ISSN(Online) : 2319-8753
ISSN (Print) : 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

GNEISSES-Strengths and Mineralogical Compositions

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ABSTRACT:Based on the laboratory assessment in respect of three Gneisses – namely, biotite gneiss, biotite granite gneiss and granite gneiss-drawn from five drill holes (all vertical) of a project in the Himalayas, the influence of mineralogical composition and strength/behavior of the rock are presented here. Along with the laboratory evaluation of various strengths and identification properties, the mineralogical composition of these gneisses has been analysed with X-ray diffraction (XRD) method. In case of engineering parameters, the influence of mineralogical content is evaluated. Because of significant variation in case of granite gneiss, drawn from two vertical drillholes, these are considered separate variants as well. The granite gneiss is found to be superior to the biotite gneiss and biotite granite gneiss in respect of all assessed engineering parameters – possibly because of the different minerals, particularly high quartz and low biotite content; but biotite gneiss is the best in respect of water-related and identification properties.

KEYWORDS:gneisses, laboratory assessment, mineralogical composition, strength properties

I. INTRODUCTION

Gneiss is a high grade metamorphic rock, often forms from the metamorphism of granite or diorite. In general, it is subjected to higher temperatures and pressures than schist.Gneiss displays distinct foliation, representing alternating layers composed of different minerals.The most common minerals in gneiss are quartz, feldspar with traces of biotite, muscovite and hornblende. Gneiss usually forms by regional metamorphism at convergent plate boundaries.

Gneiss can form in several different ways. The most common path begins with shale, which is a sedimentary rock. Regional metamorphism can transform shale into slate, then phyllite, then schist, and finally into gneiss. During this transformation, clay particles in shale transform into micas and increase in size. Finally, the platy micas begin to recrystallize into granular minerals. The appearance of granular minerals is what marks the transition into gneiss. Intense heat and pressure can also metamorphose granite into a banded rock known as "granite gneiss." This transformation is usually more of a structural change than a mineralogical transformation. Although gneiss is not defined by its composition, most specimens have bands of feldspar and quartz grains in an interlocking texture. These bands are usually light in color and alternate with bands of darker-colored minerals with platy or elongate habits. The dark minerals sometimes exhibit an orientation determined by the pressures of metamorphism.

The knowledge of gneiss including its strength, deformation behaviour in conjunction with their distinct mineralogical compositions is important in geotechnical engineering. Hence, an attempt is made in the present study to understand strength and deformation behaviour of three varied gneiss namely biotite gneiss (BG), biotite granite gneiss (BGG), and granite gneiss (GG) along with the mineralogical composition of these gneisses-its influence of minerals on rock properties.

1. Related Work:

The presented study involves three gneisses – i.e., biotite gneiss (BG), biotite granite gneiss (BGG), and granite gneiss (GG) – obtained from two drillholes each of a project in Northern India. All drill holes were vertical. In saturated condition, these rocks have been assessed for strength parameters – uniaxial compressive strength and deformability

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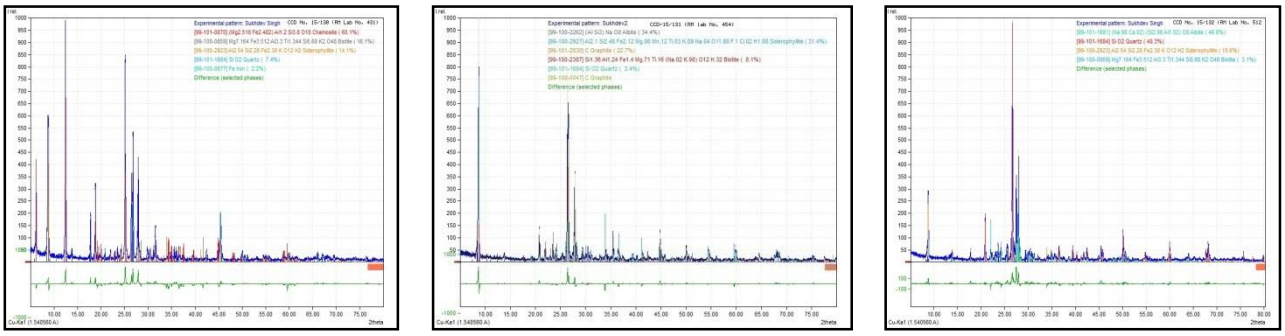
characteristics i.e., tangent modulus and Poisson's ratio, indirect tensile strength (Brazilian), apparent cohesion and angle of internal friction (through triaxial test), and point load strength index.
In addition to the above aspects, the water-related and identification properties are discussed for each variant. These include: water content at saturation, apparent porosity, slake durability index (first, and second, cycle), bulk density (dry and saturated, both) and grain density. Employing X-ray diffraction (XRD) analysis [1], the mineralogical composition of the three gneisses is also determined and influence of minerals on rock properties is discussed. In XRD, the sample is grinded and sieved through 75µ size and pressed into a sample holder with smooth plane surface.

