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The effect of different viscosity modifying additives on the mechanical and flow properties of self-compacting mortars

Farklı viskozite düzenleyici katkı maddelerinin kendiliğinden yerleşen harçların mekanik ve akış özelliklerine etkisi

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Abstract

Some requirements are needed in the rheology design of special concretes such as self-compacting concrete, underwater concrete, shotcrete. For example, in the design of the desired concrete flow, some viscosity modifying agents (VMA) are used with various plasticizer additives. However, studies are needed to determine which of these additives used to design flow parameters is more appropriate. Herein, the mechanical and rheological effects of two commercially used VMAs on self-compacting mortars were investigated. For this purpose, compressive-flexural strength tests and mini-slump, mini-V funnel tests were conducted to determine the effects of welan gum (WG), and xanthan gum (XG) included in the mixtures at various ratios (0.01-0.1%) by weight of cement. The study supported by FE-SEM analysis concluded that WS had a positive effect on mechanical behavior, while XG had a negative effect, but XG was more effective on flow properties than WG.

Keywords: Welan gum, Xanthan gum, Self-compacting mortar, Viscosity modifying agent

Özet

Kendiliğinden yerleşen beton, su altı betonu, püskürtme beton gibi özel betonların reoloji tasarımında bazı gereksinimlere ihtiyaç duyulmaktadır. Örneğin istenilen beton akışının tasarımında çeşitli akışkanlaştırıcı katkı maddeleri ile birlikte bazı viskozite düzenleyici katkılar (VDK) kullanılmaktadır. Ancak akış parametrelerini tasarlamak için kullanılan bu katkı maddelerinden hangisinin daha uygun olduğunu belirlemek için çalışmalara ihtiyaç vardır. Burada, ticari olarak kullanılan iki VDK'nın kendiliğinden yerleşen harçlar üzerindeki mekanik ve reolojik etkileri araştırılmıştır. Bu amaçla, karışımlara çeşitli oranlarda çimento ağırlığına göre (%0.01-0.1) katılan welan sakızı (WS) ve ksantan sakızı (KS)'nin etkilerini belirlemek için basınç-eğilme mukavemeti testleri ve mini-slump, mini-V huni testleri yapılmıştır. FE-SEM görüntüleri ile desteklenen çalışmada, WS'nin mekanik davranış üzerinde olumlu bir etkiye, KS'nin ise olumsuz bir etkiye sahip olduğu, ancak KS'nin akış özellikleri üzerinde WS'ye göre daha etkili olduğu sonucuna varmıştır.

Anahtar kelimeler: Welan sakızı, Ksatan sakızı, Kendiliğinden yerleşen harç, Viskozite düzenleyici katkı

1 Introduction

In order to obtain suitable rheology that will not allow segregation in concrete mixtures, a balanced plastic viscosity is required. Additives that cause viscosity reduction (such as superplasticizer) can be used to increase fluidity in special concretes such as self-compacting concrete (SCC). However, it is necessary to take various precautions to prevent the risk of reduction in the segregation resistance of concrete with the use of these additives. It is known that fine materials such as silica fume, fly ash, metakaolin are included in the mixture to prevent segregation and increase the viscosity of the mixture [1–4]. However, while these materials provide advantages such as reducing the amount of superplasticizer and increasing workability, they reduce early strength, cause shrinkage and slow down the settling time [5]. Apart from powder materials, polymeric-based viscosity modifying additives (VMA), which are used commercially to increase concrete viscosity, can also be used in mixtures. VMAs are generally used to provide the desired viscous flow by increasing the washing resistance in underwater concretes and increasing the segregation resistance in SCCs [6]. Kawai (1987) grouped VMAs under three headings: a) natural polymers containing starch, natural gums and plant proteins, b) semi-synthetic polymers containing decomposed starch and its derivatives, and c) ethylene-based polymers such as polyethylene oxide and vinyl-based polymers such as polyvinyl alcohol [7].

Welan gum (WG), a fermentation product of Alcaligenes bacteria, is a long-chain biopolymer with sugar backbones [8]. It effectively maintains viscosity in alkaline solution with a high concentration of calcium ions even at high temperatures [9,10]. Additives with long-chain polymer molecules, such as WG and cellulose derivatives, adhere around the water molecules, absorbing and fixing some of the mixing water. Moreover, molecules in adjacent polymer chains become intertwined, developing attractive forces,

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thus further inhibiting the movement of free water, causing the mixture to gel and the concrete to exhibit higher viscosity [11]. The molecular structure of the saccharide units of WG, which is a microbial polysaccharide that can be used as a stabilizer in concrete and mortar mixtures to prevent water leaching and segregation, is given in Figure 1 [5,12].

