Geol. Bull. Punjab Univ. 44, 2009

ENGINEERING PROPERTIES OF POTENTIAL AGGREGATE RESOURCES FROM EASTERN AND CENTRAL SALT RANGE, PAKISTAN

BY

MUHAMMAD MUNAWAR IQBAL GONDAL
Road Research and Material Testing Institute, New Campus, Lahore-54590

NAVEED AHSAN
Institute of Geology, University of the Punjab, Quaid-i-Azam Campus,
Lahore-54590 Pakistan

AND

AHMAD ZIA JAVID
Road Research and Material Testing Institute, New Campus, Lahore-54590

Abstaract: *A colossal quantity of aggregates derived from rocks and natural gravel are extensively used in the construction of infrastructures. The engineering properties of these aggregates determine their in-service performance. Jutana Formation, Sakeasar Limestone and gravels deposited by streams in Jabbi-Warchha and Katha Saghral area are crushed for use in ordinary Portland cement and asphalt concrete, unbound and bound pavements, railway ballast and riprap. Present study evaluates engineering properties of these local coarse aggregates for use in roads and concrete. The physical properties of aggregates like specific gravity (2.65), water absorption (0.739%), soundness (4.06%), Los Angeles abrasion value (24.48%), California Bearing Ratio (90.10%) and coating and stripping values conform to available standards thereby indicating that these aggregate deposits are potential aggregate sources for mega projects in the Punjab province.*

INTRODUCTION

Pakistan has an area of 803,950 Sq-Km and a population of around 160 Millions that use 228,206 km of road network through out the country. In 1990s, the then Government took initiative to remodel and reconstruct all the National Highways of Pakistan to provide safe and efficient communication network. In general it is believed that better roads are considered as an imperative component of the Government's poverty alleviation approaches that operate as a mechanism to create jobs (Khan, 2008). According to careful estimates, the transport sector contributes about 10% of total GDP of Pakistan by providing work for about 2 million people and transporting over 90% passengers and goods by roads.

For road construction a large quantity of aggregates (Smith and Collis, 1993) is a prerequisite. In Pakistan, aggregates are produced mainly by quarrying rocks and then crushing (Ahsan et al., 2000, 2000a; Chaudhry et al., 2000) to required sizes for use in ordinary Portland cement concrete, base, sub base, asphalt concrete, water bound macadam, railway ballast, riprap and fillers. Besides these, gravel and sand produced by natural processes is also used as aggregate (e.g. Neville and Brooks, 1999; Kandhal et al., 2000; Zadi et al., 2008). The in-service performance of above mentioned structures is bracketed with the engineering properties of the aggregate (Naville, 2000). The present study deals with the evaluation of aggregates available in Ara-Basharat-Garibwal area (Jhelum and Chakwal districts), Jabbi-Warchha gravel fan and Katha Saghral area (district Khushab) for use in ordinary Portland cement, base, sub base and asphalt concrete.

ARA-BASHARAT-GARIBWAL AREA

Location and accessibility

The Ara-Basharat-Garibwal area (lat. 32^o 40' to 32^o 45'N; long. 73° 10' to 73° 25' E, Fig 1) is accessible through Pind Daden (P.D) Khan-Jhelum road and Head Rasool to

Kharian road. Two roads off take from P.D. Khan-Jhelum road, one at Dharyala/Chak Mujahid to Rawal and Ara and the second from P.D Khan to Gharibwal via Saowal. These roads are in process of widening/improvement

Presently, a few small crushers located in Chakwal district are potential aggregate source for the area. Besides these, Irrigation Department and Pakistan Railway is using uncrushed and crushed stone aggregate picked from various Nullahs as riprap and rail road ballast, respectively. However, these sources are unable to meet the huge requirements of road sector.

