Effect of loading rate and pre-loading on compressive strength of fly ash-based geopolymer concrete

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Abstract - *Geopolymer concrete emerged as an alternative construction material to reduce the use of Portland cement as primary binder for ordinary Portland cement (OPC) concrete. Geopolymer materials is considered environmentally friendly compared to Portland cement based materials in terms of reducing the emission of carbon dioxide gas to the atmosphere. Using waste materials like fly ash as a source material make geopolymer concrete more beneficial.*

This study aims to investigate the effect of loading rate and pre-loading to the compressive strength of fly ash-based geopolymer concrete. The loading rate in the range of 0.1 MPa/sec. to 5 MPa/sec. were applied for compressive strength tests. For pre-loading effect, 40% to 80% of obtained maximum load from specimens tested without pre-loading were employed as pre-load.

Test results indicate that compressive strength tends to increase with the increase of loading rate. Within the range of targeted compressive strength around 10 to 30 MPa, the increase of compressive strength is relatively small up to around 10%. Effect of pre-loading to compressive strength is not significant and also no specific trend observed for change in compressive strength with the increase of pre-loading level.

Key Words: Compressive strength, Fly ash, Geopolymer concrete, Loading rate, Pre-loading

1.INTRODUCTION

The development of alternative materials for Portland cement to make concrete is crucial related to environmental protection. Portland cement as the major binder material for making concrete is known to have significant contribution to environmental degradation due to abundant amount of CO_2 emission to the atmosphere from the production of Portland cement. Geopolymer material that has less CO_2 emission becomes an alternative to Portland cement as a concrete binder. Geopolymer is an inorganic alumino-silicate polymer synthesized from predominantly silicon and aluminium materials. Natural or by-product materials rich in silicon (Si) and aluminium (Al) can be utilized to make geopolymer materials. In the last two decades research on geopolymer materials including geopolymer concrete becomes more popular in various places around the world.

Wide range of source materials have been studied for making geopolymer materials such as kaolinite materials, fly ash, slag, rice husk ash and silica fume. Some studies for example as reported by Davidovits (1989, 1991), Heah *et al.* (2013)) for kaolinite materials, Hardjito *et al.*, (2004), Komljenović, Baščarević and Bradić (2010) for fly ash, Huang *et al.* (2015) and Bingöl *et al.* (2020) for slag, Kim *et al.*(2014), Prabu, Shalini and Kumar (2014) for rice husk ash and Rajerajeswari, Dhinakaran and Ershad (2014) for silica fume. Combination of those materials and also some other materials have been utilized to make geopolymers. Geopolymer materials and geopolymer concretes have a wide range of application in civil engineering or construction areas such as in soil stabilization, concrete and mortar, coastal and marine, insulation of buildings and fire resistant applications (Nawaz et al., 2020).

Compressive strength is one of the important mechanical properties of concrete which is usually determined using cylinder or cube specimens based on the referred standard. For example, American Society For Testing Materials, ASTM C39/C39M-03, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (2003) is one standard commonly used for testing compressive strength of concrete. The standard designates that the application of load during the test should be consistent within the range of 0.15 to 0.35 MPa/s, especially around the latter half during of the testing period.

A review by Fu, Erki and Seckin (1992) on the loading rate effects on concrete in compression concluded that compressive strength increases with increasing strain rates. They also reported that concrete with low to moderate strength seems to have more substantial effect of higher strain rates than high strength concrete, also wet concrete is relatively more sensitive to higher strain rates compared to dry concrete. For tensile strength of concrete, the effect of loading rate is found to be significant as reported by Glinicki (1986). Water cement ratio also plays an important role on the increase of loading rate effect on tensile strength of concrete (Rossi et al., 1994). The increase of compressive strength with increasing loading rate is also confirmed by Mali, Pachpande and Jogi (2015) through an investigation of cube compressive strength with the range of loading rate from 900 kg/cm^2 to 1400 kg/cm^2 per minute.