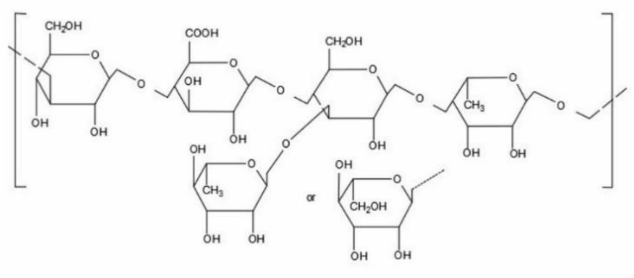

Figure 1. Molecular structure of WG [13]

Xanthan gum (XG), the fermentation product of Xanthomonas campestris bacteria, is a natural polysaccharide [14]. XG, which has high viscosity stability over a wide temperature and pH range, is an anionic polymer and dissolves rapidly in cold water [15]. XG, which is generally used in the food and cosmetics industry, is used as a viscosity modifying agent in soil stabilization works and SCCs in the field of building materials [16,17]. The molecular structure of XG, which shows a decrease in viscosity with the increase of shear stress in its solutions, is shown in Figure 2 [15,18,19].

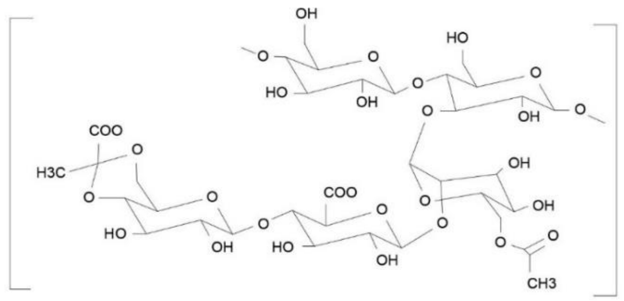

Figure 2. Molecular structure of Xanthan gum [15]

This study investigated the rheological and mechanical effects of two different additives in the same classification, currently used as VMA, on self-compacting mortars. For this purpose, the mini-slump flow diameters, flow time of fresh SCM mixtures with additives at various rates were compared by determining the compressive and flexural strengths of the 28-day hardened specimens.

2 Materials and experimental program

2.1 Mortar constituents

CEN standard sand with a specific gravity of 2.58 g/cm^3 and a water absorption rate of 0.3% and PC 42.5N Portland cement were used to prepare SCM mixes. The chemical composition of cement used is presented in Table 1. Sika Viscocrete PC-15 superplasticizer was used to provide fluidity. In addition, WG and XG were used as VMA in mortars

Table 1. Chemical composition of the cement

Component	Quantity (%)
SiO_2	18.08
Al_2O_3	4.27
Fe_2O_3	3.59
CaO	62.67
MgO	1.06
SO_3	3.42
K_2O	0.75
Na_2O	0.29
C_3S	42
C_2S	40
C_4AF	11

For the gum particles used for VMA to perform well, uniformly dispersed solutions must be obtained [15]. In order to obtain a uniform distribution in the solution and to ensure standardization, the additives weighed in the amount to be used mixed with the mixing water for 5 minutes in the ultrasonic sonicator given in Figure 3.

Figure 3. Ultrasonic sonicator

2.2 Preparation of mixtures and experimental program

Within the scope of the study, SCMs containing different ratios of XG and WG were produced. Due to the high risk of segregation in SCC-SCM mixtures, SCMs were produced at a dosage of 600 kg/m^3, with a water/binder ratio of 0.4, considering the need to keep the binder amount of the designed mixture high [20-22]. EFNARC (2005) [23] recommends the mini-slump and mini-V funnel tests that can be used in laboratory-based mixes to evaluate the mortar components of the SCC. The results of the mini-slump test recommended to decide whether the prepared mixture is SCM or not are 24-26 cm mini-slump flow and 7-11 seconds flow time for the mini-V funnel test. Therefore, to measure the mini-slump flow values of SCMs, a 60 mm high mini-slump test apparatus with 100 mm opening at the bottom and 70 mm opening at the top was used (Figure 4a), and to measure the flow time of the mortars, a 240 mm high, 270 mm wide and 30x30x60 mm narrowing section mini-V funnel was used (Figure 4b).