The samples (Smith and Collis, 1993; Baker, and Hendy, 2005) of rock pieces and crush were collected from Irrigation quarry stack, Gharibwal cement factory crushers, from rock out crops falling along the route alignment of Basharat-Ara-Rawal road and railway crusher at Rawal village on Chak Mujahid-Gharibwal factory road.

Geology

The Salt Range forms steep cliffs and scarps that rise abruptly from the Punjab Plains (Kazmi and Jan, 1997) to the south whereas to the north theses slopes are gentler and wide and form hogbacks and cuestas. The rocks exposed in the area (Shah, 1977) belong to Salt Range Formation, Khewra Sandstone, Kussak Formation, Jutana Formation, Baghanwala Formation and Tobra Formation. At places these units are overlain by Tertiary sequence comprised of limestones and shales (Shah, 1977). Besides other localities, in the present study samples were also taken from Jutana Formation and Sakeasar Limestone outcrops.

Jutana Formation, Early Mid. Cambrian Late Early Cambrian in age, is composed of cliff forming thick bedded to massive brownish weathering, cream colored to yellowish white sand dolomites to dolomitic sand stone with few shale intercalations. Thickness of this unit at village Jutana/Gharibwal cement factory is 75-90 meter thick. It runs right from Jalalpur to this area at the same level. Pakistan Railway and Punjab Irrigation Department quarries are located in this unit. Sakesar Limestone, early Eocene in age, consists of light grey to off white/cream colour nodular to massive limestone beds (Shah, 1977; Boustani, 2000). In this area it forms hogbacks and cuestas along with steep cliffs. It occurred all along the northern slopes i.e. dip slopes of the Salt Range. The exposures of these limestones are in kilometers width.

JABBI- WARCHHA AND KATHA SAGHRAL AREA

Location and accessibility

The potential quarry area of Jabbi-Warcha (lat.32º 21' to32º 26 N; long. 72º 00' to 72º 07' E) and Katha Saghral (latitude 32º 32' N; long. 72º 27' E) are well connected and accessible through existing road network. A 24 feet wide metalled road off takes from Mitha Tiwana at Khushab-Mianwali road and after traversing through plain area leads to Jabbi at 13km distance. The same road with single carriageway turned toward Dhokari, Choa Warchha, and Joins with Quaidabad Warchha road developing a loop with Khushab Mianwali road. The section from Jabbi to Warchha runs over gravel terrace nearly parallel to the Salt Range hills. Punjab Highway Department used hand broken and crushed sub base and base course aggregate from quarries located in Jabbi-Choa-Warcha area for the construction of Khushab-Mianwali road in Khushab district.

At present three small crushers with 2000-3500 ft^3 per day crushing capacity are working in the vicinity of Jabbi. In Katha Saghral area the gravel is manually picked/mined from nullah bed and transported to the crushers. In this area two crushers with the crushing capacity of 1500 to 3500 ft^3 per day are operative. The aggregate is reported to be produced by Pakistan Atomic Energy Commission for its construction works. In addition to this the crushed gravel aggregate is also used for mortar and reinforced concrete in adjoining areas.

The samples of pit run gravel, large sized boulders were collected from nullah bed and gravel fan area, whereas crush samples were collected from the crushing plants installed at Khushab-Chakwal road in Katha Saghral area and crushers located at Jabbi on Jabbi-Mitha-Tiwana road.

Geology

The relief of the Salt Range in this area varied from 300m to 1522m (Sakesar peak) and 1242m (Khura). The rock units range in age from Eo-Cambrian to Paleogene (Shah, 1977; Kazmi and Jan, 1998) and are comprised of shale, sandstone, limestone, dolomitic limestone, dolomitic sandstones and dolomite. Jabbi to Choa Warcha area is severely disturbed due to diaperic folding. Various small-scale faults are associated with these folds, which resultede into sever rock shattering into blocks, boulders and gravels. Surrakha Wahan and Choa Nullah traverse through this severely shattered area and form alluvial fans.

