing the workability but slightly extending the setting times of the concrete composites. The dispensing effect imparted by the AG tends to exhibit a good fluidity as well [6]. A study in hot weather conditions of Africa suggested that AG can be successfully deployed into the concrete production for resisting the chloride permeability and enhancing the compressive strength [7]. It was posited that the increased strength is attributed to the precipitation of the minerals during the hydration reaction and the formation of dense CSH gel [8].

The former studies on AG were mainly sourced from African region, they were sparse, and non-systematic. Since Saudi Arabia is planting the Acacia trees at thousands of hectares of land to cope with desertification and climate change, beside commercial utilization of the AG in various industries, AG can be beneficially utilized in the construction industry of Saudi Arabia. It is expected that this preliminary study will encourage the farmers to increase plantation, cut-short the construction cost, and contribute to circular economy without compromising the technical merits of the construction products.

2. Materials and methods

2.1. Raw material

Type I cement (i.e., ordinary Portland cement (OPC)) was used as a main binding material in this study. The Arabic gum (AG) was procured from local market and admixed at varying content of 0 - 1.5% at an interval of 0.5% by weight of OPC. The AG was powdered and sieved passing # 100 size prior to usage. The fine aggregate (FA) used was the dune sand which was procured from a local Ready-mix company having a maximum grain size of 600 microns. The FA to OPC and water to OPC ratios were kept invariant as 1.5 and 0.4 in mixes, respectively.

2.2. Synthesis of aqueous AG and fabrication of specimens

Firstly, aqueous AG was synthesized by mixing water content of a mix with the dosage of powdered AG powder using a stirrer. Next, the mortar specimens were fabricated using a Hobart mixer. All ingredients were added to the bowl and mixed for a duration of approximately 5 min. The mix proportion is presented in Table 1.

Table 1 Mix design (All quantities in kg/m³)

<table>
<tr><th>Mix IDs</th><th>OPC</th><th>Sand</th><th>Water</th><th>AG</th></tr>
<tr><td>M1-0% AG</td><td rowspan="4">768</td><td rowspan="4">1151</td><td rowspan="4">307</td><td>0</td></tr>
<tr><td>M2-0.5%AG</td><td>3.83</td></tr>
<tr><td>M3-1%AG</td><td>7.67</td></tr>
<tr><td>M4-1.5%AG</td><td>11.52</td></tr>
</table>

2.3. Evaluation

The workability or flow of mortar was measured in fresh state using an ELE brand flow table, as per the specifications of ASTM C230. The spread of mortar was measured in three directions and average value was reported. Next, a visual inspection was carried out on the freshly prepared specimens to qualitatively assess the rate of bleeding and segregation. The compressive strength was evaluated after 7-, 14-, and 28-days of curing on 50 x 50 x 50 mm cubes, as per the specifications of ASTM C109. Thereafter, scanning electron microscope (SEM) was employed to investigate the microstructure of the raw ingredients and OPC-AG paste matrix. The picture gallery of the experimental program is shown in Fig. 2. Finally, a strength, weakness, opportunities, and threats (SWOT) analysis was presented.

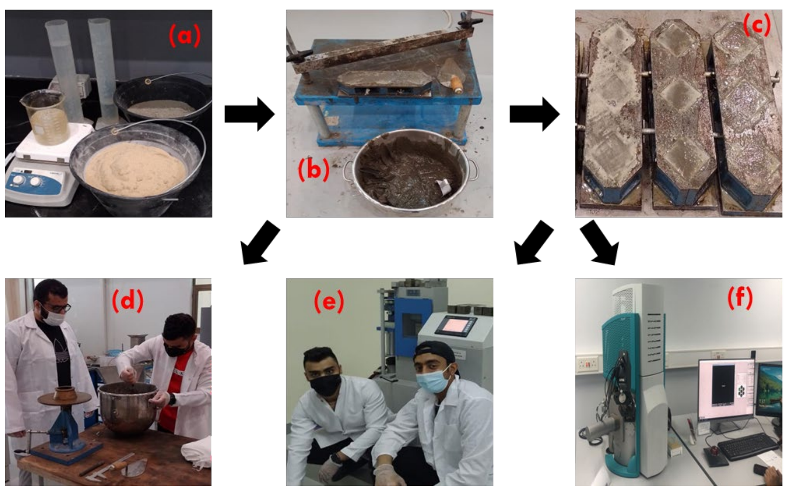

Fig. 2 Pictorial view of the experimentation: (a) raw material, (b) fresh mortar and compaction set-up, (c) fresh cubic specimens, (d) testing of flow, (e) testing of compressive strength, (f) microscopic analysis.

