Journal of Himalayan Earth Sciences 44(2) (2011) 53-60

# Engineering tests of aggregate from Lightweight Expanded Slate of Manki Formation

**Rubina Bilqees[1], Pirzada Naeem[2], Tazeem Khan[1] and M. Muhammad Junaid[2]**
[1] National Centre of Excellence in Geology, University of Peshawar, Pakistan
[2] Pakistan Council for Scientific and Industrial Research, Peshawar, Pakistan

**Abstract**

Bloatable (expandable) argillaceous raw materials suitable for use in making lightweight aggregate exist in large quantities in Pakistan. In this paper Precambrian slate from the Attock-Cherat Ranges has been used to study its engineering properties for use as a lightweight aggregate concrete. Chemical analyses of the samples showed that loss on Ignition varies from 3.45 to 4.56 %. The high contents of iron in the form of pyrite and hematite (5.23 %) and the content of alkalies (6.6 %) are indicative of better bloating properties in slate. The samples were fired in a rotary furnace at temperature ranging from 1050-1150° C to achieve maximum bloating. After bloating physical tests were carried out according to the American Standards for Testing Materials (ASTM) specifications. The results of various tests like water absorption, bulk density, chloride content, and soundness properties meets the specifications of concrete and show their suitability for use as a light weight aggregate for structural purposes.

*Keywords:* Slate; bloating; lightweight; aggregate

## 1. Introduction

With increasing trend and need for the construction of multi story buildings, the construction companies and experts are more concerned over the use of construction materials that is lighter in weight to reduce the dead load. The use of structural grade lightweight concrete reduces considerably the self-load and permits larger precast units to be handled. Lightweight aggregate concrete (LWAC) has many comparative advantages over the commonly used concrete aggregates, for example LWAC is more fire resistant and has increased thermal insulation, greater moisture resistance and made more sound proof building. It is also used in the construction of floating docks, offshore oil platforms, bridge decks and girders etc. Due to the enhanced skid-resistant character of the LWAC, these are being used in the construction of running track, sport grounds etc. in US, Canada and other developed countries.

Moreover, it is wiser to use lightweight materials in construction of buildings in earthquake prone areas due to improved seismic structural response of lightweight material (www.bst-betostyrene.com/handbook). Pakistan has quite a considerable terrain which is seismically active and the most recent example is the deadly earthquake of October, 2005 which has caused thousands of casualties.

Light Weight Aggregate (LWA) and Light Weight Aggregate Concrete are not new materials. LWAC has been known since the early days of the Roman Empire (http://www.escsi.org/ContentPage.aspx?id=525). Both the Coliseum and the Pantheon were partly constructed with materials that can be characterized as lightweight aggregate concrete (aggregates of crushed lava, crushed brick and pumice). In the United States, over 100 ships used in World War II. These ships were built from LWAC, having capacity from 3000 to 140000 tons and their successful performance led to extended use of structural LWAC in buildings and bridges. Bloating studies in Pakistan date back to 1969 when Kinniburgh carried out studies on some clays of Punjab, by adding some organic materials, at the Building Research Station. Hassan (1970; 1972) and Khan and Parker (1970) conducted crushing strength and other tests on some expanded clay aggregates. Reconnaissance investigations for the lightweight raw material in and around Peshawar (KPK) were initiated by Hussain (1981) and Hussain et al. (1983).

Bloatable (expandable) argillaceous raw materials suitable for use in making lightweight aggregate (LWA) exist in large quantities in Pakistan (Asrarullah, 1972). In the present paper, Paleozoic slate from the Attock-Cherat ranges (Tahirkheli, 1970) has been used to study its engineering properties for use as a lightweight aggregate concrete. The present work is undertaken in order to utilize our huge resources for preparing lightweight aggregate which is now a days used very commonly in the developed world.

