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Correlation between the Petrography and Physico-mechanical Properties of Commercial Granites of Jalore – Barmer Region, Rajasthan, India

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Abstract:**The quality of dimension stones not only depends on aesthetic look and elegance, but also its petrographic characteristics and physico-mechanical properties. The present study is on the determination of the quality of commercial granites of Rajasthan which are widely used for dimension / ornamental purposes. In the present paper the petrographic characteristics, physico-mechanical properties and correlationship between these two parameters of most demanded commercial granite types of Jalore and Barmer areas have been discussed.**

Index Terms: **Commercial granites, Jalore-Barmer granites, Petrography, Physico-mehanical properties, Rajasthan granites.**

I. Introduction

Granite is an important dimensional and decorative stone. Technically granite refers to a light-colored granulose plutonic rock composed essentially of potash feldspar and quartz with minor amount of plagioclase and mafic minerals, such as, biotite, hornblende, pyroxene, iron oxides, etc. However, in commercial phrasing, the term granite has become synonymous with all those crystalline rocks which have pleasing colors, strength to bear the processes of quarrying and cutting and polishing and which are used commonly for decorative purposes. Being more resistant to wear and tear as well as weathering, granite is most sought-after stone to be used as building as well as decorative stone. Commercial Granite is defined by the American Society for Testing and Materials (ASTM, 2005) as a "visibly granular, igneous rock generally ranging in color from pink to light or dark grey, and consisting mostly of quartz and feldspars, accompanied by one or more dark minerals". According to Walle and Heldal (2001),any igneous rock closely related to granite, granodiorite, porphyry, gabbro, dolerite and metamorphic rocks such as gneiss are considered as ‘granite’.

Nowadays granite has been extensively used as a dimension stone and as flooring tiles both in public and commercial buildings and monuments. The quality of dimension stones not only depends on aesthetic look and elegance, but also its petrographic characteristics and mechanical properties. The study of the mechanical properties of rocks and their respective mineralogy characteristics are important in determining the rocks strength and its capability from failure (Tugrul and Zarif, 1999). The properties of rock are influenced by the mineral composition, texture (grain size and shape), fabric (arrangement of minerals and voids) and the weathering state (Irfan, 1996). Granitic rocks have variety in their mineralogy, petrographic characteristics and engineering properties. Petrographic characteristics and mineralogy composition could be affecting the mechanical properties of the rock. In the present paper the petrographic characteristics and physico-mechanical properties of representative samples of commercial granites of the area have been discussed.

II. GRANITE RESOURCES OF RAJASTHAN

Rajasthan is richly endowed with large reserves (around 9190 million m^3) of different varieties of granites spread over in 23 districts of the state. Important production centers are mainly spread in the districts of Jalore, Barmer, Pali, Sirohi, Barmer, Ajmer, Jaisalmer, Jhunjhunu and Jodhpur (DMG, 2014; RIICO, 2016). Rajasthan experienced large number of scattered granitic emplacements in different geologic times i.e. from the Archean to Neo-Proterozoic age. However, the majority of commercial granites belong to Meso to Neo Proterozoic age. Granites of the state are having diverse mineralogy, petrochemistry and emplacement history.

Figure 1: Map showing the distribution of granite mining in Rajasthan

Jalore and Barmer districts are the leading producers of commercial granites in Rajasthan. There are 227 mining leases in Jalore and 184 mining leases in the Barmer district for granites (Figure 1). The granites of the area are considered as a part of Malani Igneous Province (Neo-proterozoic age) and there are 15 granitic plutons in the area. The granites of Malani Igneous Province are broadly classified into three types (1) Jalore Granites, Jalore district, (2) SiwanaGranites ,Barmer district and (3) Malani Granites, Barmer district (Bhushan and Chandrasekran, 2002). Commercially the granites of the area are sale in different trade names like Bala Flower, Chima Pink, Copper Silk, Golden Pearl, Imperial Pink, Rosy Pink, Royal Touch, Sunrise Yellow, Merry Gold, Rakhee Green, Platinum White, Black Granite,etc (Figures 2 and 3).