II. MINERALOGICAL COMPOSITION

Major mineral components for these gneiss samples were identified through XRD.Other distinct mineral found in BG is iron and graphite in BGG. In BG, distinct peaks of minerals such as chamosite, siderophyllite and biotite are found. The presence of high content of biotite in BG, when compared to BGG and GG affects the bonding of rock's constituents, which results in lessening of strength. Moreover the combination of quartz and albite in higher percentages contribute to the higher strength values of GG. The approximate quantity of minerals in the representative sample is shown;



(a) (b) (c)

Fig. 1.X-ray diffraction patterns for (a) BG (b) BGG (c) GG

Figure 1(a) shows XRD pattern of these samples (Counts v/s 2-THETA). XRD pattern of gneiss shows the distinct peak of Chamosite (phyllosilicate), biotite in BG;
Figure 1(b) shows XRD pattern in BGG i.e distinct peaks of Albite (Plagioclase) and Siderophyllite;
Figure 1 (c) shows XRD pattern in GG i.e distinct peaks of Albite and quartz. However, some presence of Quartz, biotite and siderophyllite is commonly noticed in all the three gneisses. In addition, graphite and iron are also found as rock-forming minerals. Table 1, briefs the chemical composition of gneiss, as shown below:

Table 1 Chemical composition of Gneiss

Mineral	Biotite	Quartz	Albite	Chamosite	Siderophyllite	Graphite	Fe Iron
BG (%)	16.1	7.4	Not detected	60.1	14.1	Not detected	2.2
BGG (%)	8.1	3.4	34.4	Not detected	31.4	22.7	Not detected
GG(%)	3.1	40.3	46	Not detected	10.6	Not detected	Not detected

III. PARAMETERS AND PROPERTIES

As per ISRM suggested methods [2], variants of BG, BGG and GG have been assessed for different properties and parameters. The Uniaxial Compressive Strength and deformability characteristics are assessed using NX size saturated specimens, with length to diameter ratio of 2.5. The Indirect Tensile Strength is assessed using NX size saturated

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specimens, with length to diameter ratio of 0.5. The justification of the test is based on the experimental fact that most rocks in biaxial stress fields fail in tension at their uniaxial tensile strength when one principal stress is tensile and the other finite principal stress is compressive with a magnitude not exceeding three times that of the principal tensile stress. For triaxial compression test, Hoek cell was employed, and saturated specimens, with length to diameter ratio of 2, were tested over the desired range of confining pressure. The Strength Envelops are drawn and shear strength parameters (i.e., c and ϕ) evaluated.

Using NX size cylindrical samples, $I_{s(50)}$ is evaluated in saturated state – under diametral and axial, both, types of loading. The test is considered valid only if the failure plane passes through both the loading points. As per standard, size correction is subsequently applied to make it correspond to 50mm size sample. The Anisotropy Index, I_a, which is the ratio of '$I_{s(50)}$under axial loading to $I_{s(50)}$ under diametral loading', is also presented.

Water-related and identification properties, comprising water content, apparent porosity, slake durability index and densities (bulk dry, bulk saturated and grain) are also evaluated.

IV. DISCUSSION

Three types of investigations – namely, assessment of mineralogical composition, various strengths, and water-related and identification properties – were undertaken, and are discussed ahead.

1. **Strengths:**

For BG, BGG and GG, Table 2 shows the various strength parameters in saturated state. Because of noticeable difference for GG samples (drawn from V_1 and V_2), these are separately listed.