Related to geopolymer materials, (Khandelwal et al., 2013) studied the effect of strain rate on geopolymer mortar under dry condition. Compressive strength, modulus of elasticity and Poisson's ratio of 50 mm / 100 mm cylindrical specimens were tested with the range of strain rates from 0.001 to 0.05 mm/s. The study found that those properties increase significantly in logarithmic trend.

A study by Feng *et al.* (2015) on geopolymer concrete subjected to high strain rate compressive loading suggested that the increase in compressive strength of geopolymer concrete under high strain loading could be attributed to the propagation of cracks. The cracks propagate along interface transition zone and matrix for low strain rate loading, while for high strain loading they occur at the aggregates as well as at the interface transition zone.

As a structural material, concrete experiences many types of loading conditions and it must be able to support those loads without significant effect during the period of service. One type of loading conditions is pre-loading either temporary or sustained pre-loading. Kukai and Lenkei (2002) investigated the effect of compressive pre-loading on the strength of concrete by applying pre-loading to the specimens about 60% of the final value at the age of 5 days, and increased at 14 and 28 days of age. The average ultrasonic velocities were used as the bases to calculate concrete strength. Their study concludes that moderate pre-loading at early ages resulted in higher density and strength due to its effect to concrete microstructure compaction. The maximum strength increase is in the range of 2 to 10%.

This paper reports the study of the effect of loading rate and pre-loading to the compressive strength of fly ash-based geopolymer concrete.

2. EXPERIMENTAL WORK

Fly ash-based geopolymer concrete in this study was manufactured using fly ash from local power station in North Sulawesi Province in Indonesia as the source material. Local coarse and fine aggregates normally used for making ordinary Portland cement (OPC) concrete were also utilized to make this geopolymer concrete. Sodium hydroxide and sodium silicate were used as alkaline activators. The specimens were oven cured at 60°C to 90°C for 24 hours and tested at the age of 7 days.

Four mixes with different targeted compressive strength were prepared for loading rate tests. For all specimens from those four mixes, four various loading rates were applied for four groups of specimens in each mix. The loading rates were 0.1 MPa/sec., 0.25 MPa/sec., 1 MPa/sec. and 5 MPa/sec. for geopolymer concrete (GPC) specimens (Table 1). These loading rates were applied at the beginning of the test and maintained continuously during the test until maximum load value reached. All tested were conducted at the age of 7 days after casting the specimens. For comparison, one mix of ordinary Portland cement concrete was also made and tested with the level of loading rates 0.25 MPa/sec., 1 MPa/sec. and 5 MPa/sec., 10 MPa/sec. and 20 MPa/sec. at the age of 7 and 28 days.

Table-1: Specimen Category and Applied Loading Rate

Specimen Category		Targeted Compressive Strength MPa)	Loading Rate (MPa/sec.)					
GPC	A	30	0,1	0,25	1	5	-	-
	B	25	0,1	0,25	1	5	-	-
	C	20	0,1	0,25	1	5	-	-
	D	10	0,1	0,25	1	5	-	-
OPC	E	30	-	0,25	1	5	10	20

For pre-loading tests, one mix of fly ash-based geopolymer concrete (GPC) was prepared, two mixes of fly-ash based geopolymer mortar (GPM) and one mix of ordinary Portland cement (OPC) concrete were also prepared for comparison. In testing of specimens from each mix, the specimens were divided into five groups and each groups was given different levels of pre-loading. One group for testing without pre-loading (designated as "0%" group) was used as a reference for determining the magnitude of pre-loading and tested first for each mix category. The level of pre-loading were 40%, 60%, 70% and 80% (Table 2) of the average maximum load obtained from tested referred specimens (0% group).