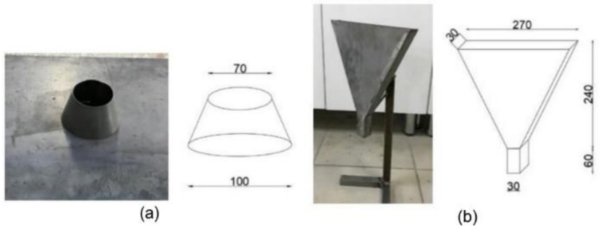

Figure 4. Mini-slump (a), mini-V funnel (b), dimensions are in mm.

The ratios that can be produced without additives at a dosage of 600 kg/m3 (providing 24-26 cm mini-slump flow and providing 7-11 seconds flow time) have been determined as the optimum mixing ratios. VMAs (XG and WG) in the range of 0.01% and 0.1% by weight of cement were added to these mixing ratios. In order to determine the fluidity properties of the produced mortars, mini-slump and mini-V funnel tests were carried out. After the fresh state experiments, the mixtures were taken into molds of 40x40x160 mm and subjected to flexural and compressive strength tests according to EN 196-1 [24] to determine the mechanical behavior. The prepared mixtures are presented in Table 2.

3 Result and discussion

3.1 Mini-slump flow diameter and flow time

The mini-slump flow diameter of fresh mortars with WG and XG additives measured by the mini-slump test is shown in Figure 5. When the results of the mini-slump flow test were examined, the control mixture (without additives) showed a mini-slump flow diameter of 26 cm (Figure 6a) and was located within the limits of EFNARC (2005), while the mixture containing 0.05% WG additive by cement weight out of the conditions of being SCM with 22 cm mini-slump flow diameter. After 0.05%, the mini-slump flow diameter continued to decrease due to the increase in the amount of additive and 16 cm mini-slump flow diameter at the maximum usage rate of 0.1%. In the case of using 0.03% XG in the mixture, the mortar spread 23 cm and could not meet the condition of being SCM. Moreover, in the case of using 0.075% and 0.1% XG, the viscosity of the mixture increased so much that [25] did not show any mini-slump flow values, unlike WG. (Figure 6b). Viscosity increase occurs since long-chain polymers such as cellulose derivatives retain the mixing water, and the molecules in the polymer chains are intertwined [11]. WG and XG included in SCM mixtures also showed this behavior.

The flow time of fresh mortars with WG and XG additives measured by the mini-V test is shown in Figure 7. When the flow times of the mixtures measured with the mini V funnel were evaluated, the WG additive increased the flow time between 8% and 193% compared to the reference mixture. In the case of using 0.05% WG additive in the mixture, the mixture has shown a flow time of 12.2 seconds and has been out of the condition of being SCM. When XG additive was used in the mixture at the rate of 0.05% by weight of the cement, it was out of the condition of being SCM. However, after this ratio was exceeded, the flow time in the mixtures was found minutes, and measurement could not be taken. As can be clearly seen from the graph given in Figure 7, the XG additive has caused a very high viscosity increase compared to the WG additive.

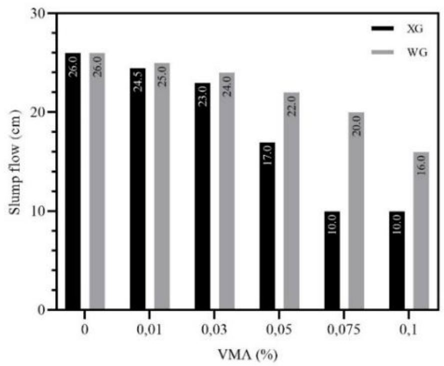

Figure 5. The slump flow of SCMs

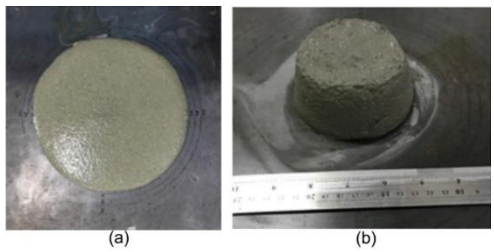

Figure 6. Control mix spread (a), XG0075 mix spread (b)

Considering all the results, it can be said that XG shows high efficacy even at much lower rates than WG.