Figure 2: View of granite quarry at Jalore

III. METHODOLOGY

Twenty seven samples of granites of different trade names have been collected for petrological and physico-mechanical studies. Thin sections of these samples were prepared and petrographic information was acquired from these thin sections. The physico-mechanical properties of the granites of the study area have been determined by following the standard procedures of the Bureau of Indian Standards (BIS) and ASTM. The analyses were conducted at Rahul Engineering Laboratory, Udaipur which is ISO/IEC accredited and ISO 9001:2008 certified laboratory and recognized for such testing work (Figure 4 and 5).

Figure 3: Few commercial varieties of Rajasthan granites

Figure 4: Photograph showing making of three cubes of granite sample for the triplicate testing of compressive strength

Figure 5: Compressive strength test by the digital compression testing machine.

IV. PETROGRAPHY

Commercial granites of the area exhibit both equigranular and inequigranular texture and vary in size from fine to very coarse grained (pegmatitic). However, the majority of granites are medium to coarse grained and showing characteristic hypidiomorphic texture. The essential minerals of the granites of the area include potash feldspar (orthoclase or microcline), quartz and plagioclase. Accessory minerals are hornblende, reibeckite, biotite, aegirine, muscovite, apatite, zircon and opaques. Secondary minerals are chlorite and sericite. Potash feldspar is the dominant mineral phase in most of the granites of the area. The granites of the area are having variations in the size and type of potash feldspar i.e. few granites are having microcline while others are having orthoclase. However, perthic intergrowth is common in majority of the granites. The Exsolution lamellae of albite are well visualized within the perthite. The perthites are of lamellar, string and braided type. Alteration along grain boundaries is very common in these grains. Partial to complete sericitization was observed in the feldspar grains. Quartz grains are variable in size and invariably anhedral with serrated margin (Figures 6, 7 and 8). The modal analysis reveals that the alkali feldspar is the dominating mineral in most of the granitic rocks of the area. The concentration of alkali feldspar ranges from 6.3% to 73.64%. Quartz is another leading mineral in these rocks which ranging from 17.43% to as high as 38.03%. Plagioclase is also present in the majority of granites but the concentration is highly variable from 1.4% to 43.12%. Amphiboles and mica are invariably present in these granites in minor concentrations.

As per the IUGS classification scheme, from the QAP diagram, it has been observed that the commercial granites of the area are not homogeneous in composition. Out of 27 granites 12 granites are “Alkali – Feldspar Granites”, 11 are “Syeno – Granites”, 2 are “Monzo Granite” and one each is “Alkali – Feldspar Quartz Syenite” and “Granodiorite” respectively (Figure 10).

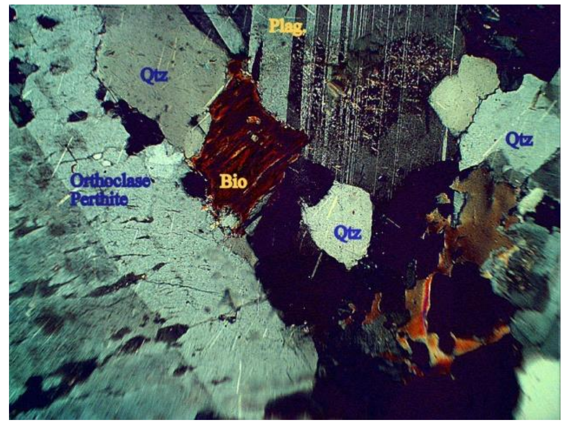

Figure 6: Photomicrograph of granites showing subhedral grains of altered perthite and plagioclase, anhedral grains quartz and biotite laths are also visible

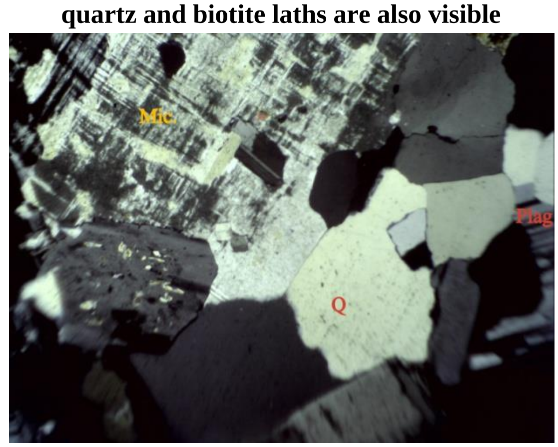

Figure 7: Photomicrograph of coarse grained granite with large grain of microcline showing cross hatched twinning and anhedral quartz grain

