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Impact Assessment of Pozzolanic Material Coupled with River Bed Aggregate on Expansive Behavior of High Strength Concrete

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Abstract: High strength concrete is widely used in engineering structures. Present work is an effort for suitability assessment of river bed aggregates in high strength concrete to be used at structural units of Dam (Spillway & Powerhouse) and the vulnerability of placed concrete expansion. Multiple sizes of coarse aggregate (5-20mm, 20-40mm, and 40-80mm) from Beor river bed material have been tested for physical (water absorption, crushing index, soundness, shape, and bulk density), and mineralogical characterization. Concrete Mix Design (CMD) for Spillway has been optimized using Fly ash and river aggregate that achieved the Unconfined Compressional Strength (UCS) up to 32.5 MPa. The accelerated mortar bar test (AMBT) has been introduced to gauge the reactive aggregates used in CMD.. Expansive properties of concrete were observed at the age of 7 days and 28 days that demonstrate more expansion of the specimen with slag rather than the Fly ash. Results of AMBT suggest that a minimum proportion of GGBS (40%) is needed to limit the AMBT expansion to less than 0.1% for crushed river bed aggregate and sand from the Beor source. The petrographical characterization of coarse aggregate shows the presence of deformed quartz in the coarse aggregate, which directly relates to water absorption (Wa), suggesting its suceseptility to Alkali-Silica Reaction (ASR). Modifications in Pozzolanic additives in CMD indicates that 30% mixing of Fly ash can reduce the expansion rate of concrete up to 96.15%.

Keywords: Beor river sand, concrete mix design (cmd), expansive properties, fly ash, uniaxial compressive strength (UCS).

Introduction

High-performance concrete (HPC) behaves more robust and durable when fly ash, silica fume, or ground granulated blast furnace slag (GGBFS), as well as a superplasticizer are incorporated (Brown, 1998). Porosity, inconsistencies, and micro-cracks in the hydrated cement paste deteriorate the strength parameters of concrete. The densification of the transition zone between cement mortar and coarse aggregate increases the concrete's load-bearing capacity and increases the durability of the concrete (Balaguru et al., 2017; Chen et al., 2020). Many studies have shown that temperature-related changes in concrete strength are related to definite composition, aggregate type, water/cement ratio, the presence of pozzolana additives, and so on (Katuwal, 2019; Thomas et al., 2012). Pozzolans improve compressive strength, quickly increasing from 60 MPa to 150 MPa. In addition, silica fume, fly ash, powdered, granulated blast-furnace slag, natural pozzolana, chemical admixtures, and other minerals may be present in HPC, either individually or in various combinations (Halstead and Crumpton, 1986). Physico-mineralogical characteristics significantly impact new and durable concrete (Sanaullah et al., 2017). The shape and texture of the aggregate play a role in defining the behaviour of unique and hard concrete (Abdullah, 2012; Neville, 2000).

Alkali-silica reaction (ASR) is considered one of the most concrete degrading phenomena that are causing substantial expansion (Carlos et al., 2004). Accelerated Mortar Bar Test (AMBT) proves to be good in detecting concrete expansion within 16 days of the potential for the deleterious alkali-silica reaction of aggregate in mortar bars (Deboodt et al., 2016; ASTM C1260). One of the most common tests to determine, if a particular aggregate will cause deleterious expansions due to ASR (Fiore et al., 2018). The volume of aggregates used in concrete defines its expansion as higher aggregate volume expands less (Choudhary et al., 2020). On the other hand, expansion damages concrete microstructure, such as cracking, increasing pore size and total volume or degrading the microstructures of aggregate and mortar interfaces. The expansion is harmful to mechanical strength and durability (Thomas, 2007). Restriction on expansion enhances microstructure densification, which improves mechanical strength, particularly at the paste-aggregate interface of expansive concrete (Mo et al., 2014). Excessive delayed expansion in cement clinker can result in structural deterioration and a reduction in the mechanical strength of cement pastes, resulting in unsoundness. As a result, before cement can be sold, it must be tested for soundness in compliance with cement regulations (Wahid, 2016).

