Journal of Himalayan Earth Sciences Volume 53, No. 2, 2020 pp. 12-22

# Characteristics of Panoba Shale as an "Aglite" lightweight concrete aggregate in Kohat-Hangu districts, NW Pakistan

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*Submitted date:01/04/2020 Accepted date:23/06/2020 Published online:*

## Abstract

The 21st century urbanization has strained the global housing sector to go vertical by developing high-rise buildings and skyscrapers to meet the growing accommodation demands. Concerns that were raised in designing and constructing such heavier building foundations and consequently their probable settlement have brought new dimensions in concrete technology by introducing lightweight concrete. Lightweight concrete produced from either natural or synthetic lightweight aggregates (LWA) has addressed such complications. Bloated shale used as LWA has shown remarkable results in many developed countries so it may be easily adopted in developing Pakistani construction industry too. For the present study, Panoba Shale from Kohat-Hangu region was evaluated as "aglite" LWA. The average geochemical concentration (in %wt) for studied shale exhibit silica 57%; alumina 20%; Fe2O3 9.45% and LOI 8.14% whereas, rest of oxides are in traces. Neither iron staining nor any organic impurities were found in these bloated specimens. The average physical characteristics for these aggregates exhibit; loose bulk density of 601kg/m3, clay lumps 0.7%, specific gravity 1.44 and water absorption 13% thus conforming to ASTM C330 specifications for structural LWA. The abundance of essential raw material (shale) and the availability of required energy resources for its processing make the study area an ideal location for the installation of LWA manufacturing plants. The end-product can be marketed in neighboring major cities of northern Pakistan (Islamabad and Peshawar), boosting economic activities in the area and bringing new dimensions in construction industry of the region.

*Keywords:* Panoba Shale, lightweight concrete aggregates, aglite, geochemistry, physical properties.

## 1. Introduction

The Pakistani construction industry has progressed over nine times in past two decades and is among the largest industrial contributors to national gross domestic products with its annual share of over 2.5% (Pakistan Bureau of Statistics, 2018). Pakistan is situated in one of the world's seismically active regions with majority of its population living in moderate to high risk seismic zones (Magsi, 2014). The October 8th Kashmir earthquake has diverted the focus of construction industry towards the development of safer buildings. Being a developing country, Pakistan's construction industry lacks modern techniques and materials and therefore, essentially depends upon traditional norms and means.

The LWA is best known for its chemical inertness, weathering durability, excellent mortar binding and concrete weight-lightness; many of renowned prehistoric and as well as modern buildings are built with it (Clarke, 1993; Chandra & Berntsson, 2002; Holm & Ries, 2007). These aggregates come from a variety of raw materials sources including those of natural and of synthetic origin. Natural LWA includes volcanic pumice, scoria and organic aggregates (Palm-oil shells) whereas, synthetic LWA are produced either as industrial by-products or by thermal treatment of argillaceous materials having expansive properties (Clarke, 1993; Chandra & Berntsson, 2002). These include industrial products such as, glass, fly ash, slag-cinder etc. and natural argillaceous materials such as, perlite, vermiculite, slate, clay and shale.

Large shale deposits are exposed throughout Pakistan which can be utilized as LWA but have never been introduced to local construction industry, probably due to the lack of knowledge and techniques. Some early workers have made some preliminary studies on various shale deposits as LWA, in Pakistan (Parker & Khan, 1976; Hussain et al., 1983; Khan & Khan, 2000). The present research is on the utilization of Panoba Shale from Kohat-Hangu districts, as an "aglite" LWA.

The targeted accomplishments during our current search were:

a. Testifying geochemically the studied shale specimens "to be bloated" in accordance with Riley (1951).
b. Physical characterization for the bloated specimens (aglite) as per ASTM C330 practice to see their suitability as LWA.
c. Developing structural LWAC mix proportion of normal and high strength using "aglite" coarse aggregates from Panoba Shale.
d. Appraising minable shale deposits and potential local energy resources for future mass production of these LWA and
e. Evaluating "production cost" for these aggregates as LWA and LWAC.

