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# A PRELIMINARY STUDY ABOUT RHEOLOGY OF GEOPOLYMER GROUT

## GEOPOLİMER GROUT REOLOJİSİ ÜZERİNE BİR ÖN ÇALIŞMA

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## ABSTRACT

In this study, preliminary research was carried out on the rheology of the grout mixture prepared with geopolymer (containing fly ash) for use in grouting applications. Rheological flow responses were tested experimentally with the help of graphs obtained according to shear stress - shear rate and viscosity - shear rate. From the research findings, it was determined that geopolymer grout showed appropriate rheological behavior depending on the rheological curves. Pseudoplastic rheological behavior has a promising feature for practical applications. In addition, rheological flow characteristics (yield stress and plastic viscosity) were evaluated depending on the shear stress - shear rate. However, further research needs to be supported to validate the use of the geopolymer grout with reference to the rheological responses of the cement-based grout.
***Keywords:*** *Geopolymer, grout, rheology*

## ÖZET

Bu çalışmada, enjeksiyon uygulamalarında kullanılmak üzere geopolimer (uçucu kül içeren) ile hazırlanan grout karışımının reolojisi üzerine ön araştırma yapılmıştır. Reolojik akış tepkileri, kesme gerilimi - kayma hızına ve viskozite - kayma hızına göre elde edilen grafikler yardımıyla deneysel olarak test edilmiştir. Araştırma bulgularından jeopolimer enjeksiyonun reolojik eğrilere bağlı olarak uygun reolojik davranış gösterdiği tespit edilmiştir. Psödoplastik reolojik davranış, pratik uygulamalar için umut verici bir özelliğe sahiptir. Ayrıca, kesme gerilimi - kesme hızına bağlı olarak reolojik akış özellikleri (akma gerilimi ve plastik viskozite) değerlendirilmiştir. Ancak, çimento esaslı groutun reolojik tepkilerini referans alarak geopolimer groutun kullanımını doğrulamak için daha fazla araştırmanın desteklenmesi gerekmektedir.
***Anahtar Kelimeler:*** *Geopolimer, grout, reoloji*

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## 1. INTRODUCTION

Geopolymer is a promising green material as a binder material for grouting applications in place of cement with increased interest due to low energy consumption and $CO_2$ emission (approximately the ratio of 80%) (Duxson et al., 2007; Deventer et al., 2010). Compared to Portland cement, geopolymer contributes to strength and durability in concrete technology and is also very promising as a sustainable environmental material. This indicates that the use of geopolymer, which does not contain cement as a binding material, in concrete or grout applications will be a very useful environmentally friendly material (Adak et al., 2017).

The alumino-silicate materials such as, fly ash, slag, bottom ash, rice husk ash, and metakaolin can be used as a precursor for obtaining the geopolymer material through the reaction with the alkaline activators solutions (e.g., sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$)) (Dupuy et al., 2019; Canakci et al., 2019). Thus, using the geopolymer, the industrial aluminosilicate-rich wastes can be converted into a value-added binder alternative to Portland cement (Sukmak et al., 2013).

Reporting to literature (Zhang et al., 2013), it is understood that the geopolymer is able to achieve a hardening process resulting in good strength and stiffness, exceptional resistance against heat, organic solvents, and acids. The use of a geopolymer also offers low shrinkage potential and excellent adhesion to aggregates that can be suggested as an effective soil stabilizer in place of cement in infrastructure construction (Duxson et al., 2007). In recent, fly ash-based geopolymer in deep soft soil improvement (i.e., grouting process) is found well comparable to cement and lime for enhancement of deep soft soils (Cristelo et al. 2012).

The effort presented in this paper aims at providing a preliminary experimental result of rheology to improve the design of geopolymer-based grout mixtures for grouting applications in ground enhancement. As it is known that one of the requirements for grouts is their fluidity which is required for proper pumping during the grouting process. The pumping of grout mixtures due to the fluidity of cement-based grouts is mainly controlled by their rheological flow responses of shear stress versus shear rate and viscosity versus shear rate. Even though some earlier efforts (Güllü et al., 2019) are performed for the rheology of geopolymer grout mixtures, the research of rheology for the issue of grout pumping is still open for well understanding of the use of geopolymer. In this context, the shear stress (pumping pressure), viscosity, shear rate (pumping rate), yield stress, and plastic viscosities of the geopolymer grout were determined and thus, the flow properties of the grout were evaluated.