Jabbi to Warchha fan deposits are one of the largest gravel terraces on the southern side of the Salt Range. These deposits comprise light gray, creamish to off white coloured limestones with subordinate off white quartzite, minor reddish coloured sandstone, dolomitic sandstone and sandy dolomite. The fine ratio in pit-run gravel varies from 4 to 30%. The width

of Jabbi-Warchha gravel fan area varied from 1.5 km to 2.5km approximately and its vertical extent is more than 100 feet.

Similarly, the fan area along the Salt Range in Katha Saghral - Katha Misral is relatively narrow (½ km to 1km in width) however large quantity of gravels are deposited in the bed of both these kathas. The gravel fan of Jabbi-Warchha area and gravel terraces of Katha Saghral-Misral are formed by deposition of sub-spherical to sub-angular boulders/gravels shed from adjoining severely shattered Salt Range hills by hill torrents during monsoon.

LABORATORY TESTING

Characterization of aggregate is of prime importance in selection of good quality and performance bound aggregate for use in construction industry (Fookes et al., 1988; Kandhal and Parker, 1998; Ahsan et al., 2000; Chaudhry et al., 2000, 2006). In order to meet the required standards specific gravity and water absorption (AASHTO T-85), sodium sulphate soundness (AASHTO T-104), Los Angeles abrasion value (AASHTO T-96), modified proctor test (AASHTO T-180), California Bearing Ratio (CBR, AASHTO T-193) and coating and stripping test with 60/70 and 80/100 bitumen (AASHTO T-182) were conducted for determination of physical properties of aggregates of Ara-Basharat-Garibwal area (Jhelum and Chakwal districts), Jabbi- Warchha gravel fan and Katha Saghral area (district Khushab). In addition to this petrographical evaluation of these aggregates were carried out to predict alkali aggregate reaction potential (Navelli, 2000; Chaudhry et al., 2000, 2006).

In the present studies 18 samples from crushers, plants, outcrops and gravel pits were collected to evaluate engineering properties following the test procedures mentioned in the published literature (e.g. AASHTO). Each sample was tested thrice to minimize the error and ensure error free results. However, average of three tests is given against each sample and results are presented in Table 1.

Specific Gravity and Water Absorption (AASHTO T-85)

Specific gravity is considered a ratio of density of material to density of water and water absorption determines the amount of water that an aggregate can absorb. Specific gravity of crushed aggregate ranges from 2.62 to 2.70 (mean = 2.65) whereas the water absorption varied from 0.445% to 1.308% (mean = 0.739%). All the 18 samples indicate more or less same vale of specific gravity while in case of water absorption the samples belonging to Sakesar Limestone outcrops and Katha Misral pit-run gravel show higher water absorption values. No limit for specific gravity has been specified in the published literature (AASHTO T-85-88; NHA, 1998). In all the samples the water absorption was found well with in 2% specified limits (AASHTO T-85-88; NHA, 1998).

Soundness Test (AASHTO T-104)

This test method is helpful in accessing the soundness/performance of aggregates during intense weathering action (e.g. freeze and thaw, attacks by various salts, etc) especially in the absence of in service records of the aggregates. The %age values obtained after completion of 5 cycles of immersion in the Na2SO4 solution and subsequently drying ranges from 2.15 to 8.47% (mean is 4.06%) against specified maximum limit of 12% for base course and 10% (maximum) for cement concrete jobs. Two samples obtained from Sakesar Limestone outcrop and railway quarry show a relatively higher value of soundness but within limits mentioned in literature as compared to the other crushed aggregates probably due to insitu weathering.

