World Academy of Science, Engineering and Technology
International Journal of Geotechnical and Geological Engineering
Vol:15, No:1, 2021

The Viscosity of Xanthan Gum Grout with Different pH and Ionic Strength

H. Ahmad Raji, R. Ziaie Moayed, M. A. Nozari

***Abstract*—**Xanthan gum (XG) an eco-friendly biopolymer has been recently explicitly investigated for ground improvement approaches. Rheological behavior of this additive strongly depends on electrochemical condition such as pH, ionic strength and also its content in aqueous solution. So, the effects of these factors have been studied in this paper considering various XG contents as 0.25, 0.5, 1, and 2% of water. Moreover, adjusting pH values such as 3, 5, 7 and 9 in addition to increasing ionic strength to 0.1 and 0.2 in the molar scale has covered a practical range of electrochemical condition. The viscosity of grouts shows an apparent upward trend with an increase in ionic strength and XG content. Also, pH affects the polymerization as much as other parameters. As a result, XG behavior is severely influenced by electrochemical settings.

***Keywords*—**Electrochemical condition, ionic strength, viscosity, xanthan gum.

I. Introduction

THE general object of soil treatment in construction engineering is to enhance soil properties and behaviors such as strength, aggregate stability and resistance against erosion. Currently there are several ways to improve soil properties; among them, cement is the most commonly used material for soil stabilization. Despite the advantages that cement provides, it has numerous disadvantages, especially in terms of environmental issues. The most important of these problems are CO_2 and NOx (nitrogen oxides) emissions and particulate air suspensions. Cement is the major factors of CO_2 emissions in the world. In the production of cement, the calcination of limestone ($CaCO_3 \rightarrow CaO + CO_2$) and the heat energy (e.g., 1450 °C in a kiln) required, so approximately one ton of CO_2 is caused to produce every ton of cement. Also that cement alone causes 5% of annual global CO_2 production. In addition to CO_2, another result of cement production is NOx. Cement kiln, with 2.3 kg/ton of clinker that produced is the main productive of these NOx. Also release of cement dust particles into the air is another environmental issue. Cement dust from concrete can be released into the air through such actions such as demolitions or earthquakes [1]. As a result, an environmentally friendly stabilizer is required instead of common materials like cement, lime, etc.

XG is a polysaccharide that has several industrial uses, especially as a common additive that may be used for food industries. It is an effective thickening agent and stabilizer to keep ingredients from separating. This additive is produced from a pure culture through a submerged fermentation named Xanthomonas. The structure of this biopolymer is formed by repeated pentazacaride units of mannose that show reaction to glucuronic acid in the molar ratio of 2.0:1.0:2.0 [2], [3]. Gum with rigid structure results in various functional properties such as high viscosity in a wide range of concentrations, and high pH stability from 1 to 11. Because of its wide applications in the oil, food, textile, cosmetic and pharmaceutical industries, the output of XG is now the largest of the natural exopolysaccharides [4].

Pseudo-plasticity is the most common property of XG that indicates relation between viscosity of liquid and shear rate [5]. In static conditions, the viscosity of the liquid increases dramatically by a small amount of xanthan increasing. Moreover, unlike other gums, XG shows high stability under a wide range of temperatures and pH [6], [7]. Also, its anionic and hydrophilic surface characteristics facilitate interactions with cations [8], [9] and other polysaccharides, such as glucose, mannose ($C_6H_{12}O_6$), potassium gluconate ($C_6H_{11}KO_7$), acetate (CH_3CO_2), and pyruvate ($CH_3COCOOH$), inducing stronger gelation. A solution of XG shows excellent resistance to temperature variations, pH and salt; however, precipitation occurs in the presence of multivalent cations.