## 2. Geology

The study area is in northern Kohat provenance and is part of northern Indus Foreland Basin (Meissner, et al., 1974). During early Cenozoic era, the continuous convergence of Indian plate has led to the closure of NeoTethyan Sea, obducting Indus Ophiolitic belt and formation of Himalayan orogenic belt with Foredeep (Kazmi & Jan 1997; Najman et al., 2017). The modes of sedimentation were changed periodically within the basin. During the late Mesozoic to early Paleocene, the shelf marine sediments of Makerwal Group smudged with Indian Shield clastic sediments followed by Paleogene period submergence of open-marine shelf sediments of Chharat Group (Shah, 2009). This Tethyan domain was seized by Neogene period resulting deposition of synorogenic estuarine Rawalpindi Group followed by fluvial molasse sediments of Siwalik Group marked by Main boundary Thrust fault (Kazmi & Jan 1997; Shah, 2009). The early Eocene Panoba Shale is the lower rock unit of the Chharat Group and is restricted to northern Kohat provenance as shown in Figure 1 (Meissner et al., 1974; Shah, 2009).

The Panoba Shale comprises predominately of shale. These shales are greenish grey to light grey in color, slightly silty, soft, thick to thinly laminated and occasionally ferruginous and calcareous, as shown in Figure 2 (Shah, 2009). Bands of calcareous sandstone, arenaceous limestone and gypsum veins are common, as shown in Figure 3. These shales were formed by diagenesis of terrigenous ooze (Ali, 1997). The Panoba Shale has maximum surficial thickness of 160meters near Uch-bazar Bandi north of Hangu city, but its subsurface thickness may be oddly higher, due to local drape folding (Meissner, et al., 1974; Pivnik & Sercombe, 1993). The formation is conformably underlain with Paleocene Makarwal Group but is disconformably overlain by other units of Chharat Group, Rawalpindi Group or recent channel deposits (Shah, 2009).

## 3. Methodology

The geological map produced by Meissner et al., (1974) was used to demarcate the lithostratigraphic units in the study area as shown in Figure 1. Twenty-eight samples were collected each weighting approximately forty (40) kilograms, from the outcrops exposed at different lithostratigraphic sections in the study area. A part of each specimen was used to evaluate shale geochemistry at the Geochemistry Laboratory of the National Centre of Excellence in Geology Peshawar whereas, the rest of the specimen was kept for its physical / mechanical characterization and developing concrete mix proportions.

For chemical analysis, specimens were pulverized in a tungsten-carbide mill to 200 mesh size for the preparation of stock solutions as per ASTM C114–15 practice. The stock solutions were analyzed on atomic spectroscopy and UV photospectroscopy. Beside major and minor oxides determination, the concentration for $SiO_2$, $Al_2O_3$ and flux (CaO, MgO, $Na_2O$ and $K_2O$) were plotted on Riley (1951) phase diagram, to determine their bloating ability. The amount of staining material e.g. iron was also dogged (ASTM C641).