Table-2: Specimen Category and Pre-loading Level

Specimen Category		Level of Pre-loading				
GPC	I	0%	40%	60%	70%	80%
GPM	II	0%	40%	60%	70%	80%
	III	0%	40%	60%	70%	80%
OPC	IV	0%	40%	60%	70%	80%

3. RESULTS AND DISCUSSIONS

3.1 Effect of Loading Rate

For fly ash-based geopolymer concrete category (specimen category A, B, C and D), the results of compressive strength obtained are presented in Figure 1 to Figure 4. It can be seen from those figures that the compressive strength shows an increasing trend with the increase of loading rate. However the changes are not significant. If the results of loading rate 0.1 MPa/sec. are used as the base, the maximum increase of compressive strength is around 12%. For most cases this value is less than 10%. The variations of targeted compressive strength (from around 10 MPa to around 30 MPa) seem not to have significant effect on the increase of compressive strength as a result of increasing in loading rate.

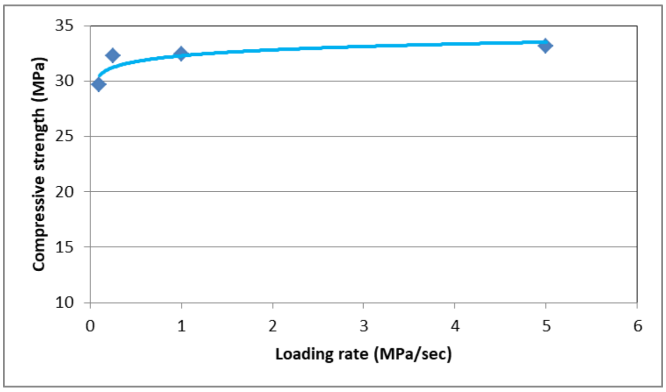

Chart – 1: Compressive strength variations with increasing loading rate for specimen category A (targeted compressive strength 30 MPa)

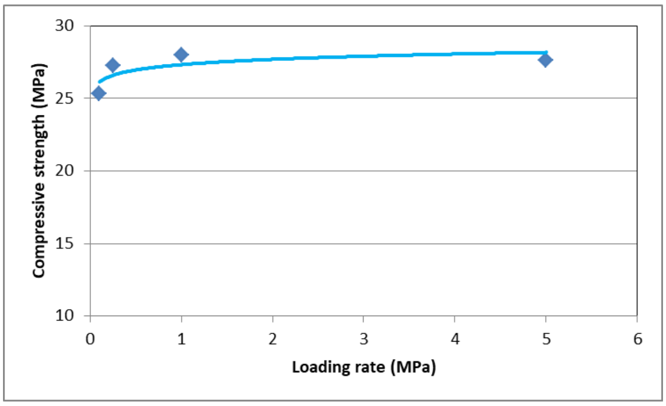

Chart – 2: Compressive strength variations with increasing loading rate for specimen category B (targeted compressive strength 25 MPa)

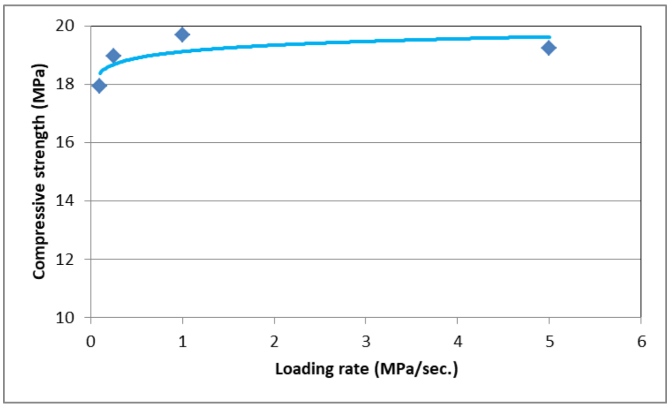

Chart – 3: Compressive strength variations with increasing loading rate for specimen category C (targeted compressive strength 20 MPa)