Previous studies [8], [9] showed that direct contact between fibersense system of XG with surface of clay that forms Xanthan structures as a hard plastic between particles which are uncharged. Results of studies [1]-[9] illustrate the effect of XG on strengthening. Also they represent a relation to have the greatest efficiency in well-graded soils and fine particles. By experiments with various XG concentrations, it was found at higher concentrations, the strengthening effect leveled off. The strengthening effect depended on the hydration level of the soils dramatically. In general, four factors play major and effective roles in strengthening effect of XG: type of soil, XG content, hydration level (e.g., moisture content) and mixing method [10]. Also, Cabalar and Canakci showed that adding 1% XG over the clean sand reduced the maximum direct shear stress under all vertical stress values in these specimens. However, 3 and 5% XG contents achieved the maximum shear strength. The maximum direct shear strength for sand with 3 and 5% XG showed 1.2 to 3.88 times increase in comparison with the clean sand [11]. Lee et al. indicated that cohesion of XG-treated sand substantially increases as XG content increases, while friction angle does not show remarkable change at low xanthan contents but slightly increases at m_{bp}/m_s = 2.0%. In details, the cohesion is increased from 18 kPa of untreated soil (it can be regarded as a negligible value) to 216.9 kPa, 252.8 kPa, and 365.2 kPa with higher XG

Mohammadamin Nozari is with the Islamic Azad University of Masal, Iran, Islamic Republic Of (e-mail: Nozari.M.A@masaliau.ac.ir).

contents [12].

Rheological behavior of XG strongly depends on electrochemical condition such as pH, ionic strength and also its content in aqueous solution. However, the relation between viscosity of XG grout with different pH, ionic and soil improvement has not been extensively reported in the preceding literature. Because of the effects of these factors, XG behavior has been studied as a soil improvement material in the present study.

II. Materials

XG (C35H49O29) – 200mesh was supplied by Jianglong Trading Mond Star.

Fig. 1 XG (C35H49O29)

TABLE I
Biopolymer XG Properties

Parameters	Specification	Result
Appearance	Cream White Free Flowing Powder	Confirm
Particle size (75 um) Through 200 mesh, %	≥ 90.00	93.20
Particle size(180um) Through 80 mesh, %	≥ 98.00	99.22
Viscosity(1% KCL,cps)	1200-1700	1565
Shear ratio	≥ 6.5	7.70
V1/V2	1.02-1.45	Confirm
PH (1% solution)	6.0-8.0	6.87
Loss on Drying(%)	≤ 13	6.57
Ash (%)	≤ 15	Confirm
Pb (ppm)	≤ 2	Confirm
Total Nitrogen (%)	≤ 1.5	Confirm
Pyruvic Acid (%)	≥ 1.5	Confirm
Total plate count(CFU/g)	≤ 2000	1100
Assay (%)	91-108	Confirm
Totally Heavy Metals (ppm)	≤ 20	Confirm
Moulds/Yeasts (CFU/g)	≤ 500	Confirm
Coliform (In 5g)	Negative	Negative
Salmonella (In 10g)	Negative	Negative
Conclusion	Confirm:GB1886.41-2015	

HCl and NaOH were obtained from Merck (Germany).

III. Experimental Methods

A. Preparation of Water-Soluble XG

At first, HCl and NaOH were added to water to achieve different pH values (3,5,7,9). Adding HCl and NaOH to water was completed in a large bucket gutty and piece by piece respectively. Then NaCl was added to the mentioned solution to prepare solutions with 0.1 and 0.2 values of Molarity. Water-soluble XG specimens were prepared with 0.25%, 0.5%, 1.0%, and 2.0% XG contents to the mass of water. In this study, the effect of pH and XG contents changes on viscosity was investigated separately.

B. Rheological Measurements

The steady shear viscosity and shear thinning behaviors were performed in a rotational rheometer (Biobase Biodustry (Shandong) Co., Ltd – BDV-5S). The steady shear viscosity was measured at a constant shear rate of 170 s^{-1}. In the shear-thinning measurements, the viscosity was recorded in the range of shear rate from 0.066 to 73.44 s^{-1}. All measurements were performed at 25.0 ºC ± 0.1 ºC.

Viscosities and rheological properties were measured in two times: 5 minutes and 24 hours after sample preparation and tests are according to Table II.

