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Technical Paper

Influence of various material parameters on the abrasion resistance of concrete by sand blasting

G.B. Ramesh Kumar; Umesh Kumar Sharma*; and Arjit Bhardwaj

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Abstract: In the present study, the abrasion resistance of concrete containing low quality aggregates was investigated and various ways and means were recommended to enhance the abrasion resistance of concrete on the basis of experimental results. Strength grade of concrete, type and quantity of pozzolana, type of aggregates and cement type were taken as different variables and their effects on the performance of concrete against abrasion were investigated. Three types of aggregates with different Los Angeles (L.A.) abrasion values (less than 30%, between 30% and 50% and more than 50%) were employed in this study. A total of 60 cubes were tested to evaluate the abrasion resistance of concrete and corresponding 60 cubes were tested for the evaluation of cube compressive strength. Results show that the abrasion resistance of concrete is affected adversely as L.A. abrasion value of aggregates increases but no direct correlation exists between abrasion resistance of concrete and L.A. abrasion value of aggregates. As the L.A. abrasion value of aggregates exceeds a value of 30%, there was a considerable decrement in abrasion resistance of resulting concrete. Important observations have been made about the role of pozzolanic additions on abrasion resistance of concrete made with weak aggregates.

Keywords: wearing concrete surfaces, abrasion resistance, marginal aggregates, stronger paste, pozzolanic additions.

1. Introduction

Abrasion of concrete 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. Hydraulic structures namely spillway aprons, stilling basin slabs, culverts, and hydro power tunnels are most likely to be damaged by abrasion [1]. Road pavements and industrial floors are also subjected to abrasive actions throughout their operational life. It is well known that apart from hydraulic and mechanical parameters, the properties of various ingredients of concrete influence the abrasion resistance of concrete to a great extent. Many studies have been carried out in the past to examine the influence of aggregate properties on the abrasion resistance of concrete. Smith [2] investigated the influence of limestone aggregates on the performance of concrete against abrasion and found limestone aggregates as less resistant to abrasion. Liu [3] and Laplantane [4] suggested that incorporation of largest maximum size of aggregates, maximum amount of the hardest available coarse aggregates, and lowest practical water-cementitious material ratio leads to higher abrasion resistant concrete. De Larrard and Belloc [5] reported that abrasion resistance of concrete gets affected by different type of coarse aggregates with different shapes, texture and mineralogy. Kilic et al. [6] used five different aggregates (gabbro, basalt, quartzite, limestone, and sandstone) in concrete mixtures and reported that aggregate strength and texture influenced the compressive strength, flexure strength, and abrasion resistance of concrete. These studies are unanimous in concluding that stronger and harder aggregates are desirable for obtaining a high abrasion resistant concrete.

The mechanical as well as chemical characteristics of the coarse aggregates depend upon location as these vary from place to place. Many times, in the construction of infrastructure projects, aggregates of poor abrasive properties become major issue and cause of unsatisfactory performance of structure against abrasion [7]. Hydro power projects

G. B. Ramesh Kumar is a Research Scholar in the Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India.
Corresponding author U. K. Sharma is an Associate Professor in the Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India.
A. Bhardwaj is an Undergraduate student in the Department of Civil Engineering, PEC University of Technology, Chandigarh, India.

are generally located in remote hilly areas. In such cases, using locally available aggregates is always an economical proposition as transporting sound aggregates from other places may not be a suitable option due to high transportation cost and efforts. Improvement of abrasion resistance of concrete containing such marginal aggregates is the only viable option under these conditions. In view of this, the main aim of the present study was to develop abrasion resistant concrete made with low quality marginal aggregates. In order to mitigate the influence of aggregates on abrasion resistance of concrete and to achieve the acceptable abrasion resistant concrete manufactured with lower L.A. abrasion value aggregates, the quality and strength of paste was enhanced. Most of the standards world over use L.A. abrasion value of aggregates to ascertain the abrasion resistance of resulting concrete [7]. On the contrary, it is the abrasion performance of concrete which matters finally rather than the abrasion properties of aggregates. Thus, to investigate the abrasion resistance of concrete containing marginal aggregates and to suggest modifications in the concrete mixture to improve the abrasion resistance of such concrete, the present investigation has been carried out.

