

MINERALOGICAL AND TEXTURAL CONTROLS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF SANDSTONES FROM NIZAMPUR AND KOHAT BASINS, NORTHWESTERN, PAKISTAN

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ABSTRACT

This research focuses on five key sandstone-bearing formations from the Nizampur and Kohat basins in northwestern Pakistan: Chichali Formation (CF), Hisartang Formation (HF), Lumshiwai Formation (LF), Murree Formation (MF), and Nagri Formation (NF). These formations were selected due to their regional importance as construction materials and their diverse mineralogical and textural characteristics, which provide an excellent opportunity to study how compositional variations influence engineering behavior.

Detailed laboratory analyses, including petrographic analysis, X-Ray Diffraction (XRD), and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS), revealed significant mineralogical and textural differences among these formations. The sandstone of the Chichali Formation is sub-arkose and is mainly composed of quartz (53%) and glauconite (35%) with lesser amount of alkali feldspar (5%) and matrix (5%) containing mainly calcite, muscovite, and clay minerals and opaque phase. It exhibits mild interlocking and less porous behavior. The sandstone of the Hisartang Formation is a quartz-rich arenite, predominantly composed of quartz (84%) and feldspar (15%), with a minor amount of clay minerals (1%). Its most distinctive features are its fracture porosity and the presence of both Stylolites and fractures. The sandstone of Lumshiwai Formation (LF-1) is quartz arenite and is mainly composed of quartz

(95%) with lesser amount of feldspar (5%) with no lithic fragments. It has well-interlocking and negligible porous nature. The sandstone of Lumshiwal Formation (LF-2) is bioclastic quartz wacke and is mainly composed of Quartz (50%) with lesser amount of pseudomorphs of bioclasts (17%) and glauconite (08%). The matrix (25%) is composed of fine-grained carbonate, micaceous and clay minerals. It exhibits less interlocking and high porous behavior. The sandstone of Murree Formation (MF) is lith-arenite and is mainly comprised of quartz (57%), lithic fragments (30%) with lesser amount of feldspar (10%), bioclasts (01%), and matrix (02%) having carbonates and micaceous minerals with traces of opaque phases. It has mildly-interlocking and less porous nature. The sandstone of Nagri Formation (NF) is feldspathic lith-arenite and is dominantly composed of lithic fragments (45%) and quartz (35%) with lesser amount of feldspar (15%), bioclasts (01%), and matrix (03%) having fine-grained carbonates and micaceous mineral with traces of opaque phase. It is also having mildly-interlocking and less porous behavior.

This study also presents a comparative analysis of the Lumshiwal Formation's two sandstone facies, LF-1 and LF-2, to elucidate the impact of bioclasts on their mechanical response. The quartz arenite (LF-1) exhibits exceptional strength (UCS: 145 MPa) due to its textural maturity and quartz-dominated framework. In stark contrast, the bioclastic quartz wacke (LF-2) shows significantly reduced strength (UCS: 74 MPa), a weakness directly attributable to its 17% bioclast content. The research demonstrates that these carbonate bioclasts degrade integrity through their low hardness, propensity for cleavage, and susceptibility to differential weathering, which increases porosity and creates preferential failure planes. The findings underscore that even within a single formation, the presence of bioclasts is a pivotal control on engineering suitability, necessitating stabilization for LF-2 in critical applications.

Physical and mechanical testing demonstrated substantial variations in engineering properties. The quartz-rich LF-1 sandstone displayed the highest values for unconfined compressive strength (UCS: 145 MPa), tensile strength (UTS: 19 MPa), and point load index (PLT: 23 MPa), along with low water absorption (0.11%) and porosity (0.26). In contrast, the feldspathic Nagri Formation had the lowest strength (UCS: 63 MPa, UTS: 5 MPa) and highest porosity (0.43). The Hisartang, Murree and Chichali formations exhibited

intermediate properties, with UCS values of 123, 105, 93 MPa, respectively, influenced by their moderate quartz content and textural maturity. Non-destructive tests, including Schmidt hammer rebound (SHT) and ultrasonic pulse velocity (UPV), correlated well with destructive test results, providing reliable proxies for rapid field assessments.

Statistical analysis (bivariate regression) revealed strong correlations between quartz content and mechanical properties. Quartz percentage showed a highly significant positive relationship with UCS ($R^2 = 0.88$), UTS ($R^2 = 0.78$), and PLI ($R^2 = 0.72$), confirming its role as the primary strength-controlling mineral. Conversely, feldspar content exhibited a weak negative influence on strength due to its cleavage planes and susceptibility to alteration. The quartz-to-feldspar ratio (QFR) also proved to be a useful predictor of mechanical behavior, with higher QFR values corresponding to greater strength (UCS $R^2 = 0.55$). Textural parameters such as grain packing, sorting, and porosity further modified these relationships, with tightly packed, well-sorted sandstones outperforming porous, poorly cemented varieties.

The findings have direct implications for the construction industry, enabling better selection of sandstone units for infrastructure projects based on their mineralogical and textural properties. Additionally, the strong correlations between quartz content and non-destructive test results (SHT, UPV) offer practical tools for preliminary field assessments, reducing the need for extensive laboratory testing.