## 2. Geology of the area

The slate belongs to Precambrian Manki Formation and the upper contact of Manki is gradational with Shahkot formation while its lower contact is covered under alluvium. The Manki Formation consists of thick sequence of slate and phyllitic slate with subordinate intercalations of quartzite and limestone. Dolerite intrusions and quartz veins are found locally. It is thin to medium bedded and highly fractured and jointed and is extensively developed in the northern foothills of the Attock-Cherat Range, west of Indus river. Its typical section is an isolated hillock, locally called Manki Ghar, located about six miles south of Nowshera, on the western bank of Indus River (Hussain, 1981). A strongly developed slaty cleavage is prominent near Manki, Ziarat Kaka Sahib, Attock, and Khairabad. Ripple marks are locally observed which are usually present in sandy bands. Some small scale cross bedding and graded bedding is also present in sandy beds. Manganese dendrites and pyrite cubes are present in abundance in lower portions of the slates of Manki Formation. Limestone occurs as pockets and lenses. Another important feature is the presence of quartz veins usually prominent near the northern parts of study area.

## 3. Experimental work

Field work was conducted and samples were collected from different locations i.e. Manki, Tangi, Ziarat Kaka Sahib, Shaidu (from an outcrop about 3 km from Shaidu) and from an outcrop on the main G.T. road (Fig. 1). The field samples were broken into small pieces of about 1-2 inch in diameter. The samples were quartered and coned and divided into two parts. One, smaller part, was used for chemical analyses and XRD studies at National Center of Excellence in Geology, University of Peshawar, while the larger part was used for engineering studies at PCSIR Laboratories Peshawar. The samples were dried and bloated in order to have lightweight material which was then put to various physical and chemical tests like water absorption, bulk density, moisture content, chlorides and compressive strength, using standard methods of the American Society for Testing Materials (ASTM).

The samples were fired in a rotary furnace at temperature ranging from 1050-1150° C to achieve maximum bloating. After bloating other physical tests were carried out according to the ASTM and American Association of State Highway and Transportation Officials (AASHTO) specifications. It is found that the results of various tests like water absorption, bulk density, compressive strength, soundness, flexural strength and abrasion meets the specifications for structural concrete.

## 4. Results and discussion

Petrographic study of the samples shows the presence of quartz, chlorite, biotite, feldspar and iron ore. Chemical composition of these samples show that Loss on Ignition varies from 3.45 to 4.56 %. The high contents of iron in the form of pyrite and hematite (5.23 %) and alkalies (6.6%) are indicative of better bloating properties in slate.

### *4.1. Bloating test*

The samples were oven dried at 110$^{o}$ C to prevent their decrepitation when placed in furnace at higher temperature. The samples thus dried, were then put in a preheated (1100$^{o}$C) rotary kiln for about 20-25 minutes. The optimum temperature of bloating was 1150-1200$^{o}$C. After heating the bloated samples were cooled and stored for the engineering (physical) tests.