Table 2 Strengths (in saturated state)

Parameters	BG			BGG			GG					
							Min		Max		Rec	
							V1				V2	
	Min	Max	Rec	Min	Max	Rec	Min	Max	Rec	Min	Max	Rec
$\sigma_{c(sat}$ (MPa)	18.5	76	35	34.1	49.8	45		45	90.8		65	
$E_{50(sat)}$ (GPa)	24	53	28	11.8	38.2	28		31	89		45	
μ_{sat}	0.17	0.21	0.2	0.18	0.36	0.25		0.15	0.28		0.23	
Shear Strength Parameters												
c (MPa)			3.5			3.5			4			4.5
Φ (degrees)			40			40			45			50
$\sigma_{t(sat)}$ (MPa)	1.7	6.1	3.5	3.2	9.3	5.5	5.2	7.6	6	7.4	9.9	8
$I_{s(50)sat-Dia}$(MPa)	2.5	5.7	3.0	1.8	3.5	2.5	3.2	4.9	3.7	4.6	5.3	4.8
$I_{s(50)sat-Axial}$ (MPa)	2	5.2	3.0	2.1	4.2	2.6	4.1	6.8	4.5	4.7	6.7	5.5
I_a (sat)			1			1.04			1.4			1.14

1.1. Uniaxial Compressive Strength:

The perusal of Table 2 reveals that the Uniaxial compressive strength ($\sigma_{c(sat)}$) increases-from 35(BG) to 45(BGG) to 65(GG) as the biotite content decreases. It shows that BG failed at very low strengths compared to BGG and GG (around 50%). The rock minerals played greater role in reducing bond between rock's constituents-thus affecting strength, resulting in decrease in strength of BG on saturation. And, the variation of $\sigma_{c(sat)}$ for BG, BGG and GG.

Fig. 2(a) reveals that both BG and BGG have similar pattern for 10 to 80% range. The higher value of GG is possibly due to presence of hard minerals like quartz and albite in higher proportions. The lesser strength in BG is due to high biotite content and less quartz content.

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(An ISO 3297: 2007 Certified Organization)

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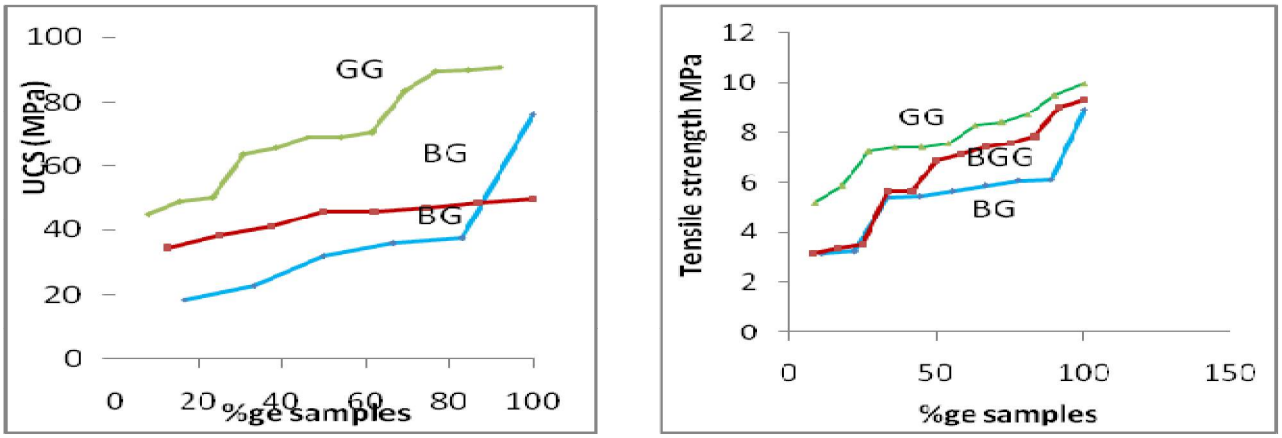

(a) (b)

Fig. 2.Variation of (a)$UCS_{(sat)}$ (b) $\sigma t_{(sat)}$

1.2 Indirect Tensile Strength (Brazilian):

Table 2 lists the recommended values of $\sigma_{t(sat)}$ as 5.5MPa for BG, whereas for BGG and GG, drawn from drillholes (V_1) and (V_2), $\sigma_{t(sat)}$ values are 6 and 8MPa, respectively. The lesser strength in BG is due to high biotite content and less quartzite in composition of minerals.