Based upon their geographical distributions and conforming to geochemical

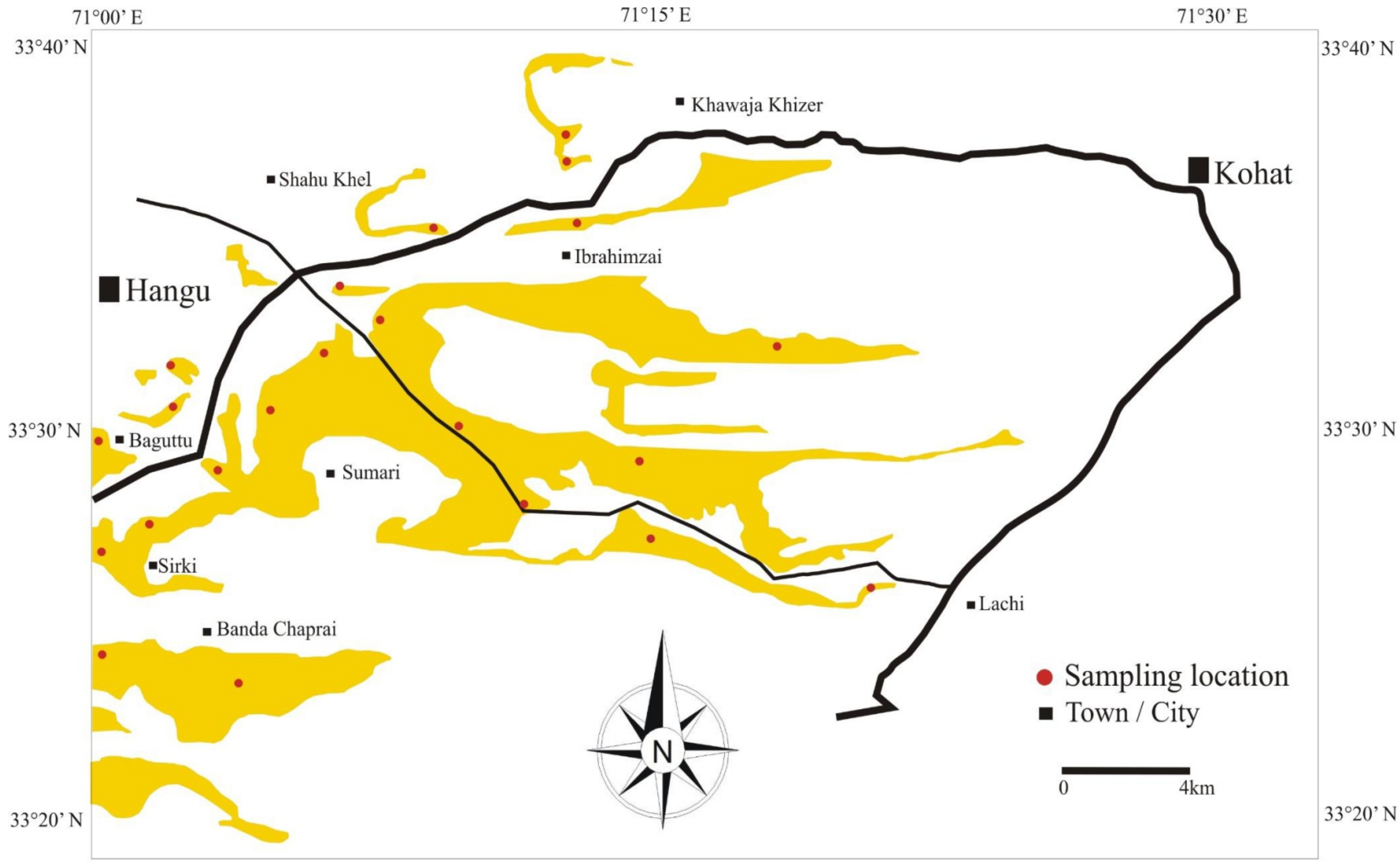


Fig. 1. Sketch geological map of the study area showing outcrop and sampling locations for Panoba Shale (modified after Meissner et al., 1974).

Fig. 2. Thickly laminated splintery shale at Sifat Banda, District Hangu.

Fig. 3. Interceded siltstone bands in Panoba Shale at Ludikhel, District Hangu.

area of bloating of Riley (1951), the field samples were regrouped into two major groups for onward bloating and studying their physical / mechanical properties. These individual groups were bloated in rotary furnace at 1050oC, at Pakistan Council of Scientific and Industrial Research (PCSIR) Laboratories complex Peshawar. The bloated aggregates as an "aglite" conforming to grading size No. 6 (ASTM C33) were studied for their physical properties in compliance with ASTM C330 (specifications for structural LWA). The determination of bulk density & voids and specific gravity & water absorption in LWA quantify the amount of concrete batching ingredients (ASTM C29, ASTM C127). The ascertainment of clay lumps and friable particles enables to find out discoloring and deleterious agents in these aggregates (ASTM C142).

These groups were further batched according to procedural calculations suggested by Chandra & Berntsson (2002), to evaluate their suitability as normal and high strength concrete mix.

## 4. Results and discussion

### *4.1. Geochemistry*

Formed by clay-cycling of primary rock forming minerals, the shales are siliciclastic sedimentary rocks (Boggs, 2006). They are primarily, composed of phyllosilicate clay minerals subordinated with quartz, feldspar, carbonates, phosphates, organic carbon etc. To study shale mineralogy, one needs intricate assaying techniques such as differential thermal analysis or geochemical analysis; and during current research work the successive geochemical technique was put into practice (Valaskova, & Martynkova, 2012). The geochemical composition of selected Panoba Shale specimens is summarized in Table 1 (a and b).