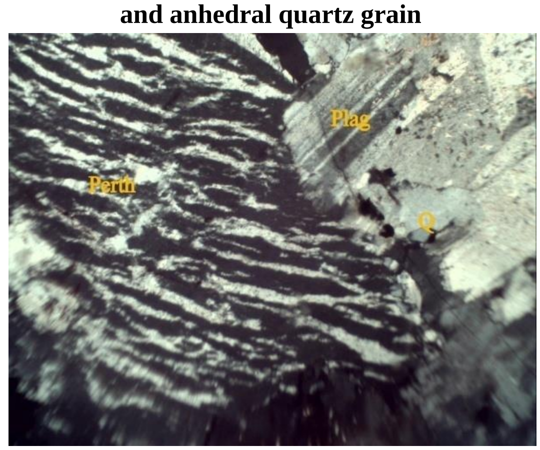

Figure 8: Photomicrograph of coarse grained granite having lamellar perthitic intergrowth with grain of plagioclase

V. PHYSICO – MECHANICAL CHARACTERISTICS

In present study few of the physico-mechanical properties like compressive strength, density, specific gravity, modulus of rupture, water absorption and rock hardness have been analyzed (Table 1).

Rock Hardness

All the 27 samples of granites were tested for rock hardness, calculated by using the Moh's scale used for minerals as per the procedure given by Hoseinie et al. (2009). The rock hardness of granites in the area varies from 5.61 to 6.22. The maximum hardness of 6.22 was reported in Mountain Green granite (JB-20) which is due to the presence of a high percentage of quartz (38.43%) and alkali feldspar (43.47%) and very low percent of mica and others. Similarly, the lowest hardness 5.61 was for Black Granite (JB – 14) which is having a low percentage of quartz (19.28%) and a high amount of mica (12.9%). Otherwise, most of the granites in the area are having rock hardness between 5.9 to 6.18.

A. Quartz to Feldspar Ratio

Since quartz and feldspar give high control and influence in rock strength and durability as such, quartz to feldspar ratio in the granites was also calculated. The ratio in the granites of the area is highly variable and ranges from 0.23 to 0.71. The lowest value of 0.23 was found in Mokalsar Green (JB-4) which is having low amount of quartz (17.43 %) and a high amount of feldspar (73.01%). Similarly Rakhi Green (JB-3), Classic White (JB-12) and Golden Pearl (JB-8) varieties are also having low ratio i.e. below 0.30 as all these rocks are having a low amount of quartz and a high amount of feldspar. The highest value of 0.71 is reported in the Mountain Green (JB-20) variety which is having a high amount of quartz (38.03%). Similarly, Platinum White (JB-23) also has high quartz to feldspar ratio due to same reason. Relatively high quartz to feldspar ratio i.e., more than 0.50 is also reported in Copper Silk (JB-9), Baltic Blue (JB-22), Merry Gold (JB-18), Urban Classic (JB-24), Bala Flower (JB-26), Kharda Red(JB-27), and Imperial Pink (JB-28).

B. Density and Specific Gravity

The density of the granite samples were calculated by using standard BIS procedure IS 1122 – 1974. From the analysis it has been observed that the density of commercial granites of the area varies from 2.59 to 2.80. The international standards (ASTM) require minimum of 2.56 gm/cc of density for commercial granites. As such, all the granites of the area are having required density. Similarly, the specific gravity of the granite samples were calculated by using standard BIS procedure IS 1124 – 1974. From the analysis it has been observed that the specific gravity of commercial granites of the area varies from 2.52 to 2.70. The rocks having specific gravity ≥ 2.55 are considered to be suitable for heavy construction work. As such, majority of the granites are having higher specific gravity i.e. more than 2.55.

