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Influence of Weathering on Mechanical Behaviour of Garnetiferous Quartzo-Feldspathic Biotite Gneiss

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Abstract. In the present study, Garnetiferous quartzo-feldspathic biotite gneisses of different weathering grades from Eastern Ghat Mobile belt of southern peninsular India were investigated in the laboratory for their uniaxial compressive strength (UCS), tangent modulus (E), and Poisson's ratio in saturated condition. To understand the influence of weathering, gneisses were divided and investigated broadly into three different grades, namely- fresh rock (FR), moderately weathered (MWR) and highly weathered (HWR). The mineralogical composition of these gneissic rock variants was quantified by X-ray diffraction (XRD)analysis. The XRD patterns depicted the presence of kaolinite and illite minerals in MWR and HWR grades. With the increase of weathering degree, the clay minerals were also increased. For HWR grade, it was observed that the diffraction peak becomes broader which indicate the presence of poorly crystalline mineral. The mode of failure of rock in compression changed from multi axial splitting to pure shear, with increase of degree of weathering. Furthermore, physical and slake durability characteristics were studied. An exponential trend was observed in slake durability values of HWR rocks when tested for 9 consequent cycles. In comparison to other grades, remarkable failure was observed in HWR gneisses on saturation, which has resulted in drastic reduction of the strength and deformability characteristics.

Keywords: Weathering, Gneiss, Laboratory Study, Mechanical Behaviour.

1 Introduction

Weathering is the process of alteration and breakdown of rock and soil materials at or near the Earth's surface by physical disintegration and chemical decomposition. Physical weathering involves breakdown of rocks, thereby unweathered rock surfaces are exposed to chemical weathering processes. Weathering considerably affects the physical and mechanical properties of rock, since it produces mineralogical and petrographical transformations of original rock, making rock slopes vulnerable [1, 12]. Studies on weathering of gneisses [6] in Central France showed that the main characteristic of the weathered gneiss is the increase in microfissuration. Weathering of most of intrusive rocks is typically time-dependant. Because of negative effects of weathering, before planning a project, it is important to assess the weathering condition of rocks from a geotechnical standpoint.

The knowledge about the strength, deformation behaviour and the failure characteristics of rocks is very essential in geotechnical engineering. The mechanical behaviour of rock is largely dependent on strength and deformability of rock material along with the inherent variations. Several researchers have showed the significant effect of weathering processes on strengths of different types of metamorphic and intrusive igneous rock variants. The study on granitic materials [2] revealed uniaxial compressive strength (UCS) for Grade I rocks varied from 214 to 153 MPa, and observed a deterioration of UCS, Elastic modulus (E) and increase of Poisson's ratio with the increase of weathering intensity, due to alteration of minerals, disruption of rock skeleton and microcrack augmentation. The weathering studies [1] on granitic gneisses from Nigeria, indicated an increase of degree of weathering and decrease of UCS (or E) with the increase of moisture content. However, the effect of weathering on gneisses of different chemical compositions is still needed to explore to find out the suitability of the rock as a foundation material in various civil constructions.

Garnetiferous Quartzo-Feldspathic Biotite gneiss (GQFBG) is a leucocratic, medium to coarse-grained metamorphic rock with well-developed foliation and bands (coarser than schistose rocks). It is characterized by alternating light and dark bands. It is mainly composed of quartz, feldspar, biotite and garnet. The light-coloured bands are made up of feldspar and quartz while the dark bands consist of biotite or garnet. Feldspars are identified by their white to grey colour, sub vitreous lustre and good prismatic cleavages. Quartz grains are distinguished by their vitreous lustre, conchoidal fracture, and lack of cleavage. Biotite grains are recognised by their flaky habit, brownish black colour, pearly lustre, transparency, perfect basal cleavage, and low hardness. Garnet grains are identified by their pink to brownish red colour, sub vitreous lustre, transparency, lack of cleavage, subconchoidal fracture and high hardness [11]. The bands are mostly discontinuous, and vary from 3mm to 1cm wide. The insitu studies [4,5] on Garnetiferous quartzo-feldspathic gneiss rock mass of southern peninsular India showed the decrease in modulus of deformation values of the order of 41.5 % and 61% from fresh to slightly weathered and to moderately weathered rock, respectively.