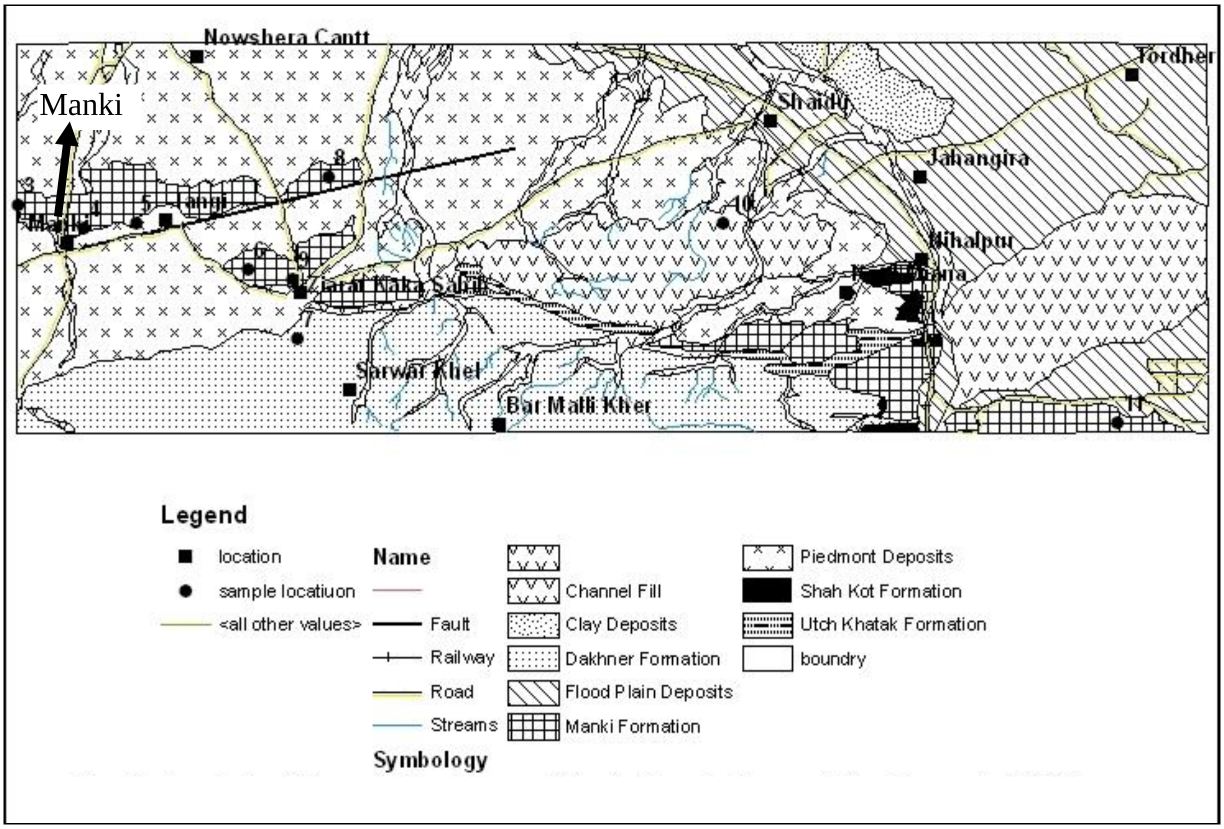


Fig. 1. Geological Map of Manki area, Attock-Cherat Range (After Hussain et al., 1983)

*4.2. Water absorption*

(Using ASTM C121-06 method)

In this method, Light weight aggregate is taken and oven dried at 105$^{o}$C. Then known weight of oven dried sample is taken and immersed in water completely for about 24 hours. Wet sample is then taken out and the difference of the two weights taken is divided by the initial weight and percentage taken out. This gives us the percent water absorption. Water absorption is highest for samples M-8 and lowest for M-2 (Table-1 & Fig. 2).

