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RESEARCH ARTICLE

Influence of anti-washout admixtures on the strength and microstructural characteristics of geopolymer concrete

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Abstract
Recent investigations proved that geopolymers produced with different industrial by-products have shown superior mechanical and microstructural performances compared to ordinary Portland cement (OPC) concrete. This study investigates the effectiveness of using different anti-washout admixtures (AWAs) to produce geopolymer concrete (GC) based underwater concrete (UWC). Two different AWAs were used in the present study i.e. Arabic gum (AG) and xanthan gum (XG). However, in the fabrication of GC two types of industrial by-products were used such as fly ash (FA) and ground granulated blast furnace slag (GGBFS). The influence of GC mixes in UWC was assessed in terms of workability, washout resistance, compressive strength, bleeding capacity and microstructural characteristics. The results indicate that among all GC samples, AG based mixes are most suitable for AWAs in the production of UWC. Moreover, enhanced compressive strength and better anti-washout resistance was observed in case of AG based UWC samples as compared to XG samples. The UWC based GC showed an enhanced compressive strength of 54.73 MPa with the addition of 0.5% Arabic gum. The XRD, SEM and EDS analysis revealed the better formation of geopolymerization products in UWC mixes produced with AG.

Keywords Fly ash · GGBFS · Geopolymer concrete · Anti-washout admixtures · Compressive strength · Microstructure

1 Introduction

In recent years the development in the usage of geopolymer binders has been observed [1]. The uses of geopolymers offer prospective solving in industrial waste management and environmental degradation [1–3]. Generally, the production of ordinary Portland cement (OPC) causes environmental problems related to carbon dioxide (CO_2) emission [2]. That can be overcome by using geopolymer concrete (GC) as a full replacement of cement with industrial by-products [4]. Geopolymers are substitute cementitious materials produced by mixing industrial by-products, which are rich in 'Si' and 'Al' such as fly ash (FA), ground granulated blast furnace slag (GGBFS) with alkali-activated liquids such as potassium/sodium-based soluble were dissolved with Al_2O_3, and SiO_2 particles possess geopolymerization to form a three dimensional aluminosilicate chain [5, 6]. The potential of GC to replace the conventional OPC concrete was supported by FA, industrial by-products of a thermal power plant, make up of 70–82% of worldwide yearly ash production [7], yielded GC with enhanced mechanical and durability characteristics, in comparison to OPC concrete [8–10]. Different factors such as alkaline solution/binder ratio, Na_2SiO_3/NaOH ratio, and NaOH molarity affect on the GC properties [11]. Reddy et al. [12] reported FA-based GC exposure to the marine atmosphere by using an electrochemical method for the corrosion test. Geopolymer and OPC concrete prisms with 13 mm reinforced bars were placed centrally, tested for the corrosion test under 28 days of curing. The experimental outcome revealed that GC samples attained better resistance to the salt environment compared with OPC. Nath and Kumar [13] used FA and GGBFS to study the mechanical and microstructural characteristics. The results show that the inclusion of GGBFS has attained better properties than FA-based GC samples.

Khayat [14] and Sikandar et al. [15] used anti-wash out admixtures (AWAs) to produce underwater concrete (UWC). When these admixtures absorb water leads to generate viscous concrete and which are water-soluble polymers. The

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workability and washout mass loss were strongly affected by water-cement ratio, percentage of AWAs, and the use of mineral admixture. The positive effect of SiO_2 based nano-particles on washout resistance of concrete has been effectively established by Grzeszczyk et al. [16]. In general, UWC is prone to problems associated with segregation, binder washout, and poor workability when used for underwater construction purposes [16]. Thus, the washout of concrete affects its flowability, strength, and durability; viscosity modifiers can be used to the concrete to reduce its fluidity [15].

On the other hand, the non-dispersible UWC samples were shown by self-compacting and self-leveling works [17, 18]. The anti-washout-based UWC holds important characteristics good viscosity, flexibility, bonding, low pollution of surrounded water, etc. Hence, this kind of UWC is more stable in large volume applications [17–19]. However, HPMC and weelan gum-based UWC samples require a huge quantity of superplasticizer, which retards the setting time of underwater concrete [14]. In another study, a similar kind of AWAs was used with the combination of FA and silica fume. He reported that the use of non-materials like silica fume has shown greater anti-washout resistance in UWC. It is because of the effect of SiO_2 based nano-particles [16]. It was reported that the washout slump flow and mass loss were significantly subjective to AWAs concentration and the water-binder ratio [20].

Previous literature on UWC reported that the addition of AWAs improves rheological properties and delays setting times [18]. Park et al. [17] used highly flowable non-dispersible UWC with 0.5–1.5 % of various AWAs and superplasticizers to obtain a compressive strength of 35 MPa for 1% AWA after 28 days. Similarly, Heniegal et al. [19] developed UWC using 0 to 0.5 % of AWA, 15 % silica fume, and 4 % superplasticizer by cement weight. Based on the results, he reported that with the increase of AWA, the slump is decreasing, and washout resistance increases. Ito et al. [21] suggested that the use of vinyl polymer-based AWAs in UWC samples showed an improved segregation resistance. Moreover, some of the previous literature reported the characteristics of structural members constructed using UWC. These studies are based on the experimental evaluation of columns made-up by UWC compared to rupture mechanics, stress-strain characteristics, and resistance to seismic forces [22, 23].

The structural performance of conventional concrete is much comparable to UWC. Other than rheological structural performances, physical characteristics like bleeding, creep, volumetric differences, and segregation were also essential for UWC. However, the shrinkage of UWC must be avoided to improve suitable bonding that can be happened with the use of AWAs in the UWC works [24]. Anti-washout admixtures are classified as synthetic (water-soluble) and natural polymers, emulsions, inorganic water-retaining materials, and water-soluble flocculants [25]. The properties of UWC vary depending on the type of AWAs, concentration, and dosage. This interaction can be classified as polymer-water, polymer-polymer, and polymer-particle interactions in the UWC mixes [26].