In the present study, Garnetiferous quartzo-feldspathic biotite gneisses (GQFBG) of different weathering grades from Eastern Ghat Mobile belt of southern peninsular India were investigated in the laboratory for their uniaxial compressive strength (UCS), tangent modulus (E), and Poisson's ratio(μ) in saturated condition. The rock belongs to Khondalite suite of Archean age. Besides, physical and slake durability characteristics on these variants were also studied.

2 Experimental Work

To assess the influence of weathering, the selected rock was broadly divided in to, i) Fresh rock (FR), ii) Moderately weathered rock (MWR), and iii) Highly weathered rock (HWR). Table 1 presents the weathering grades of selected rock along with typical sample photographs. These variants (8 numbers of specimens for each grade) were investigated in the laboratory for their uniaxial compressive strength (UCS), tangent modulus (E), and Poisson's ratio (μ) in saturated condition. To quantify the degree of weathering, X-ray diffraction (XRD) studies were carried to know mineralogical changes due to weathering. Using Cukα radiation (λ = 1.5404A^o), the representative powdered sample of each weathering grade was used for average quantification of minerals. Figure 1 shows the diffraction patterns of FR, MWR and HWR grades of rock. (Count v/s 2 THETA). Table 2 shows average mineral compositions of selected grades of weathering.

Table 1. Weathering grades of the investigated GQFBG samples

Degree of Weathering	Weathering Grade (ISRM,1981)	Characteristics observed	Typical Sample Photograph(s)
Fresh Rock (FR)	**I**	-No discolouration -Vitreous luster grains -Light coloured Garnets -No remarkable bands	
Moderately Weathered Rock (MWR)	**III**	-Moderate decomposed -Grains have sub-vi treous to dull luster -Dark coloured Garnets -Remarkable bands -Cannot be broken by geological hammer -Intact grain boundaries	
Highly Weathered Rock (HWR)	**IV**	-Loose Grain Boundaries -Highly decomposed -No luster. -Material discoloured -Presence of Red or Pink coloured garnets with dark remarkable bands -Can be broken easily by geological hammer	

2.1 Mineralogical Composition

The results of XRD analysis on the different weathering grades indicated the presence of feldspar and feldspar group minerals such as labradorite, oligoclase, and orthoclase in larger quantities (~ 70%) in both FR and MWR variants whereas in HWR, it is only ~20%. However, Almandine which belongs to Garnet structural group in only observed in HWR and could be attributed to discolouration of rock in red bands. Biotite which is phyllosillicate mineral within Mica group, is largely observed in HWR in comparison with other variants. This might have brought weak grain bonding in HWR, result in microcrack propagation under loading. The presence of clay minerals (Illite and Kaolinite) is also observed in MWR and HWR variants and these minerals are increased with the increase of degree of weathering due to dissolution of feldspars on saturation.