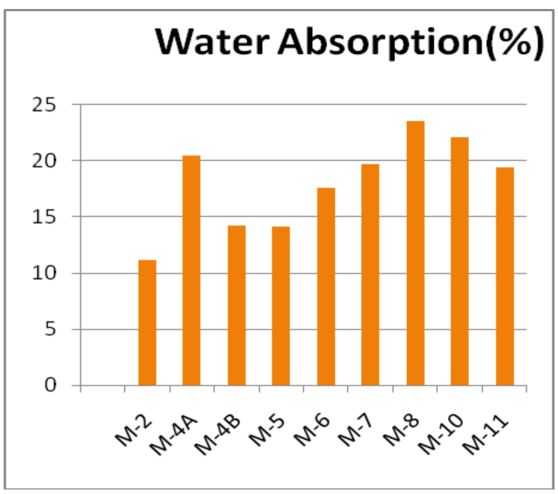


Fig. 2. Water absorption test of LWA

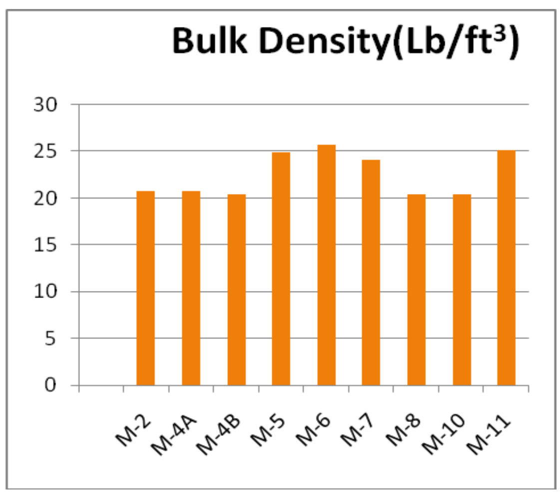


Fig. 3. Bulk density of LWA

Table 1. Water absorption and bulk density results of Manki Slate

| S. No. | Sample Number | Water Absorption (%) | Bulk Density (Lb/ft$^3$) |
|---|---|---|---|
| 1 | M-2 | 11.12 | 20.8 |
| 2 | M-4A | 20.46 | 20.8 |
| 3 | M-4B | 14.22 | 20.4 |
| 4 | M-5 | 14.15 | 24.9 |
| 5 | M-6 | 17.56 | 25.7 |
| 6 | M-7 | 19.73 | 24.1 |
| 7 | M-8 | 23.57 | 20.4 |
| 8 | M-10 | 22.16 | 20.4 |
| 9 | M-11 | 19.46 | 25.2 |

It was discussed by the Euro Light Con-partners (1998) that the test results from this test method do not give the concrete-producers the absorption information they require for their mix-design. This method gives the initial reading after 5 minutes and then 2 and 24 hrs. The initial (first 5 minutes) absorption is a “lost” information as the very porous LWA do absorb most of its moisture in the very initial minutes after immersion in water. Furthermore, the material is completely dried prior to testing, which is very rare in reality as the LWA are usually in some moist condition.

*4.3.Bulk density*
(Using ASTM C29/C29M-07 method)

Bulk density is a property of particulate materials. It is the mass of many particles of the material divided by the volume they occupy. We get the bulk density value by taking the ratio of mass to volume of the aggregate. Except for four, the bulk density for all samples is almost same i.e. around 20 (Table-1).

*4.4.Moisture content (%)*
(Using ASTM C566-97 method)

In this method, the sample is weighed, oven dried at 110$^o$ C, and again weighed. The difference of the two weights is taken and percent moisture content is calculated. Moisture content of all the samples is almost same except for sample M-7 and M-8, where it is much higher than all others (Table-2, Fig.4).

*4.5.pH*
(Using AASHTO T 289 method)

This AASHTO method has been used to measure pH of these samples which represents the acidity or basicity of a solution. It is formally a measure of the activity of dissolved hydrogen ions ($H^+$), but for very dilute solutions, the molarity (molar concentration) of $H^+$ may be used as a substitute with little loss of accuracy. pH for all the present samples is almost constant (Table-2, Fig. 5).

*4.6. Chlorides (%)*
(Using ASTM C1218 method)

In this method, water extract is taken and then titrated with silver nitrate in the presence of potassium chromate, as indicator, and percentage of chloride content, is calculated. There is very less difference in the chloride % among these samples (Table 2, Fig. 6).

*4.7. Soundness*
(Using AASHTO T 104 method)

In this method, first of all sodium sulphate solution is used. The process is composed of 5 cycles and the difference of the original weight and weight after 5 cycles is taken and the percentage loss is calculated. It must not exceed 30%. It is quite encouraging that the soundness loss for all the samples is almost negligible.

*4.8.Compressive strength*
(Using C 39 /C 39M method)

In this method, concrete cubes of size 4”x4”x4”are made with cement, sand and light weight aggregate in a ratio of 1:2:4 by weight.

Compressive strength of samples are taken after 7 days and then after. 28 days (Table-3, Figs 7 & 8).