Fig. 2(b) reveals the variation of $\sigma_{t(sat)}$ for all variants of gneiss. It can be observed that neglecting few samples, both BG and BGG have similar pattern for 8 to 42% range. The higher value of GG is possibly due to presence of hard minerals like quartz and albite in higher proportions, for both drillholes. Moreover the trend of BGG and GG is similar.

1.3 Shear strength parameters:

For assessment of shear strength parameters, each of BG, BGG and GG (V_1 and V_2-two drill holes) were tested as separate variant for the confining pressure range of 3.5 to 8MPa. The best-fit is drawn and separate values of C and φ are obtained. Fig.3, gives the recommended shear strength parameters of gneiss variants i.e BG, BGG and GG (V_1 and V_2-two drill holes) as shown below:

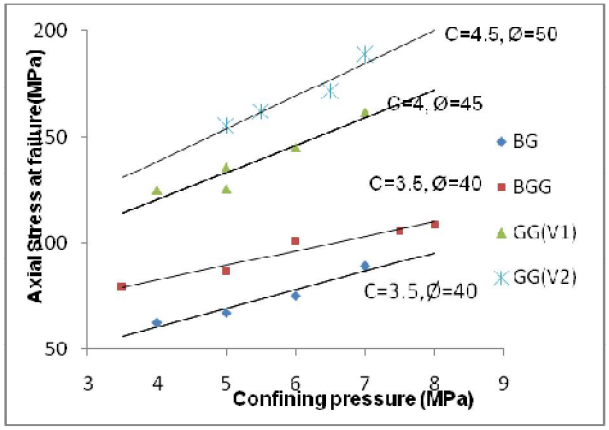

Fig.3. Strength Envelop

1.4 Point Load Strength Index:

$I_{s(50)sat}$ is evaluated in saturated state, under diametral and axial, both, types of loading. For BG, BGG and GG, under diametral loading, the recommended values of $I_{s(50)sat}$ are 3, 2.5, 3.7(V_1) and 4.8MPa (V_2) respectively; and, under

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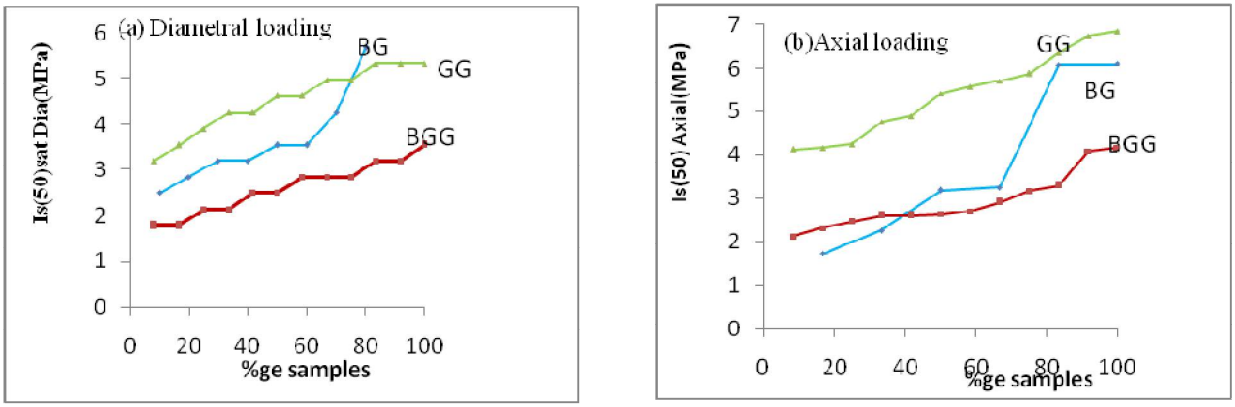
axial loading, for the same variants, the recommended values of $I_{s(50)sat}$ are, 3, 2.6, 4.5(V_1) and 5.5MPa (V_2) respectively.



