Weathering Grade Categorization and Subsequent Evaluation of Compressive and Tensile Strengths of Quartzite

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Abstract

Quartz, being the most resistant mineral to weathering, is the chief mineral constituent of quartzite. Therefore, capturing the intricate gradational change of quartzite in response to weathering, or categorization of weathering grades of quartzite rock materials, is a challenging task. Subsequently, characterization of compressive and tensile strengths with reference to weathering grades of quartzite rock materials does not seem to have gained much attention. This issue is focused in the present investigation.

Rock samples from a natural exposure at Turamdih region of Jaduguda in the Jharkhand state of India were taken, and a set of five recognition factors (staining, grain luster, grain boundaries, relative strength and slaking) was identified and used to describe the gradational changes caused by weathering of the quartzite rock materials. Weathering grades were assigned to the collected quartzite samples based on this weathering classification. Petrographic study substantiated the gradational deterioration of skeletal structure of the quartzites with the increase in the assigned weathering grades. Ultrasonic test on the quartzite materials also broadly complemented the assigned weathering grades quantitatively in terms of measured P-wave velocity.

Uniaxial compression and Brazilian tests were performed on quartzite cylinders and discs to determine compressive and tensile strengths respectively, and the test results were analyzed with reference to the assigned weathering grades. Both uniaxial compressive and Brazilian tensile strengths decrease as the weathering intensifies. However, overlapping of strength ranges is noted in adjacent weathering grades. High dependence of the absolute compressive and tensile strength decreasing patterns of the quartzite materials on the sudden augmentation of flaws/voids at early weathering stage (with the onset of weathering) and comparatively lower sensitivity of the same to the weakening of the skeletal structure at advanced stages of weathering becomes apparent from the present investigation. Loss of elasticity of the quartzite materials with increasing weathering intensity is also manifested.

Introduction

Quartzite is considered as one of the competent rocks for various engineering purposes (Gokhale, 2005). As quartz, one of the most resistant minerals to weathering (e.g. Ruxton and Berry, 1957; Irfan and Dearman, 1978; Gamon, 1985 etc.), is the chief mineral constituent of quartzite, unlike polymineralic rocks like granite etc., gradational decompositional change of quartzite is not portrayed by different minerals macroscipically. Therefore, assigning weathering grades of quartzitic materials with the help of a framed weathering classification scheme broadly in compliance with the common 6-fold classification by Anon (1995) or BS (1999) originally developed by Moye (1955) is challenging. Subsequently, evaluation of mechanical behaviour of quartzitic rock materials under compression and tension in relation to weathering grades has not gained much attention. This paper first focus on weathering grade categorization of quartzitic rock materials broadly following the common 6-fold weathering classification which is ascertained by microscopic observations and presents ultrasonic test results in order to obtain a quantitative control

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on the assigned weathering grades. Mechanical responses of these materials under uniaxial compression and indirect tension with reference to weathering grades are evaluated thereafter.

Assigning weathering grades to quartzitic materials

A total of 8 blocks of quartzite (numbered randomly as S1 to S8) that include fresh as well as differently weathered equivalents were collected from a natural exposure at Turamdih region of Jaduguda (Jharkhand, India). Geologically, the exposure belongs to the Chaibasa Formation (Saha, 1994).

A weathering classification was framed for the collected quartzite materials by recognizing a set of five factors (staining, grain luster, grain boundaries, relative strength and slaking) to describe gradational changes of the materials caused by weathering (Table 1). Assigned weathering grades to the investigated rock samples initially numbered randomly (S1 to S8) are presented in Table 2.

It is to be noted that the framed classification is broadly in compliance with the common 6-fold classification. As quartzitic rock materials are concerned in the present investigation where the chief mineral constituent (quartz) is considerably durable to weathering, gradational changes of these materials were also thought to be substantiated by salient petrographic observations. Fresh quartzite is composed mainly of quartz (>90% by volume) along with mica and chlorite. With the onset of weathering, biotite grains get chloritized (Fig. 1). Although unlike polymineralic rocks like granite weathering effect is not portrayed by different minerals in case of quartzite, loosening of quartz grain boundaries and increase in staining with increasing weathering intensity were conspicuous (Fig. 2). Therefore, the petrographic study validated the weathering grade categorization that was performed following the framed weathering classification scheme.

Table 1: Weathering classification for the investigated quartzite materials.