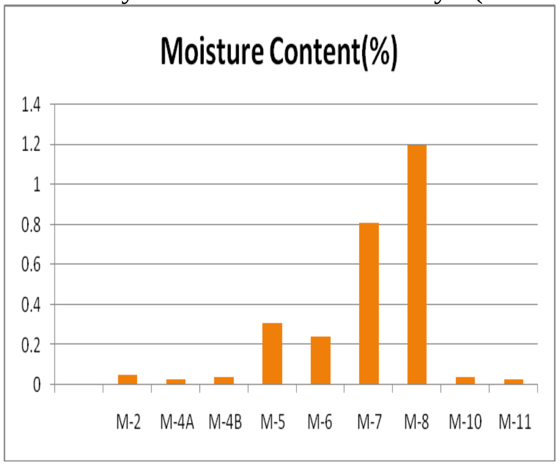


Fig. 4. Moisture of LWA

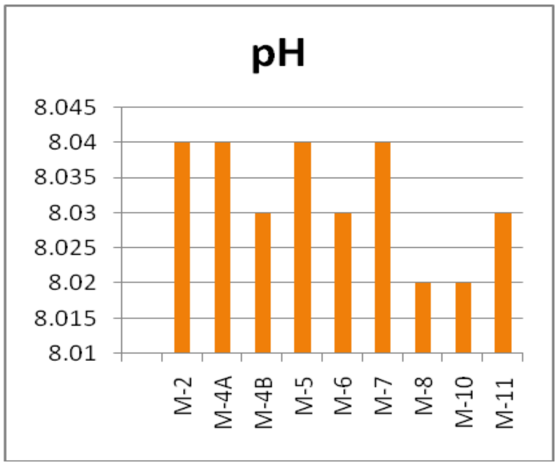


Fig. 5. pH of LWA

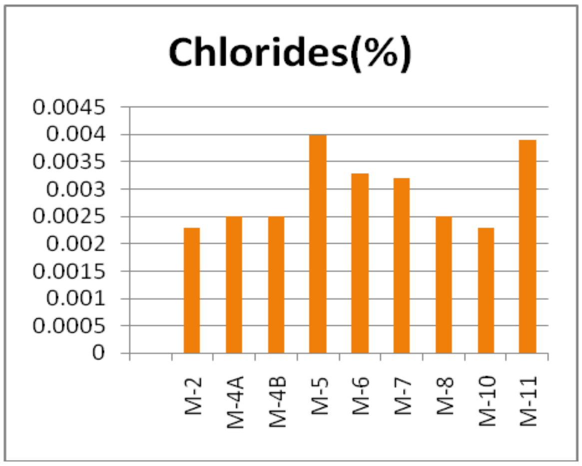


Fig. 6. Chloride content of LWA

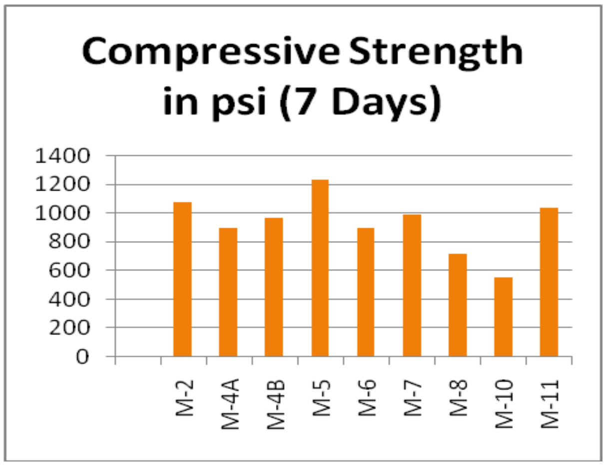


Fig. 7. Compressive strength of LWA

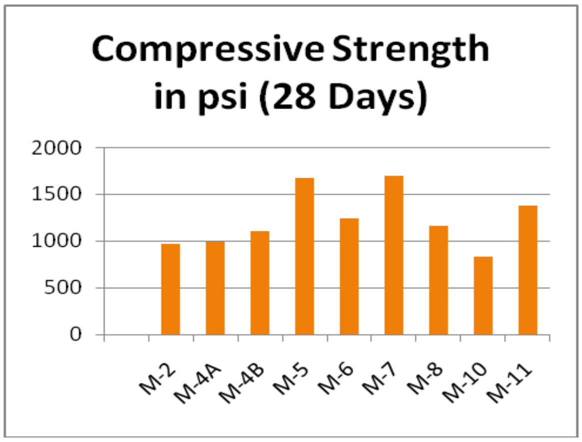


Fig. 8. Compressive strength of LWA

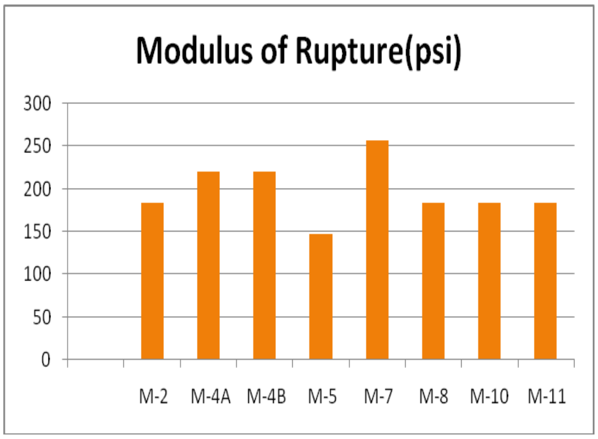


Fig. 9. Modulus of rupture LWA

Table 2. Moisture content, pH and chlorides of Manki Slate

| S. No. | Sample Number | Moisture Content (%) | pH | Chlorides (%) |
|---|---|---|---|---|
| 1 | M-2 | 0.05 | 8.04 | 0.0023 |
| 2 | M-4A | 0.03 | 8.04 | 0.0025 |
| 3 | M-4B | 0.04 | 8.03 | 0.0025 |
| 4 | M-5 | 0.31 | 8.04 | 0.004 |
| 5 | M-6 | 0.24 | 8.03 | 0.0033 |
| 6 | M-7 | 0.81 | 8.04 | 0.0032 |
| 7 | M-8 | 1.20 | 8.02 | 0.0025 |
| 8 | M-10 | 0.04 | 8.02 | 0.0023 |
| 9 | M-11 | 0.03 | 8.03 | 0.0039 |

Table 3. Compressive Strength and modulus of rupture of Manki Slate

| S. No. | Sample No. | Compressive Strength in psi (7 Days) | Compressive Strength in psi (28 Days) | Modulus of Rupture(psi) |
|---|---|---|---|---|
| 1 | M-2 | 1072.50 | 962.50 | 183.72 |
| 2 | M-4A | 894.00 | 990.00 | 220.46 |
| 3 | M-4B | 962.50 | 1100.00 | 220.46 |
| 4 | M-5 | 1229.25 | 1670.60 | 146.97 |
| 5 | M-6 | 894.00 | 1237.50 | 257.20 |
| 6 | M-7 | 990.00 | 1694.00 | - |
| 7 | M-8 | 715.00 | 1156.40 | 183.72 |
| 8 | M-10 | 550.00 | 825.00 | 183.72 |
| 9 | M-11 | 1031.25 | 1375.00 | 183.72 |

*4.9. Flexure test*

(Using ASTM C 120 method)

In this method, concrete slabs of size 11”x3”x3” are made with cement sand and Light weight aggregate in a ratio of 1:2:4 by weight. The samples, after following the method details, are tested for flexure compression test in universal testing machine with the loads acting in the manner described in ASTM C 120 testing method (Table-3).