TABLE II
Experiments

pH	Ionic Strength	XG%	Curing Time
3	0, 0.1, 0.2	0.25, 0.5, 1, 2	5min
5	0, 0.1, 0.2	0.25, 0.5, 1, 2	5min
7	0, 0.1, 0.2	0.25, 0.5, 1, 2	5min
9	0, 0.1, 0.2	0.25, 0.5, 1, 2	5min

IV. Results and Discussion

Variations of viscosity values versus shear rate are shown for a given XG content and different levels in Figs. 2-5. In Fig. 1, figures drawn for XG = 0.25% and I.S. = 0 show negligible difference for different values of pH. There is no difference between acidic and non-acidic values at highest and lowest shear rates; whilst, as shown in Fig. 3, viscosity values in solutions with XG = 0.5% and I.S. = 0 are smaller for pH = 3. The other levels of pH have similar trend. This difference is larger at lower shear rates. However, for shear rates greater than 30s^{-1}, values are same. In contrast to XG = 0.5% solutions, viscosity values versus rate of shearing in XG = 1% and 2%, do not show any change by pH as illustrated in Figs. 4 and 5.

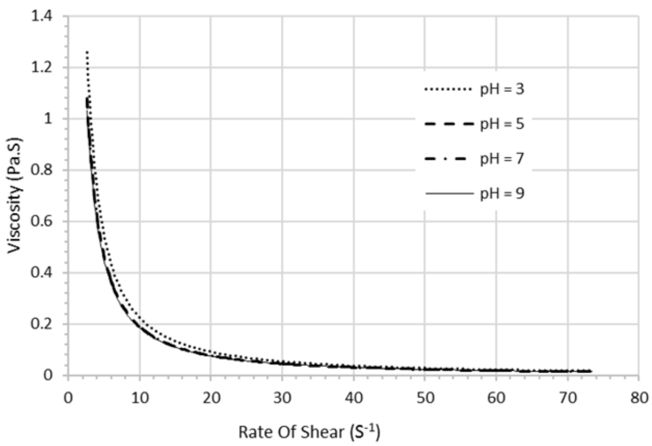

Fig. 2 Viscosity variations in different pHs for XG = 0.25% with I.S = 0 mol/lit

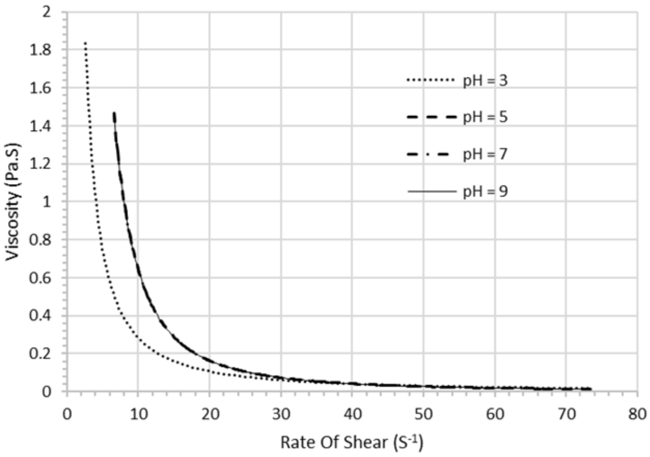

Fig. 3 Viscosity variations in different pHs for XG = 0.5% with I.S = 0 mol/lit

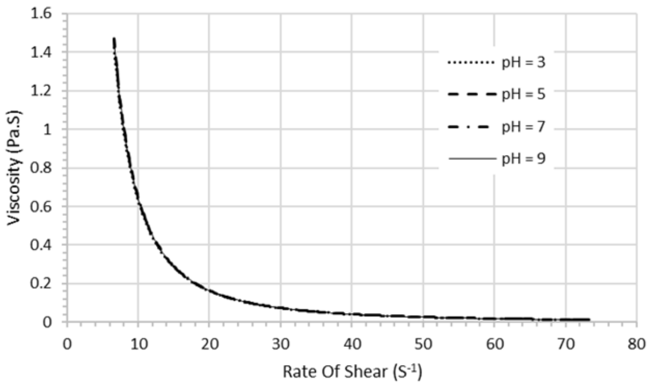

Fig. 4 Viscosity variations in different pHs for XG = 1% with I.S = 0 mol/lit

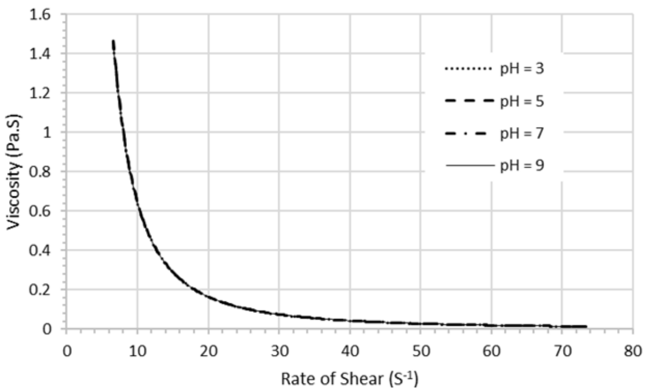