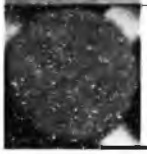
Quartzite	Characteristics	Weathering grade
	• No discoloration/staining • Grains have vitreous luster • Intact grain boundaries	I
	• Slight to moderate staining • Grains have vitreous to sub-vitreous lustre • Intact grain boundaries • Not easily broken by a geological hammer	II
	• Moderately stained • Grain boundaries not very intact • Can be broken easily by a geological hammer	III
	• Highly stained with loose grain boundaries • Large pieces can be broken by hand • Does not readily slake in water	IV

Table 2: Weathering grades assigned to the collected quartzite samples.

Sample no.	Weathering grade
S1	II
S2	III
S3	III
S4	II
S5	II
S6	IV
S7	II
S8	I

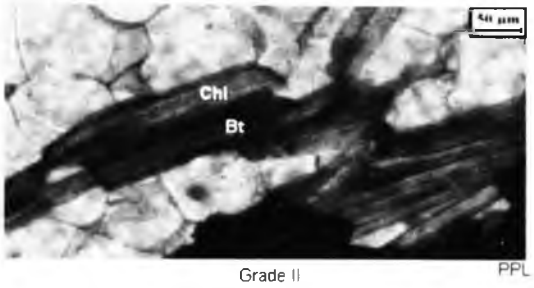


Fig. 1: Chloritization of biotite with the onset of weathering.

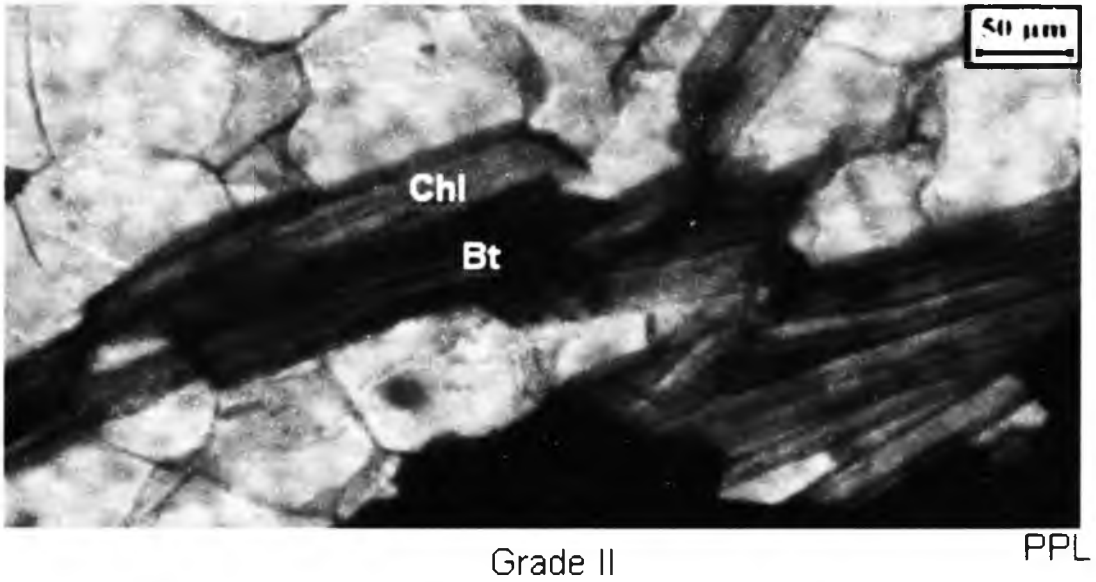


Fig. 2: Loosening of quartz grain boundaries and increase in staining with increasing weathering intensity.

Ultrasonic test

As both macro- and microscopic observations are subjective in nature, in order to gain a quantitative control on the assigned weathering grades, ultrasonic test (non-destructive in nature) was also performed on the quartzitic materials. A PUNDITplus PC1006Ó digital ultrasonic tester (measuring range: from 1 m/s to 9999 m/s; EHT voltage: 500V; pulse mode: continuous, 10 pulses per second; resolution: 0.1 ms) with one set of cylindrical piezoelectric transducers (frequency = 54 kHz, diameter = 50 mm) was used to measure longitudinal wave velocity (Vp) in case of direct pulse transmission.

