Strength Variation of Augen Gneiss in the Point Load Test under Different Loading Direction and Temperature

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Abstract. The anisotropic nature of rock strength varies with the degrees of an anisotropic plane. The study on strength index which are effect by anisotropic plane with different loading angle, the role of grain size of mineral and thermal behaviour in the point load index test. The rock material with the heterogeneous mineral of the dark and white bands of mineral with a different grain size that increases the foliation degree and reduced the strength value depends on grain size and their bounding. In Augen Gneiss the strength index depends on the anisotropy plane of the sample with loading direction, thermal variation, and fracturing pattern are controlled by the grain size of the mineral. The microcrack developed with temperature increases and the crack initiated with grain boundaries, and further developed intercrystalline crack with temperature increases. There is no significant difference in density up to 300°c when the natural moisture content is less.

Keywords: Point Load Test, Strength Anisotropy, Mineral grain, Thermal Behaviour

1. Introduction

In nature, most rocks are anisotropic the estimation of strength anisotropy is important which is determined by the ratio of maximum strength to the minimum strength of the rock [1]. The strength measurement of rock is important in designing engineering structures, underground excavation, and other construction work which is directly linked with the stability of the work. The effect on the strength of the rock is the function of the direction of the applied stress. A rock or rock mass can be anisotropic as a result of its inhomogeneity the strata in a sedimentary sequence will have different properties in the different directions parallel and perpendicular to the strata sequence. In metamorphic rock anisotropy generally developed because of stress history in which the mineral grain is aligned in parallel bands or preferred orientation [2]. The stress is responsible for the development of foliation depends on a mineral presence on a rock that may contain an inherent anisotropy due to its mode of formation, such as slate, or the gneiss. An anisotropic rock has different deformability modulus, strength, brittleness, permeability, and discontinuity frequency in a different direction [3]. The anisotropy characteristics affect the physical and mechanical properties of rock. The influence of rock strength is due to the anisotropic behavior of the rock with the directional varies of structure and also control the fracture to initiate and propagate.
Point load test is mainly used for the estimation of rock uniaxial compression strength and tensile strength and classification of rock [4]. Point load obtains the strength anisotropy and it can be determined in a rock by varying different loading angles to the anisotropic plane. The trend of increasing or decreasing strength and anisotropy depends on the mineral content. The different types of mineral aggregate with different shapes in rock have different behavior which varies the mechanical properties of rock. During heating and cooling of rock changes in physical properties because it contained different minerals. In engineering structure, the thermal behavior of rock plays an important role in the temperature change develop micro crack and reduce the strength value. When temperature increases in a rock its mechanical properties change with loading stress [5]. So the anisotropic rock is also effect by the thermal behavior.

2. Method
The desk study is the very first methodology of the research. The sample was collected for the laboratory study. Two different types of gneiss were selected for the study, i.e. Migmatitic gneiss and Augen gneiss. The laboratory work sample preparation i.e. core cutting, smoothing and sample testing was done in the laboratory the main performed laboratory testing are as follows: Point-load strength Index Test with varying temperature. In the laboratory rock with different loading angles of the sample were prepared labeled and tested (figure 1 and 2). For the temperature effect prepared core sample for axial point load test was selected in the oven for various temperatures i.e. 100, 200, and 300 for 24 hours, and that sample was tested. For normal temperature, the sample was selected directly for tested. The methodology was based on ISRM 1985.

2.1. Axial point load test
The axial point load test can be prepared and performed when the core specimen with length/diameter ratio between is 1.1 (Figure 3) at different anisotropic angles. In axial point load, there is shape effect both length and diameter were influenced and this test is used when strength anisotropy was measured. The standard size and type of point load can be calculated by:

Point load strength index \( I_s = \frac{P}{D_e^2} \)

Where \( P \) is the load at failure \( D_e \) is the diametrical diameter of the core is 50 mm.

The minimum cross-sectional area \( A \) of the plane of the point load contact in the axial test is

\[ A = WD \]

The area of that circle, of equivalent diameter \( D_e \) as:
\[ D_e = \sqrt{4A\pi} = \sqrt{4WD\pi} \]

It has been observed that \( I_s \) increases with \( D_e \) for the same point load index of rock for classification, size correction is necessary. The size corrected point load strength index \( I_s(50) \) is defined as:

\[ I_s(50) = I_s \times \left( \frac{D_e(50)}{50} \right)^{0.45} \]

\( D_e \) in millimeter.