Fig. 5 Viscosity variations in different pHs for XG = 2% with I.S = 0 mol/lit

Fig. 6 depicts the variations of viscosity values in pH = 3 and I.S. = 0 for different XG contents. No significant change is observed for solutions with XG = 0.25% against XG = 0.5%; even though for XG = 1% and 2%, a remarkable increase is obvious. The difference between viscosity values of XG solution are greater at lower shear rates so that, at highest level of shearing, all solutions behave similar. It means that under higher level of shear rate the solutions' responses as additive material are the same while varying XG content leads to different resistance under lower level of shearing.

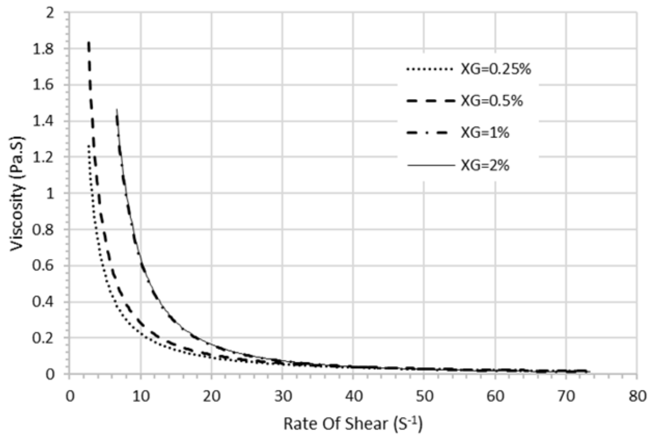

Fig. 6 Viscosity variations in different XG content for pH = 3 with I.S = 0 mol/lit

Solution behavior under electrochemical condition of pH = 5 to 9 and I.S. = 0 are depicted in Figs. 7-9. There is a noticeable difference in viscosity values for solutions with XG = 0.25% against the other XG contents; although no difference is observed between XG = 0.5%, 1% and 2%.

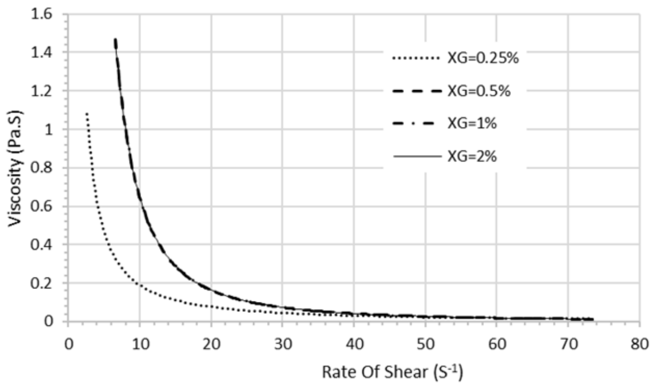

Fig. 7 Viscosity variations in different XG content for pH = 5 with I.S = 0 mol/lit

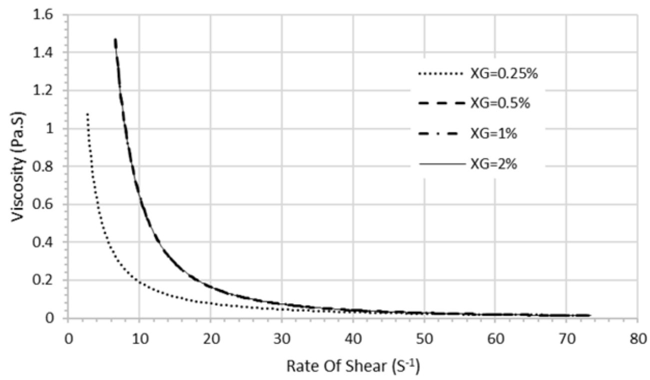

Fig. 8 Viscosity variations in different XG content for pH = 7 with I.S = 0 mol/lit