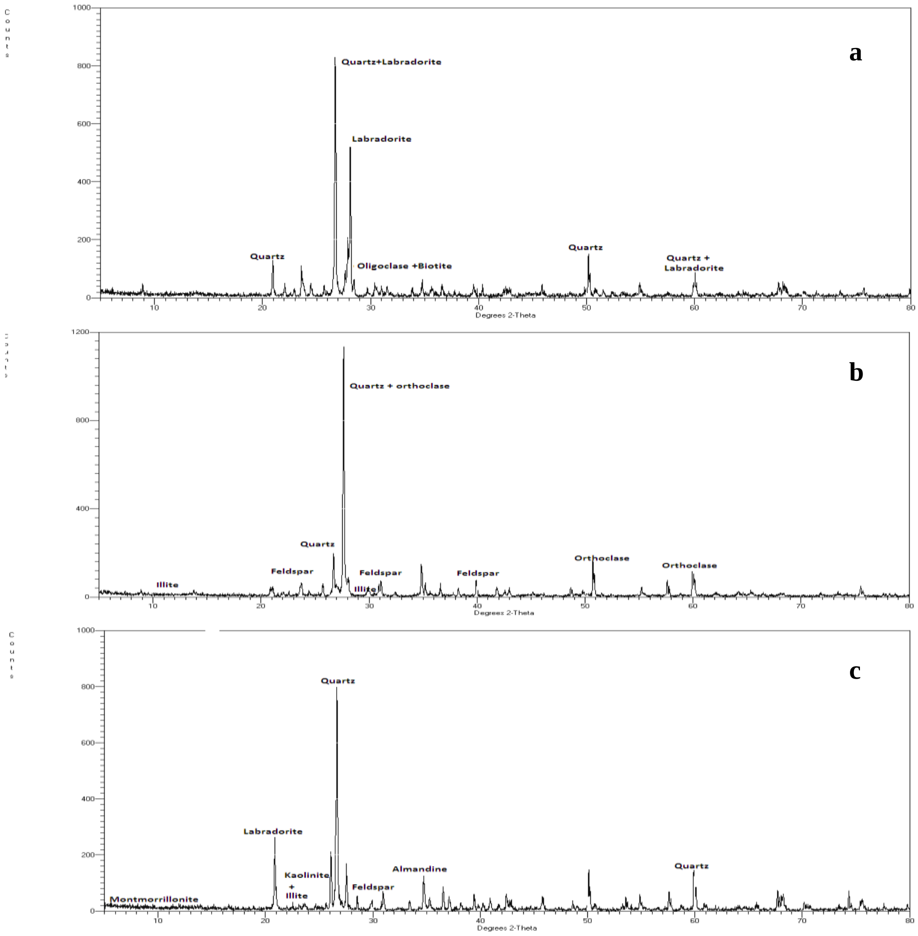


Fig. 1. Diffraction patterns for, a) FR, b) MWR, c) HWR grades

Table 2. Average mineralogical composition of GQFBG variants

Mineral	Q	La	Oli	Ortho	Al	F	B	I	Ko
FR (%)	27	49	20	ND	ND	2	2	ND	ND
MWR(%)	17	5	ND	26	ND	48	1	3	ND
HWR(%)	48	8	ND	ND	15	15	7	2	5

Q-Quartz; La-Labradorite; Oli-Oligoclase; Ortho-Orthoclase; Al-Almandine;
F-Feldspar; B-Biotite; I-illite; Ko-Kaolinite ; ND-Not detected

Rock samples were saturated by water immersion and a vacuum not less than 800Pa is applied for a period of no less than one hour, and all the investigations, were carried out as per procedures suggested by International Society of Rock Mechanics, ISRM [8]. The rock specimens of cylindrical cores (NX size) for carrying out UCS were prepared with length to diameter ratio (L/D) of 2.5 and ensured the dimensions of prepared specimens were within the tolerances as suggested by ISRM.

The uniaxial compressive strength (UCS) was evaluated under statically applied compressive load. The longitudinal and lateral strains of the specimen were measured with the help of electrical resistance strain gauges. Two vertical and two circumferential strain gauges were pasted at the middle of the specimen. The strain gauges were connected to the Data Acquisition System to find out the change in strain. For different weathering grades, the plots of the longitudinal strain, and lateral strain, each, versus the uniaxial compressive stress were used for evaluating the tangent modulus (at 50% of the ultimate uniaxial compressive strength) and the corresponding Poisson's ratio. For holistic analysis, physical, durability properties were also evaluated for these variants. The assessment of durability was done using slake durability test which generally based on second cycle slake durability index. To understand the effect of degree of weathering on durability of the rock, the slake durability test as per ISRM procedure [8] was carried up to 9 cycles. Accordingly, the results were deliberated under the following major categories: i) physical properties, ii) mechanical behaviour, and, mode of failure and iii) durability properties.