The ranges of measured Vp values for different grades were found to be as follows: Grade I: 4950-3546 m/s; Grade II: 2025-777 m/s; Grade III: 1759-606 m/s; Grade IV: 468-171 m/s. The result shows that Vp decreases as weathering intensifies. The ranges of Vp values shows overlaps between Grade II and Grade III quartzites. Nevertheless, in the present study, Vp proves to be quite efficient in categorizing weathering grades of the concerned quartzite materials quantitatively.

Uniaxial compression and Brazilian tests, results and analysis

From the collected quartzite blocks, preparation of a total of 9 uniaxial

compression test specimens (diameter » 54.70 mm) was possible. Specimen dimensions were in compliance with ASTM D4543 (2001) specifications. An automatic compression test machine (AIM-314-FAÓ) of 1000 kN load capacity was used for uniaxial compression test along with axial deformation measurement of the 9 specimens. However, for one specimen (U2B), deformation could not be measured because of some technical problem. Deformation for each specimen was measured up to a load level that was greater than 70% of the peak load or equal to the peak load. The test procedure followed was in accordance with ASTM D2938 (2001).

Calculated uniaxial compressive strength (UCS) of the quartzite specimens are presented in Table 3. When UCS values were compared with the weathering grades of the specimens, a conspicuous decreasing trend of strength was noted with increasing weathering intensity (Table 3). Grade II and Grade III quartzites showed overlapping in UCS ranges (Table 3).

The stress-strain curves for all specimens (except U2B) obtained by processing the raw data of load and axial deformation in Microsoft Excel© are presented in Fig. 3. Although the stress-strain curves mainly represent the elastic deformational stage for each specimen, the subtended angle between the curve and the stress axis (Y-axis) becomes larger as weathering intensifies (Fig. 3). In other words, as degree of weathering of quartzite increases, axial deformation with respect to applied stress gets enhanced. Average slope of the more-or-less straight line portion of each stress-strain curve was calculated to obtain Young's modulus (E) as per ASTM D3148 (2001) (Table 3). When Young's modulus was compared with weathering grades of the related quartzite specimens, E not only showed a decreasing trend with increasing weathering intensity, but also depicted unique range for individual grade (Table 3).

A total of 39 Brazilian test specimens (discs with diameter » 54.7mm) were prepared from the collected quartzite blocks. Dimensions of all disc specimens complied with the ISRM (1978) stipulations. In this study, a Brazilian test frame fitted within the GCTS© point load system (PLT-100) of 100 kN load capacity was used. The test procedure was in accordance with the suggested method by the ISRM (1978). Calculated Brazilian tensile strengths (s_t) are presented in Table 4. Most specimens failed in splitting mode that is valid for Brazilian test whereas specimen 4F failed in invalid mode and specimens 2F and 6B showed strength below the detectable threshold of the equipment (Table 4). Some pre-existing cracks might have caused such unusual failures. In general, s_t of the concerned quartzite materials decreases as

Table 3: Uniaxial compression test results.

Block Sample No.	Core Specimen No.	UCS (MPa)	E (GPa)	Weathering Grade	UCS (MPa) Range as per weathering grade	E (GPa) Range as per weathering grade
S-8	U8A	205.76	45.56	I	-205.76-	-45.56-
S-1	U1A	51.71	6.07	II	114.75-51.71	15.88-6.07
S-4	U4A	114.29	15.88			
S-5	×	×	×			
S-7	U7A	114.75	10.77			
	U7B	78.30	9.11			
S-2	U2A	80.00	5.22	III	80.00-42.46	5.22-3.45
	U2B	42.46	×			
	U2C	54.41	3.45			
S-3	×	×	×			
S-6	U6A	42.44	1.08	IV	-42.44-	-1.08-