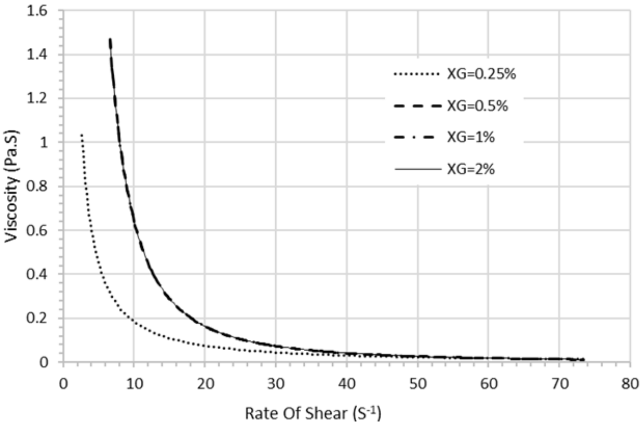

Fig. 9 Viscosity variations in different XG content for pH = 9 with I.S = 0 mol/lit

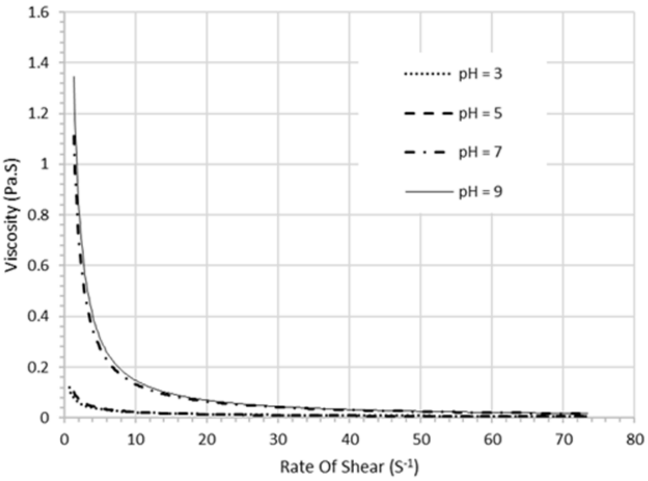

Fig. 10 Viscosity variations in different pHs for XG = 0.25% with I.S = 0.1 mol/lit

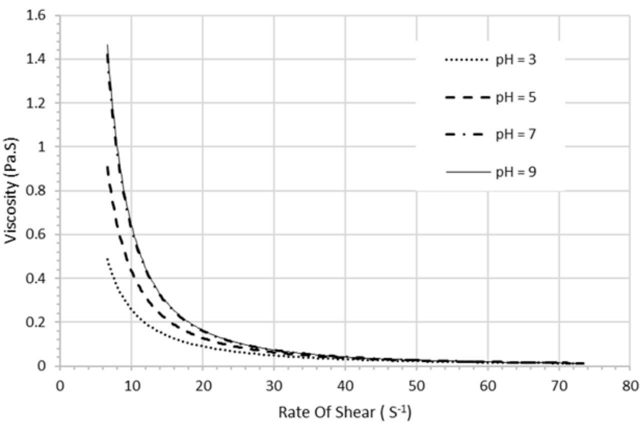

Fig. 11 Viscosity variations in different pHs for XG = 0.5% with I.S = 0.1 mol/lit

Despite the I.S. = 0, increasing 0.1 molar in ionic strength results in more considerable change in viscosity values. As shown in Figs. 10 and 11, viscosity values are smaller under pH = 3 and 5 for XG = 0.25% and 0.5%. The difference between acidic and non-acidic values is greater at lower shear rates so that, at highest level of shearing all solutions behave similar. For example, at shear rate of 10 s^{-1}, viscosity is about 8 times larger for pH = 7 than corresponding value at pH = 5. On the other hand, as shown in Figs. 12 and 13, no change exists for different values of pH.