3 Results and Discussion

3.1 Physical Properties

Figure 2 shows the variation of densities (bulk densities both in dry and, saturated condition, and grain density) for three weathering grades of GQFBG. It is observed that HWR variant has resulted in lower densities in comparison with other variants. However, there is a marginal variation observed in densities among MWR and HWR variants. The results depicted that all the densities were decreased with the increase of degree of weathering from FR to HWR.

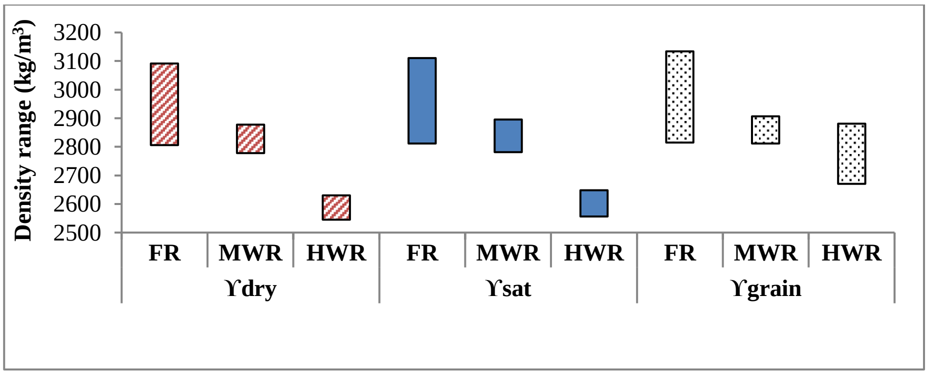


Fig. 2 Variation of densities

Figure 3 shows the variation of percentage of moisture content, and apparent porosity, in three weathering grades of rock. It can be observed that the percentage of moisture content and apparent porosity, are increased with the increase of degree of weathering. As the weathering grade increases, the clay minerals become more dominant due to dissolution of feldspar minerals in the rock on saturation, which in turn resulted in the increase of porosity. Also, the effect of moisture is more pronounced in HWR grade rock than other grades of weathering.