Therefore, from the literature, it is noticeable that GC's use improves the utilization of industrial by-products such as FA and GG BFS to fabricate sustainable construction. The main objective of this study is to understand the behavior of GC for underwater construction works. The specimens are prepared using anti-washout based admixtures with the GC. The washout resistance and bleeding capacity of AWAs based GC mixes were studied to know geopolymer concrete stability for underwater construction. The compressive strength test and microstructural studies (XRD, SEM and EDS) were also performed. After 28 days of compressive strength testing of GC sample failure, pieces were taken for microstructural analysis.

2 Materials, mix proportions and cast of specimens

FA and GGBFS were used as primary and secondary binding materials conforming to ASTM C 618 – 19 [27] and ASTM C 989–2018 [28]. As a control mix, cement is used in this paper according to ASTM C 150–2019 [29] was obtained from UltraTech cement limited, Vijayawada. Table 1 represents the chemical composition of binders used in this paper. Locally available coarse and fine aggregates having particle sizes of 12–20 mm and 2-2.46 mm, respectively, obtained from natural River and granite quarry were used according to ASTM C 33-2003 [30]. The grain size distribution cures are presented in Fig. 1. The combination of sodium-based silicate and hydroxide were used as an alkaline solution. Sodium silicate in the liquid form obtained from Kiran global solutions, Hyderabad, and sodium hydroxide in pellets form purchased from Vamshi Krishna chemicals, Vijayawada. The locally available two natural gums are used as AWAs to prepare non-dispersible UWC, i.e., Arabic gum (AG) and Xanthan gums (XG) from the origin of polysaccharides gums. Table 2 shows the mix proportions of GC mixes produced in this study. A total of nine mixes were considered to produce AWAs based geopolymer concrete samples as WUC. Out of nine mixes three mixes were prepared with AG (0.25, 0.5 and 0.75 %), another three mixes were prepared with XG (0.25, 0.5 and 0.75 %), two cement based mixes were also used (with 0.5 % AG and 0.5 % XG) and one control mix was used without any AWAs. The mix id's represents the percentage of AWAs used in the production of UWC. Example, AG0.25, indicates the addition of 0.25 % Arabic gum in the GC. Similarly XG0.25 represents

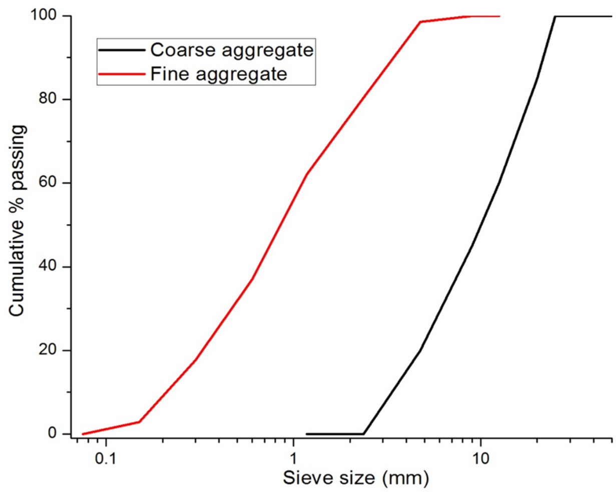

Fig. 1 Grain size distribution cures of fine and coarse aggregates

the addition of 0.25 % of XG in the production of GC. However, C-AG0.5 indicates the addition of 0.5 % AG in the production of cement concrete samples.

After mixing FA, GGBFS, the aggregate, alkaline solution was added in different ratios and mixed for 2–3 min to achieve a workable and sustainable GC. The freshly manufactured GC was assessed for workability. A height of 500 mm glass bucket filled with water was used to simulate the underwater atmosphere. The 100 mm cube moulds were placed in water (glass bucket), and the distance between the surface of the water and the top of the mould was roughly 200 mm. Then the AWA based GC mixture was poured into the moulds and continued until the moulds were filled. After 24 h, the casted samples were detached from moulds followed by curing for 28 days in the water tub at a constant 15˚C heat. Figure 2 represents the preparation process of AWAs based GC samples for underwater concreting.

3 Test methods

The workability of AWAs based GC was determined by using a slump cone test was conducted as per ASTM C143-20 [31]. A slump test was held in the laboratory with 7 mixes of fresh GC and 2 mixes of cement based concrete.

The 2000 kN capacity of AIMIL digital CTM with a 140 kg/cm^2 loading rate was used. The experiment was conducted by the application of stress at a consistent rate after placing the sample properly at the centre in CTM. The load was applied steadily until the reading get changes its direction. The reversing of the needle indicates the total failure load of the specimen. The dial gauge reading is noted at the instant of failure, which is the ultimate load on a specimen. From which the compressive strength of a particular mix can be determined by dividing the ultimate load by the