C. Compressive Strength

The compressive strength of the granite samples were tested by using standard BIS procedure IS 1121 – 1974 (Pt – I). From the test results it has been observed that the compressive strength of commercial granites of the area varies from 1106.00 kg/cm^2 to as high as 1920.6 kg/cm^2. The lowest value was found in Imperial Pink granite (JB-28) and the highest compressive strength was observed in Kharda Red granite (JB-27). The Indian standards for commercial granites require minimum compressive strength to the tune of 1000 kg/cm^2. As such, all the granites of the area are full filled the BIS requirements of commercial granites. However, for the export of granites the international standards (ASTM) require compressive strength minimum 1335.83 kg/cm^2. When the compressive strength of the commercial granites of the area is compare with the ASTM standards, it has found that few of the granites are not having the required standards.

The commercial granites when classified into different grades on the basis of compressive strength, it can be observed that only one variety of granite i.e. Kharda Red (JB-27) is classified under "A" grade. Five commercial granite of the area i.e. Mokalsar Green (JB-4), Golden Pearl (JB-8), Jeerawal White (JB-16), P. White (JB-23) and Urban Classic (JB-24) are of "B" grade granites. Rest of the varieties is of "C" grade. None of the granite of the area is categorized as "D" grade.

D. Water Absorption

The water absorption of the granite samples were tested by using standard BIS procedure IS 1124 – 1974. From the test results it has been observed that the water absorption of commercial granites in the area varies from 0.04 % to as high as 0.70 %. The Indian standards for commercial granites require maximum amount of water absorption of 0.50 %. As such, all the granites except Merry Gold (JB-18) of the area full filled the BIS requirements with respect to water absorption. However, for the export of granites the international standards (ASTM) require a water absorption maximum value 0.40 %. When the water absorption values of the commercial granites of the area are compared with the ASTM standards, it has been found that two granite varieties i.e. Merry Gold (JB-18) and Chima Pink (JB-15) are having higher values.

E. Modulus of Rupture

The modulus of rupture of the granite samples were tested by using standard ASTM procedure C-99. From the test results, it has been observed that the modulus of rupture of commercial granites of the area varies from 112.12 kg/cm^2 to as high as 234.45 kg/cm^2. The ASTM standards for commercial granites require a minimum value of modulus of rupture as 105.43 kg/cm^2. As such, all the granites of the area are full filled the ASTM requirements with respect to the modulus of rupture.

VI. DISCUSSION

The physical and mechanical properties of a rock depend on petrographic characteristics like mineralogical concentrations of essential minerals, sizes and shapes of constituent minerals, their degrees of variation, preferred orientation of mineral grains, the volume of empty spaces, nature of alteration etc. A number of investigations have studied the relationship between petrographical and physico-mechanical properties of granites. The results of these investigations indicated that the mechanical strength of granites are generally a function of a wide range of petrographic parameters including grain size (Eberhardt et al., 1999; Tuğrul and Zarif, 1999; Akesson et al., 2001; Prikryl, 2006 and Yılmaz et al., 2010), mineral composition (Miskovsky et al., 2004), and weathering (Tuğrul, 2004; Vasconcelos et al., 2008 and Basu et al., 2009). According to Quick (2002) an accurate description of the texture, mineralogy, and other microscopic features one can predict the physical, chemical, and mechanical behaviour of rock. Mineralogical composition is one of the main properties controlling the rock strength. The increase of quartz in rock would increase the strength of rock. Similarly, rocks with finer grain sizes are stronger than their coarse-grained counterparts (Bell, 2007). Raisanan (2004) reported that mechanical properties are significantly influenced by the abundance of fine-grained minerals, grain-size distribution, and degree of interlocking of grain boundaries of minerals. Higher strength in granitic rock can be related to the degree of interlocking. Interlocking or intergrowth of grain would result in the lowest strength values (Tugrul and Zarif, 1999). The strength of rock is also highly affected by the process of alteration and weathering. The strength of a rock undergoes a notable reduction in weathering (Bell, 2007).