3. Results and Discussions

3.1. Flow

The variation of the flow of fresh mortar is depicted in Figure 3. It was clearly noticed that an increment in flow is likely when the amount of the AG in increased to 1.5%. The control specimen registered a flow of 170 mm, whereas the flow in M2-0.5%AG, M3-1%AG, and M4-1.5%AG were 195, 242, and 250 mm, respectively. These flow values in AG-based mixes were 14, 42, and 47% higher than that recorded in AG-free mix. An increase in flow values due to an increase in the AG content is attributable to its superplasticizing nature or lubricating feature which provides ball bearing effect and consequently enhancing the flow mobility. Thus, AG can be used as an alternative to the commercial superplasticizer or as a pumping aid. The trend of flow results follows Athman et al. [9] who found AG as a superplasticizer during the manufacture of a self-consolidating concrete. Elsewhere [10] also reported that the flow of AG-free mortar was 120 mm which was linearly or exponentially increased with the addition of AG content of up to 1.1%. The authors found that the increased flow due to an increase in the dosage of the AG is basically due to the emulsifying effect provided by the AG itself. Mbugua et al. [11] observed a 19% increase in the flow when AG was admixed between 0.4 and 0.7%, whilst any further addition led to a flow of more than 70% of AG-free mortar.

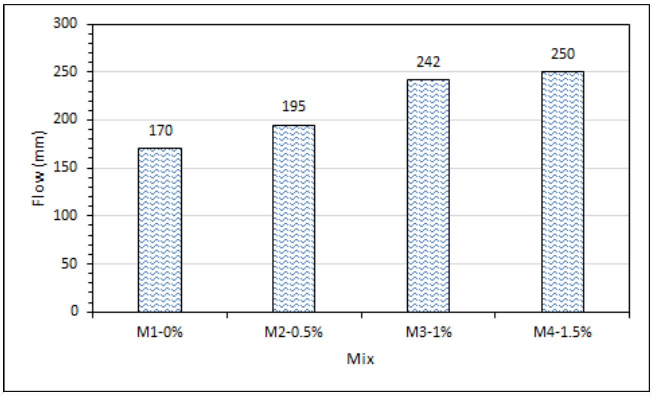

Fig. 3 Flow of mortars.

3.2. Visual inspection

Once the specimens were cast, a visual inspection was carried out to qualitatively assess the rate of bleeding and segregation in each mixture. Generally, the rate of bleeding appeared to be increased due to increment in the amount of the used AG, as the trend noticed in the flow data. However, the bleeding was significantly increased in M4 specimens prepared with 1.5% dosage of the AG. This is evident from Figure 4(a) which shows the sheen of water appeared on the surface of the fresh mortar, as compared to that prepared with ≤ 1% of AG. This indicates that the content of AG should be limited to 1% to avoid significant bleeding and segregation. Similar bleeding phenomenon was confirmed by [11] by measuring the rate of bleeding in AG-based mixes. They reported a marginal bleeding in specimens prepared with up to 0.8% AG content, whereas excessive bleeding was observed in specimens synthesized with a threshold limit of 1% of AG mainly due to occurrence of de-flocculation that converts the mix in to waterier.

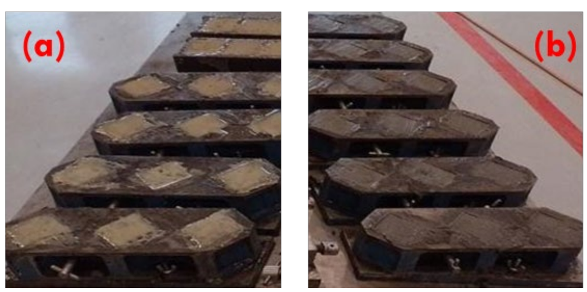

Fig. 4 Visual inspection of fresh mortar: (a) bleeding sign in M4-1.5% and (b) non-bleeding in typical mortar prepared with ≤ 1% of AG.