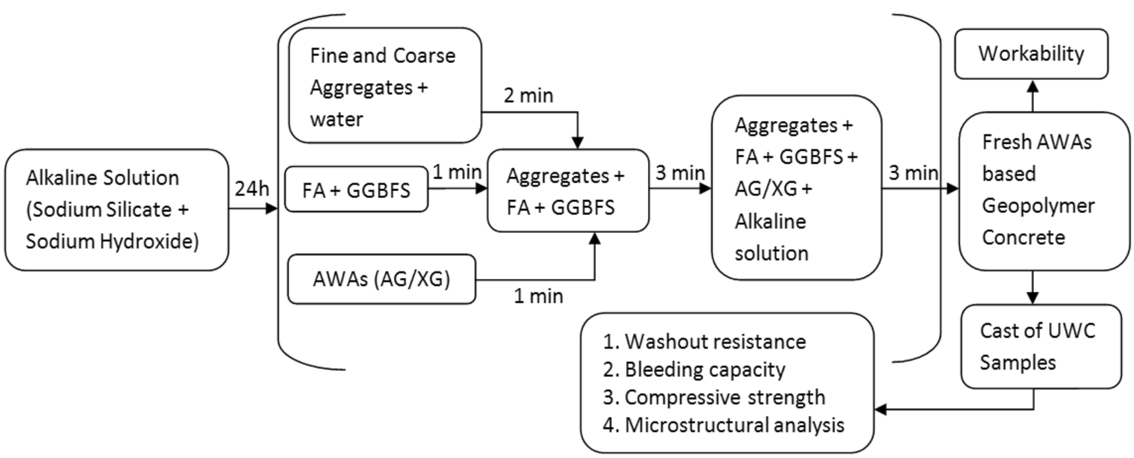

Fig. 2 Flow chart of AWAs based GC samples preparation for UWC

Table 1 Chemical composition of materials used in this study

Material	Al_2O_3	Fe_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SO_3	TiO_2	LOI
FA (Class-F)	25.08	4.56	58.23	2.87	1.21	0.41	0.87	2.94	0.2	1.16	0.83	1.59
GGBFS	12.14	1.10	32.25	44.7	4.23	0.87	–	1.96	–	0.84	–	1.98
Cement (OPC)	4.18	3.10	21.47	65.15	1.97	0.63	1.01	–	–	1.96	–	0.37

Table 2 Mix proportions of AWA based GC

Mix Id	Binders	Aggregates	AWA	Solution	Water				
	FA	GGBFS	Cement	Fine	Coarse		Na_2SiO_3	NaOH	
AWA0	315	135	–	675	1350	0	128.58	51.43	–
AG0.25	315	135	–	675	1350	1.125[a]	128.58	51.43	–
AG0.5	315	135	–	675	1350	2.25[a]	128.58	51.43	–
AG0.75	315	135	–	675	1350	3.375[a]	128.58	51.43	–
XG0.25	315	135	–	675	1350	1.125[b]	128.58	51.43	–
XG0.5	315	135	–	675	1350	2.25[b]	128.58	51.43	–
XG0.75	315	135	–	675	1350	3.375[b]	128.58	51.43	–
C-AG0.5	315	135	450	675	1350	2.25[a]	–	–	180
C-XG0.5	315	135	450	675	1350	2.25[b]	–	–	180

[a]Arabic gum

[b]Xanthan gum

cross-sectional area of the test sample. The test specimens for compressive strength were made on cubes in cast-iron moulds having a size of 100 mm, according to ASTM C-39 [32].

TESCAN Brno S.R.O (VEGA 3 SBH) SEM equipment was used to estimate the microstructural properties. For morphological study assessed with a low-vacuum approach with the high energy of 10–40 kV was adopted.

RIGAKU XRD-600 with Cu-Ka radiation created under 40 kV and 15 mA at room temperature was used to study phase transformations of GC samples. This test was performed at a scanning angle of 2θ between 5–70° at a constant rate of one minute. The X' Pert High Score" software was used to analyze the diffraction patterns to identify automatch peaks.

To assess anti-washout resistance of GC based UWC; the 0.5 kg of fresh geopolymer concrete was slowly grouted in a bucket. After 2 min, 500 ml of water from the top surface of the bucket was extracted using a pipette and was immediately evaluated for pH. As the lower pH of drawn water indicate high anti washout resistance of GC samples for UWC. The anti washout resistance of GC mix for UWC was estimated by following the test procedure given in CRD-C 61-89 A [33].

A total of 60 GC samples were prepared in the laboratory to measure 100 × 100 × 100 mm for the uniaxial compression test. In every mix, three samples are cast by placing the moulds in water, as shown in Fig. 2; in the same mix, another three samples are cased normally.

4 Result and discussions

4.1 Workability

Figure 3 presents the workability of GC by using the slump cone test. Generally, GC's workability is lower than that of conventional concrete as the presence of silica in geopolymers would bring a sticky nature [34, 35]. Compared to the AWA0 mix, the slump values increased with AWA content in the geopolymer and OPC concretes mixture. This can be attributed to the accelerated reaction of AWAs to GGBFS and FA. Figure 3 was evident that with AWA (AG/XG) percentage increases, the slump values were also increased. However, the slump value of AG0.5, AG1.0, AG1.5, XG0.5, XG1.0, XG1.5 and AG1XG1 increased 4.39 %, 12.24 %, 19.65 %, 6.72 %, 16.42 %, 23.70 and 27.52 % respectively as compared to AWA0. The mixture combined with both the AWAs (AG and XG) showed improved workability compared to all other mixes of GC. Arabic gum is shown fewer slump values compared to Xanthan gum based GC samples. However, the AWAs have shown a significant effect on the workability of FA-GGBFS based GC.

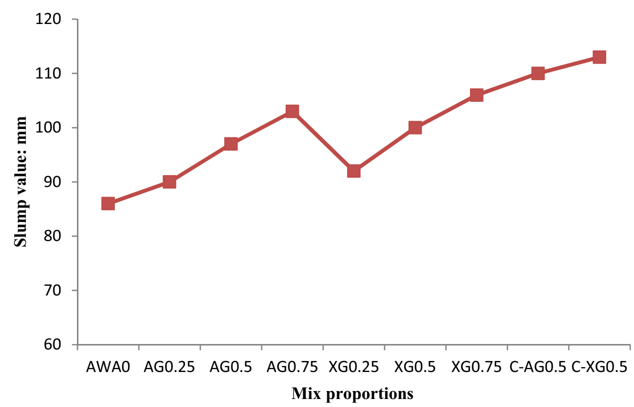

Fig. 3 Slump values of AWAs based GC

4.2 Washout resistance

Figure 4 presents the washout resistance for both geopolymer and OPC based UWC mixes. It was observed from Fig. 4

