Full Length Research

Petrography and physico-mechanical properties of the granitic rocks from Kumrat valley, Kohistan Batholith, NW Pakistan

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The granitic rocks of the Kumrat area (upper Dir group of Kohistan Batholith) have been investigated in terms of their petrographic features and mechanical properties. Field observation and petrographic studies of representative samples reveal that the Kumrat granites are sub-equi-granular to inequigranular, coarse to medium grained and without any preferred orientation. They essentially consist of plagioclase, quartz and alkali feldspar (exclusively orthoclase) with accessory amounts of biotite, muscovite, sericite, an opaque ore mineral and trace amounts of apatite. Chlorite observed in the studied samples is undoubtedly a secondary mineral. The quartz grains are mostly strained and display strong undulose extinction.

As a part of present study, some of the mechanical and physical properties including uniaxial compressive strength (UCS), uniaxial tensile strength (UTS), shear strength, specific gravity, porosity and water absorption of samples representing different textural varieties of Kumrat granites were also determined. The average UCS values for coarse and medium grained varieties are 49.15 and 58.50 respectively. On the basis of UCS values, the coarse grained and medium grained varieties fall in the category of moderately strong and strong rocks respectively. Correspondingly the values of their specific gravity, porosity and water absorption are within the range permissible for their use as construction material. A detailed investigation of petrographic features and mechanical properties reveals that the medium-grained granites are stronger than the coarse-grained ones, probably because of their relatively finer grain size. Elaboration of the relationship between physico-mechanical properties and petrographic characteristics is needed.

Key words: Granitic rocks, petrography, mechanical properties.

INTRODUCTION

The study area (upper Dir group, Kumrat valley, Figure 1) (35°31' 41.03” N, 72° 14' 06.47” E) is believed to be the part of Kohistan Batholith (Sullivan et al., 1993). Paleocene and younger volcanic and volcano-clastic rocks of the southwestern part of Kohistan arc are defined as Dir Group (Sullivan et al., 1993; Tahirkheli, 1979).

The Cenozoic magmatism in the KIA (regarded as cretaceous intra oceanic Kohistan Island Arc) is represented by Sharmar volcanics along north Kohistan, and Dir-Utror volcanics along southwestern Kohistan (Sullivan et al., 1993), which were later intruded by stage-2 plutons (granodiorites and granites) of Kohistan batholith (Searle and Cox, 1999). The Dir group in the southwest half of Kohistan arc terrain forms a gently folded belt (10-15km width) that stretches approximately 120km from the upper swat valley into Dir (Sullivan et al., 1993). After Lamutai we enter into the granitic rocks of Kumrat valley and Tall area which are the stage-2 plutons of Kohistan Batholith which intrude the Utror volcanics (Searle and Cox, 1999).

Geology and tectonics

Granitic rocks are widely distributed throughout the continental
crust and constitute abundant basement rocks that are overlain by relatively thin strata of continents. Granitic rocks are located in many localities in NW Pakistan either in the form of large batholiths or as small intrusions (Tahirkheli and Jan, 1979). However, the suitability of materials for use in construction requires an adequate knowledge of their geotechnical properties. The mechanical properties are greatly affected by petrographic characters including grain size, shape of grains, fabric, mineralogical composition and the degree of weathering (Irfan, 1996).

Three distinct volcano-sedimentary sequences are exposed within the Kohistan island arc (KIA). From the south to north (Figure 1); these include the Kamila amphibolite, the Jaglot group and the Chalt volcanic group (Bignold et al., 2006). The Kamila amphibolite extends E-W across the southern part of the arc and has been studied in detail in the Swat and Indus valley of central Kohistan (Jan, 1988; Treloar et al., 1996). It consists of amphibolite facies, metavolcanics and metaplutonic oceanic rocks. The Kamila amphibolite belt extends westward into Dir valley (Bignold et al., 2006). The Chilas complex is a mafic to ultramafic, calc-alkaline intrusive body, which extends up to 300 km E-W along the length of the arc, with a maximum width of 40km (Khan et al., 1989). In the west of the arc, in the Dir valley, it is intrusive into the Kamila amphibolites (Sullivan et al., 1993; Treloar et al., 1996).