\( I_s(50) \), is used to classify rock and corrected to strength parameters such as uniaxial strength (\( \sigma \)) or tensile strength.

### 2.2. Sample description

The sample of migmatitic gneiss consists of quartz, plagioclase, biotite, and tourmaline with white and dark mineral band with gneissosity texture with slightly weathered and the augen gneiss consists of feldspar, quartz, biotite, and muscovite mineral with moderately weathered. The grain size of feldspar are varying in size (figure 4).

The behavior of the metamorphic rock as the main source of anisotropy fabric that is the foliation index [6]. The classification of point load strength anisotropy of foliated rock.

| Nature of Rock Strength          | Anisotropy Index(\( I_a \)) | Descriptive term   |
|----------------------------------|-------------------------------|--------------------|
| Very strongly Foliated           | >3.5                          | Very highly anisotropy |
| Strongly Foliated                | 3.5-2.5                       | Highly anisotropy   |
| Moderately Foliated              | 2.5-1.5                       | Moderately anisotropy |
| Weakly Foliated                  | 1.5-1.1                       | Fairly anisotropy   |
| Very weakly foliated(Non Foliated)| <1.1                          | Quasi-isotropic     |
3. Result and Discussion

The main purpose of this test to determine the strength anisotropy in the different loading directions with a thermal variation. In this axial test, the maximum strength is obtained when the loading angle is perpendicular to anisotropic planes, and the minimum strength is obtained when the loading angle is 45° to anisotropic planes. The strength anisotropic index $I_a$ of augen gneiss is 2.9 which is strongly foliated and migmatitic gneiss 2.06 is moderately foliated in nature. The change in strength of rock due to presence of anisotropic planes, in which the mineral grain contain of feldspar, quartz and mica minerals which is highly influenced by its grain size the presence of feldspar, quartz mineral with dark mineral i.e. mica mineral developed anisotropy and also influence the strength of rock. This effect of anisotropy is observed in the axial test because when the load is applied perpendicular the crack developed from grain to grain is difficult and more energy requires and the strength value increases but in a case when the angle is at 45° shear stress is maximum and strength is minimum because the crack developed at the tip of sample in weakness plane (anisotropic plane) and is easy to split or break (figure 5 and 6). The density of the rock sample lies between range of 2.63 g/cm³ and 2.78 g/cm³ in augen and migmatitic gneiss respectively.

| Loading Angle | Migmatic Gneiss $I_s(50)$ MPa | Axial Loading | Augen Gneiss $I_s(50)$ MPa |
|---------------|-------------------------------|--------------|-----------------------------|
| 0             | 3.93                          | 1.65         | 2.85                        | 2.12                        | 3.33                        |
| 30            | 3.29                          | 1.48         | 2.32                        | 1.89                        | 2.38                        |
| 45            | 2.47                          | 0.99         | 1.63                        | 1.20                        | 1.92                        |
| 60            | 2.85                          | 1.42         | 2.07                        | 1.90                        | 2.84                        |
| 90            | 5.08                          | 2.90         | 4.42                        | 3.04                        | 4.89                        |
| Anisotropy    | 2.06                          | 2.92         | 2.71                        | 2.52                        | 2.55                        |

Table 2. Axial point load-tested data at different temperatures.

$\text{Figure 5. Point Load Index } (I_s(50)) \text{ with different loading angles in migmatitic and augen gneiss at room temperature.}$

$\text{Figure 6. Point Load Index } (I_s(50)) \text{ with different loading angles in augen gneiss at different temperatures.}$
4. Thermal change

In augen gneiss the strength value at room temperature (25°C) to 100°C is slightly increased. The increases in temperature from 100o to 200o the strength value were decreases than value at 100°C. This indicates that when temperature rise, a microcrack start to develop at the boundary of minerals in weathered and dry condition of sample it was easy to break from the plane of weakness. The temperature at 300 o C strength slightly rises because trans-crystalline crack initiated at the contact between the grain and pass along one or more grains the fracture from grains to grain requires more energy during loading. The temperature and strength vary with the anisotropic loading angle (figure 7). The density of augen gneiss obtained at room temperature and the thermal condition is no significant difference on density up to 300° C because the natural moisture content on the sample was very less as shown in Table 3.