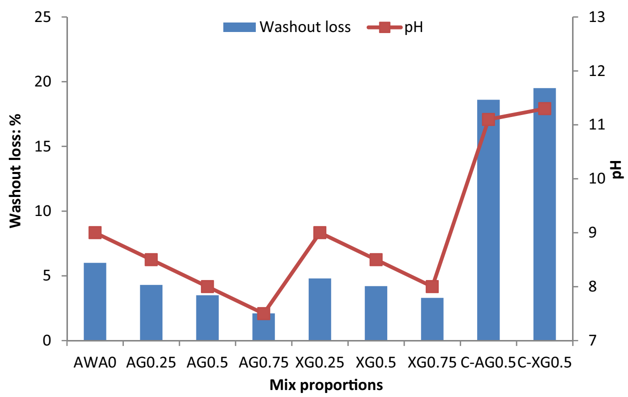

Fig. 4 Washout resistance and pH values of geopolymer and OPC concrete mixes

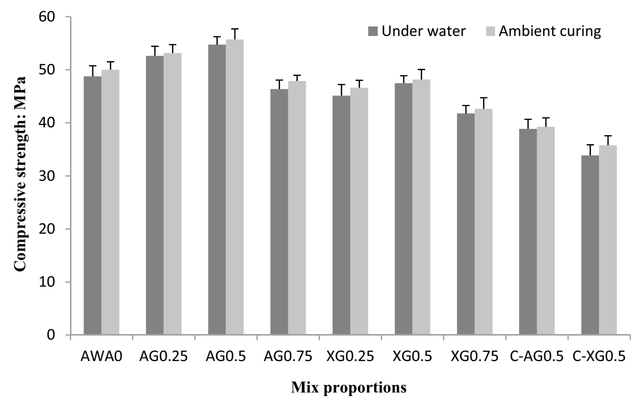

Fig. 5 Compressive strength of AWAs based concretes

that the GC samples retain water and seize suspended particles to lower the dilution tendency. Anti-washout admixtures are water-soluble hydrophilic polymers; these admixtures increase the viscosity and yield stress of the geopolymer based matrix. Figure 4 represents that the low washout as well as pH values obtained for all GC samples. This observable fact can be recognized as the lower bleeding rate of GC samples, improving the denser structure of UWC [36]. However, more anti-washout resistance was obtained for AG0.5, AG0.75, and XG0.75 with washout loss of 3.5, 2.1, and 3.3 %, respectively. The highest washout was observed for the mixes C-AG0.5 and C-XG0.5 with 18.6 and 19.5 %, respectively. It is a fact that the high molecular weight based AG and XG are well known for the reduction of segregation/bleeding properties [37].

4.3 Compressive strength

Figure 5 represents the result for 28 days compressive strength of anti-washout admixtures based on geopolymer and OPC concrete samples. The results show that the AWAs based GC mixes attained adequate strength as comparable to AWAs based OPC concrete mixes. Polysaccharide-based AG and XG in GC lead to enriching the compressive strength, which is also interpenetrating the microstructure [38]. GC containing AWAs exhibited better resistance to washout of the binder while impeding the bleeding of external water into the fresh geopolymer. Figure 5 describes that the type of AWA has a significant effect on the compressive strength of GC. The highest compressive strength was measured in the concrete specimens prepared with Arabic gum, while the lowest compressive strength was noted in the concrete specimens prepared with Xanthan gum. For example, the compressive strength of GC samples after 28 days of water curing and prepared with 0, 0.25, 0.5, and 0.75 Arabic gums were 48.75, 52.62, 54.73, and 46.35 MPa, respectively. It indicates that the increase of Arabic gum from 0 to 0.5 % the strength was increased, while the further increase of this percentage the strength was decreased.

On the other hand, the use of Xanthan gum as an AWA was not shown much impact on the compressive strength of GC as compared to Arabic gum. The microstructural studies also reviled that the Arabic gum based GC samples shown the denser structure with augmented geopolymerization process. This can be attributed to the strong bond between the aggregate and geopolymer binder. The SEM images are illustrated that the formation of C-A-S-H gel was greater in Arabic gum-based samples as compared to Xanthan gum. However, the use of AWAs (Arabic gum/Xanthan gum) not shown much impact on the strength attainment of OPC concrete samples as compared to GC samples. It was also observed that the cement-based samples had struggled more while placing the concrete under water. The results indicated that the GC samples were shown much forward resistance to the binder's washout compared to cement samples. In this contrast, the addition of anti-washout admixture to GC, viscosity was increased and its resistance to segregation under the washing action of GC can be enhanced.

4.4 Bleeding capacity

Figure 6 shows the bleeding resistance/straggles of AWAs based concrete samples grouted in water tub for UWC. Figure 7 illustrates the bleeding capacity of AWAs based geopolymer and OPC concrete. It was observed that irrespective of the AWA type in geopolymer and OPC concrete samples, the bleeding rate was increased over time. Both AG and XG based geopolymer samples exhibited the lowest bleeding rate as compared to OPC concrete samples. The previous reports [39] also mentioned that the nature of AWAs would not allow any segregation/bleeding, lead to an increase in the viscosity of the concrete samples. In reality, a little bleeding is useful in resisting the drying out of concrete. Some of the previous literature reported a reduction in bleeding