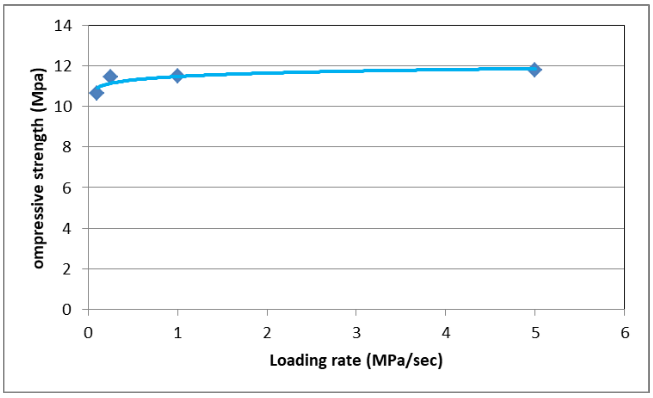

Chart – 4: Compressive strength variations with increasing loading rate for specimen category D (targeted compressive strength 10 MPa)

Chart - 5 and Chart - 6 show the compressive strength of OPC concrete tested at 7 days and 28 days respectively for various level of loading rate. Those charts also show that the compressive strength of OPC concrete tends to increase with the increase of loading rate level. However like that of geopolymer concrete (GPC), the increase is not significant below 10%. Also there is no significant difference between the results of 7-day and 28-day testing.

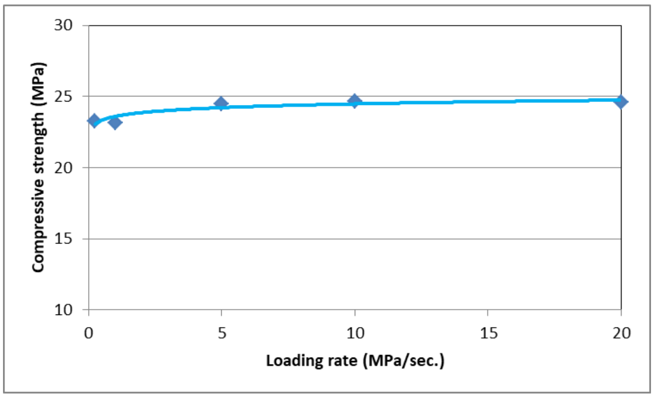

Chart – 5: Compressive strength variations with increasing loading rate for OPC at 7-day testing

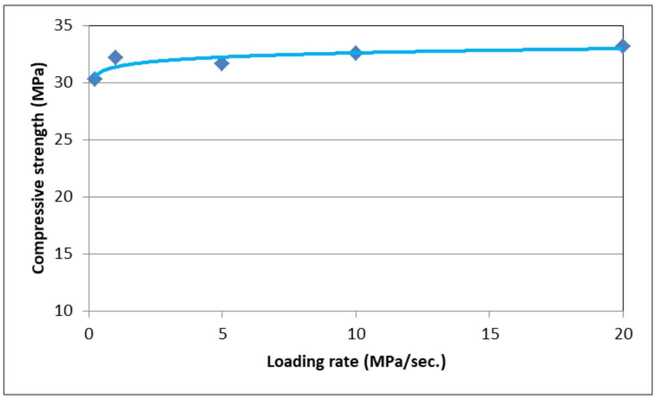

Chart – 6: Compressive strength variations with increasing loading rate for OPC at 28-day testing

3.2 Effect of Pre-loading

Chart 7 presents the value of compressive strength for various levels of pre-loading, while Chart 8 shows the ratio of compressive strength of specimens at certain level of pre-loading to the compressive strength of specimen without pre-loading (%). Those figures depict that the change in compressive strength with the increase of pre-loading level does not show a specific trend. However, those figures also shows that the compressive strength at any level of pre-loading is higher than that without pre-loading. As can be seen from Chart 8, the increase of compressive strength for pre-loading condition is relatively small, below 10%.