## 2. MATERIAL AND METHOD

The aluminosilicate-rich material as a precursor used in the study for producing geopolymer grout is fly ash (Class C). It is a by-product of coal combustion collected from a thermal power plant. It is reported (Sukmak et al., 2013) that, among by-products, fly ash becomes one of the greatest opportunities for commercially producing geopolymer technology due to its plentiful availability worldwide.

As for the alkali activators for geopolymer, they are sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$). The concentration of sodium hydroxide (NaOH) used is mainly 12 molar scale. To add to aluminosilicate material (fly ash), the alkaline solution (NaOH + $Na_2SiO_3$) is in the ratio of ($Na_2SiO_3$ / NaOH) = 2.5 (by weight). Consequently, the geopolymer is obtained by the ratio of alkaline activator (NaOH + $Na_2SiO_3$) to stabilizer (fly ash) equal to r = 0.85. The procedure for the production of the geopolymer in detail can be found in the past effort (Canakci et al., 2019). In the laboratory conditions (23 ± 3°C and 55% – 65% humidity), the materials were mixed in the amounts and ratios given above to obtain a geopolymer grout sample and rheological experiments were carried out.

The rheological properties of geopolymer-based grout mixtures regarding the shear stress versus shear rate and viscosity versus shear rate have been determined using a classical rotational-type viscometer (Rheomat R 180 type of the proRheo) equipment in accordance with DIN 53019-1 and ASTM D4016-08. The rheometer (viscometer) test have been performed at the shear rates of $500s^{-1}$, $571.43s^{-1}$, $642.86s^{-1}$, $714.29s^{-1}$, $785.71s^{-1}$, $857.14s^{-1}$, $928.57s^{-1}$, and $1000s^{-1}$.

From the testing, the rheological flow graphs of shear stress, and viscosity versus shear rate have been drawn, the rheological behavior (dilatant or pseudoplastic) has been determined with help of the rheological curves and also the rheological flow characteristics of yield stress and plastic viscosity have been estimated depending on shear stress versus shear rate. The yield stress and plastic viscosity have been estimated regarding modified Bingham behavior (Sahmaran et al., 2008).

## 3. RESULT AND DISCUSSION

The rheological responses properly obtained for geopolymer grout are illustrated in Figs.1-2, respectively for shear stress versus shear rate and viscosity versus shear rate. The rheological characteristics of yield stress and plastic viscosity of geopolymer grout are presented in Table 1. For practical applications, we can comment that shear stress refers to pumping pressure, while shear rate represents the pumping rate (Güllü et al., 2019).

As shown in the rheological responses of geopolymer grout (Figs.1-2), shear stress increases and viscosity decreases with an increased shear rate in a nonlinear trend. This behavior of increasing stress and decreasing viscosity can be defined by pseudoplastic (shear thinning) behavior. In this behavior, a thin response of grout is obtained with an increased pumping rate. It can be said that a decreased viscosity with an increased shear rate could improve the flow performance during exert of vibration or pumping pressure. Thus, this behavior can be commented as less energy during grout (Güllü et al., 2019). This can be beneficially used for practical applications.

As for the rheological characteristics of geopolymer grout (Table 1), yield stress particularly for high stabilizer rates can be well compared with previous works (Güllü et al., 2019), while plastic viscosity appears relatively higher.