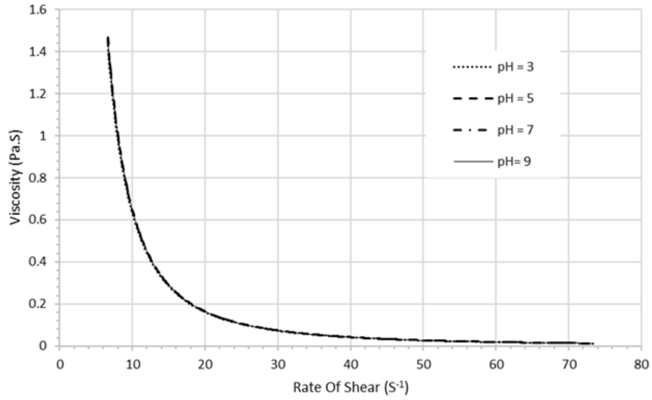

Fig. 12 Viscosity variations in different pHs for XG = 1% with I.S = 0.1 mol/lit

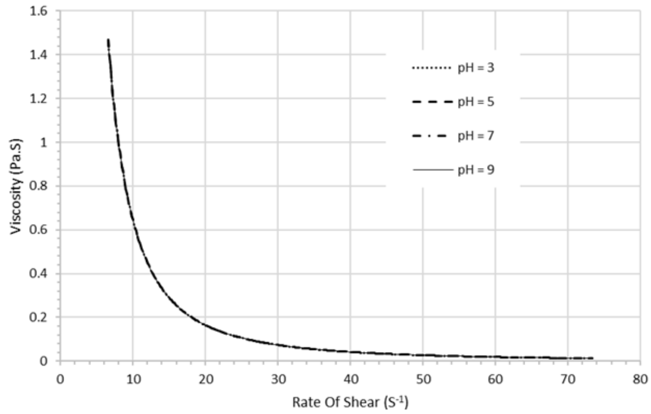

Fig. 13 Viscosity variations in different pHs for XG=2% with I.S=0.1 mol/lit

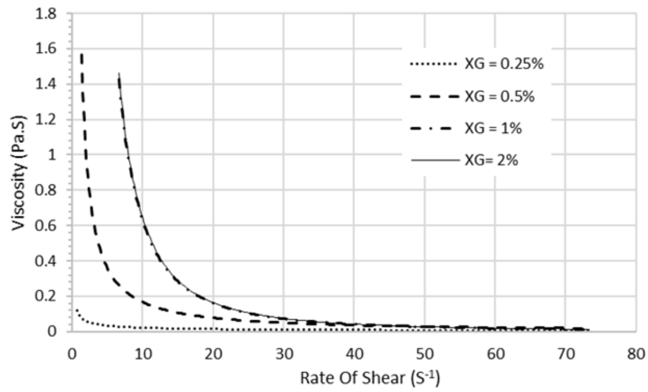

Fig. 14 Viscosity variations in different XG content for pH = 3 with I.S = 0.1 mol/lit

XG content effects on viscosity of solutions are depicted in Figs. 14-17. The general trends are similar to null ionic strength condition. Meanwhile, the differences are more noticeable for XG = 0.25%. At lowest value of pH which shows larger increase in viscosity by XG content in Fig. 14, solution with XG = 0.5% are clearly smaller than more non-acidic conditions. This discrepancy is either for the other pH values or same pH and null ionic strength condition.

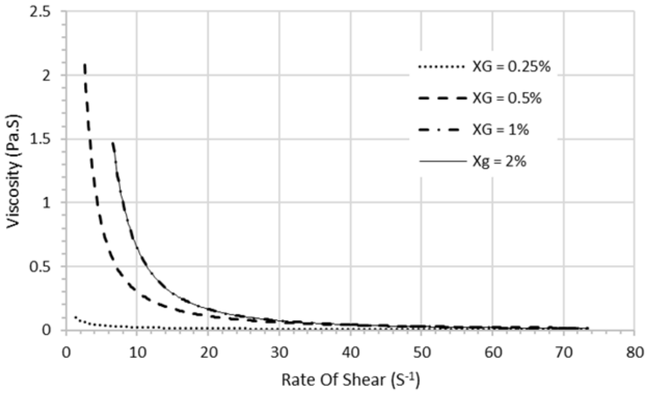

Fig. 15 Viscosity variations in different XG content for pH = 5 with I.S = 0.1 mol/lit

