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Engineering Characteristics of widely used Coarse Aggregates in Pakistan: A Comparative Study

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Abstract

Pakistan has vast potential of concrete aggregates due to having numerous mountainous ranges. However, the properties of these aggregates are yet to be explored as scant research has been carried out in this area. In this study, an experimental approach was adopted to compare the engineering properties of widely used coarse aggregates in Pakistan. Aggregate samples were gathered from four various quarries in accordance with ASTM sampling procedure and their physical as well as mechanical properties were evaluated through laboratory testing according to ASTM and BS standards. Tests were performed on Margalla, Sargodha, Barnalla and Mangla crushes. Different concrete specimens were also prepared using the above mentioned aggregates and tested for their mechanical properties (compressive, tensile and flexural strengths). Test results revealed that the aggregates from evaluated quarries are suitable to be used in concrete. Each sample of aggregates have different characteristics which is very important keeping in view the type of construction, economy and its environment. It was observed that Margalla aggregates resulted in better concrete mechanical properties, while Sargodha aggregates showed improved physical characteristics.

Key Words: Coarse aggregates; physical properties; mechanical properties.

1. Introduction

Normally, concrete mixture consists of coarse aggregates, mortar matrix and interfacial zone. Aggregates are the basic raw materials, which are essential for all construction activities. Aggregates are extensively used in concrete blocks, steel reinforced beams, flooring and retaining walls, mass concrete for mega structures, road construction, rail ballast and filter media for water and sewage treatments. Coarse aggregates are the main component in concrete and responsible for the adequate strength of concrete. The aggregates having undesirable properties do not result in desired strength and durable concrete and hence, flaws exist in the structural performance leading to durability issues in concrete. Aggregates are the main component of concrete (i.e. up to 75% by concrete volume) that significantly affect the concrete properties and mixture proportions [1]. Economically, it is important to use as much aggregates as possible due to its cheaper cost in comparison with other concrete ingredients. Therefore, the quality of aggregates is of great importance [2]. In addition to being economical, aggregates usually supply concrete with better wear resistance and dimensional firmness. Properties of aggregates greatly affect the mechanical properties of concrete as well as its performance and durability [3, 4]. Furthermore, the importance of aggregate strength cannot be denied in high strength concrete [5]. For optimum concrete strength properties, a low water/cement ratio (w/c) and high cement content is required along with the quality aggregates with limits on aggregate size (i.e. maximum 9.5 mm) [6]. Natural aggregates are formed by the process of weathering and abrasion or by crushing of the rocks. Properties of the aggregates that are dependent on the parent rocks are mineralogy, hardness, strength, specific gravity and porosity [7-10], while surface texture, particle size distribution and absorption are the properties independent of the parent rock [11-14]. Quality of concrete whether it is in fresh or solid state has greatly influenced by the above mentioned properties.

Although the aggregates occupy a large part of concrete and enormous research work has already been carried out to understand the behavior of the concrete. Nevertheless, focus to explore the aggregate properties is comparatively less [1]. For the last decade, mostly the concrete researchers have focused on the binder phase (i.e. Portland cement and supplementary cementitious materials). It must be recognized that high performance concretes would not be prepared without an intelligent selection of the aggregates [15]. In this study, engineering properties of coarse aggregates, which are commonly used in Pakistan have been focused. The aggregates from four different sources namely Margallah, Sargodha, Barnala and Mangla were selected and investigated for their properties in accordance with ASTM and British Standards. British Standards were used to evaluate the physical properties of aggregates (impact and crushing strength) as no ASTM standard is available in this regard.

2. Experimental Investigation

2.1 Material Selection

To conduct this study, a comprehensive testing program was formulated. The selection criteria of the aggregate sources were based upon the following facts:

1. Margalla and Sargodha crush are being extensively used in construction since 1960s and considered as standard aggregate sources for concrete works in federal and Punjab area. In this study, Margalla and Sargodha crush properties were treated as standard properties to assess the suitability of the aggregates samples collected from the other potential sources.

2. Two potential aggregate sources, Mangla and Barnalla were selected for the sake of investigation and comparison with Margalla and Sargodha. Currently, these aggregate sources are being used as local quarries for the construction of minor projects like residential buildings. As these quarries are located in the proximity of some major projects like Gulpur Hydropower project, UCET Campus MUST Mirpur AJK, Pearl Continental Hotel Mirpur AJK and Infrastructure Development at New City Mirpur AJK; their suitability will reduce the haulage of borrow material and hence the total cost of the projects.