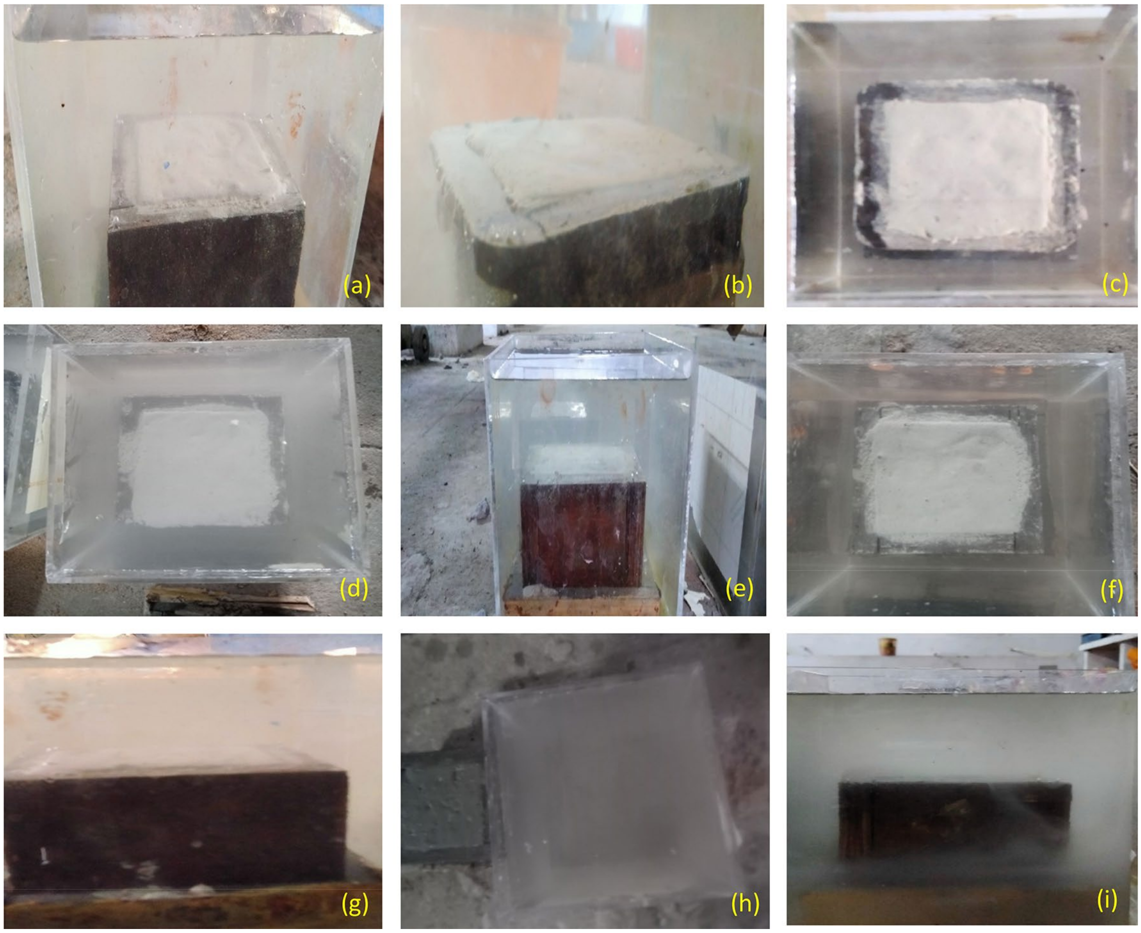

Fig. 6 AWAs based concrete samples, **a** AWA0, **b** AG0.25, **c** AG0.5, **d** AG0.75, **e** XG0.25, **f** XG0.5, **g** XG0.75, **h** C-AG0.5, **i** C-XG0.5.

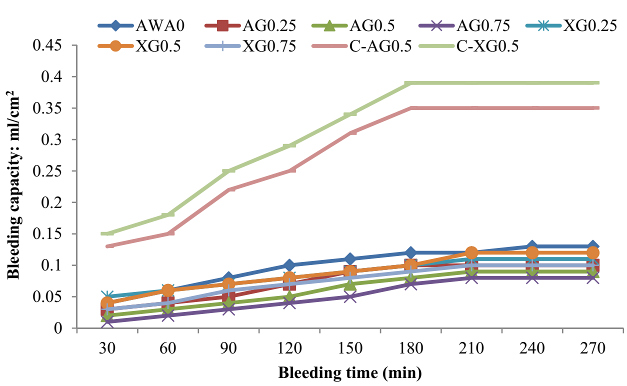

Fig. 7 Bleeding capacity of geopolymer and OPC concretes

using polysaccharides based Arabic gum [40]. The Xanthan gum based GC samples shown a greater bleeding rate compared to Arabic gum-based samples. However, the maximum bleeding was found in OPC concrete samples for both the gums. Figure 6 was evident that the AWAs based OPC concrete samples shown higher bleeding rate. Compared with Xanthan gum based samples, bleeding control is obtained at a speed rate for Arabic gum-based GC. Besides, the smectite colloidal magnesium of alumino-silicate also efficiently bonds the FA and GGBFS particles. This magnesium will decrease the bleeding rate of GC. As an outcome, using Arabic gum in GC-based UWC helps to stabilize by obtaining the utmost suspension

The Consolidated results for various tests such as comparing workability, compressive strength, washout loss, pH and bleeding rate were presented in Table 3. From the consolidated data it can be clear that the addition of AWAs has shown greater impact on the development of UWC works. However, the influence of AWAs in the strength attainment and anti-washout resistance was better in case of geopolymers as compared to cement concrete samples.

4.5 XRD

The XRD technique was used to estimate the mineral phases in AWAs based concrete mixes. The identification of peaks through XRD analysis for all the mixes is qualitative,

Table 3 Consolidated results for various tests

Mix Id	Slump (mm)	Compressive strength (MPa)	Bleeding rate (after 270 min) (ml/cm^2)	Washout loss (%)	pH
AWA0	86	48.75	0.13	6	9
AG0.25	90	52.62	0.1	4.3	8.5
AG0.5	97	54.73	0.09	3.5	8
AG0.75	103	46.35	0.08	2.1	7.5
XG0.25	92	45.12	0.11	4.8	9
XG0.5	100	47.47	0.12	4.2	8.5
XG0.75	106	41.76	0.1	3.3	8
C-AG0.5	110	38.86	0.35	18.6	11.1
C-XG0.5	113	33.86	0.39	19.5	11.3