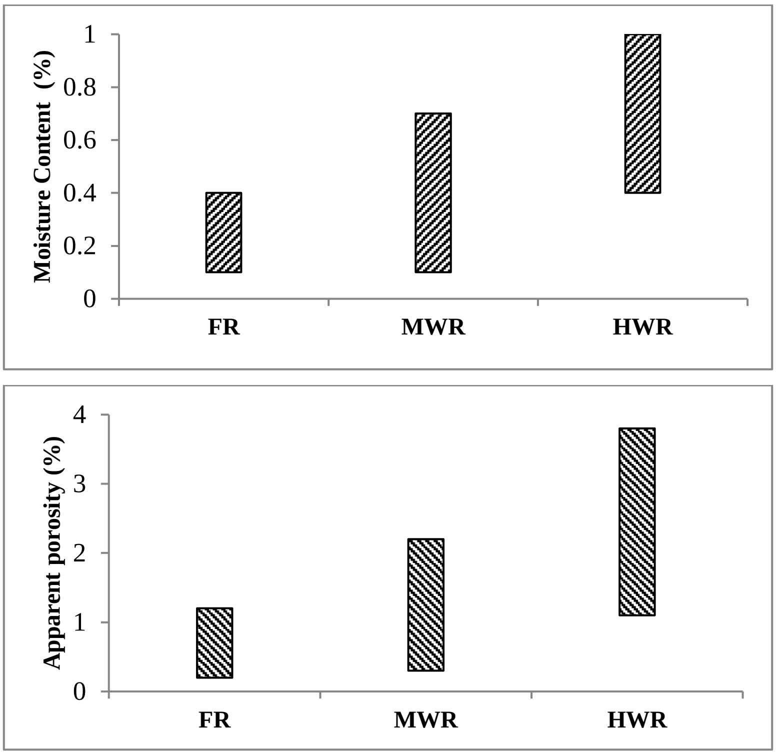


Fig. 3 Variation of moisture content and apparent porosity

3.2 Mechanical Behaviour

In this section, the mechanical behaviour of the GQFBG rock variants is discussed through uniaxial compressive strength and deformability parameters - tangent modulus (E) and Poisson's ratio (μ). The failure characteristics in uniaxial compression are also illustrated.

Uniaxial Compressive Strength. It is observed from Fig. 4 that HWR grade samples are failed in significant lower strengths (UCS_{sat} < 10MPa) than other variants of rock. This is possibly because of changes in microfabric due to alteration of original minerals to clay particles on saturation. In MWR grade, UCS_{sat} is varied around 30MPa; and a large range of UCS_{sat} is observed in FR grade (40 to 75MPa). On observation of the failure modes (Fig.5), it is evident that FR grade samples are failed in axial splitting mode along with chipping out of edges. This is a common failure behavior for any brittle material due to fractures developed from coalescence of micro cracks. The types of failure in MWR grade are by axial splitting and by shear along with secondary axial cracks. A closer observation of shear failure plane revealed the propagation of crack along weak mineral fabric of rock. Minerals in a rock behave differently during cracking and the failure mechanisms are dependent on both mineralogy and grain orientation [9]. In HWR grade, the samples were failed in pure shear with two shear planes. And most of samples in HWR grade were crushed under static loading. Hence, it can be inferred that as the weathering grade increases from FR to HWR, the mode of failure changes from axial splitting to pure shear. This observation is in line with studies of other researchers on granitic materials [2,7].

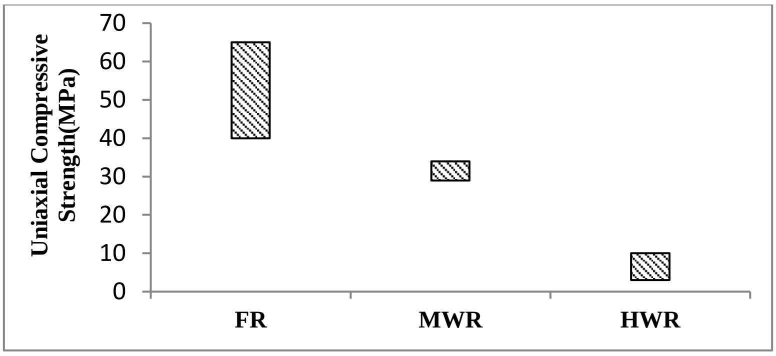
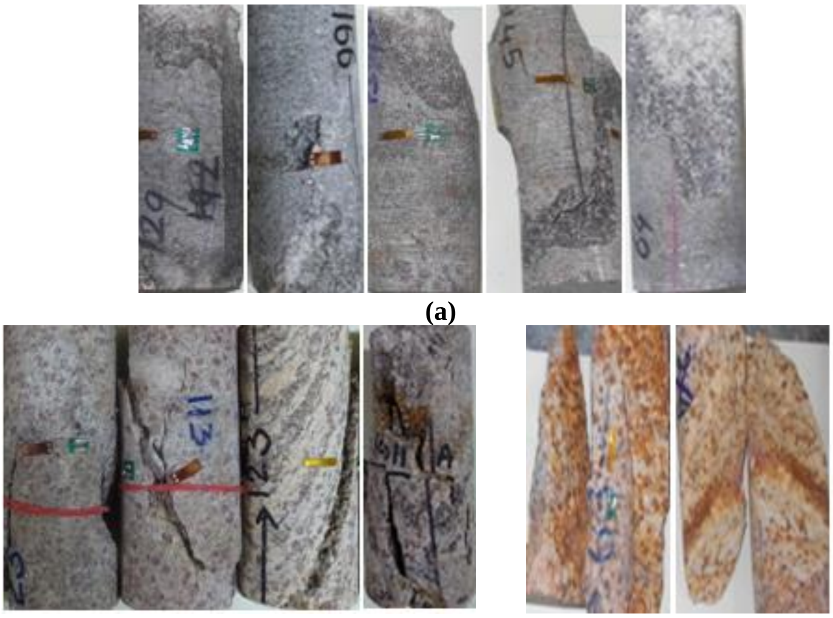