2. Experimental program

The standards and codes do not specify any minimum acceptable value of abrasion resistance of concrete. In the absence of this, the abrasion resistance of concrete having cube compressive strength of 25MPa with sound aggregates (L.A. abrasion value less than 30%) is considered as benchmark value for acceptable abrasion resistance of concrete in this study. It was aimed to enhance the performance of paste content so that the influence of weak aggregates gets subsided. Towards this end, different cementitious and pozzolanic materials like fly ash, silica fume, GGBS were employed in the design of concrete mixes. In addition to type of aggregates and cementitious materials, other variables of the study were strength grade of concrete, cement type, and age of concrete with an aim to achieve a desired performance against abrasion. Influence of all the chosen variables on the performance of concrete against abrasion resistance was also investigated. Two types of cement namely ordinary Portland cement (OPC) and Portland pozzolana cement (PPC) and two strength grades of concrete (M40 and M60) were employed. A total of 20 concrete mixtures were designed from which 60 cubes were casted for abrasion resistance test and 60 companion cubes were casted for compressive strength test. The description of various concrete mixtures and their proportions are shown in Tables 1 and 2, respectively.

2.1 Material properties

All the specimens were cast using materials conforming to the specifications of relevant Indian Standards [8-12]. Cement, fine aggregates, coarse aggregates, silica fume, fly ash, GGBS, superplasticizer, and tap water were used in making various concrete mixes. As part replacement of cement, three types of pozzolanas, i.e. fly ash, Ground Granulated Blast Furnace Slag (GGBS), and silica fume were used in the mixes to enhance the properties of paste. Low quality coarse aggregates were categorised into two types, i.e. aggregates with L.A. abrasion value less than 50% (but more than 30%), denoted as A2 and aggregates with L.A. abrasion value more than 50%, denoted as A5. Two size fractions, 10 mm and 31.5 mm were employed for each category of low quality coarse aggregates and these aggregates were mixed thoroughly to obtain the grading of 20 mm graded aggregates per IS: 383 [13]. For benchmark mixes, sound aggregates with L.A. abrasion value less than 30% and grading per 20 mm graded aggregates were used. Physical properties of cements and aggregates are shown in Table 3 and Table 4, respectively.

2.2 Mixing, casting and curing

As per design, the required proportions of each ingredient, i.e. cement, sand, coarse aggregates, water, pozzolana, and super plasticizers were kept ready before each casting. Tilting type mixer was used for preparing the mixes in the laboratory. In this investigation, modified poly-carboxylic ether (PCE) polymer with solid content of 9.2% based high range water reducing admixture was used to prepare the concrete mixes. On completion of mixing procedure, workability of fresh concrete was determined using slump cone test. A slump value appropriate for a pumpable concrete, i.e. 100-150 mm was maintained in all the mixes. The mixes were checked visually for bleeding and segregation. For casting, cleaned and oiled moulds were placed on the vibratory table with a speed range of 12000 ±400 rpm and an amplitude range of 0.055 mm. Specimens were removed from the moulds after 24 hours and were kept in water for curing until the day of testing.

2.3 Testing

All the specimens were removed from curing tank after 28 days and the abrasion resistance and compressive strength tests were performed under laboratory ambient conditions. The abrasion resistance of concrete was measured as per the Sand

Blasting Method (IS 9284 -1979) [14]. The measurement of abrasion resistance of concrete by Sand Blasting Method as per IS 9284 -1979 is based on the principle of producing abrasion by sand blasting. This procedure simulates the action of mechanical as well as waterborne abrasion on concrete surfaces. The apparatus consists of a wooden cabinet with tightly closing door, carbon steel nozzle, brass air tub and compressor. The test setup of pneumatic sand blasting apparatus is shown in Fig. 1. The 100 * 100 * 100 mm concrete cube specimens were used for the abrasion test. The surface of the specimens was rubbed to remove cement laitance and to expose aggregate grains before conducting the test. The rubbed specimen was placed on the specimen carrier with the test surface facing the nozzle tip. An abrasive charge of 4000g ennore sand conforming to IS 650-1966 [15] was placed in the hopper for each impingement. During the blasting process, the cradle was moved between the two fixed points. The used charges were collected in the cabinet. The test was repeated on the same surface after rotating the specimen by 180 degrees on the horizontal plane for enabling two impressions on the same surface. After the test was completed, the specimen was cleaned and weighed to determine the mass loss for one surface of the specimen. This procedure was then repeated on the three other vertical surfaces on the same specimen. The abrasion loss of the concrete specimen for each surface was determined by the following expression:

$$m = a - b \tag{1}$$

Where,
m = mass loss, g;
a = mass of the concrete specimen before each test, g; and
b = mass of the concrete specimen after each test (on one surface with two impingements), g.

The uni-axial compressive strength tests were conducted on the cube specimens using compression testing machine. Three specimens were tested for each result and the average values were found.

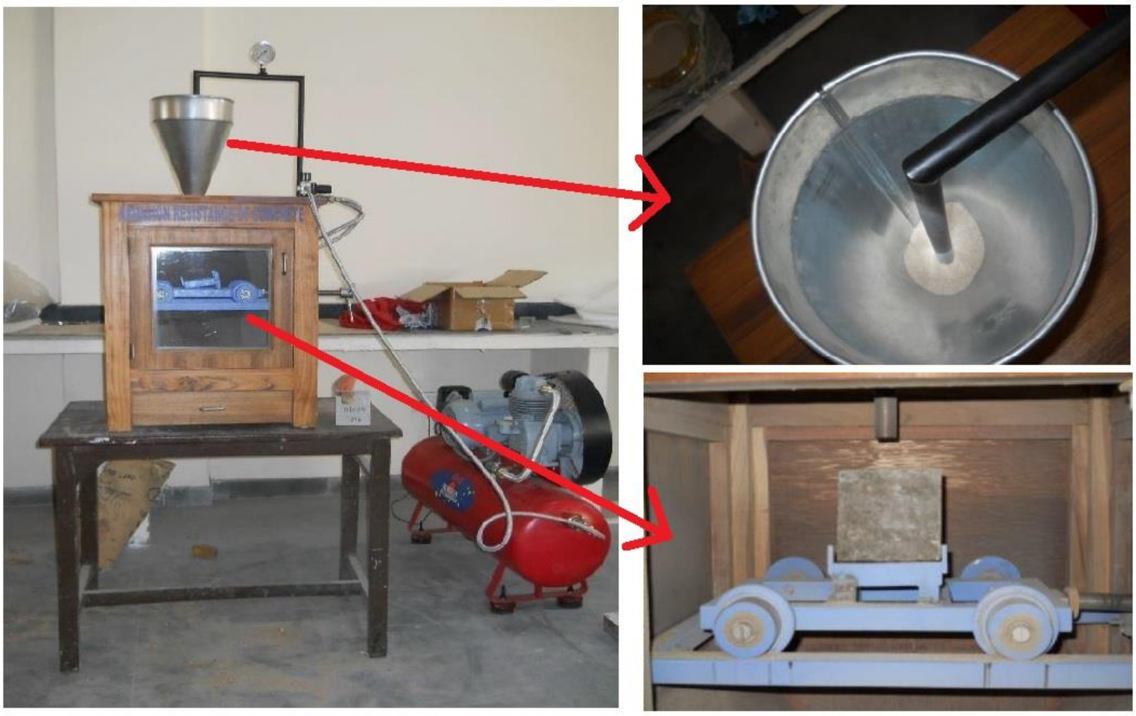


Fig. 1 – A view of sand blasting test setup

Table 1 – Description of concrete mixtures

Mix	Grade of concrete	L.A. abrasion value of aggregate	Type of cement	Pozzolana type and % replacement with cement		
				Fly ash	GGBS	Silica fume
M1	M25	<30%	PPC	-	-	-
M2	M25	<50%	PPC	-	-	-
M3	M25	>50%	PPC	-	-	-
M4	M40	<30%	PPC	-	-	-
M5	M40	<50%	PPC	-	-	-
M6	M40	>50%	PPC	-	-	-
M7	M40	<50%	PPC	-	-	10
M8	M40	>50%	PPC	-	-	10
M9	M40	<50%	PPC	-	15	-
M10	M40	>50%	PPC	-	15	-
M11	M40	<50%	OPC	-	-	-
M12	M40	>50%	OPC	-	-	-
M13	M40	<50%	OPC	-	-	10
M14	M40	>50%	OPC	-	-	10
M15	M40	<50%	OPC	-	40	-
M16	M40	>50%	OPC		40	-
M17	M40	<50%	OPC	40	-	-
M18	M40	>50%	OPC	40	-	-
M19	M60	<50%	OPC	-	-	10
M20	M60	>50%	OPC	-	-	10

Table 2 – Details of mix proportions of concrete mixtures

Mix	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Fly ash (kg/m^3)	GGBS (kg/m^3)	Silica fume (kg/m^3)	Super-plasticizer (kg/m^3)
M1	381	179	614	1270	-	-	-	3
M2	415	199	653	1080	-	-	-	5
M3	415	199	653	1149	-	-	-	5
M4	525	199	581	1078	-	-	-	6
M5	525	199	577	1072	-	-	-	9
M6	554	199	557	1098	-	-	-	8
M7	471	205	604	1100	-	-	54	7
M8	498	199	589	1055	-	-	55	8
M9	458	204	599	1108	-	81	-	7
M10	530	199	553	1119	-	93	-	9
M11	525	199	589	1131	-	-	-	8
M12	554	199	572	1080	-	-	-	8
M13	485	199	573	1073	-	-	54	8
M14	513	199	578	1139	-	-	57	9
M15	342	199	559	1102	-	228	-	9
M16	373	234	598	989		249	-	9
M17	315	199	632	1174	210	-	-	9