Los Angeles Abrasion Test (AASHTO T-96)

In order to work out the toughness and durability of crushed aggregate, Los Angeles abrasion test is recommended in the published literature. The Los Angeles abrasion values (LAV) ranges from 18.60% to 29.40% (mean = 24.48%). The samples collected from Gharibwal cement factory crushers show minimum LAV whereas samples collected from Jabbi, railway crusher, Chukki Whan and Khata Saghral show slightly higher LAVs (27.8% to 29.4%), though within safe limits, as compared to other samples. Mostly pit run gravel indicate such higher values as they contain the boulders derived from both competent and incompetent lithologies. The maximum allowed LAVs of aggregates for sub-base, base course and ordinary Portland cement and asphalt concrete are 50%, 40% and 35%, respectively.

Modified Proctor Test (AASHTO T-180)

This test is a pre-requisite for executing good quality civil projects specially roads. The samples were tested to evaluate the maximum dry density and optimum moisture content on ratio of 75% coarse and 25% fine. The value of maximum dry density for sub-base ranges from 143.0 lb ft^{-3} to 144.8 lb ft^{-3} (mean = 144.3 lb ft^{-3}) whereas value of maximum dry density for base course varies from 2.227 lb ft^{-3} to 2.414 lb ft^{-3} (mean = 2.315 lb ft^{-3}) .The optimum moisture content for these samples varies from 5.4% to 5.6% (mean value is 5.5%).

CBR Value (AASHTO T-193)

This test method is intended for determination of bearing value of material when subjected to intense loading. Therefore to assess the strength of material under load, CBR test procedure was carried out at 100% compaction level under soaked conditions. The coarse and fine ratios were combined,

Table 1

Engineering Properties of Potential Aggregate Resources from Eastern and Central Salt Range

Description	**Specific Gravity**	**Water Absorption %**	**Sulphate Soundness %**	**Los Angles Abrasion Value%**	**Max. Lab. Density pcf**	**Optimum Moisture Content%**	**CBR Value %** **100% compaction**	Area coated 60/70 Grade Bitumen Immersion in water **(16-18 hrs)**	Area coated 80/100 Grade Bitumen Immersion in water **(16-18 hrs)**
Surrakha wahan pit-run gravel	2.67	0.588	4.42	26.6	144.5	5.4	95.8	Above 95%	Above 95%
Chukki wahan pit-run gravel	2.67	0.551	3.56	27.2	143.0	5.5	96.2	Above 95%	Above 95%
Chukki wahan boulder	2.66	0.612	3.45	27.1	144.2	5.6	90.2	Above 95%	Above 95%
Jabbi boulder	2.65	0.659	3.44	28.9	144.5	5.5	83.5	Above 95%	Above 95%
Jabbi boulder 1	2.65	0.659	3.45	29.4	144.8	5.6	83.4	Above 95%	Above 95%
Crush (Dr. Hadayat crusher) Jabbi-Mitha Tiwana Road	2.66	0.586	4.28	24.8	144.6	5.4	85.2	Above 95%	Above 95%
Katha Saghral pit-run gravel	2.67	0.556	4.25	27.3	144.3	5.4	94.1	Above 95%	Above 95%
Katha Saghral pit-run gravel A	2.66	0.610	4.20	27.6	144.7	5.4	94.2	Above 95%	Above 95%
Crush (Dr. Hadayat crusher) Katha Saghral (Khushab Chakwal Road)	2.66	0.920	2.15	26.6	144.8	5.5	91.4	Above 95%	Above 95%
Katha Misral pit-run gravel	2.65	1.218	4.36	25.9	144.0	5.6	90.3	Above 95%	Above 95%
Dolomite rock Irrigation Quarry	2.70	0.557	4.24	2.61	144.5	5.4	89.9	Above 95%	Above 95%
Crush Gharibwal cement factory crusher	2.67	0.541	3.52	20.6	143.0	5.4	91.1	Above 95%	Above 95%
Crush Gharibwal cement factory crusher	2.68	0.445	3.67	18.6	144.2	5.5	88.7	Above 95%	Above 95%
Sakesar lime stone outcrop	2.66	1.117	3.46	24.8	144.8	5.6	94.7	Above 95%	Above 95%
Sakesar lime stone outcrop	2.62	1.020	3.11	24.0	144.6	5.5	94.1	Above 95%	Above 95%
Sakesar lime stone outcrop	2.64	1.308	3.86	25.4	144.3	5.6	90.2	Above 95%	Above 95%
Sakesar lime stone outcrop	2.65	0.690	8.47	25.6	144.8	5.6	83.4	Above 95%	Above 95%
Mixed crush Railway crusher	2.65	0.671	5.21	27.8	144.0	5.6	85.2	Above 95%	Above 95%