The Dir group of Tahirkheli (1979) is confined to the western half of the Kohistan arc terrain and forms a 10-15 km wide, moderate to steeply dipping, gently folded belt that stretches approximately 120 km from the Upper Swat valley southwestward into Dir. Tahirkheli (1979) divided the Dir group into two; the Baraul Banda slates and the Utror volcanics. Paleocene volcanism is represented by the Sharman volcanic along northern Kohistan and the Dir-Utror volcanic along southwestern Kohistan (Figure 1). Both these groups consist of basaltic andesites, rhyolites, pyroclastic flows, ignimbrites, and volcanic breccias (Sullivan et al., 1993). The Utror volcanic Formation comprises a structurally complex and lithologically diverse succession of volcaniclastic rocks and lava flows that crop out in the hanging wall of the Dir Thrust, and is intruded by the ca. 48-45 Ma (i.e. stage-2 plutons) calc-alkaline granitoid plutons (Sullivan et al., 1993).

Mechanical properties of rocks from the different localities in NW Pakistan have been determined by various workers. Din et al. (1993) and Din and Rafiq (1997) worked on the strength properties of some granitic rocks from the different areas of NW Pakistan. They have compared the strength values of

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**Figure 1.** Geological map of Kohistan Island Arc (KIA), showing the study area.
Malakand granite and Manki slates, and concluded that Manki slates have higher strength values than the Malakand granite, although the latter type is much harder (because of high quartz content). This is because of the difference in grain size and geologic defects, i.e. the Manki slates are finer and almost free from shear planes, whereas Malakand granite is coarse-grained and has more shear planes. Arif et al. (1999) investigated the mechanical properties of the Manshehra granites and concluded that these rocks have very low values of compressive strength as compared to other granites from elsewhere in northern Pakistan due to their older age, coarser texture, altered and the deformed nature. Sajid (2012) studied the mechanical properties of the different textural varieties of the Utla granites, NW Pakistan and explored their relationship with their petrographic features.

**METHODOLOGY**

Two fresh bulk samples (one coarse-grained and another medium-grained) were collected from the granitic rocks of the Kumrat area. These samples were processed and used for the detailed petrographic investigation and determination of their geotechnical properties. A total of six core samples were obtained from the two bulk samples to study the mechanical behavior of the granitic rocks. The core drilling machine in the Rock Cutting laboratory, Department of Geology, University of Peshawar was used for preparing the samples. The following tests were performed on each core sample in the Rock Mechanics laboratory, Department of Mining engineering, NWFP University of Engineering and Technology Peshawar.

1. Unconfined compressive strength (UCS).
2. Unconfined tensile strength (UTS).

Specific gravity and water absorption of the granitic samples were determined in the geochemistry laboratory of the National Centre of Excellence in Geology, University of Peshawar.

**Petrography**

Texturally, the Kumrat granites are sub-equigranular, hypidiomorphic and does not display any preferred orientation. The modal mineralogical composition of the studied samples is presented in Table 1. The essential minerals include orthoclase, plagioclase, quartz, biotite and muscovite. Accessory minerals are apatite and opaques. Secondary minerals are chlorite and sericite. The modal abundance of the essential minerals is illustrated by plotting on the relevant IUGS classification diagram. The studied samples fall within the compositional field of granite (Figure 2).