M18	363	199	540	1048	242	-	-	9
M19	504	142	683	1108	-	-	50	9
M20	525	147	648	1077	-	-	52	9

Table 3 – Properties of cements

Characteristics	Ordinary Portland cement		Pozzolana Portland cement	
	Results obtained	Limits as per IS 8112:1989	Results obtained	Limits as per IS 1489:1991 (Part 1)
Blaine's fineness (m^2/kg)	271	225 (min.)	323	300 (min.)
Specific gravity	3.15	-	3.0	
Soundness (mm)	3	10 (max.)	4	10 (max.)
Normal consistency (%)	28	30	33	-
Setting time (minutes)				
- Initial	103	30 (min.)	165	30 (min.)
- Final	196	600 (max.)	353	600 (max.)
Compressive strength (MPa)				
- 3 days	26.3	23	18.34	16
- 7 days	35.6	33	26.17	22
- 28 days	46.2	43	37.5	33

Table 4 – Properties of aggregates

Physical properties	Fine aggregate		Coarse aggregate					
	As per IS 383:1970	Result obtained	As per IS 383:1970	A2		A5		Sound aggregate
				4.75-10 mm	10-31.5 mm	4.75-10 mm	10-31.5 mm	10-20 mm
Fineness modulus	2-3.5	2.95	5.5-8	6.12	6.16	6.07	6.69	6.49
Specific gravity	2.6-2.7	2.68	2.6-2.7	2.67	2.69	2.63	2.68	2.7
Density, kN/m^3	-	13.05	-	15.62	15.86	15.58	15.79	15.23
Water absorption, %	-	1.16	-	0.96	1.15	1.1	0.85	0.81
L.A. abrasion value	-	-	should not be more than 30%	45.98	28.86	69.69	59.27	19.29
Type of aggregate	River sand		-	Dolomite		Dolomite		Lime-stone

3. Results and discussion

The test results of abrasion resistance of concrete are given in Fig. 2. Three replicate specimens were tested to get the average result in each case. The results show that the abrasion performance of concrete depends on the properties of aggregates, strength grade of concrete, type of cement, type and quantity of pozzolana. The effects of all these variables of the study are explained in the subsequent paragraphs. The typical appearance of specimens of various mixes before and after testing is shown in Fig. 4.