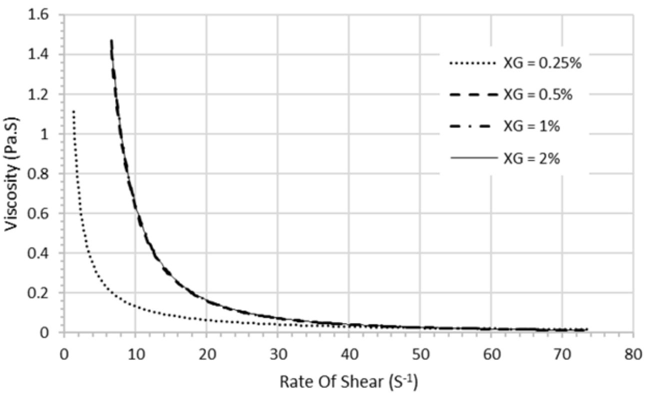

Fig. 15 Viscosity variations in different XG content for pH = 7 with I.S = 0.1 mol/lit

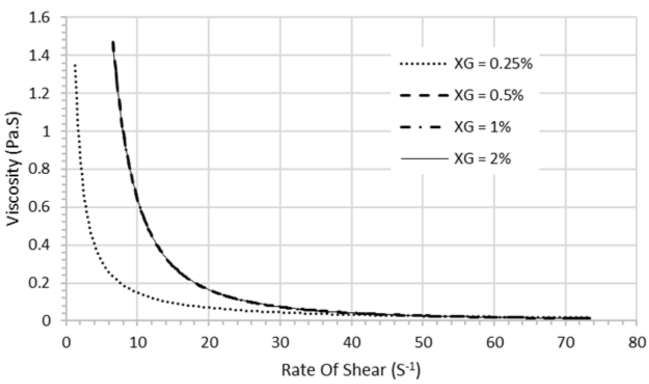

Fig. 16 Viscosity variations in different XG content for pH = 9 with I.S = 0.1 mol/lit

Clearly, compressibility and shear resistance of grouted soil strongly depend on the viscosity of additive material. The peak of compaction changes with the viscosity of the pore fluid. More viscose material not only changes the optimum value of compaction but also transforms the minimum value of dry density. So, change in viscosity directly influences the shear resistance of soil. The results indicate that this effect is more considerable at lower levels of XG. It might be originated from the solubility of XG. When the maximum value of XG solubility is exceeded, all solutions behave similar such as XG contents of 1% and 2%. On the other hand, previous works [2]-[4] have reported treated soil in term of XG ratio to soil weight, even though the main chemical reaction is between XG and water. So, varying viscosity by pH and ionic strength of water can cause different behavior of grouted soil as mentioned. According to the results, pH values are as influential as XG content especially in lower XG content.