3. Mangla crush and Barnalla crush are river/nullah bed materials and hence, do not involve mining and blasting costs. However, they require processing before their use in construction projects. Presently, localized crushers are installed by the contractors and the reported processing cost per 100 m^3 is almost Rs.12,000. It is believed that this cost may be reduced to 80% of present processing cost if mass scale crushing units are installed.

A total of eleven samples: 3 samples each, from different crushers of Margallah, Sargodha and Barnala and 2 samples from different crushers of Mangla crush were collected and subjected to laboratory testing for evaluation. Margallah crush samples were collected from a quarry in Margallah hills in Taxila. Sargodha crush samples were collected from a quarry in Sarghodha whereas, samples of Barnala crush were collected from a quarry in Barnala, located 46 km from the district Gujarat. Remaining two samples of Mangla crush were obtained from a quarry near the Mangla dam. Fig. 1 shows the Margallah quarry site. Various aggregate samples collected from different quarries are shown in Fig. 2.

Fig. 1 Margallah quarry site

2.2 Test Methodology

In the first phase of testing, physical and mechanical properties of the selected aggregates were determined. Afterwards, the properties of the hardened concrete prepared using the aggregates, were investigated to assess the effect of the coarse aggregates.

a) Barnala crush

b) Mangla crush

c) Sargodha crush

d) Margallah crush

Fig. 2 Various coarse aggregates

Following physical properties of the aggregates were studied:

1) Water absorption;
2) Specific gravity;
3) Bulk density and voids;

***Water absorption*:** The ratio of the water weight absorbed by aggregates to the weight of dry sample of aggregates expressed in percentage, is termed as the water absorption. It excludes the water adhered to the surface of the particles [12]. Water absorption of selected aggregates was determined using the ASTM C-127 standards. The aggregate specimens were surface dried by placing them in an oven. Afterwards, the aggregates were immersed in water for 24 hours and then weighed in saturated surface dry condition (SSD). Aggregates were then placed in an oven at 110 ºC for 24 hours and weighed again. Water absorption can be measured as (Eq. 1):

$$A = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100 \qquad (1)$$

Where, A = water absorption, W_{SSD} = saturated surface-dry aggregates weight and W_{OD} = oven-dry aggregates weight.

***Specific gravity of aggregates*:** Specific gravity of tested aggregates was determined in accordance with ASTM C-127. Oven dried bulk specific gravity, apparent specific gravity and saturated surface dry bulk specific gravity were calculated by weighing aggregates in different states i.e., saturated surface dry, saturated and oven dry conditions.

***Bulk density and voids*:** Bulk density and voids in aggregates were determined according to ASTM C-29. During this test, water was used to calibrate the volume of bucket and then the unit weight of coarse aggregate was determined using the calibrated bucket. Voids in aggregates were calculated using the following formula (Eq. 2):

$$Voids = \frac{((S \times W) - D)}{(S \times W)} \times 100 \qquad (2)$$

Where, D = aggregate bulk density (kg/m^3), S = bulk specific gravity (determined following ASTM C-127) and W = density of water (998 kg/m^3).

The mechanical properties of the aggregates were examined using impact value and crushing value tests.

***Impact value of aggregates*:** Impact value of aggregates was determined using British Standard (BS-812). It measures the resistance of the aggregates against crushing when impact loads are applied. Impact value can be calculated as follows (Eq. 3).

$$\text{Impact Value} = \frac{W_2}{W_1} \times 100 \qquad (3)$$

Where, W_1 = weight of the tested aggregates and W_2 = weight of the aggregates passed through 2.36 mm sieve after applying impact loads.

Crushing value of aggregates: Crushing value of the aggregates was evaluated following the British Standard (BS-812). It measures the resistance of the aggregates against crushing using the compressive loads. Crushing value of the aggregates is given by (Eq. 4):

$$\text{Crushing Value} = \frac{W_2}{W_1} \times 100 \qquad (4)$$

Where, W_1 = weight of tested aggregates placed in three layers in steel cylinder and W_2 = weight passed through 2.36 mm sieve after applying compressive loads.