The results of compressive strength of the cube specimens are shown in Fig. 3. It can be observed that the target cube compressive strength of the requisite grade was achieved in each of the mixes. It is interesting to note that the compressive strength for a given mix at a given age remained more or less same irrespective of the L.A. abrasion value of the aggregates. The cube compressive strength of concrete constructed with aggregates of higher L.A. abrasion value was only marginally less than the comparable mixes made with sound (low L.A. abrasion value) aggregates. This shows that for the range of aggregates investigated in the present study, the L.A. abrasion value of the aggregate does not influence much the cube compressive strength of concrete.

3.1 Effect of aggregates

Figure 5 shows the effect of the abrasion properties of aggregates on the abrasion resistance of the concrete mix. It can be seen that, for a particular grade of concrete, the abrasion resistance decreases with increase in the L.A. abrasion value. The mass loss gets increased with L.A. abrasion value. The least mass loss in case of M25 strength grade of concrete was found in the specimens with L.A. abrasion value < 30%. As the L.A. abrasion value increases beyond 50%, the mass loss increases by 135% of the value at L.A. abrasion value < 30%. With the aggregates having L.A. abrasion value between 30 to 50%, the mass loss shows an increase of 77%. In general, the results show that the concrete containing weak aggregates having high L.A. abrasion value had more abrasion loss than the concrete containing sound aggregates having low L.A. abrasion value. A comparison of mixes M4 with M5 and M6, each having M40 grade of concrete, also proves that the type of aggregate has an appreciable effect on the abrasion resistance of concrete. The comparisons of the abrasion values of concretes made with the two weaker aggregates, i.e. M2 and M3, M5 and M6, M7 and M8, M9 and M10, M11 and M12, M 13 and M14, M15 and M16, M17 and M18, M19 and M20 indicate that the abrasion loss of concretes made with aggregates having L.A. abrasion value > 50% was about 1.3 to 2.4 times higher than the abrasion loss of concretes with aggregates having L.A. abrasion value < 50%. This further shows that the abrasion performance of concrete gets influenced significantly once the L.A. abrasion value of aggregates becomes higher than 30%. Hence, the Indian Standard recommended L.A. abrasion value limit of 30% is a reasonable upper limit. The results also show that the influence of aggregate type on abrasion performance is more pronounced in lower strength grades than in higher strength grades of concrete.

The results of this study show similar trends as reported in the literature, though only very limited number of studies have been reported on the influence of L.A. abrasion value of aggregates on the dry abrasion of concrete. Kilic [6] investigated the influence of aggregate type on the dry abrasion resistance of concrete and reported that when the L.A. abrasion value index of aggregates varies from 10 to 95%, the Bohme abrasion index reduces by 33%, while the L.A. abrasion value index of concrete reduces by 58%. Houston [16] reported a dry abrasion loss of 14% for an aggregate with L.A. abrasion value of 42.7%, while the abrasion loss reduced to 0.6% for aggregates with L.A. abrasion value of 23.9%.

3.2 Effect of pozzolana

The influence of type and quantity of pozzolanic material on the abrasion resistance of concrete can be studied from the results of mixes M5 to M18. The mixes had different pozzolanic material properties but similar concrete grade, cement type, and aggregates. As can be seen from the results in Fig. 2, the percentage increase in mass loss in case of M6 specimens was 44% than the M5 specimens. The M5 specimens were made with the aggregates with L.A. abrasion value < 50%, while the M6 specimens had aggregates with L.A. abrasion value >50%. In case of M7 and M8 specimens which had silica fume as the pozzolanic material, the percentage increase in the abrasion mass loss from M7 to M8 was found to be 57%. The M9 and M10 specimens which were made with GGBS based pozzolana, the increase in mass loss was found to be 77%. The trend shows the better performance of silica fume in mitigating the abrasion loss in concrete. Similarly, as shown in Fig. 6, the percentage increase in the abrasion loss was found to be 48%, 21%, 64% and 74%, respectively, in case of M11 and M12, M13 and M14, M15 and M16, M17 and M18 specimens.