3.3. Compressive strength

The variation in the development of compressive strength of mortar is depicted in Figure 5. In general, the strength tended to increase as the curing progressed, regardless of the dosage of the AG. However, the strength values tended to slightly drop when more that 1% dosage of AG was admixed. It was also observed that the rate of strength development was rather slow at early ages of 7 and 14 days in the AG-based specimens, whereas the degree of strength development was more pronounced after a curing period of 14 days. This trend was expected as AG was already found to be act like a retarder in the investigation carried out by Mohamed et al. [10] and Mbugua et al. [11]. According to the results obtained in this study, the compressive strength in AG-free specimens, M2-0.5%, M3-1%, and M4-1.5% was recorded to be 27.4, 29.8, 31.7, and 31.1 MPa at the age of 7 days, respectively. Likewise, these strength values were recorded to be 38.5, 40.4, 47.4, and 47.1 MPa after 28 days of curing, respectively. This indicates that the optimum mix is M3 prepared with admixing 1% of AG for enhancing both the early-age and later-age strength of mortar. Numerically, up to 8.8%, 22.9%, and 22.2% increment in strength values were noticed in AG-based mixes prepared with 0.5, 1%, and 1.5% dosage, respectively. These findings are complying to Elinwa et al. [8] who reported an optimum dosage of AG of about 0.75% which results in increment of the strength of up to 39.5% due to the extra formation of the minerals.

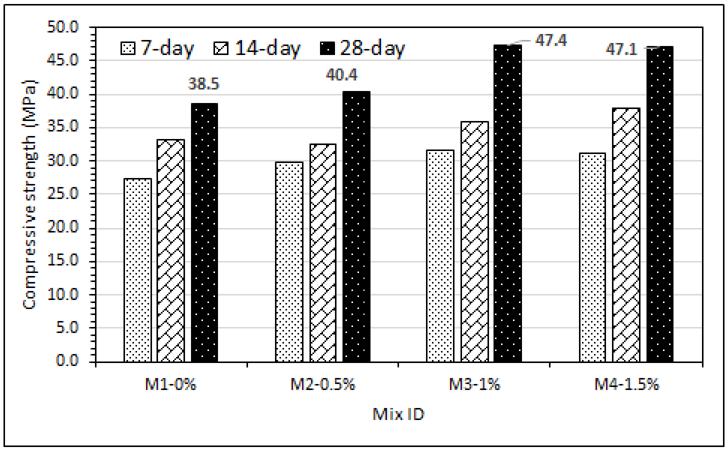

Fig. 5 Compressive strength of mortars.

3.4. Scanning electron microscopy

The variation in the morphology of the neat OPC and neat AG alongside the evolved microstructure of OPC-alone and OPC-AG paste matrix is depicted in Figure 6. It can be noticed that the texture of both raw materials was heterogeneous, and the grain sizes were also widely varied. Obviously, the morphology of the paste was significantly changed due to the hydraulic reaction. Among the paste mixes the microstructure of the M3 specimens was more compact with fewer unreacted particles and micro-cracks, whereas the microstructure of the excessive AG mix exhibited high porosity and non-uniformity of reaction products. It can be hypothesized that the increased compressive strength with an increment of the used AG dosage can be attributed to the microstructural densification or the more formation of the gel products in contrast to AG-free specimens; however, excessive AG content does not necessarily contribute to the microstructural densification and may only act as pore-filling agent. This argument is in compliance with the previous findings. For instance, Rustum and Oweed [12] carried out SEM analysis to investigate the microstructure of the AG-free and optimum AG-based specimens. They revealed a significant reduction in the porosity of the AG-based specimens compared to the former. Nonetheless, upon visual inspection of the freshly cast specimens, it was confirmed that there was remarkable bleeding in the specimens prepared with more than 1% AG compared to other counterparts (Fig. 4). This bleeding caused non-uniform or non-cohesive mixture resulting in strength retrogression at higher dosage of AG.

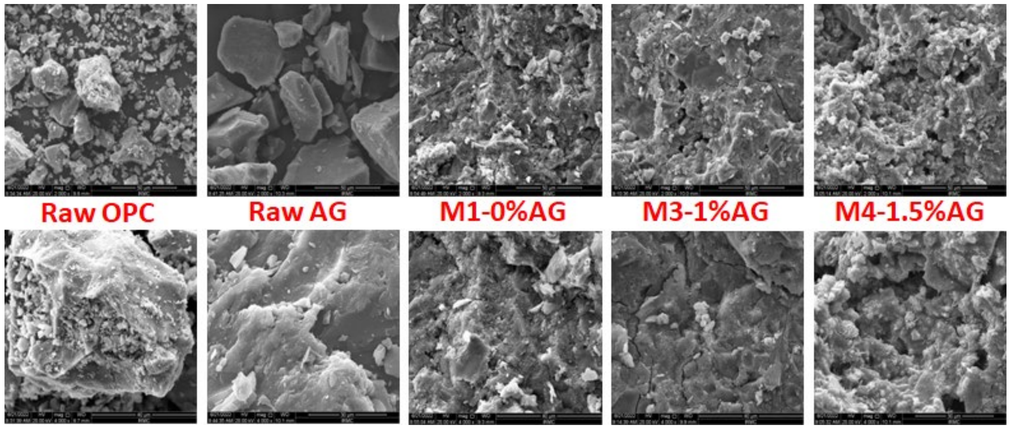

Fig. 6 Morphology of the raw materials and OPC-AG pastes.