as they were available in natural deposits. The values ranged from 83.4% to 96.2% at 100% compaction. The normal requirement specified by AASHTO for sub-base and base course is 30% and 80% at 100% compaction, respectively.

Coating and Stripping of Bitumen-Aggregate Mixture (AASHTO T-182)

This test is primarily conducted to counter check the petrographic analysis towards adhesive properties of certain grade asphalt. Usually it is conducted under typical laboratory conditions following standard specifications, however it may also be conducted at actual temperature prevailing at road surface during extreme hot conditions. Sixteen samples of crush were tested for determining their ability to retain bituminous film (AASHTO T-182) method, in case of 80/100 and 60/70 grade bitumen all the samples at 25°C qualified the test requirements depicting values greater than 95%.

Alkali aggregate reaction potential (ASTM C-295)

Alkali aggregate reaction is considered a reaction between alkalis in cement and certain rock aggregates (e.g. Smith and Collis, 2001). Besides other engineering properties, petrographic testing is a microscopic examination that evaluates the aggregate material (French, 1991) in respect of deleterious alkali aggregate reaction potential that is believed to be one of the major cause of deterioration in hardened concrete (Lopez-Buendia et al., 2006). Petrographically, Sakeasar Limestone is composed of carbonate, quartz (upto 0.5%) that shows normal optics, hematite/limonite (≈ 0.5), clay ($\approx 1.0\%$) and minor dolomite (less than 0.5%). Percentages of constituent minerals indicate that the rock can safely be used as an aggregate with ordinary Portland cement and high alkali cement. Although, crushed rock aggregate of Ghraibwal area contains about 6% quartz but it is non-deleterious as quartz shows normal optics.

Besides these observations, modal analysis of crushed rock aggregates of Jabbi-Warchha area shows the presence of about 2.1% quartzwackes that indicates its potentially deleterious character when used with ordinary Portland cement and high alkali cement. Moreover, Jutana Formation composed of dolomite may show alkali carbonate reaction potential with ordinary Portland cement.

DISCUSSION

The Jutana Formation is composed of sandy dolomite, dolomitic sandstone, hard and tough to hammer. The physical and petrographical results show that aggregate derived from this formation is suitable for road sub base and base course. Because of hydrophobic character reflected by above mentioned 95% adhesion value, it gives an excellent binding with bitumen when used in asphalt wearing course. In addition to this Jutana Formation aggregate will provide anti-skidding characteristics to asphalt wearing course as reflected by less polishing value. It is an excellent dimension stone for building construction however, it may not be suitable as cement concrete aggregate due presence of dolomite that may trigger potentially deleterious alkali carbonate reaction.

Sakesar Limestone outcrops on the back slopes of Salt Range escarpment. It is exposed in a very large area of Bashart and Ara Union Councils. In Basharat Union Council area Sakeasar Limestone outcrops are a potential source of raw material for Gharibwal cement factory that has established its crusher at Sirhadi above village Jutana. However, Sakeasar Limestone outcrops in Ara Union Council has not been leased out by the Mine and Mineral Department, Govt. of Punjab. The engineering properties of the Sakeasar Limestone indicate that this lithostratigraphic unit is hard, tough, and durable with excellent strength properties and being hydrophobic in nature it gives good adhesion characteristics. Therefore this formation is suitable for road sub base, base course, Ordinary Portland cement concrete (PCC/RCC), riprap and railway ballast. However in Ara Union Council area and where substantial reserves of the formation are available, careful planning is required to develop quarries for local construction industry.