Current work includes borrow area stream deposits with artificial sand to be used at the structural units of the Karot Hydropower Project (Fig. 1). At the project site river, Jhelum flows through a narrow gorge between 120 m high banks consisting of gently dipping alternate beds of sandstone and siltstone rocks of Nagri Formation belonging to the Siwalik system.The main dam's central/most profound part is founded on thick sandstone beds, whereas both flanks will be located on alternate beds of sandstone and claystone/siltstone. Almost all components of the Karot hydropower project are to be constructed by concrete of varying strengths. The spillway and powerhouse structures involve the incorporation of high-performance concrete. The primary rock available at the dam site and in the vicinity of sandstone is soft and friable. The alluvial deposits in the channel consist of sandy gravels and boulders (Gautam et al., 2018; Feasibility Report, 2009).

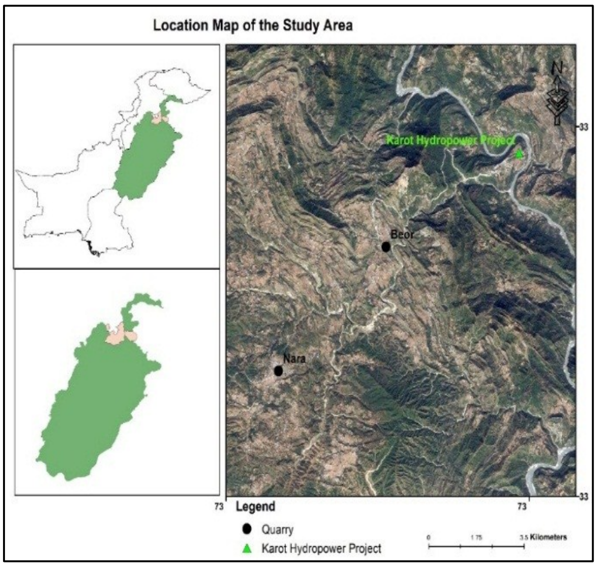

Fig. 1 Location map of the aggregate sampling and the Dam site.

Materials and Methods

The water to cement ratio is the weight of water/cement mixing that defines the volume of the concrete to place (ASTM C 33-03 2002). Admixtures are usually added to the mixture before or during mixing to reduce the cost of concrete construction, modify reinforced concrete structures, to ensure the quality of concrete during mixing, moving, laying, and healing to overcome specific emergencies during concrete operation (ASTM C / 494 1999; ASTM C / 989. 2005). Combined values are calculated based on dry unit weights, but composites are usually based on the actual weight of concrete components (ASTM C 33/02, 2002).

The proper mechanical mixing of concrete components involves batch to batch drum mixing. Cylinder placement is usually done according to the standard ASTM C-617. The instruments used for the cylindrical type recording were (i) Capping Plate (ii) Alignment Device (iii) Melting Pot (iv) Fume Hood. Materials were used to manufacture wet cured concrete cylinders and sulfur mud (at about 265 F/130□C). Concrete is prepared from continuous volume-based materials, mixed into a constant mixture, and then delivered for pouring (ASTM C 192/C 192M-02, 2002). ACI Method of Proportioning Concrete Mixes ACI-211.1 (2005) has been used. The required amount of water-cement is determined by the strength, durability, and dissolving capacity. The average water content of cement (air made inwards) is 0.41 of 41.4 Mpa (6000 psi) binding forces for 28 days. Materials include Bestway OPC, slag, fly ash, water, and sand. Crush Beor is compiled to provide a sample to meet the requirements. If slag is used, measured specimen replace 25% or 40% of the cement with the same mass of slag (ASTM C 494/C 494M-99a, 1999). In case of fly ash used, a replacement of 20%, 25%, or 30% of the cement with the same mass of flyash is adopted. Furthermore, various blends of types of cement and proportions of Ground Granulated Blast Furnace (GGBS) were tested to determine the minimum proportion of GGBS required for different types of cement (ASTM C 989-05, 2005).

Accelerated Mortar Bar Test (ASTM C1567 and ASTM C1260)

A rapid test of aggregates, immersion of mortar bars in NaOH 1 M at 80 °C for 14 days is used to quickly identify highly reactive aggregates or quasi non-reactive aggregates (Sivrikaya et al., 2019). Besides an elevated temperature, the C1260 method also involves using a large quantity/inventory of NaOH in the solution where the mortar bar is immersed. In the case of non-decisive results, the long-term ASTM C1293 test method must be used for final screening (Math et al., 2011). The main advantage of the ASTM C1260 test is that it quickly identifies extreme cases: very insensitive or very reactive aggregates (Musaoglu et al., 2014). The quantities of dry materials for the Accelerated Mortar Bar Test (ASTM C1567 and ASTM C1260) are mixed in the mortar batch to make three specimens of 440g of cementitious material and 990g of an aggregate made up of sand and mixed crushed aggregates. Reference specimens without slag or fly ash and, only 440g cement and 990g sand are used for casting three specimens. Each specimen size is 25mm*25mm* 275mm. If slag is used, measured specimens replace 25% or 40% of the cement with the same slag mass. If fly ash is used, it replaces 20%, 25%, or 30% of the cement with the same mass of fly ash (Table 1).