Fig. 4 Variation in UCS_{sat}



(a)

(b) (c)

Fig. 5 Mode of failure of a) FR, b) MWR, c) HWR grades in uniaxial compression

Deformability Characteristics. The variation of deformability characteristics namely Tangent Modulus (E_{sat}) and Poisson's ratio (μ_{sat}) for all the grades of rock is as shown in Figure 6. Similar to UCS, HWR grade samples have shown low Esat compared to other variants. However, Poisson's ratio is higher for HWR grade. This can be attributed to porous nature of HWR grade rock, in which pronounced deformation can be possible. As degree of weathering increases in the selected rock, decrease in tangent modulus and increase in Poisson's ratio is observed. The typical stress and strain plots for the three grades of weathering (Fig.7) shows HWR samples were failed in much lower strains than the other variants. It is also evident from figure 7 that deformational behaviour of selected grades changes from brittle to ductile mode with the increase of weathering intensity.

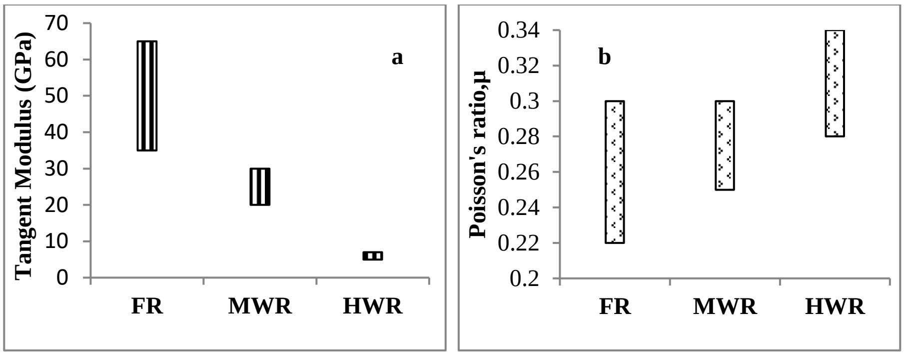


Fig. 6 Variation in a) E_{sat} , b) μ_{sat} in uniaxial compression

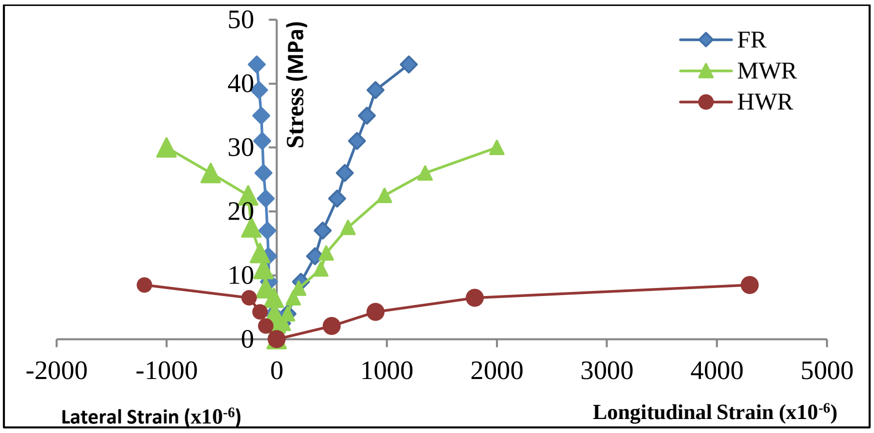


Fig. 7 Typical Stress-Strain Plot

3.3 Durability

The slake durability test was performed on the weathering grades of GQFBG and the indices are as shown in Figure 8. In general, the slake durability indices are obtained from second cycle of test as per ISRM [8]. However, as the variation from 1st cycle to 2nd cycle is high, the test was continued by increasing number of cycles up to 9.

