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Abrasion resistance of concrete containing marginal aggregates

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HIGHLIGHTS

- Ninety concrete cylinders made with marginal aggregates were tested for under water abrasion resistance as per ASTM C 1138.
- The effect of aggregate and cement type, pozzolana, age and grade of concrete on abrasion resistance of concrete was studied.
- Increasing Los Angeles (L.A.) abrasion value of aggregates beyond 30% significantly degrades abrasion resistance of concrete.
- Addition of pozzolanic admixture improves the abrasion resistance with maximum advantage observed in case of silica fume.
- High strength concrete using marginal aggregates and silica fume shows abrasion loss close to a mix with sound aggregates.

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ABSTRACT

The main aim of the present study was to recommend ways and means to upgrade abrasion resistance of concrete made of low quality aggregates to acceptable levels on the basis of laboratory experimental investigations. The variables of the study were grade of concrete, type & quantity of pozzolana, type of aggregate, cement type and age of concrete. Various mixtures of concrete were designed and cast using different cements and pozzolanas. Three types of aggregates with three different Los Angeles (L.A.) values (less than 30%, between 30% and 50% and more than 50%) were employed in the study. A total of 90 cylindrical specimens were tested as per ASTM C 1138 procedure in this study to evaluate the abrasion resistance of concrete. Several companion cubes were also tested for evaluating the compressive strength of various mixes. The results indicate that while the abrasion resistance of concrete depends upon the properties of aggregates, no direct correlation exists between the L.A. abrasion of aggregates and the abrasion resistance of resulting concrete. The abrasion resistance of concrete degrades considerably once the L.A. value of aggregates goes beyond 30%. Incorporation of pozzolanic admixtures in concrete mix improves the abrasion resistance of resulting concrete with maximum benefits being observed in case of silica fume. Important observations have also been made about the influence of age of concrete and type of cement.

1. Introduction

Abrasion is one of the major problems in hydraulic structures resulting from the abrasive effects of waterborne silt, sand, gravel, rocks, ice and other debris being circulated over a concrete surface during operation of a hydraulic structure. Spillway aprons, stilling basin slabs, culverts and hydro power tunnels are most likely to be damaged by abrasion in hydraulic structures [1]. Based on the characteristics of coarse aggregate, the strength and other properties of concrete differ. Abrasion resistance of concrete is strongly influenced by the hardness of its coarse aggregates. The mechanical and chemical characteristics of the coarse aggregates vary from area to area. Hydro power projects are generally located in remote hilly areas, where it becomes important to use locally available aggregates. Many times the locations, possessing aggregates with poor abrasive properties, become cause of concern as the concrete hydraulic structures constructed with such aggregates show inadequate abrasion resistance. In such cases, transporting sound aggregates from other places may not be a viable option as it entails considerable cost and efforts. Using locally available aggregates is the only viable option under these conditions.

Many studies have been reported in the literature on the influence of properties of aggregates on the abrasion resistance of concrete. Smith [2] reported that concrete containing soft limestone aggregate is less resistant to abrasion than similar concrete containing relatively harder aggregates. Liu [3] and Laplantane [4] suggested that the abrasion resistant concrete should include the largest maximum size of aggregate particle, the maximum amount

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of the hardest available coarse aggregate and lowest practical water–cementitious material ratio. De Larrard and Belloc [5] concluded that for the same quality mortar, different types of coarse aggregates with different shapes, textures, mineralogy, and strengths may result in different concrete abrasive properties. Kilic et al. [6] investigated five different aggregate types (gabbro, basalt, quartzite, limestone and sandstone) in the concrete mixtures. The results of the investigation showed that aggregate strength and texture influenced the compressive strength, flexure tensile strength and abrasion resistance of concrete. The author explained that concrete with a low w/cm ratio develops less porosity, higher strength and a stronger interfacial bond in the hardened mortar and thus enhances the overall concrete abrasion erosion resistance performance. For a given aggregate and finishing procedure, the abrasion resistance of concrete increases with an increase in the compressive strength of concrete.

Siddique [7] reported that wear resistance of concrete mixtures containing fly ash was lower than that of control mixtures and decreases with increasing fly ash content. Wu et al. [8] investigated the effect of adding blast furnace slag as replacement of cement in concrete to improve the abrasion erosion resistance. The results of the investigation showed that an increase in slag content produced a denser and stronger concrete surface, thus resulting in a higher resistance to wear for slag concrete at later age. The concrete made with 45% slag resulted the best abrasion erosion performance. Thus the literature shows that while addition of blast furnace slag has been shown to benefit the abrasion performance of concrete, addition of flyash may not provide benefits in terms of improvements in abrasion resistance of concrete. Adding silica fume and high range water reducing admixture to a concrete mixture greatly increases the compressive strength and abrasion resistance of concrete [9].

The existing literature suggests that both the sand blasting method of ASTM C 418 [10] and under-water method of ASTM C 1138 [11] are suitable for evaluating the abrasive erosion resistance of water-borne particles on hydraulic structures. Other methods proposed by Indian Standard, IS 9284 [12] and ASTM Standards, ASTM C 779 [13] and ASTM C 944 [14], are applicable to measure the abrasion resistance of pavements and floors. All these methods allow only an evaluation of a measure of relative quality without any defined acceptable or unacceptable limits. At present, the absence of standard criteria for abrasion erosion of concrete surfaces in hydraulic structures prevents specifications of quality in terms of abrasion resistance. Abrasion properties of aggregates in terms of Los Angeles (L.A.) values are generally used in various standards world over to ascertain the abrasion resistance of resulting concrete. Most of the abrasion resistance related studies in the past have been performed for industrial floors and pavements. The investigations on abrasion resistance of concrete in hydraulic structures are very limited. The earlier studies did not relate the quality of aggregate in concrete used in hydraulic structures with the abrasion resistance of concrete. In view of this, the present investigation has been planned to investigate the abrasion resistance of concrete containing marginal aggregates and thereby to suggest modifications in the concrete mixture to improve the abrasion resistance of such concretes.