Table 1 Multiple Aggregate Combinations used for AMBT.

Sample No.	Cement	Slag		Fly ash		Sand	Water
	(g)	%	(g)	%	(g)	(g)	(g)
AMB-1	440	0	0	0	0	990	206.8
AMB-2	330	25	110	/	/	990	206.8
AMB-3	264	40	176	/	/	990	206.8
AMB-4	352	/	/	20	88	990	206.8
AMB-5	330	/	/	25	110	990	206.8
AMB-6	308	/	/	30	132	990	206.8

Physico-mechanical Testing

Water Absorption Test (ASTM C 127) is used to measure the increase in weight of the aggregate due to the presence of water in the pore space of the aggregate. It is expressed as the percentage (%) of dry oven weight, which is called water absorption. The soundness of aggregates (ASTM C 33; C 136, C 670) is tested for soundness of aggregate to the weathering action on concrete. This is achieved by repeated immersion in saturated solutions of sodium or magnesium sulfate followed by drying in the oven (ASTM C128, 2004). Unconfined Compression Strength Test (D 2938 – 95) is applied to the soil cylinder without lateral support for failure with light pressure, and with continuous degree of difficulty. Slump Test (ASTM C143) is frequently applied on all concrete mix designs. The test was performed to determine the performance of the fresh concrete. A concrete sample has been placed in a 12" steel cylinder using three equal layers.

Petrography (ASTM C-295)

Selected specimens of the riverbed aggregate are subjected to the standard procedure of preparation of petrographic cross-sections and are analyzed for mineral compositions.

Results and Discussion

Lab tests for the determination of physical characterization of coarse aggregate (the stream deposits of Beor) show a significant variation of water absorption for different aggregate sizes. The aggregate size 5-20 mm demonstrate very high-water absorption ranging from 0.62-0.69% contrasting the other of 0.35-0.55mm. The same trend of higher values for aggregate impact has been observed for the size 5-20 mm, greater than 4% in all tested samples of this size. Apparent and bulk density variations are well in the proper guidelines for using aggregate in high-performance concrete (Table 2).

Table 2. Physical Testing of Beor coarse aggregate.

Sample No.	Particle Size	Water Absorption	Apparent Density		Bulk Density		Crushing Index	F.I/ E.I
	(mm)	%	(Kg/m³)		(Kg/m³)		%	%
			Dry	SSD	Loose	Comp.		
BCA-1	20-40	0.55	2700	2670	1445	1590	4	2.8
	20-5	0.62	2670	2665	1540	1660	4.2	3.5
	40-80	0.35	2660	2680	1440	1670	3.9	0
BCA-2	20-40	0.64	2720	2655	1440	1590	4	3
	20-5	0.69	2680	2650	1540	1660	4.1	3.5
	40-80	0.35	2660	2650	1435	1675	3.8	0
BCA-3	20-40	0.6	2680	2650	1430	1600	4	3
	20-5	0.67	2680	2655	1545	1655	4.2	4
	40-80	0.39	2655	2640	1445	1670	4	0
BCA-4	20-40	0.48	2660	2665	1435	1580	4.1	3.2
	20-5	0.70	2685	2665	1535	1670	4.3	4

It has been observed that an increase in aggregate size exhibit a reciprocal effect on its soundness. The largest size aggregates are also susceptible to Alkali-Silica Reaction. In different concrete mix designs, it has been observed that the ratio of sand used is in direct proportion with the water-cement ratio. The water-cement ratio and the slump pose reciprocal relation; the higher the water-cement ratio, the lower will be the slump. The concrete mix design uses JM-II approved high range water reducing admixture (Fig.2; DL/T 5100-2014).