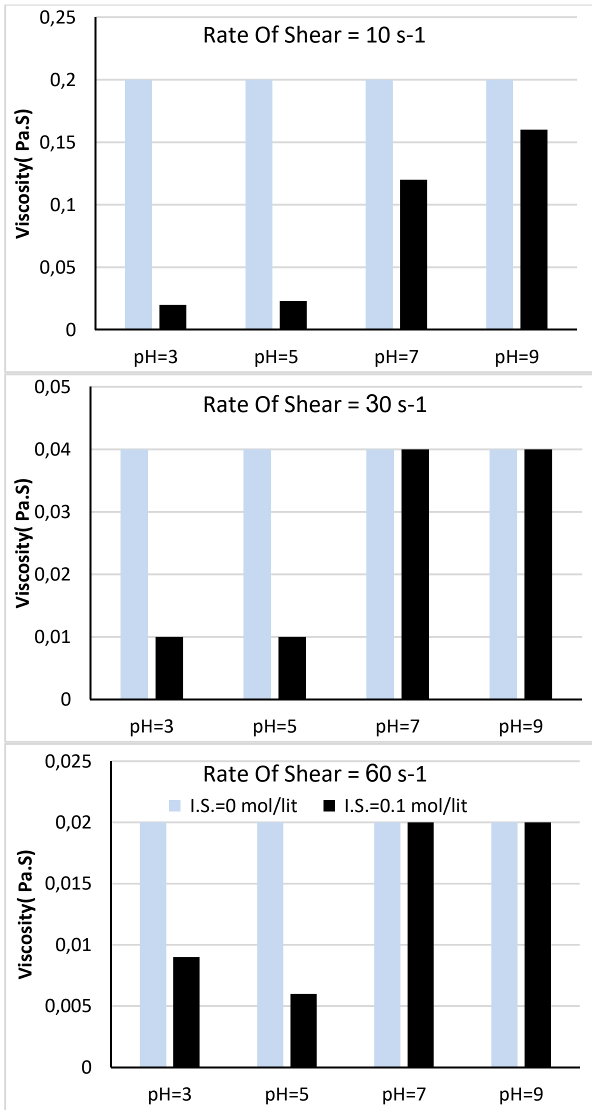

Fig. 17 Viscosity change against pH for solution of 0.25% XG

Fig. 17 shows a comparison between salty solutions and non-salty ones for 0.25% XG and different pH values. Obviously, viscosity has an upward trend when the ionic strength is 0.1 mol/lit. However, under null-ionic-strength condition, viscosity is constant. So, NaCl boosts the effect of pH value on rheological behavior of XG solution.

V. Conclusion

The water-soluble XG polymer was obtained in this work. In this study, the effect of pH and XG contents on viscosity has been investigated separately as well as ionic strength.

To sum, change in viscosity and ionic strength make some considerable difference in viscosity. This effect causes different responses of stabilized soil to loading and compaction. So, it is crucial to analyze the rheological behavior of additives. XG as a green polymer product has different rheological trends under various electrochemical conditions. Specifically, at lower levels of XG content the changes are more noticeable such as solutions with XG = 0.25% and pH = 3 and 5.

References

[1] Chang I, Im J, Prasidhi AK, Cho G-C. Effects of Xanthan gum biopolymer on soil strengthening. Construction and Building Materials. 2015;74:65-72.
[2] Garcia-Ochoa F, Santos V, Alcon A. Xanthan gum production: an unstructured kinetic model. Enzyme and Microbial Technology. 1995;17(3):206-17.
[3] Rosalam S, England R. Review of xanthan gum production from unmodified starches by Xanthomonas comprestris sp. Enzyme and Microbial Technology. 2006;39(2):197-207.
[4] Palaniraj A, Jayaraman V. Production, recovery and applications of xanthan gum by Xanthomonas campestris. Journal of Food Engineering. 2011;106(1):1-12.
[5] Casas J, Santos V, Garcıa-Ochoa F. Xanthan gum production under several operational conditions: molecular structure and rheological properties. Enzyme and microbial technology. 2000;26(2-4):282-91.
[6] Zohuriaan M, Shokrolahi F. Thermal studies on natural and modified gums. Polymer Testing. 2004;23(5):575-9.
[7] Sun C, Gunasekaran S. Effects of protein concentration and oil-phase volume fraction on the stability and rheology of menhaden oil-in-water emulsions stabilized by whey protein isolate with xanthan gum. Food Hydrocolloids. 2009;23(1):165-74.
[8] Bergmann D, Furth G, Mayer C. Binding of divalent cations by xanthan in aqueous solution. International journal of biological macromolecules. 2008;43(3):245-51.
[9] Nolte H, John S, Smidsrød O, Stokke BT. Gelation of xanthan with trivalent metal ions. Carbohydrate polymers. 1992;18(4):243-51.
[10] Laneuville SI, Turgeon SL, Sanchez C, Paquin P. Gelation of native β-lactoglobulin induced by attractive electrostatic interaction with xanthan gum. Langmuir. 2006;22(17):7351-7.
[11] Cabalar AF, Canakci H. Direct shear tests on sand treated with xanthan gum. Proceedings of the Institution of Civil Engineers-Ground Improvement. 2011;164(2):57-64.
[12] Lee S, Im J, Cho G-C, Chang I. Tri-axial shear behaviour of xanthan gum bipolymer-treated sand2019. 179-86 p.