Both above described rock units could be mined through open pit excavation. In case of quarrying of Sakesar Limestone, “the principle potential aggregate source”, in Ara Union Council area, the land is required to be reclaimed, which is not just a requirement of environmental protection and conservation but an essential part of financial planning and overall viability of aggregate production. The underlying rock/sediments comprise Patala Formation (Shah, 1977) composed dominantly of shales, so the pits and quarries can successfully be used for agriculture as well as for forestry purpose. Presently the major vegetation is restricted to the shale outcrops and limestone shows sporadic vegetation.

This potential aggregate source area may be developed for quarrying activity either by Govt. or private sector or as a joint venture. It will serve as a cheap and durable aggregate source for civil construction works for Chakwal, Jhelum, Gujrat, Mandi Baha-ud-Din, Gujranwala, Sialkot, Sheikhupura, Lahore and Kasur Districts. These areas are major aggregate consumers since major industrialization is taking place in these areas.

The engineering properties of crushed gravel of Jabbi-Warchha area and Katha Saghral-Misral revealed that it qualifies all specified limits indicated in AASHTO for sub base and base course. These deposits predominately comprise hydrophobic carbonaceous rocks (limestone/dolomite) which is

further supplemented by good adhesion with bitumen of 60/70 and 80/100 grade. The hydrophobic nature and good adhesion with bitumen suggests that the crush of these deposits can safely be used in asphalt concrete and surfacing work (Triple surface treatment). The presence of minor impurities like quartzite when crushed along with limestone will act as good anti-skidding material for road surface. The calcitic composition of rock clasts crushed aggregate strongly recommends its use in cement concrete work.

Due to inadequate crushing facility, presently it is not an approved aggregate source of Highway Department for base, asphalt concrete, surfacing and cement concrete. The area under study has good potential for open pit mining and crushers can be installed in gravel fan area of Jabbi-Choa Warchha section as well as along the terraces of both Katha Saghral and Jabbi Warchha area. The operation cost of crushing activity will be less if plant is installed close to or on to the deposits. These potential quarry sites are easily accessible through existing road network. Moreover, it is strongly suggested that environment friendly quarrying and crushing procedures may be applied.

The area in general is barren with sporadic vegetation due to poor rainfall. The local population has very limited economic activity. If these quarries are developed as potential resources of construction materials, it will definitely serve the needs of public and private sector construction activity in district Khushab, Bhakkar and part of Mianwali. Due to exploitation of this natural resource, there will be drastic change in the socio-economic conditions of the local populace.

RECOMMENDATIONS

1. The coarse and fine fraction of both Jutana Formation and Sakesar limestone are suitable aggregates for road construction. However in ordinary Portland cement concrete aggregates derived from Sakesar Limestone should be used.
2. The coarse and fine fraction of gravel from Katha-Saghral and Jabbi- Warchha qualifies in strength, durability and other associated tests. They are recommended for use in construction works. However, Jabbi- Warchha gravel contains greywackys that have potential for deleterious alkali silica reaction.
3. The pit-run gravel after bringing it into proper grade and size should be used as sub base and base material.
4. For Lahore Sheikhupura, Kasur, Gujranwala, Sialkot, Wazirabad, Gujrat, Mandi Bauha-ud-Din, etc. these aggregates are cheap due to less transportation cost as compared to Kirana Hills and Margalla Hills aggregates.
5. They show excellent bitumen affinity so they are more suitable for road surfacing.
6. The mining should be done with environment friendly procedures.

ACKNLWLEDGEMENT

The authors would like to acknowledge Mr. Muhammad Akbar for typing this manuscript.