Following mechanical properties of hardened concrete using same aggregates were also studied:

1) Compressive strength
2) Flexural strength
3) Splitting tensile strength

***Compressive strength*:** Compressive strength of the concrete was determined using ASTM C 39. Concrete cylinders were cast and tested at 28 days in saturated surface dry condition. Specimens were capped before testing. For each aggregate type, tests were performed on three concrete cylinder specimens.

***Splitting tensile strength*:** Split tensile strength was determined according to ASTM C 496. Specimens were cast and tested at 28 days in saturated surface dry condition. Cylindrical specimens were cured in water till the testing date. For each aggregate type, tests were performed on three cylindrical specimens.

***Flexural strength*:** Flexural strength was determined according to ASTM C 78. Beam specimens were cast and cured in water till the testing age (i.e. 28 days). Specimens were cured in water till the date of test. For each aggregates type, tests were performed on three concrete beams.

2.3 Concrete Composition

Ordinary Portland cement (OPC) was used in this study. Lawrencepur sand was used as fine aggregates. Concrete proportion was set to 1:2:4 and water-cement ratio of 0.50 was kept constant. Grading of aggregates was done as per ASTM C 33. Casting of each quarry was done in separate batch. Quantity of materials used for casting of each batch are shown in Table 1.

Table 1: Concrete mixture composition

Materials	Quantity
Cement	14.8 kg
Sand	33.5 kg
Aggregates	66.5 kg
Water	7.5 kg

3. Results and Discussion

3.1 Water Absorption of Aggregates

Water absorption results of different aggregate samples are presented in Table 2. Water absorption indirectly measures the porosity in aggregates. In addition, it represents the resistance against frost action. More water absorption of aggregates indicates higher porosity, which lead to serious durability concerns [12]. Fig. 3 shows that Mangla aggregates have the highest water absorption (1.49%) and Sargodha aggregates have the lowest (1.0%). Margalla aggregates have higher water absorption value than Barnalla aggregates. Barnalla aggregates have approximately the same water absorption as Sargodha aggregates (1.04%).

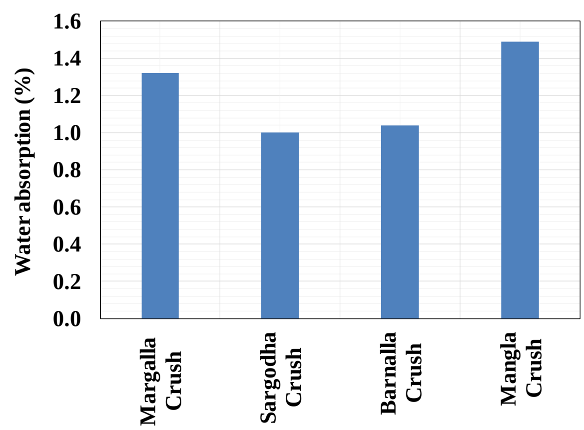

Fig. 3 Water absorption of various aggregates

This shows that Sargodha as well as Barnalla aggregates are good for concrete as far as porosity and durability ~~is~~ are concerned.

3.2 Specific Gravity of Aggregates

Table 2 shows the specific gravity results of different aggregate. The interfacial properties (i.e. bond between the cement paste and the aggregate) are influenced by the pores at the surface of the particles. Smaller the number of pores, higher is specific gravity and the bond strength, which leads to enhanced concrete strength. Though higher specific gravity of aggregate represents its high strength; nevertheless judging the suitability alone on this basis without finding other mechanical properties is impossible. Fig. 4 depicts that Margalla aggregates have the highest bulk specific gravity (2.83) which infers smaller pores as well as greater strength when used in concrete. Previous research depicts that coarse aggregates containing sandstone exhibit higher water absorption and lower specific gravity [15]. As sand stone is major component of Mangla aggregates [16], therefore, results of this study are similar to the previously published literature.