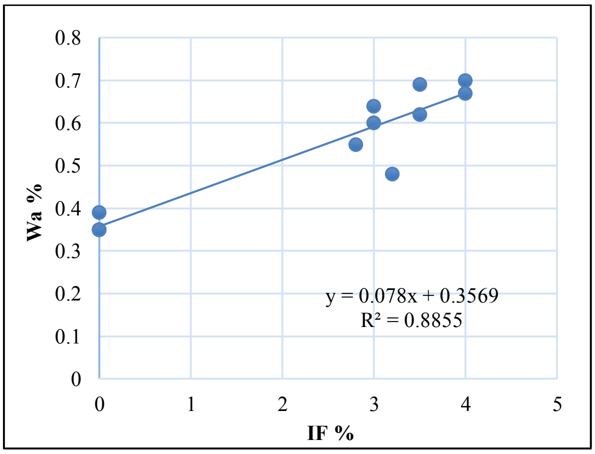

Fig. 2 Correlation between Water Absorption (W_a %) and Flakiness Index (I_F %).

Concrete Mix Design

The selection of optimum mix design is based on a test mix with a different combination of the estimated value of the mix/collection rate and the total amount of cement in a particular water/cement scale (Ahmad, 2007). The absolute volume balance calculates the gravitational strength of concrete ingredients and the number of suitable compounds. The Ordinary Portland Cement (OPC) is adopted for the concrete mixture (Hager et al., 2016). All the technical indicators of OPC meet the requirements of GB 175-2007 (Ahmad, 2014). Flyash is used, which meets all technical indicators of grade II concrete. The (OPC), had a density of 3120 kg/m³, soundness 1.0, standard consistency of 26.0%, and loss on ignition up to 4.13%.is used The initial set time was 140 minutes, and the final of 222 minutes. The compressive strength (MPa) for three days has been observed at 32.9 and 51.5 for 28 days. The fineness (%) of used fly ash is 15.6%, with a water requirement ratio of 96%, loss on ignition, 1.39%, moisture content 0%, and 0.34% Alkali. The natural river exhibited Fineness Modulus (FM) of 2.70, an apparent density of 2680 kg/m³, water absorption of 1.2%, and has 15.2% stone powder. Water Absorption for various sizes ranges between 0.32-0.58%. The particles from 5-40 have more incredible soundness. The aggregate Flakiness Index and its Water Absorption shows a strong correlation (Table 1, 2; Fig. 2). Five CMD's were formulated having average target strength of 34.5 MPa at the age of 28days. The CMD's with W/C ranging between 0.40-0.42, exhibit high values and achieved strength while CMD's of W/C ranging between 0.48-0.50 have moderate acquired strength of 35.3MPa. So, the used CMD is suitable for the requirement (Fig. 3).

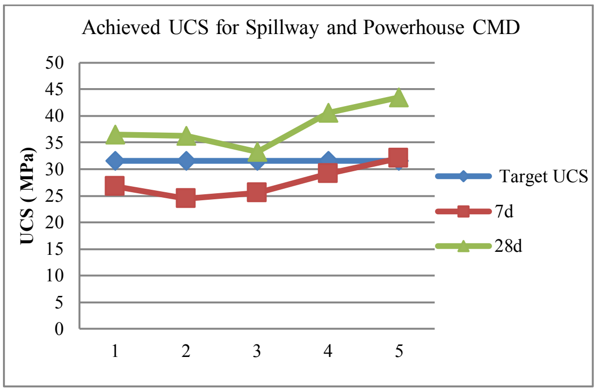

Fig. 3 Achieved UCS for spillway and powerhouse.

Expansive Characterization of Concrete

Results of thin section studies of various aggregate sizes (5-20mm, 20-40mm, and 40-80mm) exhibit that the most common deleterious materials identified are strained quartz, allotriomorphic quartz and mylonized quartz. The distortion signatures in the quartz grains may lead to ASR presence. It has been observed that the reactivity of the quartz mounts as an increase in deformation of the crystalline structure (Tiecher, 2017; Fig. 4A). Sub-grains are developed in the quartz grains, reflecting the alteration in the quartz; this may significantly lead to increased concrete expansion (Shayan et al., 1996). The recrystallized grains are less