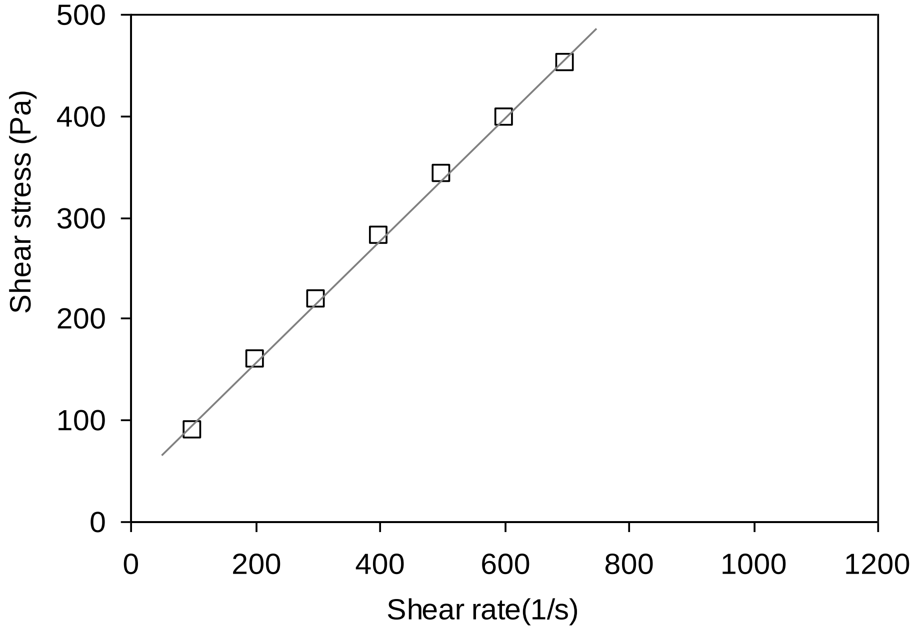


Figure 1. Shear stress versus shear rate

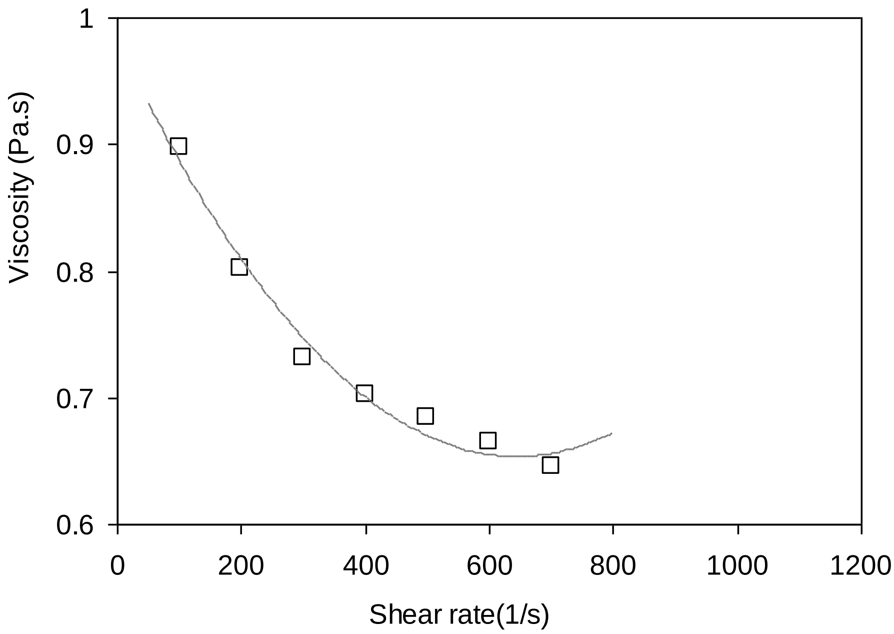


Figure 2. Viscosity versus shear rate

Table 1. Yield stress and plastic viscosity

| Parameter | Value |
|---|---|
| Yield Stress (Pa) | 36.73 |
| Plastic Viscosity (Pa.s) | 0.601 |

As a consequence of the study, the geopolymer grout is relatively able to result in proper rheology between shear stress, viscosity, and shear rate. Moreover, the pseudoplastic behavior of geopolymer grout from rheological responses offers good opportunities for grouting applications. However, it can be generally said that we can take the rheological behavior and responses of the traditional Portland cement-based grout, which is mostly used in soil improvements made with grouting, as a reference (criterion). Therefore, it is understood that geopolymer grout containing fly ash has a good potential for soil improvement due to its rheological response very close to cement-based grout and it will make significant contributions to grout applications. Thus, further studies will be significant for the validation of rheological responses of geopolymer grout by comparing it with native cement.

## 4. CONCLUSION

In this study, the rheological properties of geopolymer grout containing fly ash were investigated experimentally. Fly ash-based geopolymer grout for use in grouting applications, the rheological flow responses of shear stress and viscosity versus shear rate, and also the rheological characteristics with yield stress and plastic viscosity have been determined. It is found that the geopolymer grout is relatively able to provide proper rheological responses between shear stress, viscosity, and shear rate. The geopolymer grout provides pseudoplastic behavior that could be a good opportunity for practical applications. Consequently, the findings obtained from the study showed that the rheological properties of geopolymer grout containing fly ash are very close to cement grout.

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