3.3 Bulk Density and Voids

Bulk density is a measure of the effort required to compact the concrete. Generally, for normal weight concrete, the bulk density of aggregates varies from 1200 to 1760 kg/m^3 [12]. The percentage of voids affects the grading of aggregates, which is important for concrete strength. Bulk density and voids values are shown in Table 2. Fig. 5 and 6 reveal that Mangla aggregates have the highest bulk density (1601 kg/m^3) and the lowest percent voids (34%). This indicates that these aggregates are denser and the product concrete will have a higher strength. But this was not true with concrete having Mangla aggregates. Because of their river source, Mangla aggregates were mostly round and smooth; that resulted in reduced strength as observed during the study. Besides, concrete having Mangla aggregates needs lesser compaction effort.

Margalla aggregates have the lowest bulk density (1508 kg/m^3) and the highest voids (45.56%). Sargodha and Barnala aggregates have the values of bulk densities in between those of Mangla and Sargodha aggregates. The results show that bulk density of aggregates has an inverse relation to the air voids which is in close agreement with previous research [15].

Table 2 Comparison between engineering properties of various types of coarse aggregates

Test	Margalla Crush	Sargodha Crush	Barnalla Crush	Mangla Crush
Water absorption (%)	1.32	1.00	1.04	1.49
Specific gravity	2.83	2.72	2.60	2.51
Bulk density (kg/m^3)	1508	1533	1595	1601
Voids (%)	45.56	42.80	37.69	34.11
Impact value (%)	16.50	11.60	20.90	13.20
Crushing value (%)	29.80	17.90	26.00	28.20

Table 3 Strength properties of concrete specimens incorporating various coarse aggregates

Sample	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)
Margalla Crush	26.30	2.25	4.90
Sargodha Crush	21.10	2.00	4.78
Barnalla Crush	25.10	2.53	4.60
Mangla Crush	20.70	2.12	3.70

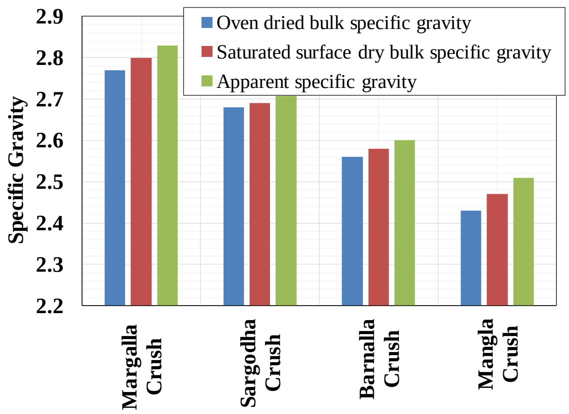

Fig. 4 Specific gravity of various aggregates

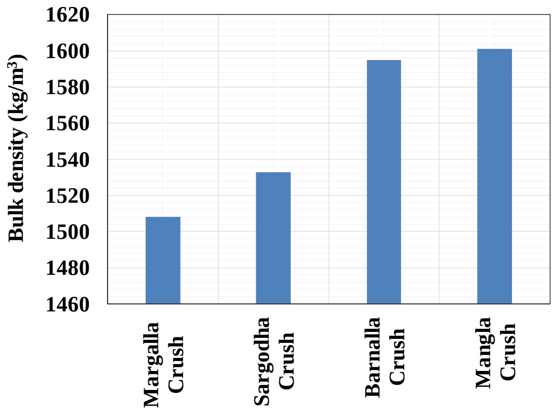

Fig. 5 Bulk density of various aggregates

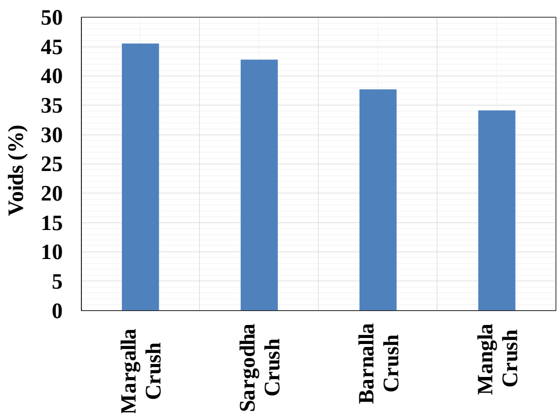

Fig. 6 Voids in various aggregates

3.4 Impact Value of Aggregates

Impact values of various aggregates are shown in Table 2. The aggregate with the impact values below 10 are considered as strong while above 35 are normally regarded as weak aggregates for construction applications [12]. Fig. 7 shows that Sargodha aggregates are the strongest against impact loading as they have minimum impact value of 11.6%. Barnala aggregates have maximum impact value of 20.9%. Margalla and Mangla aggregates have good impact values of 16.5% and 13.2%, respectively. It may be concluded that Sargodha, Margalla and Mangla aggregates have adequate strength.