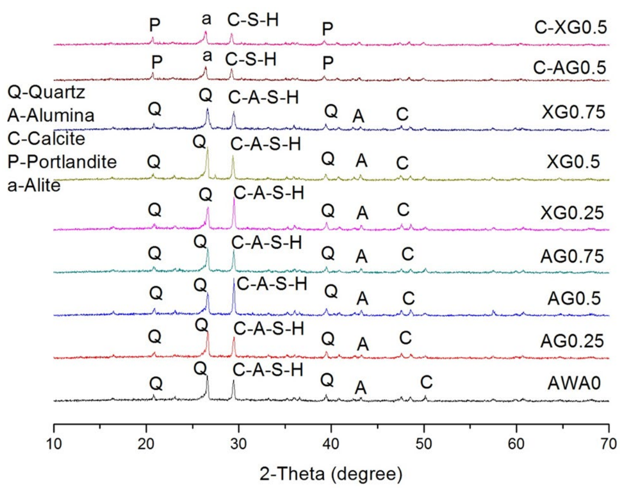

Fig. 8 XRD patterns of AWAs based geopolymer and OPC concretes

evolved only on relative peak intensity. For all GC mixes, intense quartz peak identified at 2-theta values of 21°, 27°, and 39° [41, 42]. Similarly, calcite and alumina are identified at a 2-theta value of 43° and 49°. However, for OPC concrete mixes, portlandite peaks are recognized at a 2-theta value of 21° and 39° [43]. The second mineral peak identified in cement concrete is alite at a 2-theta value of 27°. Figure 8 shows that the GC mix contains 0.5% of Arabic gum, showing a sharp peak due to the higher generation of geopolymerization products. It is recognized that Arabic gum attributes in the greater development of C-A-S-H gel due to the existence of quartz and calcium in its composition in higher quantities [44]. Another reason for enhanced geopolymerization is due to the presence of GGBFS in AWAs based geopolymer samples. From XRD analysis, it is clear that using Arabic gum leads to a higher degree of C-A-S-H gel formations compared to Xanthem gum-based geopolymer samples. Besides, improved geopolymeric gel formations and greater compressive strength were observed in Arabic gum-based GC. This is because of the strong alkaline medium presence in AG based GC to improve the leaching of Si^{4+}, Al^{3+}, and Ca^{2+} ions. The monovalent (Na^+) and divalent cations (Mg^{2+}, Ca^{2+}) in FA and GGBFS pore solution bind with polysaccharides-based AG grains, which lead to generating stable complexes [35, 45, 46]. As an effect, the water preservation ability of AG grains reduces over time.

On the other hand, due to the absence of carboxylic groups in polysaccharides-based XG, the prospect of the structure of steady complexes is inferior. Figure 8 is evident that AWAs based cement samples shown lower intensity portlandite peak. This indicates a comparatively lesser degree of C-S-H gel formation in the presence of either AG or XG based AWAs. Moreover, this leads to a decrease in the compressive strength of cement-based UWC mixes as compared to geopolymers-based UWC mixes.

4.6 SEM with EDS analysis

Figure 9 represents the SEM images of AWAs based GC samples placed in water for about 28 days. Figure 9 clearly showed that the Arabic gum-based GC samples showed denser microstructure with a greater generation of C-A-S-H gel. Similarly, Xanthem gum-based geopolymer mix was also observed to be a relatively denser structure. On the other hand, increasing the amount of AWAs percentage in GC samples leads to the looser matrix. A clear difference was found with the sample contain 0.5 % AWAs and 0.75 % AWAs. The more AWAs have not produced proper geopolymerization products; it was the reason the strength properties are less for the samples AG0.25, AG0.75 compared to AG0.5 sample. Moreover, the compressive strength results also strengthening to SEM analysis of AWAs based GC samples. However, AWAs based cement concrete samples were shown low portlandite and C-S-H gel formations, observed in Arabic and Xanthem gum-based samples. Compared to AWAs based geopolymer samples, cement-based samples (C-AG0.5 and C-XG0.5) developed irregular microstructure with different pores and internal cracks. Moreover, irrespective of the mix in GC, unreacted FA particles were observed.