The bloating index for any argillaceous materials primarily depends upon its physiochemical traits rather lengthening in firing period (Cougny, 1990; Kamran et al., 2006; Lee et al., 2019). To achieve necessary glassy cellular microstructure for shale aggregates in the kiln, Riley (1951) accentuate their chemical characteristics (silica, alumina, and flux – the gas generating oxides) abiding within "area of bloating" on ternary phase diagram. In order to determine their conformation for the Riley (1951) area of bloating, two major groups were identified (the specimen selection is hinged on their geographical accessibility and vastness); Group A comprises geochemical specimens KHT-11, KHT-13, KHT-15, KHT-16, KHT-17 & KHT-18 along Kohat-Hangu-Thal road, whereas Group B includes geochemical specimens HSL-1, HSL-2, HSL-3, HSL-4 & HSL-5 along Hangu-Sumari-Lachi road. The geochemistry for selected specimens were recalculated to plotted on Riley's ternary diagram as shown in Figure 4 (a and b). The selected specimens' groups show compliance with Riley's "area of bloating" hence evidencing their potential source as LWA.

The iron sulfides are common expansive inclusion in the coarse aggregates (Newman & Choo, 2003; Alexander & Mindess, 2010; Neville, 2016). These sulfides upon reaction with cement alkalis, pop-out cement paste and stains concrete surface. No stain index was unveiled in these present specimens when tested as per ASTM C641 practice as shown in Figure 5 (a and b).

### *4.1. Physical properties*

The physical properties for the bloated specimens shown conformance to ASTM C330 specifications as given in Table 2.

The fundamental physical properties studied, as required for ASTM structural concrete LWA, include their grading, loose bulk density and their animosity to clay lamps and friable particles (ASTM C330). To prepare LWA for these physical tests, the anticipated undersize and oversize coarse aggregates in the bloated LWA were removed manually through sieving to obtain the required grading of size No. 6 as specified in ASTM C33. The bulk density will quantify amount required during concrete mix proportioning and batching. Due to fragility of these LWA, shoveling technique was opted to determine loose bulk density for LWA (ASTM C29). Presence of any deleterious or expansive material within concrete may have

Table 1a. Geochemistry of selected shale specimens along Kohat-Hangu-Thal road.

| | KHT-1 | KHT-2 | KHT-3 | KHT-4 | KHT-5 | KHT-6 | KHT-7 | KHT-8 | KHT-9 | KHT-10 | KHT-11 | KHT-12 | KHT-13 | KHT-14 | KHT-15 | KHT-16 | KHT-17 | KHT-18 | KHT-19 | KHT-20 | KHT-21 | KHT-22 | KHT-23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52.12 | 57.23 | 57.45 | 62.12 | 57.54 | 58.34 | 57.12 | 57.22 | 58.67 | 55.34 | 58.11 | 54.78 | 54.89 | 51.02 | 61.12 | 54.12 | 57.56 | 53.67 | 56.44 | 58.10 | 59.12 | 52.12 | 52.01 |
| $TiO_2$ | 0.25 | 0.02 | 0.22 | 0.04 | 0.07 | 0.09 | 0.10 | 0.01 | 0.05 | 0.29 | 0.18 | 0.37 | 0.37 | 0.44 | 0.09 | 0.49 | 0.11 | 0.15 | 0.02 | 0.14 | 0.20 | 0.44 | 0.34 |
| $Al_2O_3$ | 18.89 | 22.61 | 18.56 | 18.87 | 19.34 | 20.24 | 24.36 | 18.92 | 17.45 | 22.53 | 20.23 | 22.82 | 23.29 | 23.40 | 19.34 | 20.56 | 21.67 | 23.11 | 20.22 | 19.10 | 17.50 | 20.91 | 19.89 |
| $Fe_2O_3$ | 8.40 | 9.08 | 11.69 | 5.98 | 6.69 | 10.84 | 8.02 | 8.32 | 5.59 | 10.76 | 9.53 | 13.31 | 11.01 | 9.68 | 9.38 | 9.24 | 10.62 | 10.79 | 12.10 | 8.37 | 8.71 | 9.29 | 11.84 |
| MnO | 0.03 | 0.09 | 0.04 | 0.02 | 0.02 | 0.05 | 0.15 | 0.14 | 0.03 | 0.05 | 0.08 | 0.07 | 0.10 | 0.03 | 0.03 | 0.17 | 0.11 | 0.05 | 0.10 | 0.03 | 0.01 | 0.02 | 0.03 |
| MgO | 0.73 | 0.81 | 0.71 | 0.18 | 0.54 | 1.00 | 1.39 | 0.71 | 1.05 | 1.34 | 1.21 | 0.92 | 0.98 | 1.18 | 0.97 | 1.16 | 1.27 | 1.28 | 1.59 | 1.44 | 0.98 | 0.95 | 1.17 |
| CaO | 3.51 | 0.64 | 0.62 | 2.50 | 2.78 | 0.53 | 0.89 | 0.70 | 3.13 | 1.12 | 0.67 | 0.49 | 0.79 | 2.39 | 0.54 | 3.09 | 0.64 | 1.09 | 1.53 | 2.34 | 2.37 | 3.47 | 3.69 |
| $Na_2O$ | 0.87 | 0.18 | 0.36 | 0.06 | 0.15 | 0.32 | 0.31 | 0.20 | 0.12 | 0.29 | 0.83 | 0.24 | 0.62 | 0.33 | 0.52 | 0.57 | 0.50 | 0.53 | 0.89 | 0.65 | 0.21 | 0.33 | 0.39 |
| $K_2O$ | 0.04 | 0.04 | 0.03 | 0.00 | 0.03 | 0.04 | 0.05 | 0.03 | 0.02 | 0.04 | 0.03 | 0.04 | 0.05 | 0.04 | 0.04 | 0.03 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 |
| $P_2O_5$ | 0.26 | 0.04 | 0.39 | 0.04 | 0.07 | 0.06 | 0.19 | 0.10 | 0.16 | 0.14 | 0.35 | 0.15 | 0.29 | 0.09 | 0.30 | 0.27 | 0.08 | 0.07 | 0.18 | 0.17 | 0.17 | 0.21 | 0.20 |
| LOI | 11.92 | 6.81 | 7.18 | 9.80 | 10.24 | 5.04 | 5.74 | 11.46 | 10.77 | 7.18 | 5.68 | 5.46 | 6.06 | 10.49 | 6.39 | 8.59 | 5.63 | 6.87 | 6.56 | 7.57 | 8.59 | 11.08 | 11.84 |
| **Total** | **97.02** | **97.56** | **97.24** | **99.62** | **97.48** | **96.54** | **98.32** | **97.81** | **97.03** | **99.09** | **96.89** | **98.65** | **98.43** | **99.10** | **98.72** | **98.29** | **98.23** | **97.66** | **99.67** | **97.94** | **97.90** | **98.87** | **101.44** |