3.5. SWOT analysis

The strength, weakness, opportunities, and threats (SWOT) analysis is summarized in Fig. 7.

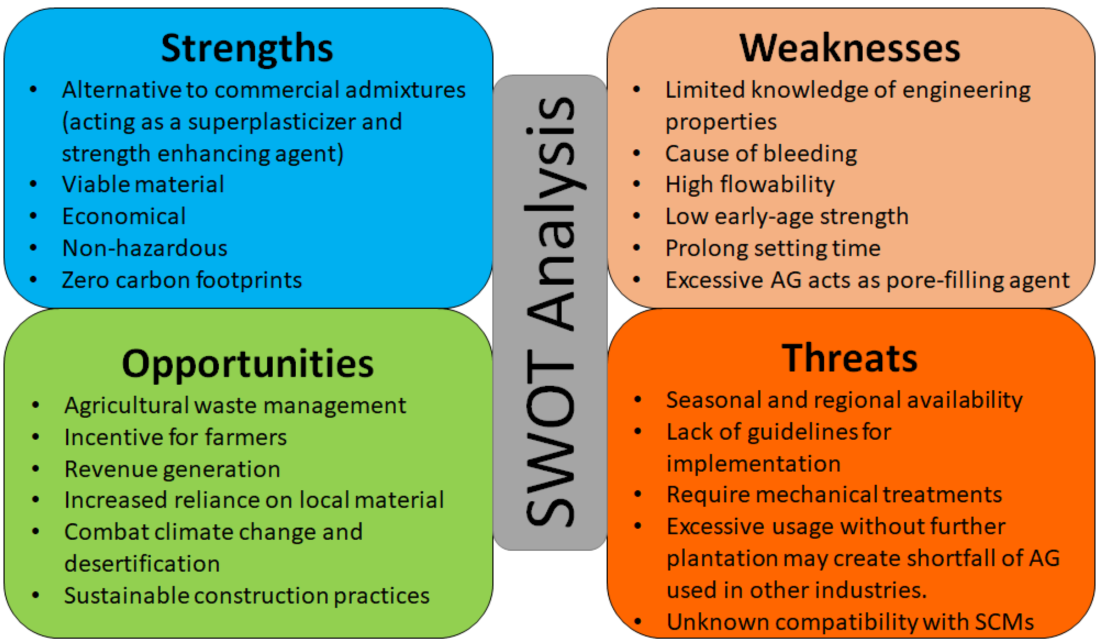

Fig. 7 SWOT analysis of the AG as an alternative admixture.

4. Summary

Following are the conclusions based on this experimental study:

1. A flow of 195, 242, and 250 mm was recorded in M2-0.5%AG, M3-1%AG, and M4-1.5%AG, respectively. These flow values were 14, 42, and 47% higher than that recorded in AG-free mix. The increased in flow values has direct relationship to the dosage of AG attributable to its superplasticizing nature or lubricating feature which provides ball bearing effect and consequently enhancing the flow mobility.
2. The compressive strength in AG-free specimens, M2-0.5%, M3-1%, and M4-1.5% was recorded to be 27.4 to 38.5 MPa, 29.8 to 40.4 MPa, 31.7 to 47.4 MPa, and 31.1 to 47.1 MPa at the age of 7 to 28 days, respectively. Numerically, up to 8.8%, 22.9%, and 22.2% increment in strength values were noticed in AG-based mixes of 0.5, 1%, and 1.5% dosage, respectively.

3. The visual inspection of freshly cast specimens revealed that the increased compressive strength up to 1% dosage of AG enabled a homogeneous mix leading to a dense mortar matrix, whilst strength retrogression above 1% dosage of AG was ascribed to excessive bleeding and the formation of a non-cohesive mixture.
4. The incorporation of AG significantly improved the workability and strength characteristics. The SEM analysis confirmed that the optimum mix is M3 prepared with admixing 1% of AG for maximizing both the early-age and later-age strength of mortar.
5. The SWOT analysis of the AG as an additive in cementitious composites indicated a high potential for its usage from techno-economic-ecological point of views. However, certain weaknesses and threats associated with the use of AG are imperative to be resolved.

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