The physico-mechanical properties of the commercial granites of the area when compared with the petrological characteristics then it has been observed that majority granites of the area are showing positive relationship between quartz percentage and compressive strength of rocks. It is believed that the quartz percentage generally influenced the compressive strength of a rock i.e. higher percentage of quartz has higher strength of rocks. However, in two varieties i.e. Merry Gold (JB-18) and Imperial Pink (JB-28) the quartz percentage is high (more than 31%) but the compressive strength is low (less than 1200 kg/cm2). The possible reason behind this is that both the granites are medium to coarse grained, inequigranular and the feldspar is altered. According to Bell (2007) the strength of rock is highly affected by the process of alteration and weathering. Surprisingly in two granites i.e. Mokalsar Green (JB-4) and Rakhee Green (JB-3), although the quartz percentage is low (below 20%) but, the compressive strength is high (1590.5 kg/cm2 and 1355.74 kg/cm2 respectively). This is due to the fact that both the granites are equigranular and one feldspar granite i.e. plagioclase is absent. The presence of the plagioclase causes a reduction in strength (Meriam et. al., 1970).

The strength is of granite decreased significantly as the grain size is increase in igneous rock (Onodera et al, 1980). In the present area, it has been observed that the fine-grained varieties are having more compressive strength in comparison to the coarse to very coarse grained varieties. Z. Brown (JB-10), Jeerawal White (Jb-16) and Kharda Red (JB- 27) are fine to medium grained varieties and are having higher compressive strength, while the Merry Gold (JB-18), Sunrise Yellow (JB-19) and Imperial Pink (JB- 28) are coarse grained varieties and having low compressive strength i.e. below 1200 kg/cm2.

The availability of weak minerals (i.e. plagioclase, biotite and muscovite) can have opposite effects on the strength parameters of the rocks. This is indicative by the mica verses compressive strength variation diagram (Figure 9) for the granitic rocks of the area where more or less negative correlationship has been observed. In the present case the Black granite (JB-14) which is rich in plagioclase has low compressive strength (1234.45 kg/cm2). Similarly the granites which are rich in mica (biotite and muscovite) are also having low compressive strength e.g. Black granite (JB-14), Sunrise Yellow (JB-19), Baltic Blue (JB-22) and Imperial Pink (JB-28).

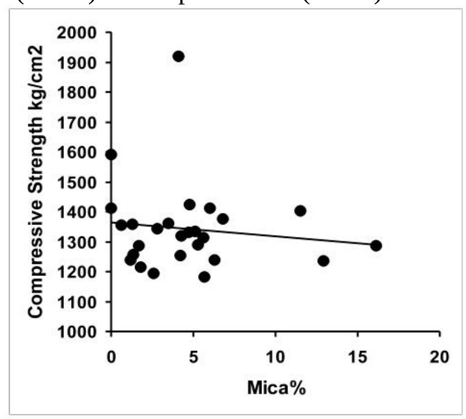

Figure 9: Mica v/s compressive strength variation diagram of commercial granites of the area

The quartz to feldspar ratio has an impact on the compressive strength of the granitic rocks. When the quartz to feldspar ratio of different granites were plotted against the rock hardness, it has been observed that there is a positive correlation between these two parameters i.e. in most cases there is an increase in rock hardness with the increase in quartz to feldspar ratio (Figure10). However, in the case of Black Granite, Baltic Blue and Platinum White varieties there has been a decrease in rock hardness which is due to the fact that these granites are having a high amount of mica content, causing a lowering of rock hardness.

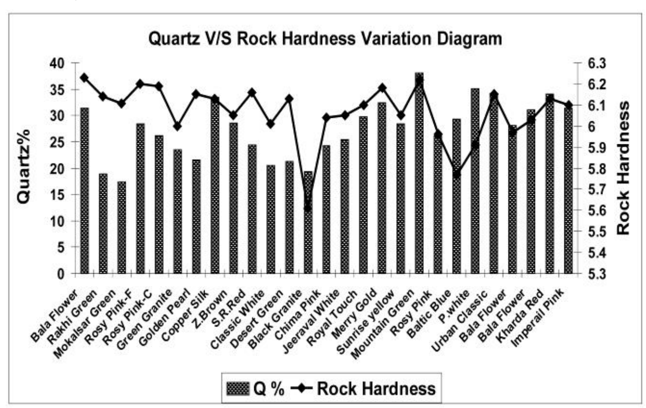

Figure 10: Quartz v/s rock hardness variation diagram of commercial granites of the area