It is observed that the weight retained for FR and MWR grades of rock shows linear trend even after 9 cycles (~ 98%) due to presence of hard minerals such as quartz, feldspar, which led to achieve higher durability than HWR grade rock. In

HWR grade, a remarkable decrease in weight retained can be observed from 1st cycle to 9th cycle because of damage of rock structure and adsorption of clay minerals emerged on alteration of original minerals. The water reaction with clay mineral increases the thickness of the diffused double water layer, surrounding the discrete clay particles. Consequently, this change causes, an increased repulsive force which can overcome the attractive force, and lead to the particles suspension in the water. It is therefore the clay-bound rocks such as HWR have much low durability.

The increase of number cycles in the present study is to reduce the weight loss trend gradually, especially for assessing durability of HWR grade variants. Studies carried out on granitoid rocks [10] of highly weathered and completely weathered grades, proposed at least 20 to 25 test cycles to achieve consistent weight reduction during cycles.

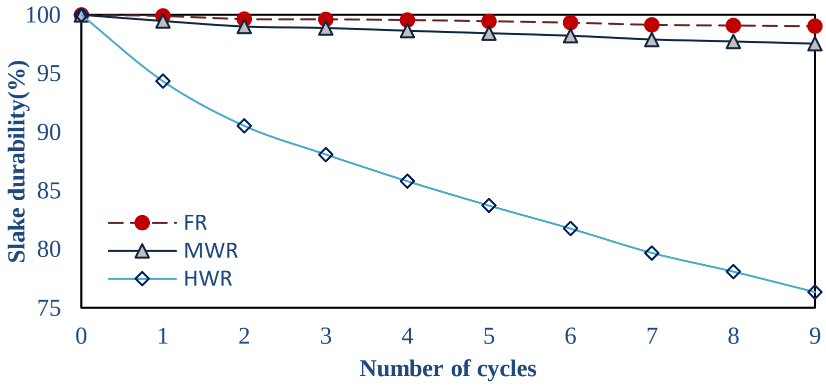


Fig.8 Variation of durability against number of cycles

Conclusions. In this study, the influence of weathering on mechanical behaviour of Garnetiferous quartzo-feldspathic biotite gneisses of fresh (FR), moderate(MWR) and high weathering(HWR) grades, from Eastern Ghat Mobile belt of southern peninsular India were investigated in the laboratory. Based on results, it is inferred that,

- The percentage of clay minerals is increased with the increase of degree of weathering. The clay minerals might have emerged due to alteration or dissolution of feldspar group of minerals, on saturation.
- The presence of clay minerals has drastically reduced the uniaxial compressive strength, UCS (<10 MPa) and tangent modulus, E (< 6 GPa) in HWR grade rock; whereas, Poisson's ratio (μ) is increased in HWR grade than other variants of rock. The reason could be increase of porous nature of HWR grade, which results in pronounced deformation of rock.
- As the degree of weathering increases, there is a decrease in UCS (or E) and increase in Poisson's ratio (μ) is observed.
- The mode of failure is changed from axial splitting to pure shear, with the increase of weathering intensity from FR to HWR. Also, the deformation behaviour is changed from brittle to ductile mode.
- All densities (bulk and grain) have decreased with the increase of degree of weathering.

- On slaking, the substantial reduction in durability indices is observed in HWR grade when increased slaking cycles up to 9. For long term evaluation of durability in HWR grade rock, the number of cycles may be increased while two cycles are sufficient for evaluation of weathering grade.

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