The modal abundance of orthoclase ranges from 42 to 51% (Table 1). Some of the orthoclase is a part of myrmakitic texture (Figure 3a). Most of the orthoclase grains are subhedral...
Figure 3. Photomicrographs showing the petrographic features in the investigated samples of Kumrat granites (a) myrmakitic texture between orthoclase and quartz (b) alkali feldspar with abundant inclusions of biotite and other minerals producing piokilitic texture (c) quartz grain with undulose extinction (d) euhedral plagioclase grain with thin outer rim and most probably much more sodic than the dominant inner part showing pattern of normal zoning (e) subhedral grain of plagioclase shows carlsbad-albite polysynthetic twinning (f) less altered grain of plagioclase displaying zoning (g) biotite-chlorite-muscovite-opaque mineral association (h) grain of biotite that is totally altered to (pseudomorphed by) chlorite (i) topotaxial growth of chlorite after biotite.

to euhedral. Some grains contain abundant inclusions of other minerals (i.e. biotite and opaques) thereby producing piokilitic texture (Figure 3b). Quartz is the next most abundant mineral (19 to 35%) in the Kumrat granites. It occurs as medium sized, anhedral grains that more or less commonly display strongly undulose extinction. The prevalence of
strained quartz grains gives us a clue about the degree of deformation of the Kumrat rocks (Figure 3c). The unstrained quartz grains, on the other hand, are only scarcely observed in the studied samples.

The modal abundance of plagioclase ranges from 5 to 20% (Table 1). The plagioclase generally occurs as euhedral to subhedral grains (Figure 3d and e) that display variable degree of alteration to sericite. Most of the plagioclase grains display zoning, while some show carlsbad albite polysynthetic twinning (Figure 3e and f).

The modal abundance of biotite ranges from 3 to 15% (Table 1). It exhibits strongly light brown to dark brown pleochroism and occurs in the form of medium sized, well developed flakes (Figure 3b). The biotite is mostly associated with chlorite, opaque minerals and in some cases, with muscovite (Figure 3g). The modal abundance of chlorite ranges from 1 to 4% (Table 1). It exhibits light green to dark green pleochroism. Its intimate association with biotite clearly demonstrates its formation through alteration of the latter. Some of the biotite grains are totally altered to chlorite (Figure 3h), whereas others are partially altered. The occurrence of chlorite along cleavages in some of the partially altered biotite grains demonstrates its

### Table 1. Modal mineralogical composition of the Kumrat granitic rocks.

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Coarse-grained granite</th>
<th>Medium-grained granite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali Feldspar</td>
<td>42.5 50 47.3 44.3 44.8</td>
<td>48 45.5 45.8 51.9 47</td>
</tr>
<tr>
<td>Quartz</td>
<td>32 31 32 35.1 23 26 19.5 29.1</td>
<td>19.5 19.5 22.2</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>5.6 6.8 8.5 9.2 16.8</td>
<td>10.3 19.9 9.7 14.2 11.2</td>
</tr>
<tr>
<td>Biotite</td>
<td>15.7 3.5 5.6 5.7 7</td>
<td>9.4 9.1 8.11 8.1 6.8</td>
</tr>
<tr>
<td>Muscovite</td>
<td>1 1.7 1.4 1.4 0.8</td>
<td>1.4 1.3 1.4 1.8 2.2</td>
</tr>
<tr>
<td>Chlorite</td>
<td>1.2 4.2 1.6 1.6 3.3</td>
<td>1.2 1.5 1.3 1.4 3.6</td>
</tr>
<tr>
<td>Apatite</td>
<td>0.2 0.2 0.1 0.2 0</td>
<td>0 0 0.2 0 0</td>
</tr>
<tr>
<td>Sericite</td>
<td>1 1 2 1.5 3</td>
<td>2.3 1.3 1.3 1.3 3.4</td>
</tr>
<tr>
<td>Opaques</td>
<td>0.6 1.6 1.3 1.7 1.6</td>
<td>1 2.8 2.8 1.6 3.4</td>
</tr>
</tbody>
</table>
topotaxial growth after the latter (Figure 3i). Alteration of biotite to chlorite coupled with sericitization of plagioclase indicates low-grade hydrothermal alteration (Reference Please) of the granitic rocks.

The overall modal abundance of muscovite in the studied samples ranges up to 2% (Table 1). Muscovite occurs in the form of tabular crystals and flakes (Figure 3g). Grains of an opaque mineral are also observed in the studied granitic samples. They are mostly associated with biotite.