KHT-1: Hangu city, KHT-2: Ibrahimzai, KHT-3: Ziarat Shah Sikandar, KHT-4: Ludikhel – I, KHT-5: Ludikhel – II, KHT-6: Shahuwaram, KHT-7: Uch Bazar Bandi, KHT-8: Mohallah Darwaizi, KHT-9: Banda Shinwari, KHT-10: Ghitharwan, KHT-11: Burka, KHT-12: Mirubuk, KHT-13: Sifat Banda, KHT-14: Mardukhel, KHT-15: Lakhti Banda, KHT-16: Spin Kharai, KHT-17: Bagattu, KHT-18: Chambagul road, KHT-19: Kotki Bala, KHT-20: Barhabbaskhel, KHT-21: Anir China road, KHT-22: Banda Chaprai road, KHT-23: Banda Chaprai

Table 1b. Geochemistry of selected shale specimens along Hangu-Sumari-Lachi road.

| | HSL-1 | HSL-2 | HSL-3 | HSL-4 | HSL-5 | Mean |
|---|---|---|---|---|---|---|
| $SiO_2$ | 56.12 | 59.23 | 56.78 | 57.34 | 59.56 | 56.62 |
| $TiO_2$ | 0.17 | 0.31 | 0.39 | 0.47 | 0.08 | 0.21 |
| $Al_2O_3$ | 23.12 | 18.92 | 16.89 | 17.34 | 18.42 | 20.30 |
| $Fe_2O_3$ | 9.22 | 7.73 | 8.84 | 11.49 | 8.18 | 9.45 |
| MnO | 0.03 | 0.03 | 0.15 | 0.07 | 0.03 | 0.06 |
| MgO | 1.16 | 1.05 | 1.12 | 1.21 | 0.72 | 1.03 |
| CaO | 1.68 | 1.93 | 2.40 | 1.67 | 1.40 | 1.74 |
| $Na_2O$ | 0.32 | 0.42 | 0.45 | 0.75 | 0.24 | 0.42 |
| $K_2O$ | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 |
| $P_2O_5$ | 0.23 | 0.05 | 0.28 | 0.11 | 0.22 | 0.17 |
| LOI | 7.78 | 7.80 | 9.60 | 7.71 | 7.99 | 8.14 |
| **Total** | **99.87** | **97.51** | **96.94** | **98.19** | **96.88** | |