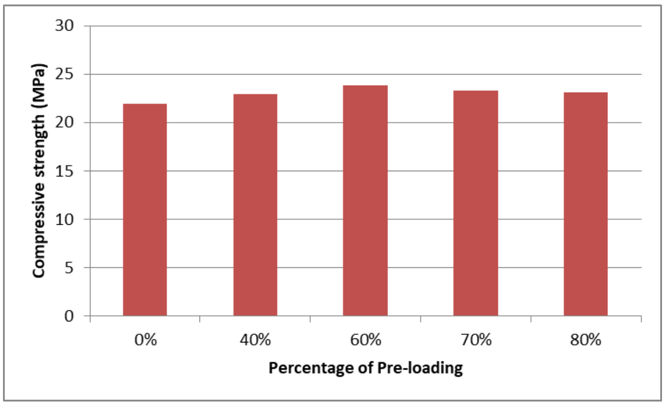

Chart – 7: Compressive strength of geopolymer concrete at various level of pre-loading

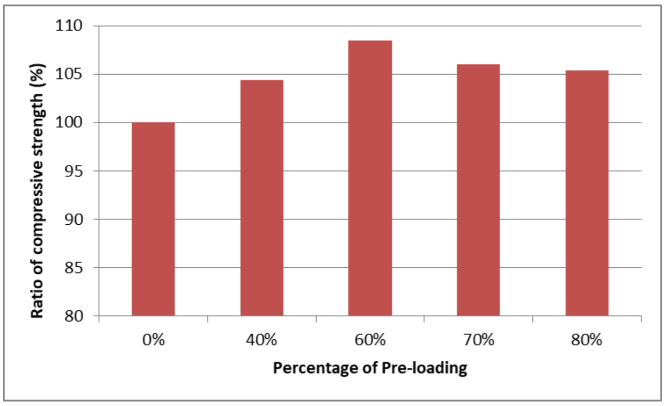

Chart – 8: Ratio of compressive strength of geopolymer concrete

The variations of compressive strength of geopolymer mortar with different level of pre-loading are presented in Chart 9 for low strength mortar and Chart 10 for mortar with higher strength. There is no specific trend of compressive strength change with the increase of pre-loading level for both cases.

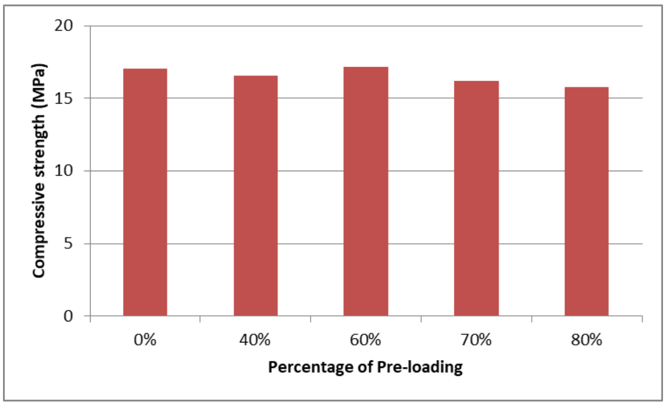

Chart – 9: Compressive strength of geopolymer mortar with low strength at various level of pre-loading

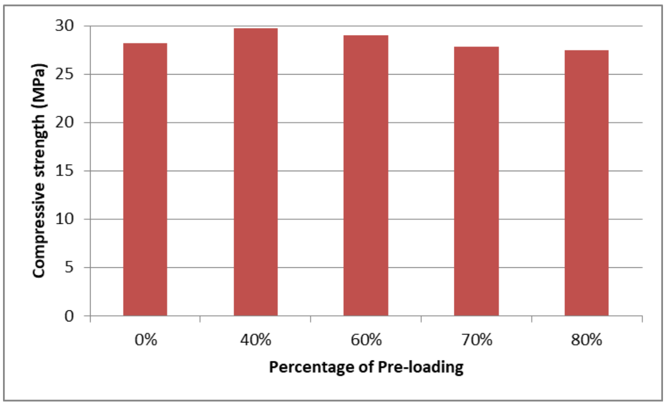

Chart – 10: Compressive strength of geopolymer mortar with higher strength at various level of pre-loading

Chart 11 presents the results of compressive strength test for OPC concrete at various level of pre-loading. It can be seen from that chart that the compressive strength is fluctuated with the increase of pre-loading level, but the variation is relatively not significant compared to the compressive strength without pre-loading.