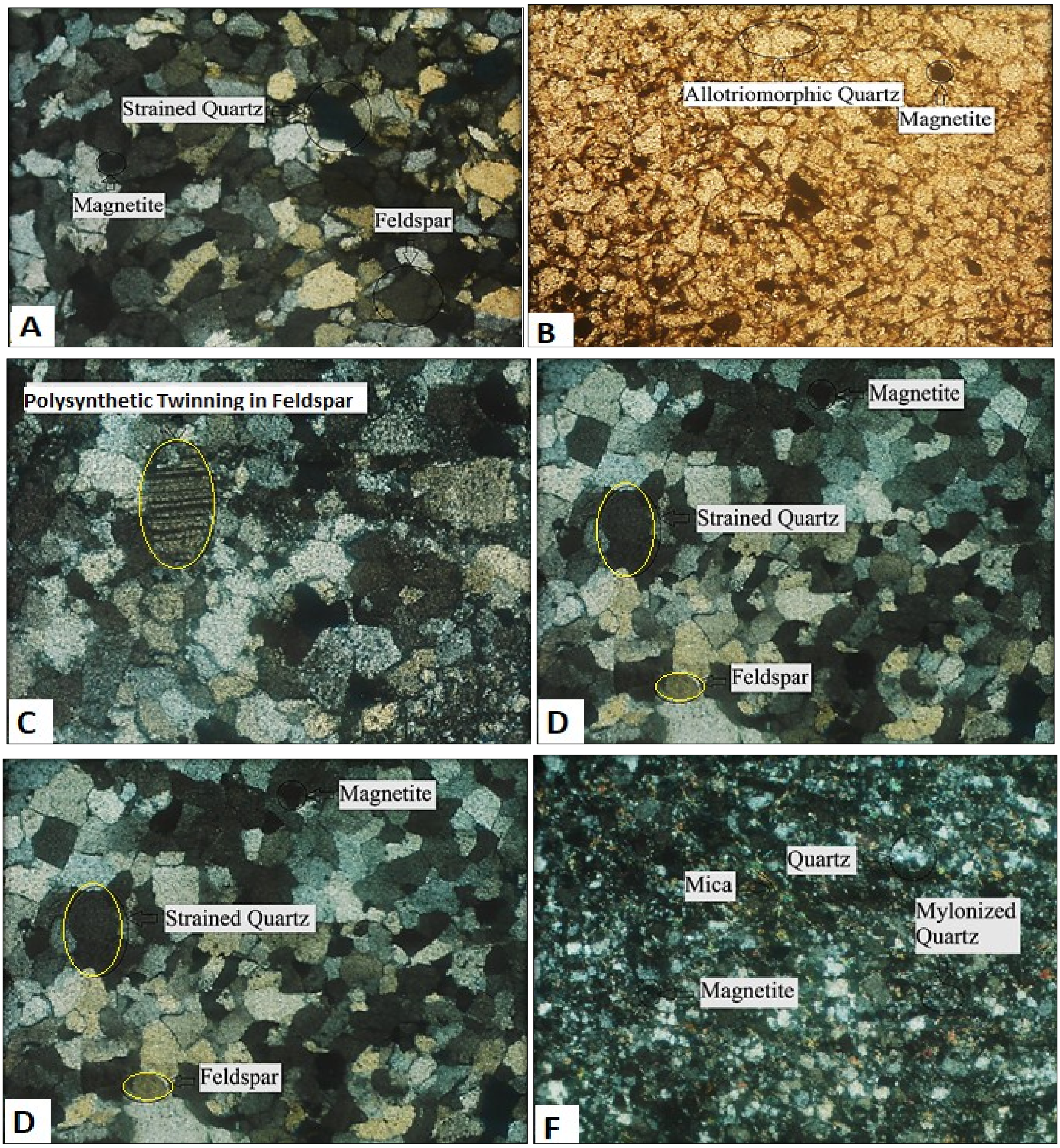

Fig. 4 Microphotograph of river bed aggregate A) strained quartz, magnetite and feldspar, B) allotriomorphic quartz and magnetite, C) polysynthetic twinning in feldspar, D) strained quartz, magnetite and feldspar, E) highly strain quartz, F) mylonized quartz, quartz, magnetite and micas.

in number, do not cause deformation, and contribute to the propagation of the ASR (Tiecher, 2017, Fig. 4A, 4D, 4E, 4F).

The strong extinction in quartz and the high number of cherts in calcareous sandstones make the aggregate from the Beor source susceptible to Alkali-Silica Reaction (ASR) potential. The aggregate of smaller size (5-20mm) has lower quantities of deleterious material than the aggregate of larger size, which demonstrates higher values of deleterious material (Thomas, 2007; Naeem et al., 2014). It has been found that mean deleterious content strongly correlates with water absorption of the aggregate study (Fig. 5, 6).