(a) (b)

Fig.4 Variation of $I_{s(50)sat}$ (a)diametral , (b) axial loading

Figures 4-a and 4-b show the variation of $I_{s(50)sat}$ (for BG, BGG and GG) under diametral and axial loading respectively.It is observed that under both i.ediametral and axial loading, the data is instantly spread over the entire range in case of BGG and GG, whereas for BG, there is a sudden increase in the value beyond 60% data. The Anisotropy index, is "the ratio of $I_{s(50)}$ under axial loading to diametral loading". The computed values of I_a are 1.0, 1.04, 1.4(V_1) and 1.14(V_2) for BG, BGG and GG respectively. Except for V_1 of GG, anisotropy index values for all others are similar.

The foregoing clearly demonstrates that the uniaxial compressive strength cannot be taken as a fixed multiple of either the point load strength index or the tensile strength, even when the rock involved has little, if any, strength anisotropy.

Table 3 shows the recommended values of water related properties i.e water content, apparent porosity and slake durability of three gneisses.

Table 3 Water related properties

Parameters	BG			BGG			GG		
	Min	Max	Rec	Min	Max	Rec	Min	Max	Rec
w.c(%)	0.2	0.33	0.4	0.4	0.5	0.5	0.26	0.38	0.4
app.Porosity (%)	0.6	0.9	1	1	1.3	1.5	0.7	0.91	
Porosity Class	Very Low			Low			Very Low		
S.D.I.(I cycle,%)	99.3	99.5	99.3	98.4	99.2	98.5	99.2	99.6	99.3
Durability Class	Very High			High			Very High		
S.D.I.(II cycle,%)	99	99.3	99	97.7	98.8	97.5	98.8	99.4	99
Durability Class	Very High			High			Very High		

2. **Water related Properties**:

2.1 Water Content:

Table 3 shows that percentage of water content is similar for all variants.

2.2 Apparent Porosity:

For the variants of BG, BGG and GG, the recommended apparent porosity values, in percent, are 1, 1.5 and 1 respectively. BGG belong to the 'Low porosity; class (1-5%) and both BG and GG belong to the 'Very Low Porosity' class (<1%).

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2.3 Slake Durability Index:
BGG falls in High durability category in both cycles; and BG and GG, both, fall in Very High durability category, in both cycles of slaking.

3. **Densities**:

Table 4 Densities

Parameters	BG			BGG			GG		
	Min	Max	Rec	Min	Max	Rec	Min	Max	Rec
γ_{dry} (kg/m^3)	2686	2983	2700	2589	2689	2615	2612	2634	2620
Density class	High			High			High		
γ_{sat}(kg/m^3)	2693	2932	2710	2600	2699	2630	2620	2642	2630
γ_{grain}(kg/m^3)	2714	2944	2730	2615	2720	2640	2645	2663	2645

The bulk densities were measured in both states, dry and saturated. Table 4 shows that all rock variants, BG, BGG and GG pertain to High Density class, though there is very little difference between the grain density of BGG and GG, and the grain density of BG is higher. The high grain density of the BG is due to the presence of high Biotite and Chamosite content (around 3190kg/m^3).The perusal of Tables 3 and 4 reveal that in respect of all the identification and water-related properties, the BG is the best, followed by GG and BGG, though the first two pertain to the same class. The density class, as High, is same for all three, but the 'Durability class' and 'Porosity class' is superior for BG and GG than BGG. According to Slake Durability Index, both, first and second cycle criteria, BG and GG are of very high durability, whereas BGG belongs to High Durability. With regard to apparent porosity, the first two belong to Very Low porosity class, whereas BGG has low porosity.

V. CONCLUSIONS

The mineralogical composition and strength, both, influence the properties and parameters of the variants of gneiss. Even for a given variant from a given area, two nearby drillholes may yield cores that may have to be treated differently because of the substantial variation in the test data.
The engineering parameters and 'water-related and identification properties' may be superior for different variants; and even all the engineering parameters need not be better for a given variant of gneiss. Therefore, for each and every variant, all the properties and parameters, including mineralogical content, need to be ascertained.
In the instant case, all the investigated engineering parameters of GG are superior to those of BG and BGG. With regard to water-related and identification properties, BG scores over the other two variants of GG and BGG.

VI. ACKNOWLEDGEMENT

The Project Authorities deserve thanks for entrusting CSMRS the work of assessment of these gneisses, for making the rock cores available at CSMRS and for their whole hearted cooperation. Thanks are due to Director, CSMRS, for granting permission to publish, and to co-workers from Rock Mechanics Laboratory and Concrete Chemistry Division at CSMRS' for their respective contributions.

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