Mechanical and physical properties

Strength

The unconfined compressive strength (UCS) and unconfined tensile strength (UTS) of the Kumrat granite samples were determined in the laboratory. Besides, the values of shear strength were also determined. Measurement of the UCS and UTS were done directly by strength testing machine while cohesion and angle of internal friction, both of which collectively determine the shear strength, were derived from the value of the UCS and UTS. Relevant information regarding definition of various tests and details regarding the nature and preparation of the granitic samples and different methods used for their determination and calculation have been outlined elsewhere (Sajid et al., 2009).

Three core granitic samples per bulk sample were used for determination of UCS and UTS. The value of the studied rocks, including coarse-grained and medium-grained Kumrat granite who’s USC values is lowest, are high enough (48 to 62 MPa; Table 2) to group them with the moderately-strong to strong category of Anon (1977, 1979 and 1981). It is generally believed that UCS of rock is 8 to 10 times of UTS. The UCS and UTS ratios of almost all the studied samples fall within this range.

Water absorption

Determination of water absorption is an important factor to investigate the effect of hydration and dehydration result in mechanical disruption of rock close in contact with water to allow access of water and thus causing increase in degree and rate of weathering (Bell, 2007). The method and calculations of water absorption described (Sajid et al., 2009), the value of water absorption for the studied samples of Kumrat granite. This is shown in Table 3.

Porosity

Determination of porosity is an important factor influencing the physical properties of the rock determining how much pores available in the rock and the amount of water the sample can hold enhancing weathering process. Employing the method and calculations described by other workers (Harrison, 1993), the porosity of the kumrat granitic samples are shown in Table 3.

Specific gravity

Morgenstern and Eigenbrod (1974) carried out a series of compressive softening tests on engineering material and found that the rate of softening of rock specimens on immersion in water depends on their origin. However, they swell slowly hence decreasing density and strength. The resulting loss in strength is very significant in controlling the engineering properties of rocks. The specific gravity of the Kumrat granite rocks are determined in the laboratory using equipment and formula mentioned elsewhere (Sajid et al., 2009). The values obtained are given in Table 3. The Kumrat granites having specific gravity ≥ 2.55, which are suitable for the heavy construction work (Blyth and Freitas, 1974). This suggests that in terms of specific gravity, the Kumrat granites are suitable

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Table 2. UCS, UTS, and shear strength of the Kumrat granitic samples.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Rock type</th>
<th>UCS (Mpa)</th>
<th>UTS (Mpa)</th>
<th>UCS:UTS</th>
<th>Cohesion (Mpa)</th>
<th>Angle of Internal friction (Φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coarse-grained granite</td>
<td>47.59</td>
<td>5.15</td>
<td>9.2</td>
<td>8</td>
<td>36.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51.72</td>
<td>5.38</td>
<td>9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>48.27</td>
<td>4.44</td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Medium-grained granite</td>
<td>55.17</td>
<td>5.79</td>
<td>9.5</td>
<td>9.3</td>
<td>36.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62.09</td>
<td>5.92</td>
<td>10.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>58.26</td>
<td>5.79</td>
<td>10.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Water absorption value (%), specific gravity, porosity and their relationship with UCS, Kumrat granitic samples.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Rock type</th>
<th>Water absorption</th>
<th>Specific gravity</th>
<th>Porosity</th>
<th>Average UCS (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coarse-grained Granite</td>
<td>2.6</td>
<td>0.24</td>
<td>1.42</td>
<td>49.19 ± 1.68</td>
</tr>
<tr>
<td>2</td>
<td>Medium-grained Granite</td>
<td>2.57</td>
<td>0.23</td>
<td>1.84</td>
<td>58.50 ± 2.38</td>
</tr>
</tbody>
</table>
for use as heavy construction materials.