UCS: Uniaxial Compressive Strength

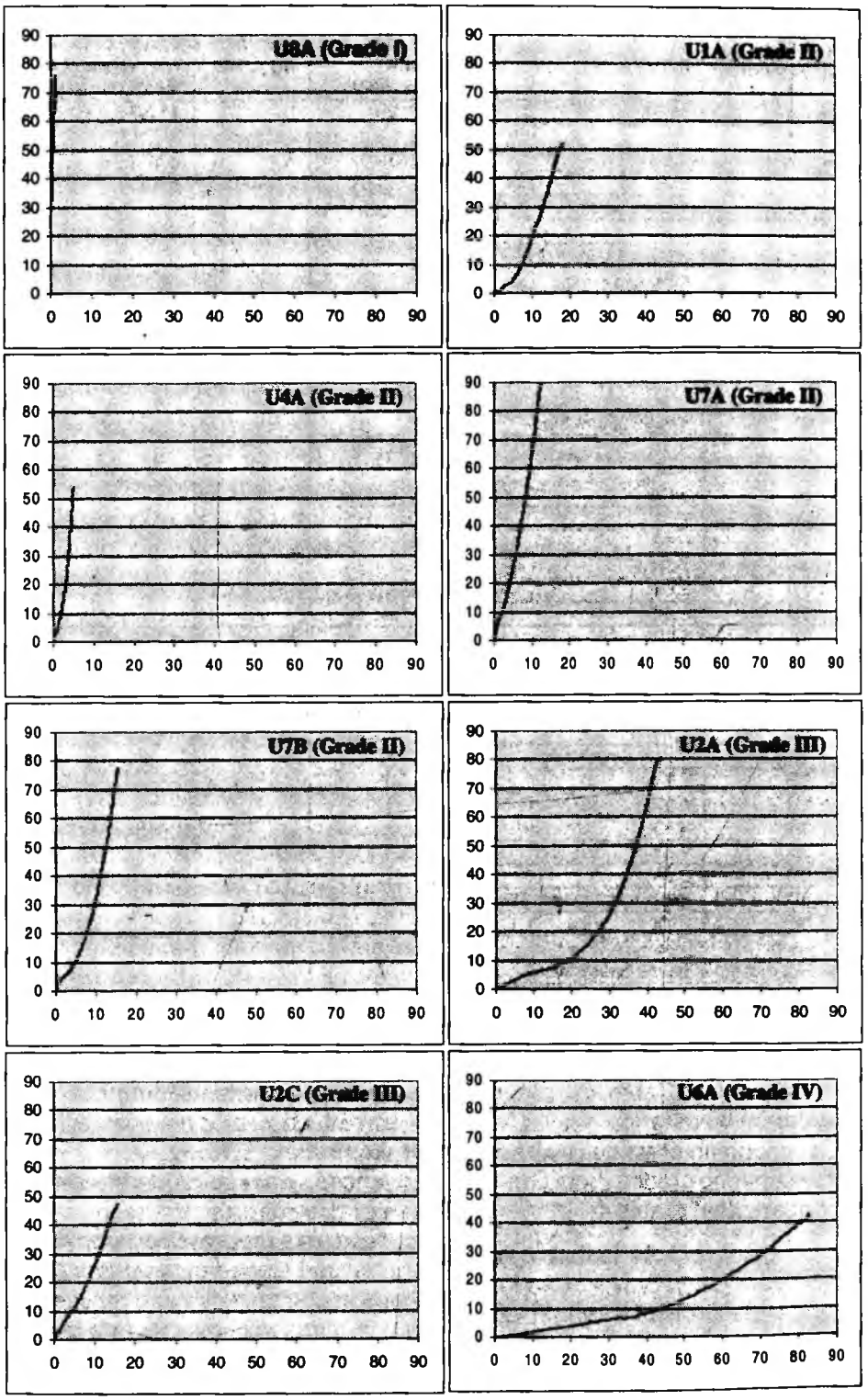


Fig. 3: Stress-strain response of quartzite specimens under uniaxial compression (note: maximum applied stress does not necessarily represent the peak stress).

Table 4: Tensile strength results.

Block sample No.	Core specimen no.	σ_t (Mpa)	Range of σ_t for block sample (MPa)	Weathering grade	Range of σ_t with reference to weathering grade (MPa)
S-8	8A	11.35	11.35-8.99	I	11.35-8.99
	8B	8.99			
S-1	1A	6.55	6.55-3.02	II	8.50-2.54
	1B	6.22			
	1C	4.61			
	1D	3.02			
	1E	6.00			
	1F	4.98			
S-4	4A	8.12	8.45-4.84		
	4B	8.45			
	4C	4.84			
	4D	5.66			
	4E	5.91			
	4F	Invalid failure mode			
S-5	5A	4.64	5.62-4.64		
	5B	5.62			
	5C	4.97			
S-7	7A	7.31	8.50-2.54		
	7B	6.10			
	7C	7.74			
	7D	2.54			
	7E	8.50			
S-2	2A	3.13	4.79-2.47	III	4.79-1.87
	2B	4.36			
	2C	2.47			
	2D	4.72			
	2E	4.79			
	2F	Below threshold			
	2G	2.76			
	2H	1.87			
S-3	3A	3.83	4.53-2.70		
	3B	4.53			
	3C	3.96			
	3D	4.24			
	3E	2.70			
S-6	6A	1.65	2.29-1.65	IV	2.29-1.65
	6B	Below threshold			
	6C	2.29			
	6D	1.70			

weathering intensifies (Table 4). When s_t ranges of different weathering grades were compared, overlapping of ranges was noted in adjacent weathering grades (from Grade II to Grade IV quartzites) (Table 4).