![Figure 7. Axial test Bar Diagram showing strength index and loading angle.](image)

### Table 3. Density with different temperature

| Augen Gneiss g/cm³ | Room Temp (25°C) | 100°C | 200°C | 300°C |
|--------------------|------------------|-------|-------|-------|
| Average            | 2.63             | 2.7   | 2.72  | 2.74  |
| Room Temp.         | -                | 2.705 | 2.7   | 2.73  |
| Thermal            | -                | 2.705 | 2.7   | 2.73  |

5. Fracturing Pattern

According to ISRM when the rock is compressed between the platen it fails in one or more extensional planes containing the line of loading which is a valid failure whereas deviation from this failure is indicated as invalid. In anisotropic rocks, the invalid mode along the weakness planes is common [7].

The strength value with different temperatures in different loading angles by axial test might not be significant in anisotropic rock. The fracturing nature of augen gneiss with a strongly foliated sample at different loading angles are failed from the plane of weakness generally half of the sample are fracture with non-central (invalid) modes (figure 8). According to ISRM the strength are insignificant from invalid nature. The invalid failure modes are common in sample of strongly foliated rock of augen gneiss whereas moderately foliated sample of migmatitic gneiss the mode of failure is valid. In augen gneiss the grain size and foliation plays an important role to develop cracks between the planes of weakness the boundary of large size of augen structure of feldspar with bands of mica mineral are interlayered so invalid modes are common.

![Figure 8. Percentage of valid and invalid fracture in augen gneiss.](image)
Figure 9. Types of failure modes in Augen Gneiss and Migmatitic gneiss.
When the sample is load perpendicular, the crack developed from grain to grain are difficult and more energy requires, and the strength value increases but in the case when the angle is at 45° the shear stress is maximum and strength is minimum because the crack developed to the foliation and in weakness plane (anisotropic plane) is easy the grain size have highly influenced the presence of feldspar, quartz mineral with dark mineral i.e. mica mineral developed anisotropy which influences the strength in rock. The grain size effect the strength of anisotropic rock. In gneiss abundance of feldspar and pyroxene mineral show high mineralogical phase change, thermal treatment decreases strength and increases in porosity and above 600°C loss of 80 % of its original mechanical properties [8]. The grain size plays an important role to develop cracks between the plane of weakness where the boundary of the large grain size structure of feldspar and mica mineral effect by thermal change.

According to ISRM standards stipulate that the point load strength determined from the point load test that leads to invalid specimen failure mode should be rejected. This should be also valid in an anisotropic sample of moderately foliated rocks or a moderately anisotropic sample of migmatitic gneiss in which the failure pattern was valid (figure9) but in the case of augen gneiss which is highly anisotropy, the failure pattern was invalid around 50% (figure 9) this is because a failure occurred in augen gness along with the weakness planes when these planes are at an angle with loading direction. For the real condition strength values obtained from invalid failure modes along with the weakness, planes would use the data in an engineering environment. The fracturing pattern [7] and [9] give the classification according to the fracture pattern. The observed result was classified according to them.

6. Conclusion

The change in the strength of rock due to different loading angles with different temperatures and the fracturing pattern of rock was tested. Both the migmatitic and augen gneiss samples are foliated metamorphic rock with gneissosity texture and different minerals compositions. The variation in grain sizes of gneiss shows different failure modes. The thermal effect in anisotropy rock of augen gneiss shows the increases and decreases of strength behavior with temperature rise in foliated rock. The different grain sizes play an important role to developed micro-cracks at the boundary with a rise in temperature that shows a phase change due to multiple cracks which reduced the strength. The heterogeneous rock with the different minerals of the dark and white band with different grain sizes increases the anisotropic degree and reduced the strength value depending on the grain size and their bonding. The failure pattern depends on the cracking behavior of the brittle material of rock containing fissures. When loading is applied micro-crack developed from grain to grain depends on the orientation of mineral different failure modes are obtained (single failure, twisted and layer activation, and non-central (Invalid) modes of failure).
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