*4.10. Chemical composition*

All the samples selected for engineering tests were analyzed chemically. These analyses were carried out using atomic absorption at NCEG, University of Peshawar (Table-4). The average values of Manki slate are: $SiO_2$ 59.07%, $TiO_2$ 0.57%, $Al_2O_3$ 15.85%, $Fe_2O_3$ 4.80 %, MnO 0.08%, MgO 2.05%, CaO 1.98%, $Na_2O$ 2.05%, $K_2O$ 2.03%, $P_2O_5$ 0.22% and Loss on ignition is 3.87 %. There is some relationship between the chemical analysis and bloatable clays (Klinifelter, 1960), and the bloatable clays usually contains 6 % iron oxide and about 6 % of alkalie. If alkalies exceed more than 6 %, then clay has tendency towards slagging and stickiness. Excessive amount of iron seems to make little difference, however, in Manki slate the total alkalies varies from 5.85 % to 6.98 %, while sample M-8 shows a little higher value i.e. 7.8.

## 5. Conclusions

Various engineering tests carried out for this lightweight material show that no definite relationship is found between the chemistry of the rock to the engineering properties. Chloride content of Manki slates is within the permissible limits of the required lightweight aggregate material. Loose bulk density is also comparable with that of pumice stone which is a naturally occurring LWA. Water absorption is also within limits as for pumice it is 9-19% and for scoria 6.3 %. Moisture content is low as compared to pumice stone and scoria (Eurolight Con, 1998).

Table 4

Loss on ignition (Table-4) also is comparable with the other standard lightweight aggregate materials. Though the compressive strength and flexure strength of the slate concrete prepared for the present studies are lesser than those of the gravel concrete but this is far lighter in weight as compared to the later one. So if expanded slates are mixed with some sort of high strength cementing materials, it may prove to be a good quality light weight aggregate material.

## Acknowledgements

We are indebted to Mr. Jamil Akhtar, E.O., PCSIR Laboratories Complex, for his cooperation and help in making the location map (Fig.1), Mr. Yaqoob Talib, Mr. Liaqat Ali and Mr. Hashim of PCSIR Laboratories Complex, Peshawar, for extending help in bloating and sample preparations for various tests.

## References

Asrarullah, 1972. Economic resources of North West Frontier Province. Geological Survey of Pakistan Unpublished Report, 59.

Euro Light Con, 1998. LWAC material properties, state-of-the-Art Economic Design and Construction with Light Weight Aggregate Concrete, European Union- Brite EuRam III.

Hassan, A., 1970. Crushing strength of concrete made from locally expanded clay aggregate. West Pakistan. Engineering Congress, Lahore, 15, 39-49.

Hassan, A., 1972. Pilot plant for expanded clay aggregate. Engineering News, 17, 43-51.

Hussain, A., 1981. An introductory note on prospects and potential for lightweight aggregates in Pakistan. Geological Survey of Pakistan Unpublished Report, 4.

Hussain, A., Chaudhry, M. A., Siddiqi, F. A., Zubair, M., 1983. Lightweight aggregate; A study of raw material in Pakistan, Islamabad-Peshawar region. Geological Survey of Pakistan Records, 66.

Khan, M., Parker, N. A., 1970. Claystone and shale of Chittagong region (Bangladesh) for lightweight aggregate production. Geological Survey of Pakistan Records, 20, 2-17.

Kinniburgh, W., 1969. Technical Feasibility of producing lightweight aggregate from clay of West Pakistan. Building Research Station, London, 4, 1-9.

Klinifelter, T. A., 1960. Lightweight aggregates. In: Gillson, J.L. et al., Eds., Industrial Minerals and Rocks (Nonmetallic other than Fuels) (3rd ed.), AIME, New York, 487–495.

Tahirkheli, R. A. K., 1970. The geology of Attock-Cherat Range, West Pakistan. Geological Bulletin University of Peshawar, 5, 26.

www.bst-betostyrene.com/handbook

www.escsi.org/ContentPage.aspx?id=525