2. Experimental program

The cube compressive strength of concrete 25 MPa is commonly used for the tunnel lining works of the hydro power projects in India. Therefore, in the absence of any acceptable value of underwater abrasion of concrete, the abrasion performance of this concrete with sound aggregates (LA less than 30%) was assumed as the benchmark acceptable abrasion resistance of concrete. In order to obtain acceptable abrasion resistant concrete manufactured with low quality aggregates, it was aimed to enhance the quality and strength of paste in such concrete so that paste assumes the dominating role and the influence of aggregates is shadowed. Thus, it was proposed to design and test higher grades of concrete with enhanced compressive strength and improved paste phase. The variables chosen for the investigation were grade of concrete, type and amount of pozzolana, cement type and age of concrete. Different mixes were designed using the different selected aggregates and trying various cementitious materials namely cement, micro-silica, slag and flyash in order to achieve a denser and stronger paste. Two grades of concrete namely M 40 and M 60 were employed in this investigation. The description of concrete mixtures is given in Table 1. The proportions of various mixes are provided in Table 2. The cylindrical specimens were cast for evaluating abrasion resistance of concrete while the companion cubes were cast for measuring the compressive strength of concretes. A total of 90 cylindrical specimens and 270 cubes made from 20 batches of concrete were cast and tested.

2.1. Material properties

Different test specimens were cast using Ordinary Portland Cement or Portland Pozzolona Cement, fine aggregate, coarse aggregate, silica fume, fly ash, GGBS, super-plasticizer and tap water. All the materials conformed to the specifications of relevant Indian Standard Codes [15–19]. Two types of cement, i.e. Ordinary Portland Cement (OPC) and Pozzolana Portland cement (PPC) were used. Three types of pozzolanas, i.e. Fly ash, Ground Granulated Blast Furnace Slag (GGBS) and Silica fume were used in the mixes as part replacement of cement. The sand conforming to zone II of IS 383:1970 [20] was used as fine aggregate throughout in the study. Overall three types of coarse aggregates were used in the present study. Two different types of low quality coarse aggregates with L.A. value less than 50% (but more than 30%) and L.A. value more than 50% were employed. The aggregates with L.A. less than 50% was designated as A2 and that with LA more than 50% was designated as A5. Each of the above mentioned low quality aggregates had two types of fractions, i.e. 10 mm and 31.5 mm. These fractions were finally mixed appropriately to obtain the grading of IS: 383 Code for 20 mm graded aggregates. Another aggregate type with L.A. value less than 30% and grading per 20 mm graded aggregate was also used for benchmark control testing. The physical properties of fine and coarse aggregates are given in Table 3.

2.2. Mixing, casting and curing

The mixes were prepared in laboratory using laboratory tilting type mixer. Before each casting, the quantities of various ingredients, i.e. cement, sand, coarse aggregate, water, pozzolana and super plasticizer were kept ready in required proportions. Initially, the fine aggregate, cement and pozzolana were mixed thoroughly to get a uniform mix in the dry state. The uniformity was indicated by the uniform colour of the mix and no concentration of any one material being visible. Then the coarse aggregate were added to this dry mix and turned over twice or thrice in the dry condition itself in a tilting type rotary drum mixer for about 1 min. About half of the total water was added slowly to get a uniform mix. After this, the remaining water with the superplasticiser thoroughly mixed in it was added, and the mixing was continued for about 1 min. The moulds for casting the specimens were cleaned, brushed, oiled and placed on a vibrating table with a speed range of 12,000 ± 400 rpm and an amplitude range of 0.055 mm. After the mixing procedure is completed, test was conducted on the fresh concrete to determine the slump by Slump cone test. It was proposed to design the mixes in such way that a slump of 100–150 mm was maintained in all the mixes. Normally for pumpable concrete, the slump in this range is desired. In this study, commercially available high range water reducing admixture based on modified poly-carboxylic ether (PCE) polymer with solid content of 9.2% was used to prepare the concrete. Segregation and bleeding were visually checked during the test and was not observed in any of the mixes. At the age of 24 h, the specimens were removed from the moulds and stored in water until the date of testing.

2.3. Testing

After 28 days or 90 days of water curing, whatever the case may be, the specimens were removed from curing tank and the abrasion resistance test and compressive strength tests were carried out under laboratory ambient conditions. It was proposed to investigate the abrasion resistance of various above mentioned concrete mixes using under-water Abrasion Resistance Method of ASTM C 1138. ASTM Test method for abrasion resistance of concrete was originally developed in 1981 for evaluating the resistance of concrete surface subjected to abrasion action of water particles on hydraulic structures such as stilling basin and spillways. The apparatus consists of essentially a drill press, an agitation paddle, a cylindrical steel container and 70 steel grinding balls of various sizes. Fig. 1 shows the schematic view of the test apparatus. The water in the container is circulated by the immersion of agitation paddle that is powered by drill press rotating at a speed of 1200 rpm. The circulating water, in turn, moves the abrasive charges on the surface on the concrete specimen, producing the abrasion effects. Two such test setups