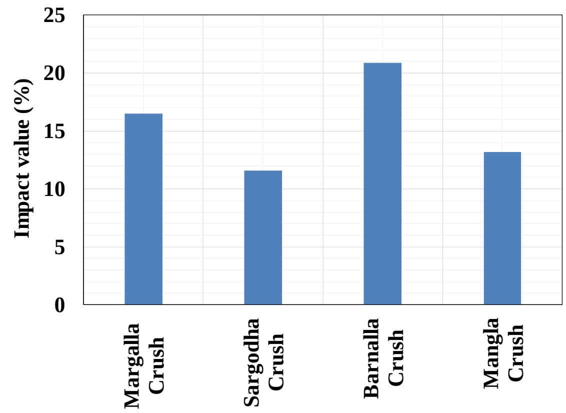

Fig. 7 Impact value results for various aggregates

3.5 Crushing Value of Aggregates

Results of crushing values for different aggregates are summarized in Table 2. Crushing values of aggregates less than 30% are acceptable. The lower the crushing value, the stronger will be the aggregates [12]. Fig. 8 shows that Sargodha aggregates have minimum crushing value of 17.9% and are therefore, the strongest among all. Margalla aggregates have maximum crushing value of 29.8%, therefore, can be considered as weaker than Sargodha. Barnala and Mangla have crushing values closer to Margalla aggregates. In general, all the four aggregates showed satisfactory results against crushing limit (30%).

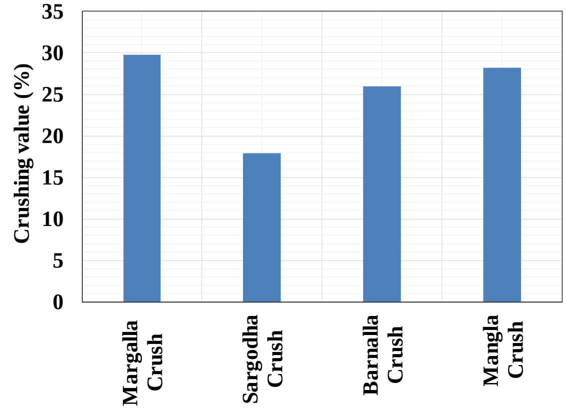

Fig. 8 Crushing value results for various aggregates

3.6 Compressive Strength

Compressive strengths of concrete specimens using different aggregates are shown in Table 3. Fig. 9 shows that the concrete specimens having Margalla and Barnalla aggregates have higher compressive strength as compared to concrete specimens made with Sargodha and Mangla aggregates. This shows that Barnalla and Margalla aggregates may be recommended for use wherever higher compressive strength is required.

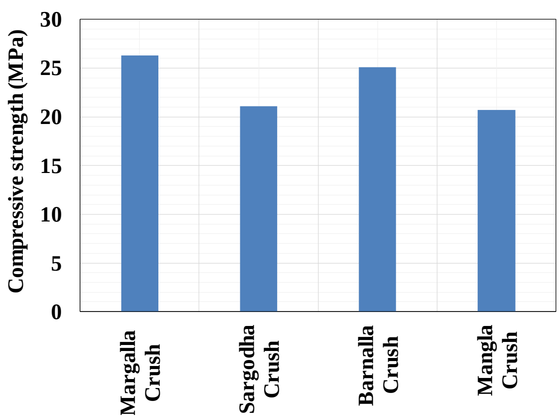

Fig. 9 Effect of various aggregates on compressive strength

Compressive strength of concrete is influenced by the integrity of the transition zone (interface) between the cement paste and aggregates. Bleeding in concrete, attributed to higher water cement ratio, augments water accumulation in the paste-aggregate interface. If the accumulated water is not absorbed by the aggregates, the compressive strength of concrete decreases [17]. In case of Margalla, Sargodha and Barnalla aggregates, similar trend in relation with the water absorption of these aggregates was observed. However, this trend was not verified in case of Mangla aggregates. This may be due to the fact that the aggregates belong to river bed have very smooth surfaces which lead to formation of weak bond between cement paste and aggregate. Similar behaviour of aggregates was reported by Islam et al. (2016) and Zainab et al. (2008) [17-18].