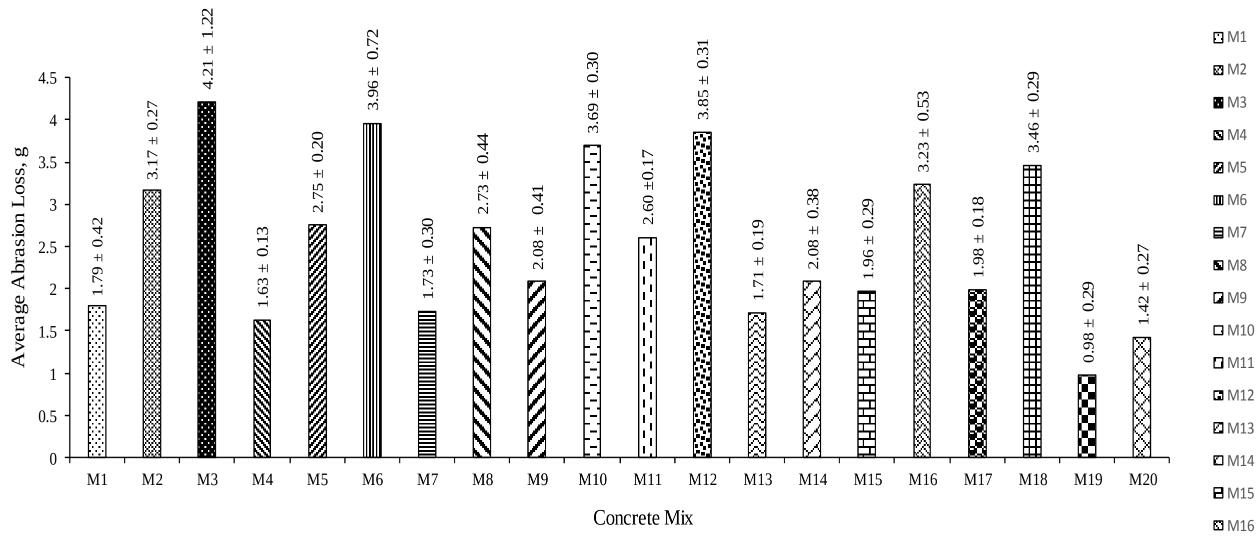


Fig. 2 – Dry abrasion test results with statistical parameters

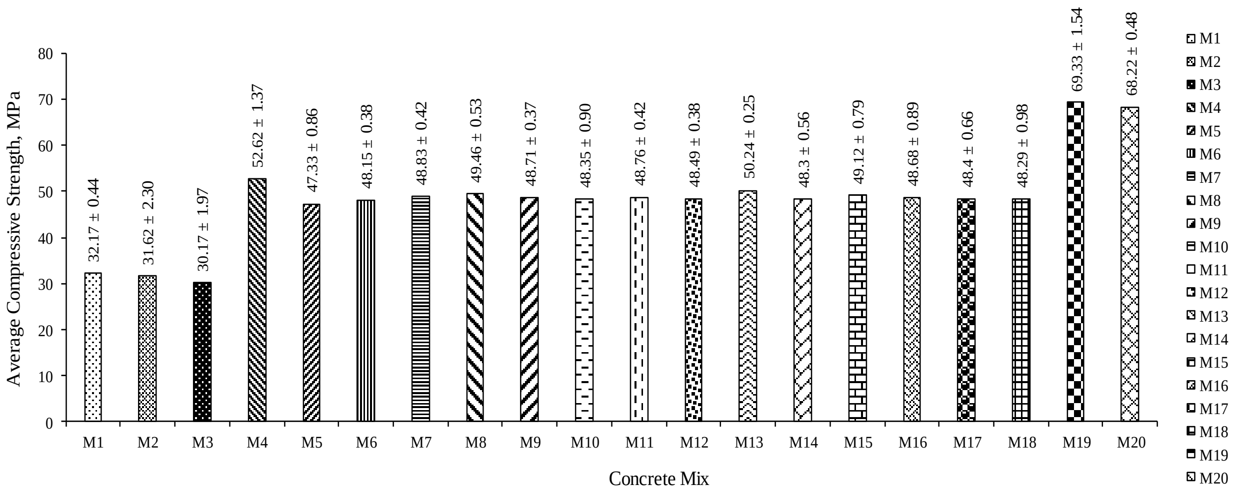


Fig. 3 – Average cube compressive strength of concrete mixes at the age of 28 days