HSL-1: Khajora police post, HSL-2: Sumari Bala, HSL-3: Ziarat Sheikh Ismail, HSL-4: Sumari road, HSL-5: Sumari Payan

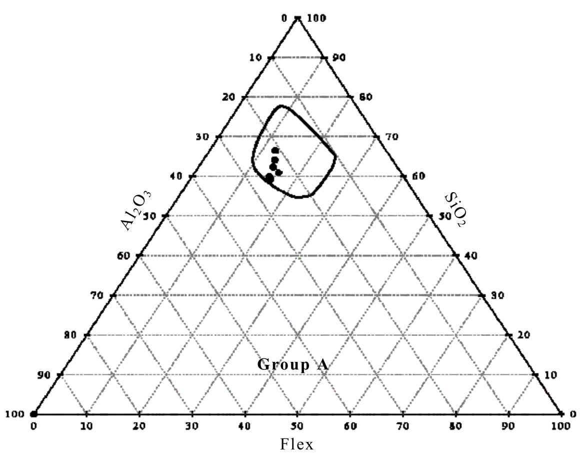


Fig. 4a. Bloating zonation for specimen group A based upon Riley, 1951.

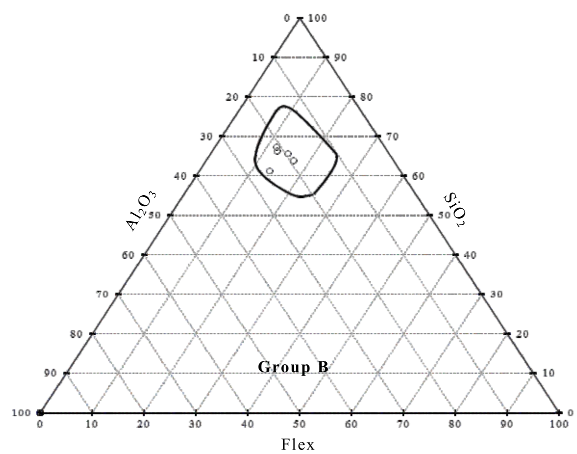


Fig. 4b. Bloating zonation for specimen group B based upon Riley, 1951.

detrimental effect over its properties (Alexander & Mindess, 2010; Neville, 2016). Negligible amount of material was found as clay lamps and friable particles during the analyses. Since the presence of minute undersize material have no deleterious effect over concrete performance therefore, their presence was neglected (ASTM C330).

## 5. Conclusions

The introduction of new seismic provisions in country's building codes after the Kashmir earthquake, the Pakistani housing industry has initiated constructing safer high-rise buildings e.g., Bahria Icon Tower Karachi, Centaurus Islamabad etc. Pakistan being an earthquake-prone region with majority of its population living in moderate to high risk seismic regions, the use of LWA can be a revolutionary material for structural and masonry construction. Being lighter in weight, it reduces foundation / structure dead-load, especially for high-rise building construction.


Fig. 5a. Photograph showing zero iron stain index over filter-paper to evaluate Group A, as per ASTM C641 practice.