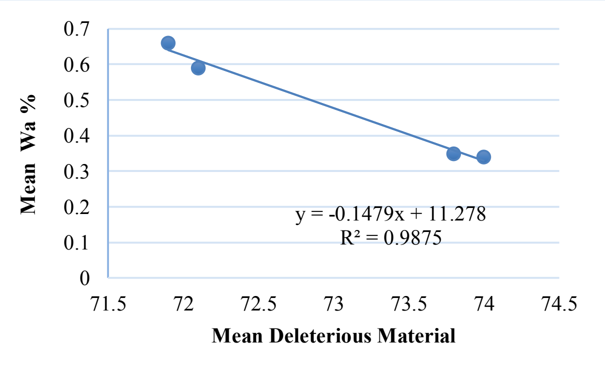

Fig. 5 Correlations between Mean Water Absorption and Mean Deleterious Material.

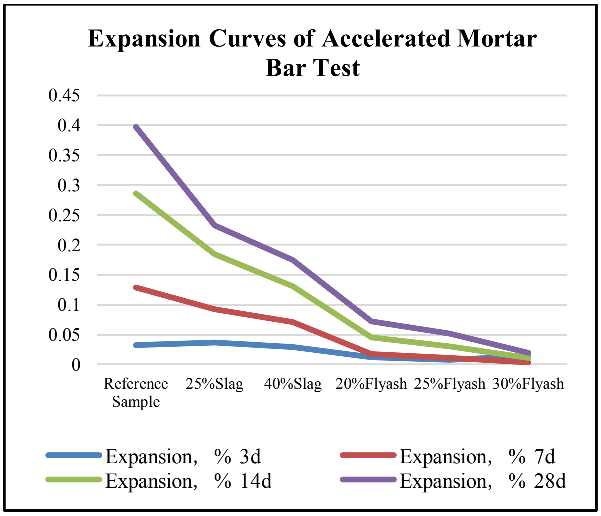

Fig. 6 Expansion of concrete specimen at different ages.

Expansion through Accelerated Mortar Bar Test (AMBT)

After 14 days, as compared with the reference sample, the expansion decline rate of the sample mixed with 25% slag was 35.66%, and the expansion decline rate of the sample mixed with 20% fly ash was 84.27%. The expansion of the specimen mixed with slag is more significant than that of the specimen with fly ash of the same age. At the age of 14d, compared with the reference sample, the expansion decline rate of the sample mixed with 25% slag was 35.66%, and the expansion decline rate of the sample mixed with 20% fly ash was 84.27%. The expansion of the specimen with slag is more significant than that of the specimen with fly ash at the same age (Table 1; Fig. 6). Mixed with 25% slag, the expansion, at the period of 14 days, decreases by 35.66 %, and with 40% slag, it reduces by 54.20 %. Furthermore, on mixing up with 20% fly ash, the expansion at the age of 14 days decreases by 84.27%. In the case mixed with 25% fly ash, the expansion at the age of 14d decreases by 89.51%, while combined with 30% of fly ash, the expansion rate of 14 days decreases by 96.15%.

Conclusion

The coarse aggregate of sizes 5-20mm, 20-40mm, and 40-80mm from Boer bed material along with river sand has been assessed to be used in high-performance concrete for structural units of the dam and to estimate the risk of concrete expansion. Coarse aggregate size 5-20mm demonstrates higher physical and mechanical characteristics. According to the petrographic analysis of Beor aggregate, it is found susceptible to Alkali-Silica reaction (ASR). There is a strong relationship between water absorption and the deleterious mineralogical material in coarse aggregate. The aggregate larger than 20mm reflected low expansion when crushed into smaller fractions. So, a blended cement consisting of 50% to 70% of slag proved to be good to minimize the total alkali content by 40%. Results reflect that Ordinary Portland Cement (OPC) used for CMD of Spillway exhibits a final setting time of 222 min that satisfies the standard requirements Appropriate concentrations of fly ash and slag are used to mitigate the expansive character of Beor aggregate by the Accelerated Mortar Bar Test (AMBT). Furthermore, the Beor aggregates (crush stone and river sand) could be used at the dam project if 25% slag or 20% fly ash is used in place of cement in the concrete.

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