(a) M2

(b) M5

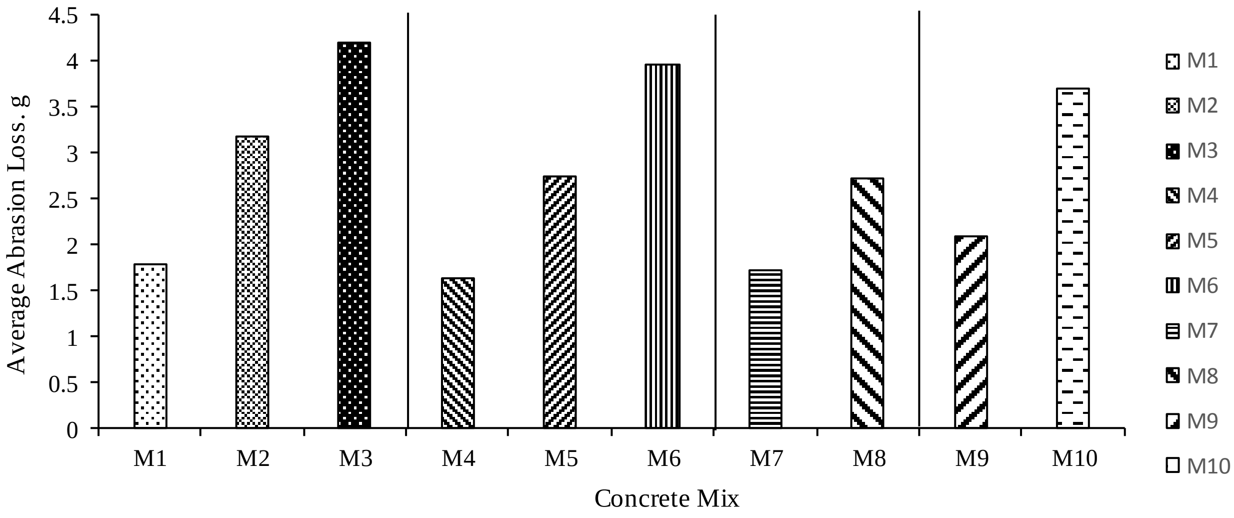
(c) M11

Fig. 4 – The appearance of few typical specimens before and after the abrasion resistance test by sand blasting

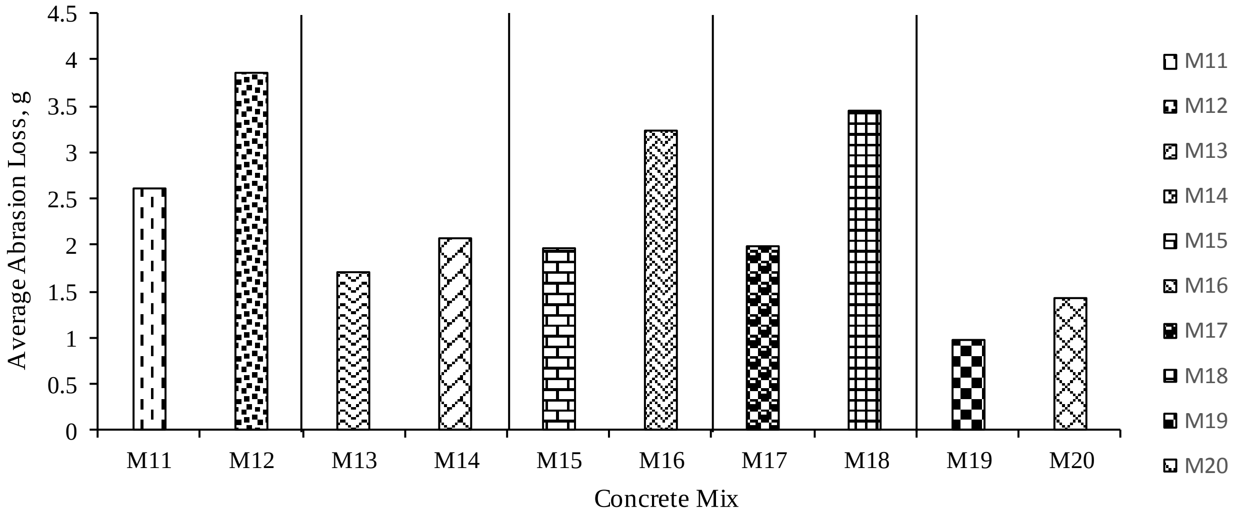
The best performance to reduce the abrasion loss is shown by the silica fume based specimens, while the fly ash based specimens showed a large increase in the abrasion mass loss. The abrasion loss of silica fume based mixes, i.e. M40 and M60 were the least followed by GGBS based mixes. This can be attributed to the stronger and denser paste resulting from pozzolanic additions and the use of lower water-cementitious ratio being a higher strength grade of concrete. Further, the higher strength grades of concrete usually have higher paste content making the role of paste more prominent than the aggregates and thus the stronger paste provides better abrasive properties.