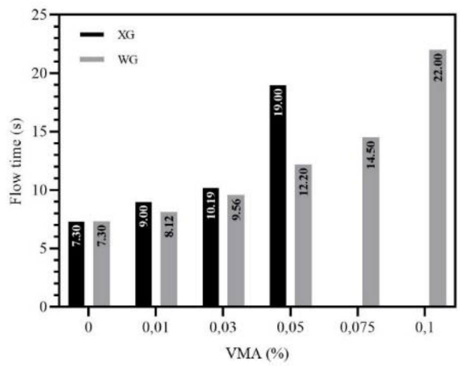

Figure 7. The flow time of SCMs

3.2 Compressive and flexural strength

The results of flexural and compressive strength tests carried out on hardened specimens results are given in Figure 8 and Figure 9. When the compressive strength results of the WG added specimens were examined, it was determined that there was a stable increase until the use of 0.05% additive. WG additive at the rate of 0.05% increased the compressive strength by approximately 6% compared to the reference specimen. It is known that there is an increase in compressive strength with the decrease of micro-voids (porosity) in concrete [26].

Table 2. SCM mixing proportions

Mix.	Cement (kg/m^3)	Cen sand (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)	VMA* (%)
Reference	600	1437	240	60	-
XG001	600	1437	240	60	0.01
XG003	600	1437	240	60	0.03
XG005	600	1437	240	60	0.05
XG0075	600	1437	240	60	0.075
XG01	600	1437	240	60	0.1
WG001	600	1437	240	60	0.01
WG003	600	1437	240	60	0.03
WG005	600	1437	240	60	0.05
WG0075	600	1437	240	60	0.075
WG01	600	1437	240	60	0.1

* by weight of cement

Zhang et al. (2018) [27] reported that the porosity decreased and the compressive strength increased in the case of using up to 0.05% WG additives in the mixtures.The results found in this study also confirm this literature knowledge. However, when the WG additive was used at the maximum rate (0.1%) selected for this study, it was determined that the compressive strength decreased by approximately 4% compared to the reference specimen. The WG, which is used at high rates (>0.05%), is located on the C-S-H structures and causes a decrease in strength by increasing the porosity of the mixture [27]. Moreover, Isik and Ozkul (2014) [28] used three different VMAs in SCC mixtures and found that VMAs had no significant effect on strength up to 0.02% usage rate.

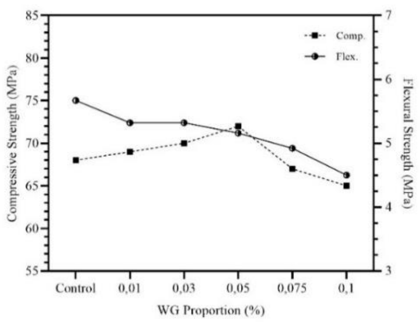

Figure 8. The results of flexural and compressive strength tests of WG added mortars

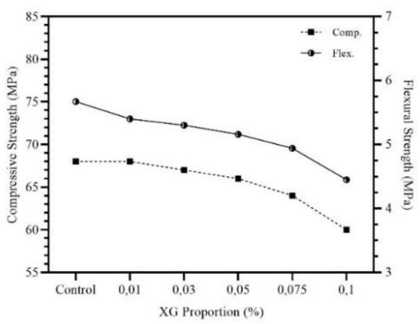

Figure 9. The results of flexural and compressive strength tests of XG added mortars

FE-SEM and EDX analyzes of WG added cement pastes are given in Figure 10. In these analyzes, it is seen that the amount of carbon in the electron pulses (spectrum 1) thrown on structures similar to wheat grains is relatively high. Typically, carbon is not expected in hydration products. Therefore, these structures are estimated to be WG. In the images, it is seen that the gum particles become a ball, surrounded by an ettringite-like reticulate structure, which is a kind of hydration product. In the light of these images, it is understood that the use of additives in low proportions creates a filling effect and causes an increase in compressive strength; however, it causes a decrease in strength since it can replace hydration products at high rates.

On the other hand, according to the flexural strength results, the WG additive caused the flexural strength of the mortars to decrease between 6% and 20%. A loss of flexural strength of about 9% was observed in the specimen, where the increase in compressive strength was maximum (6%). It is debatable whether a 9% loss of flexural strength versus a 6% gain in compressive strength is advantageous or not.