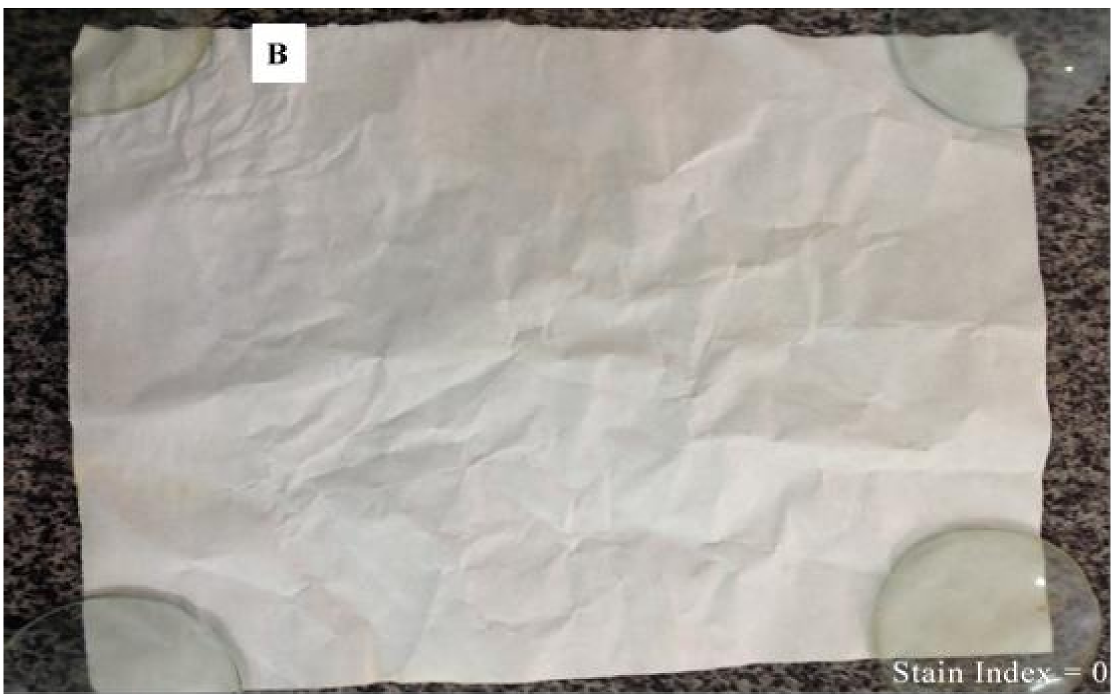


Fig. 5b. Photograph showing zero iron stain index over filter-paper to evaluate Group B, as per ASTM C641 practice.

The chemical and physical properties of LWA manufactured from Panoba Shale show harmonization with all applicable international standards. Trial normal strength (21MPa) concrete mix proportion made from these LWA with >25% cement content (as specified in National Highway Authority specifications – the only available nationwide civil engineering materials specification) (National Highway Authority, 1998) shown satisfactory results. Panoba Shale is exposed over 500km2 area in the study area of district Hangu with depth variation in hundreds of meters (Meissner et al., 1974; Pivnik & Sercombe, 1993; Shah, 2009). Over

90% of the said area is barren and uninhabited as shown in Figure 6. Large energy resources (coal and natural gas) have been recently explored in the surrounding areas. The presence of shale deposits and energy resources made the area an ideal location for installing LWA manufacturing plants.

The state-owned PCSIR Laboratories, Peshawar, has two pilot furnaces for LWA manufacturing. The smaller furnace can bloat fifty (50) kgs of raw material in a single batch. The larger furnace has batching capacity of 500kg with minimum manufacturing cost of US$ 100 per metric ton whereas, Chinese "Xinwei Zq" is marketing their similar product for as lowest as US$50 per metric ton (Chen, 2019). This incompatibility of manufacturing cost to local and international market can be reworked by introducing small and medium enterprises to install compatible commercial manufacturing facilities in the area. This will greatly reduce manufacturing cost create employments and enhance economic activities in this poor region.

This submitted probe is focused on to develop substantiated LWA resources affirming to international standards, for our developing country. The end-product can easily be marketed to neighboring mega cities of Islamabad and Peshawar.

Table 2. Physical properties of Panoba Shale bloated groups as per ASTM C 330.

| **Physical Parameter** | **ASTM test procedure** | **ASTM max limit** (ASTM C330) | **Bloating Group** | |
|---|---|---|---|---|
| | | | A* | B** |
| Loose bulk density (kg/m$^3$) | ASTM C29-17 | <880 | 566 | 636 |
| Clay lump & friable particles (%) | ASTM C142-17 | <2 | 0.9 | 0.5 |
| Water absorption (%) | ASTM C127-15 | Not specified | 12 | 14 |

* consists of geochemical specimens KHT-11, KHT-13, KHT-15, KHT-16, KHT-17 & KHT-18.

** consists of geochemical specimens HSL-1, HSL-2, HSL-3, HSL-4 & HSL-5

Fig. 6. A road track in nearly flattened thick beds of Panoba Shale near Bagattu, District Hangu.

**Acknowledgements**

The work presented in this paper is part for doctoral research work carried out by the first author. The authors acknowledge the technical and financial support from the National Center of Excellence in Geology Peshawar.

***Authors' Contribution***

*Aqeel Goher, first author, executed field & laboratory work and wrote primary manuscript. Rubina Bilqees supervised field & physical investigations and proofreading of manuscript. Mohammad Tahir Shah supervised geochemical investigation and proofreading of manuscript.*

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