DISCUSSION

A detailed petrographic examination in thin section reveals that the Kumrat granites are coarse to medium grained and sub-equirugular to inequigranular, hynpidomorphic and without any preferred orientation. The essential minerals are orthoclase, quartz, plagioclase, biotite and muscovite. Accessory and secondary minerals included apatite, chlorite, sericite and ophakes. Some of the orthoclase grains display piokilitic texture. Almost all the quartz grains exhibit strong undulose extinction owing to intra-crystalline deformation.

The investigated samples hardly differ in terms of abundance and type of accessory and minor constituents (Table 1). Both the coarse-grained and medium-grained granitic varieties contain about the same overall proportion of mafic phases (about 15 modal %), i.e. biotite, and opaque grains. Chlorite observed in the studied granites is produced exclusively by the alteration of biotite. Some of the biotite grains are partially altered to chlorite, i.e. chlorite has grown topotaxially along cleavages within the biotite flakes. This relationship most probably represents hydrothermal alteration of biotite. Furthermore, some of the biotite grains are totally pseudomorphed by chlorite.

There are several scales for the comparison of the UCS values. Geological materials are graded on the basis of compressive strength values and designated for specific use in construction. According to Anon (1977and 1979), the coarse-grained granites are moderately strong, whereas medium-grained samples of mineralogically similar rocks are strong. Later on, Anon (1981), grouped both the medium-grained and coarse-grained varieties of otherwise similar rocks as moderately strong.

The average UCS and UTS values of the coarse-grained and medium-grained granitic varieties are calculated as 49.19 and 58.50 MPa, respectively. It is generally believed that the UCS of Kumrat granites is 8-10 times of the UTS. According to Brady and Brown (2004), UCS is generally eight times UTS and cohesion is two times UTS. Application of these observations by previous workers to the Kumrat granite leads to the following conclusions:

1. For coarse-grained granite the UCS is 9.8 times that of UTS which follows the above relations whereas cohesion of coarse-grained granite is 1.6 times that of UTS which is low as compared with the above relations.
2. For medium-grained granite the UCS is 10 times that of UTS which follows the above relations whereas the cohesion of medium-grained granite is 1.6 times that of UTS which is low as compared to the above relations.

The physical and geotechnical properties of Kumrat granites are influenced by their mineralogical composition, texture (grain size and shape), fabric (arrangement of minerals and voids) and the degree of weathering (e.g. Irfan, 1996). Rocks containing a large amount of physically stronger minerals are obviously strong. Similarly, rocks with finer grain size are stronger than their coarse-grained counterparts (Bell, 2007). A wide range of grain size variation within a rock is also supposed to add to the strength of rock. In case of the current investigation, medium-grained granites are stronger than coarse-grained granite probably because of their relatively finer grain size.

Rocks whose constituent mineral grains are irregularly shaped are likely to be stronger than otherwise similar rocks composed of grains with regular shapes. Boundaries between euhedral (regularly shaped) grains may act as discontinuities where cracks may initiate in the structure (Lindqvist et al., 2007). The influence of increasing complexity in the grain shape and grain boundary geometry on strength is also reflected by properties such as resistance to drilling penetration (Howarth, 1988). Most of the mineral grains in both the textural varieties of the Kumrat granite samples are irregular in shape; although some of the grains are perfectly euhedral but their abundance is too low to adversely affect the rock strength. As stated earlier, that the studied samples are barely distinguished on the basis of their modal mineralogy. The only reason for the difference in their strength values is attributed to their contrasting textural characteristics.

The strength of rock is also highly affected by the process of alteration and weathering. The strength of a rock undergoes a notable reduction on weathering (Bell, 2007). Generally the alteration product of plutonic rocks has high clay content. The features of alteration do occur in the investigated samples however their scarcity eliminates any possible adverse effect on the geotechnical properties.

The values of specific gravity, porosity and water absorption of the investigated granitic samples are also in the range of suitability for use as a construction material (Table 3). The average values for both the varieties are calculated as 0.24 and 0.23 respectively.

Conflict of interest

Authors have none to declare

REFERENCES