When the strengths of the XG added specimens are examined, it is clearly seen that the XG additive reduces both the compressive strength and the flexural strength of the mortars. Up to 12% decreases in compressive strength and up to 20% decreases in flexural strength were observed up to the highest usage rate.

The effect of VMAs on compressive strengths is examined; another essential issue is the adsorption of polysaccharides by cement particles. Bessais-Bey et al.[29] that microbial polysaccharides such as WG can be adsorbed by cement. As a result of absorption, it is clear that the dissolution rate of cement and the kinetics of hydration can change. This situation explains the decrease in strength at increasing VMA ratios. Both this study and Zhang et al.'s (2018) [27] study demonstrated that WG's use of up to 0.05% of the binder weight could increase the compressive strength with the filling effect. Up to 0.05%, the filling effect created by WG can be responsible for the increase in compressive strength, and the effect of WG on the hydration kinetics can be responsible for the decrease in flexural strength.

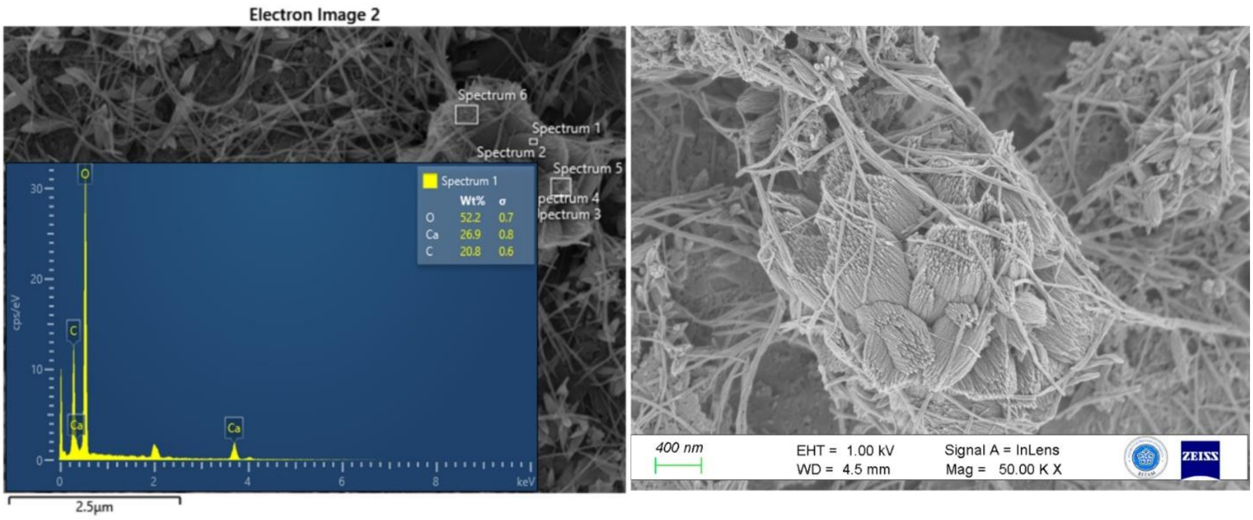

Figure 10. FE-SEM images of WG added cement paste

However, after 0.05%, the tendency of WG, which is a polysaccharide, to reduce the hydration of cement and its replacement by hydration products became more dominant, causing a decrease in both compressive strength and flexural strength.

When the two additives are compared, it is understood that WG is more advantageous in terms of mechanical behavior than XG. However, it was determined that the XG additive was more effective than the WG additive in the fresh state experiments of the mortars. Therefore, where the strength loss is not very important, it is concluded that sufficient fresh behavior could be obtained by using fewer XG amounts than WG.

4 Conclusions

The following conclusions were reached in this study which includes the mechanical and rheological comparison of two different VMA types that can be included in the mixtures for purposes such as increasing the segregation resistance, improving the washing resistance, and increasing the sag resistance in special types of concrete;

- It was concluded that XG was more effective than WG at the same rates in terms of fresh state behavior activity.
- While WG caused an increase in compressive strength up to 0.05% in terms of mechanical behavior, it caused a decrease after this rate. According to the FE-SEM images, it was understood that WG caused an increase in strength by making a filling effect at low rates, and it could replace hydration products at high rates.
- XG reduced the compressive strength in all ratios.
- Both types of additives negatively affect flexural strength.
- It was concluded that in cases where such additives must be used, care should be taken, and the effects of strength should be investigated after the mixture design is made.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (Turnitin): %15

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