An interesting point to note is that in both uniaxial compression and Brazilian tests, the maximum absolute drop of strength takes place from Grade I to Grade II. The maximum absolute drop in ultrasonic P-wave velocity was also noticed to have happened in the early stage of weathering. This can be attributed to sudden augmentation of flaws/ voids of the quartzitic materials with the onset of weathering (Grade II). As weathering advances, weakening/deterioration of the skeletal structure of the quartzite also proceeds in a progressive manner. However, at elevated stages of weathering, absolute drops in compressive and tensile strengths and in ultrasonic velocity due to change in weathering grade do not remain as sensitive to weakening of the skeletal structure or mechanical coherence of the quartzite due

to induced heterogeneity and flaws/voids as they do at early weathering stage.

Conclusions

Influence of weathering on mechanical behaviour of rock materials under compression and tension is an important issue in rock engineering. Nevertheless, a lack of studies focusing mainly on gradational changes of quartzite due to increasing weathering intensity and on mechanical behaviours of quartzites with reference to weathering grades seems to exist. This issue was explored in the present study.

Microscopic study also validated the classification. Ultrasonic P-wave velocity demonstrated good quantitative agreement with the assigned weathering grades.

Although both uniaxial compressive and Brazilian strengths showed a decreasing trend with increasing weathering grades, overlapping of strength ranges was noted in adjacent weathering grades for the concerned quartzitic materials. When Young's modulus was compared with weathering grades of the related quartzite specimens, it not only showed a decreasing trend with increasing weathering intensity, but also depicted unique ranges for individual grade. The maximum absolute drop in uniaxial compressive and Brazilian strengths and in ultrasonic P-wave velocity could be attributed to sudden augmentation of flaws/voids of the quartzitic materials with the onset of weathering (Grade II). However, at elevated stages of weathering, such absolute drops in compressive and tensile strengths and in ultrasonic velocity due to change in weathering grade do not remain as sensitive to weakening of the skeletal structure or mechanical coherence of the quartzite due to induced heterogeneity and flaws/voids as they do at early weathering stage.

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References

Anon (1995): The description and classification of weathered rocks for engineering purposes: Geological Society Engineering Group Working Party Report. Q. J. Eng. Geol., Vol. 28, 207-242.

ASTM D2938 (2001): Standard test method for unconfined compressive strength of intact rock core specimens. ASTM Standards on Disc, 04.08.

ASTM D3148 (2001): Standard test method for elastic moduli of intact rock core specimens in uniaxial compression. ASTM Standards on Disc, 04.08.

ASTM D4543 (2001): Standard practice for preparing rock core specimens and determining dimensional and shape tolerances. ASTM Standards on Disc, 04.08.

BS (1999): Code of practice for site investigations. BS5930.

Gamon, T. I. (1985): The influence of weathering on the engineering properties of the Hong Kong granite. PhD thesis, The University of Newcastle upon Tyne, United Kingdom.

Gokhale, K. V. G. K. (2005): Principles of engineering geology. BS publications, 268.

Irfan, T. Y. and Dearman, W. R. (1978): Engineering classification and index properties of a weathered granite. Bull. Int. Assoc. Eng. Geol., Vol. 17, 79-90.

ISRM (1978): Suggested methods for determining tensile strength of rock materials. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., Vol.15, 99-103.

Moye, D. G. (1955): Engineering geology for the Snowy Mountain scheme. J. Inst. Eng., Vol. 27, 287-298.

Ruxton, B. P. and Berry, L. (1957): The weathering of granite and associated erosional features in Hong Kong. Bull. Geol. Soc. Am. Vol. 68, 1263-1292.

Saha, A. K. (1994). Crustal evolution of Singhbhum, North Orissa, Eastern India. Geol Soc. Ind. Mem., Vol. 27, 341.