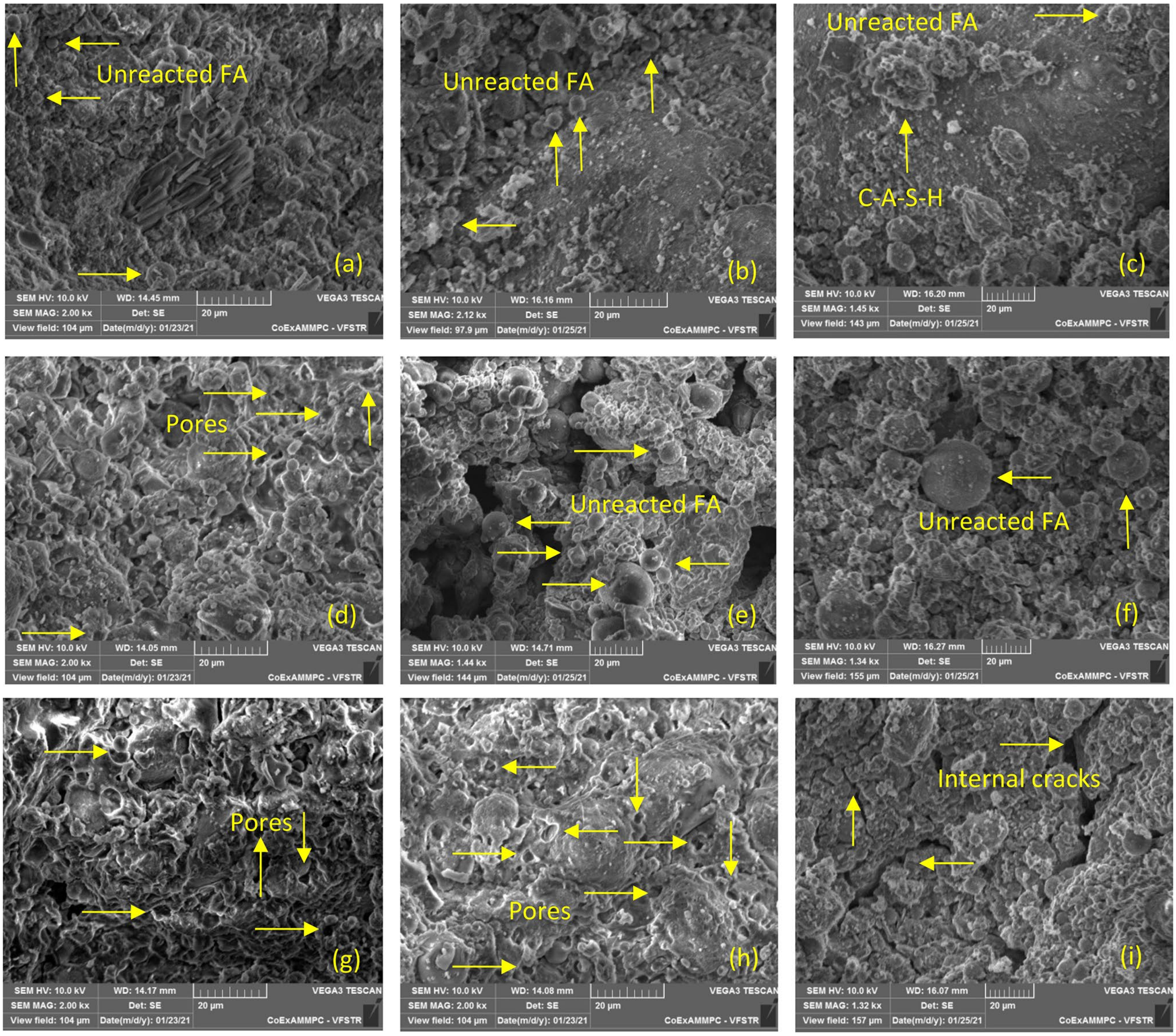

Fig. 9 SEM images of AWAs based UWC samples, **a** AWA0, **b** AG0.25, **c** AG0.5, **d** AG0.75, **e** XG0.25, **f** XG0.5, **g** XG0.75, **h** C-AG0.5, **i** C-XG0.5

The EDS analysis in combination with SEM analysis was studied to understand the formation of geopolymerization products. Figure 10 shows the EDS images of AWAs based concrete samples after 28 days of underwater curing. Table 4 presents the weight % of mineral elements obtained from EDS analysis. It was observed that the Arabic gum-based GC samples rich in silica compared to the mix AWA0. However, the Si/Al ratios for AWA0, AG0.25, AG0.5, XG0.25, and XG0.5 are 2.06, 2.27, 2.74, 2.22, and 2.03. Similarly, the Si/Ca ratios in cement-based UWC samples are shown at approximately 0.18. The mixes contain higher ratios of Si/Al shown greater compressive strength values, observed in Arabic gum-based GC samples. However, lower Si/Al ratios were attained relatively less compressive strength and were found for Xanthem gum-based geopolymer samples.

5 Conclusions

This paper focused on the influence of AWAs in the development of geopolymers based UWC mixes. From the detailed experimental studies AWAs based geopolymer concrete, the following conclusions are drawn,

- The workability AWAs based GC mixes increased with the increase of AWAs percentage compared to control mix (AWA0). However, the cement-based UWC samples

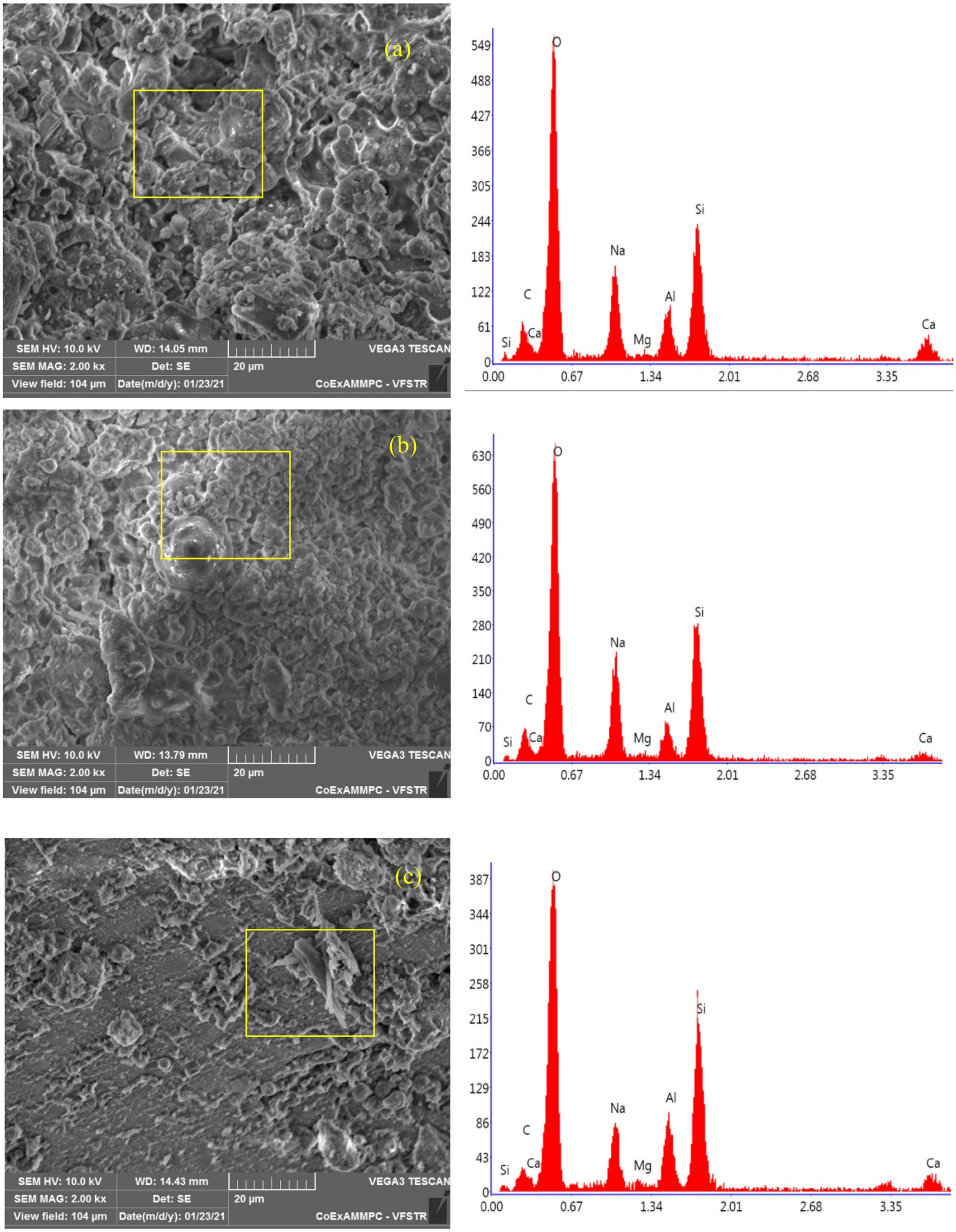

Fig. 10 EDS analysis, **a** AWA0, **b** AG0.25, **c** AG0.5, **d** XG0.25, **e** XG0.5, **f** C-AG0.5