3.7 Splitting Tensile Strength

The Split tensile strengths of concrete specimens using different aggregate samples are summarized in Table 3 and Fig. 10. Concrete specimens made with Barnalla aggregates showed the highest split tensile strength. Mangla aggregates specimens have shown the lowest split tensile strength. Fig. 11 shows the splitting of concrete specimen into two pieces during the splitting tensile test.

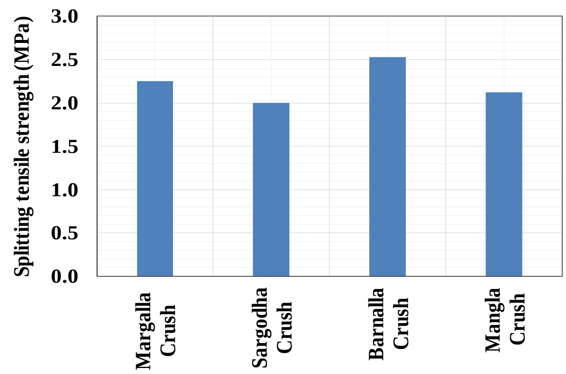

Fig. 10 Effect of various aggregates on splitting tensile strength

Fig. 11 Splitting of specimen into two pieces during tensile test

3.8 Flexural Strength

Flexural strengths of concrete specimens using different aggregate samples are summarized in Table 3. Fig. 12 shows that the concrete specimens made with Margalla aggregates have the highest flexural strength and Mangla aggregates have the lowest flexural strength. Concrete specimens with Sargodha and Barnalla aggregates have flexural strength closer to Margalla aggregates concrete specimens. Barnalla and Mangla aggregates were obtained after crushing river stones whereas, Margalla and Sargodha aggregates were obtained from blasting and crushing of rocks. That is why Barnalla and Mangla aggregates are mostly round and have smooth surfaces whereas, Margalla and Sargodha aggregates are usually rough and angular. Generally aggregates shape and texture influence the flexural strength [1, 15, 19]. Zainab and Enas (2008) also observed decrease in flexural strength due to smooth surface of aggregates [18]. The results show that concrete with angular aggregates have more flexural strength than having round aggregates.

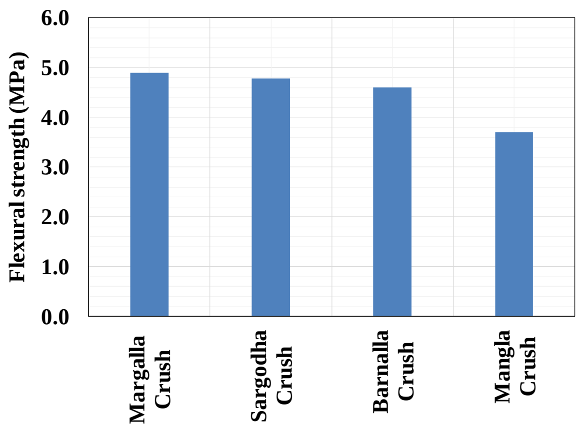

Fig. 12 Effect of various aggregates on flexural strength

The study was conducted on physical and mechanical properties of aggregates obtained from Margalla, Sargodha, Barnalla, and Mangla quarries in Pakistan. Results indicate that all the tested aggregates are suitable for making concrete. Barnalla and Mangla aggregates due to high bulk density and lesser voids may be used where lesser compaction of concrete is required. To avoid the durability problems in concrete, Sargodha and Barnalla aggregates may be preferred. Similarly, Sargodha aggregates due to their good impact and crushing strength may be used in road construction with high traffic loads. Margalla and Barnalla aggregates possess relatively good mechanical properties i.e., compressive, flexural and tensile strengths and can be used where concrete strength is important. In general, performance of all the four aggregate samples was found satisfactory and may be used with confidence, if they are economical. In the future research work, the focus will be on the durability issues (i.e. alkali aggregate reaction) of concrete incorporating similar aggregates acquired from various quarries (Margalla, Sargodha, Barnalla and Mangla).

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