Table 1: Physico-mechanical properties of commercial granites of Jalore – Barmer areas, Rajasthan

S. No.	Commercial Name	Rock Hardness	Quartz/ Feldspar Ratio	Bulk Density gm/cc	Specific Gravity	Water Adsorption (%)	Compressive Strength kg/cm^2	Modulus of Rupture kg/cm^2
JB - 2	Bala Flower	6.23	0.47	2.69	2.53	0.11	1358.70	234.45
JB - 3	Rakhi Green	6.14	0.25	2.71	2.64	0.10	1355.74	122.32
JB – 4	Mokalsar Green	6.10	0.23	2.77	2.68	0.09	1590.50	126.14
JB - 5	Rosy Pink (Fine)	6.20	0.41	2.59	2.52	0.06	1238.52	163.09
JB - 6	Rosy Pink (C)	6.19	0.37	2.71	2.60	0.19	1286.74	122.45
JB - 7	Green Granite	6.00	0.37	2.68	2.61	0.17	1375.04	121.86
JB - 8	Golden Pearl	6.15	0.29	2.73	2.53	0.12	1412.80	142.71
JB – 9	Copper Silk	6.13	0.58	2.65	2.60	0.04	1360.84	193.67
JB - 10	Z.Brown	6.05	0.34	2.60	2.57	0.09	1342.56	142.38
JB - 11	S.R. Red	6.16	0.34	2.60	2.57	0.15	1214.54	123.21
JB - 12	Classic White	6.01	0.28	2.63	2.52	0.24	1334.43	116.56
JB - 13	Desert Green	6.13	0.31	2.60	2.57	0.07	1257.23	122.13
JB - 14	Black granite	5.61	0.39	2.80	2.70	0.06	1234.45	117.89
JB - 15	Chima Pink	6.04	0.38	2.62	2.58	0.43	1320.07	122.32
JB - 16	Jeeraval White	6.05	0.38	2.63	2.58	0.08	1423.45	119.79
JB - 17	Royal Touch	6.10	0.48	2.63	2.57	0.12	1253.81	183.48
JB - 18	Merry Gold	6.18	0.54	2.61	2.53	0.70	1192.65	147.80
JB - 19	Sunrise Yellow	6.05	0.46	2.66	2.60	0.14	1183.50	137.61
JB - 20	Mountain Green	6.22	0.71	2.62	2.59	0.05	1332.32	120.43
JB - 21	Rosy Pink Dark	5.96	0.42	2.63	2.56	0.17	1238.52	120.34
JB - 22	Baltic Blue	5.77	0.56	2.67	2.64	0.11	1287.68	131.04
JB - 23	Platinum White	5.91	0.70	2.65	2.58	0.20	1401.62	112.12
JB - 24	Urban Classic	6.15	0.57	2.60	2.57	0.07	1412.45	135.65
JB - 25	Bala Flower	5.97	0.45	2.64	2.61	0.24	1288.52	229.15
JB - 26	Bala Flower	6.03	0.53	2.66	2.59	0.25	1312.24	227.32
JB - 27	Kharda Red	6.13	0.59	2.67	2.57	0.05	1920.60	145.23
JB - 28	Imperial Pink	6.10	0.52	2.65	2.59	0.15	1106.00	132.51

VII. CONCLUSION

The excellence of dimension stones greatly depends on the petrographic characteristics and physico-mechanical properties. To determine the long-term stability of the commercial granites of the area the durability index on different parameter has been calculated on five point scale and scoring was made accordingly to each of the granite variety. Finally an amalgamated durability index sheet was prepared. The parameters used for such calculations were texture, alteration, quartz modal percentage, quartz to potash feldspar ratio, mica percentage, rock hardness, compressive strength, specific gravity, water absorption and modulus of rupture. The results of amalgamated durability index sheet reveal that two varieties of granites i.e. Rosy Pink Fine (JB – 5) and Kharda Red (JB-27) are the most durable stone because their amalgamated durability index is 40 (80%) and the least durable stone are Chima Pink (JB-15) and Classic White (JB-12) as they are having amalgamated durability index 30 or below (60% or less). The other granite varieties are having amalgamated durability index ranging from 31 to 39, and can be considered durable to some extent.

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