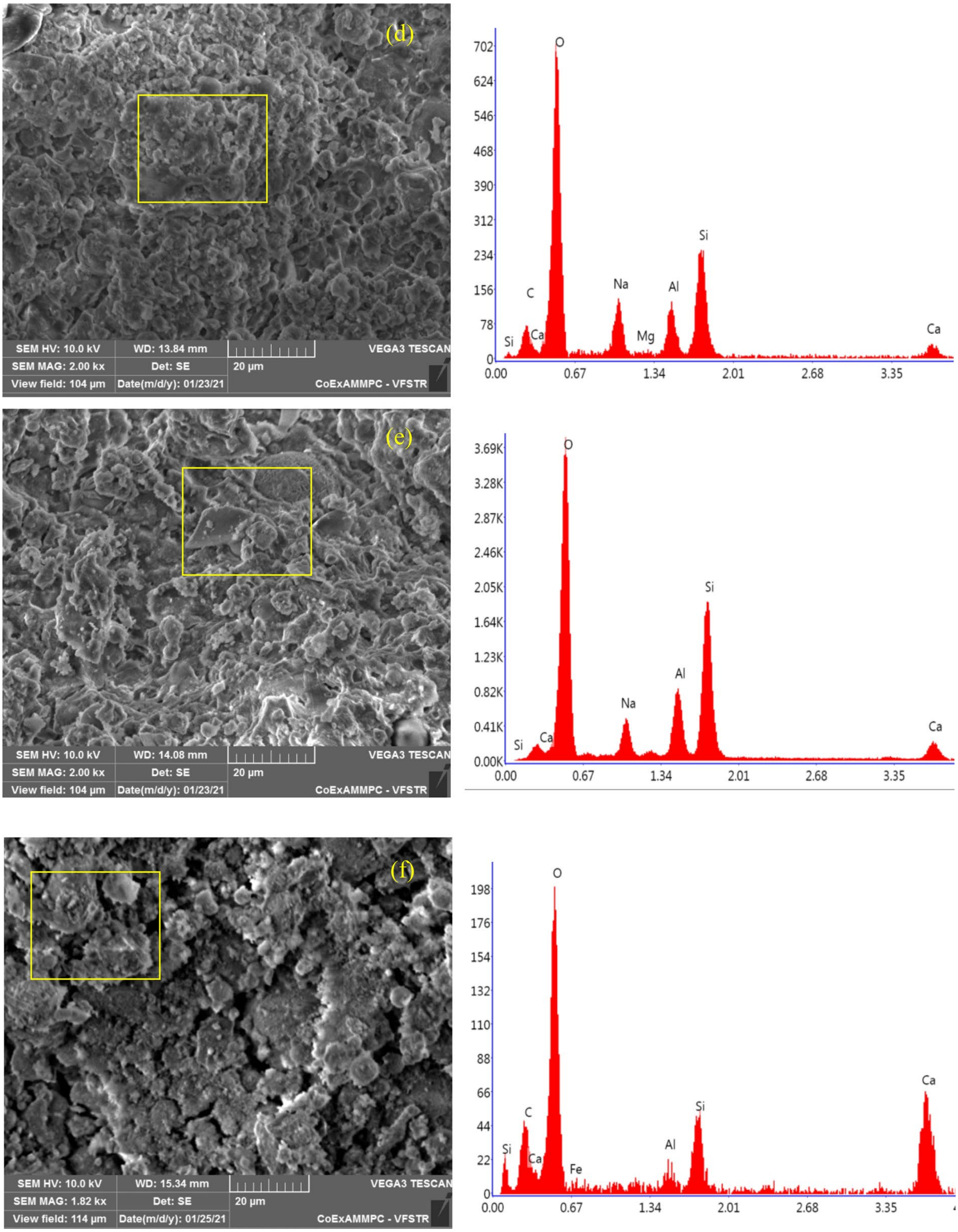

Fig. 10 (continued)

Table 4 EDS analysis of AWAs based geopolymer and OPC concrete samples

Mix Id	O	C	Si	Al	Ca	Na	Mg	Fe	Si/Al	Si/Ca
AWA0	43.89	4.32	17.56	8.52	12.70	12.71	-	-	2.06	-
AG0.25	43.94	4.73	16.07	7.35	11.15	16.15	0.61	-	2.27	-
AG0.5	42.86	2.97	25.12	9.15	10.02	9.23	0.64	-	2.74	-
XG0.25	46.47	6.12	17.03	7.65	10.51	11.72	0.49	-	2.22	-
XG0.5	47.18	-	20.95	10.34	10.70	10.83	-	-	2.03	-
C-AG0.5	43.47	5.34	7.72	1.69	41.26	-	-	0.53	-	0.18

shown good slump values as compared with geopolymers-based UWC mixes.

- The 0.5% AG-based GC samples for UWC was attained better compressive strength value as 54.73 MPa. The microstructural results of XRD and SEM with EDS are reliable with the compressive strength results of geopolymers based-UWC mixes. Because of the stable geopolymerization products with a denser structure, a higher degree of C-A-S-H gel formations is identified in Arabic gum-based GC samples for underwater concreting.
- The microstructural analysis of XRD and EDS reviled that the mixes contain more silica, alumina, and calcium content leads to attain greater compressive strength. The ratios of Si/Al-rich mix (AG0.5) shown the enhanced properties in all aspects.
- The bleeding capacity results revealed that the AWAs could not allow the bleeding of GC samples placed at underwater. Both the Arabic and Xanthem gums shown the lowest bleeding rate. The long-chain molecule by water absorbance based AWAs helps enhances the particle suspension capability in geopolymers-based UWC samples. As a result, the cohesiveness and stability of the GC mix increase for underwater construction

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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