REFERENCES

Ahsan, N., I.H. Baloch, M.N., Chaudhry,Ch M. Majid, 2000. Strength Evaluation of Blends of Lawrencepur, Chenab and Ravi Sands with Lockhart and Margala Hill Limestones for use in Concrete. *Special Issue Pak. Muse. Nat. Hist.* Pakistan Science Foundation, pp. 213-240.

Ahsan, N., M.N. Chaudhry, and M. Muzaffar, Ch.2000a, Mineralogy, Engineering Properities and Alkali Aggregate Reaction Potential of Maira Sand, Thakot, Pakistan. *Third South Asia Geological Congress*, Lahore, Pakistan Sept. 23-26, 2000, pp. 150-151

Baker, D., and Hendy, B., 2005. Planning for Sustainable Construction Aggregate Resources in Australia. *The Queensland University of Technology Research Week International Conference*, Brisbane, Australia.

Boustani, M., 2000. Depositional and diagenetic environments of the (Eocene) Sakesar Limestone in the Salt Range Area, Pakistan. Unpublished Ph. D. Thesis, Qauid-e-Azam University, Islamabad, Pakistan, pp. 1-208.

Chaudhry, M.N., I.H. Baloch, N. Ahsan, and Ch. M. Majid, 1999. Engineering properties, Mineralogy, Alkali Aggregate Reaction Potential and Provenence of Lawrencepur Sand Pakistan, *Special Issue Pak. Muse. Nat. Hist.* Pakistan Science Foundation, pp. 241-254.

French, W.J., 1991. Concrete Petrography. *Quarterly Journal of Engineering Geology*, Vol. **3,** pp 17-48.

Kandhal, P.S., Mallick, R.B., and Huner M., 2000. Measuring Bulk Specific Gravity of Fine Aggregates: Development of a New Test Method. *Transportation Research Board, Transportation Research Record*, **1721**.

Kazmi, A.H. and Jan, M.Q., 1997. Geology and Tectonics of Pakistan. Graphic Publishers, Karachi, pp. 1 – 554.

Khan, R. A., 2008. Role of Construction Sector in Economic Growth: Empirical Evidence from Pakistan Economy. In: *First international conference on construction in developing countries (ICCIDC–I) "Advancing and integrating construction education, research and practice"* August 4-5, 2008, Karachi,, Pakistan.

Liu, H., Kou, S. and Arne, P., 2004. Microscope Rock Texture Characterization and Simulation of Rock Aggregate Properties". *SGU Project* **60**-1362.

Lopez-Buendia, A.M., Climent, V., Verdu, P., 2006. Lithological Influence of Aggregate in the Alkali- Carbonate Reactio. *Cement and Concrete Research*, Elsevier Ltd. Valencia, Spain, Vol. **36**.

Neville, A.M. 2000. Properties of Concrete 4th ed. Pearson Education Asia Pte. Ltd. Edinburgh, U.K. 844p.

Neville, A.M., and Brooks, J.J., 1999. Concrete Technology Longman Group U.K. First ISE reprint 1999 Edinburgh, U.K. 438p.

Quiroga, P. N. 2003. The Effect of Aggregate Characteristics on the Performance of Portland Cement Concrete. PhD Dissertation, The University of Texas at Austin, Austin, TX.

Smith, M. R. and Collis, L. 2001. Aggregates – Sand, Gravel and Crushed Rock Aggregates for Construction Purposes (3rd edition). The Geological Society London. 339p.

Shah, S.M.I., 1977, Stratigraphy of Pakistan: *Geol. Surv. Pakistan*, Quetta, Mem. No. **12**, pp. 138.

Zaidi, S. M., Rafeeqi, S. F.A., Ali, M. S. and Khan, A. M., 2008. Aggregate characterization - An Important Step towards Addressing Construction Issues in Pakistan. In: First international conference on construction in developing countries (ICCIDC–I) "*Advancing and integrating construction education, research & Practice*" August 4-5, 2008**,** Karachi,, Pakistan.