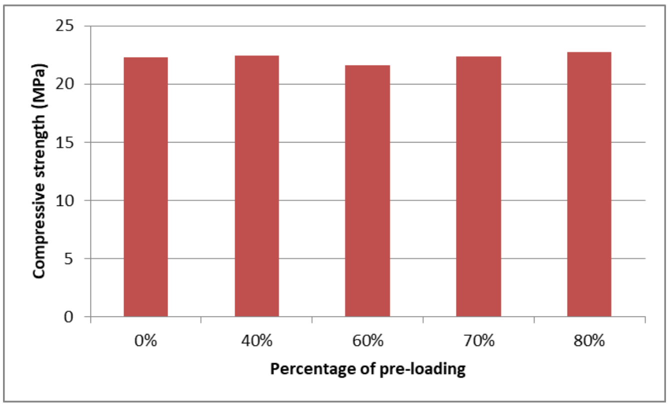

Chart – 11: Compressive strength of OPC concrete at various level of pre-loading

For comparison, Chart 12 shows the ratio of compressive strength at various level of pre-loading to the compressive strength without pre-loading for geopolymer concrete, geopolymer mortar and OPC concrete. That chart shows that there is no specific trend of compressive strength variations with the increase of pre-loading level for geopolymer concrete, geopolymer mortar and OPC concrete. For all cases, the compressive strength at various level of pre-loading is fluctuated within the range of 10% below or above the compressive strength without pre-loading. These results are still in agreement with the study reported by Kukai and Lenkei (2002) that the maximum strength increase due to pre-loading effect is in the range of 2 to 10%.

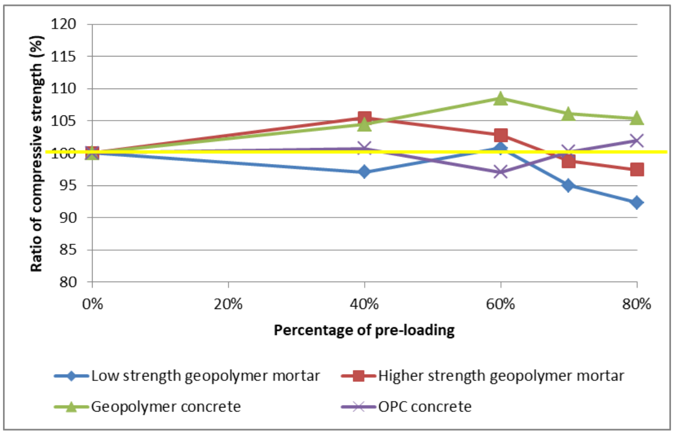

Chart – 12: Ratio of compressive strength of geopolymer concrete, geopolymer mortar and OPC concrete

From the results presented previously, generally pre-loading does not give significant effect to compressive strength of fly ash-based geopolymer concrete and mortar. The same is true for OPC concrete. For all cases the compressive strength is fluctuated with the increase of pre-loading level. The maximum or minimum values of compressive strength do not refer to specific level of pre-loading.

4. CONCLUSIONS

- The values of the resulted compressive strength of fly ash-based geopolymer concrete tend to increase with the increase of applied loading rate. For loading rate in the range 0.1 MPa/sec. to 5 MPa/sec. the maximum increase of compressive strength is around 10%.
- For compressive strength of around 10 to 30 MPa, the variations of strength do not have significant effect to the increase of compressive strength with increasing loading rate.
- The effect of pre-loading to compressive strength of fly ash-based geopolymer concrete is not significant.
- There is no specific trend of compressive strength change with the increase of pre-loading level. The compressive strength with pre-loading varies up to 10% above or below the compressive strength without pre-loading.

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