Previous researchers also reported similar trends with respect to the effect of pozzolanic additives on the dry abrasion of concrete, though, only few studies have been reported in the literature on this aspect. This study had taken up this parameter more comprehensively by using all the three conventionally used pozzolanas and using them in conjunction with varying strength grades of concrete and L.A. abrasion values of aggregates. Turk and Katras [17] observed that the abrasion resistance of self-compacting concrete mixes with silica fume was highest among all the mixes containing different type and quantity of pozzolana. The authors used silica fume and fly ash as pozzolanic additives. The increasing amount of silica fume improved the abrasion resistance across all the mixes except for 20% silica fume replacement with cement due to inadequate water-cement ratio. However, the abrasion resistance of self-compacting concrete specimens with fly ash decreased when fly ash content increased from 25 to 35%.

Siddique [18] reported reduction in abrasion resistance of concrete with the addition of fly ash in concrete. Reduction in dry abrasion resistance at seven days was 14.7%, 33.8%, and 73.50% at 30%, 40%, and 50% fly ash content, respectively. At 28 days, reduction in abrasion resistance was 8.5%,



(a)



(b)

Fig. 5 – Effect of L.A. abrasion value of aggregates on the abrasion resistance of concrete at the age of 28 days

28.8%, and 35.6% at 30%, 40%, and 50% fly ash content, respectively. This reduction was 7.8%, 27.5%, and 37.3% at the age of 56 days, for 30%, 40%, and 50% fly ash contents, respectively. Naik et al. [19] partially replaced cement with Class C fly ash at levels of 15, 30, 40, 50 and 70%. The results show that the abrasion resistance of concrete having cement replacement up to 30 % was comparable to the reference concrete without fly ash. Beyond 30% cement replacement, fly ash concrete exhibited slightly lower resistance to abrasion relative to concrete without fly ash.

3.3 Effect of strength grade of concrete

The effect of the strength grade of concrete on the abrasion resistance of concrete can be observed from Fig. 6(b)-(c). A comparison of volume loss of concrete due to abrasion between the mixes M13 and M19, M14 and M20 shows that the abrasion resistance of concrete generally tends to improve with an increase in grade of concrete. The results show that, with keeping all other variables same, the abrasion loss in M40 concrete is 73% higher than in M60 concrete when aggregates with L.A. abrasion value < 50% are used. The same value is 46% when aggregates with L.A. abrasion value > 50% are used in concrete. This phenomenon can be explained on the better performance of denser cement paste phase of the concrete in higher strength grades. The resistance to the abrasion in higher strength concrete is provided by the dense cement paste-mortar phase. Similar results were obtained in case of under-water abrasion tests on similar concrete mixes performed by the authors [7]. However, the amount of influence of strength grade of concrete on abrasion loss is different in these two different types of abrasion tests.

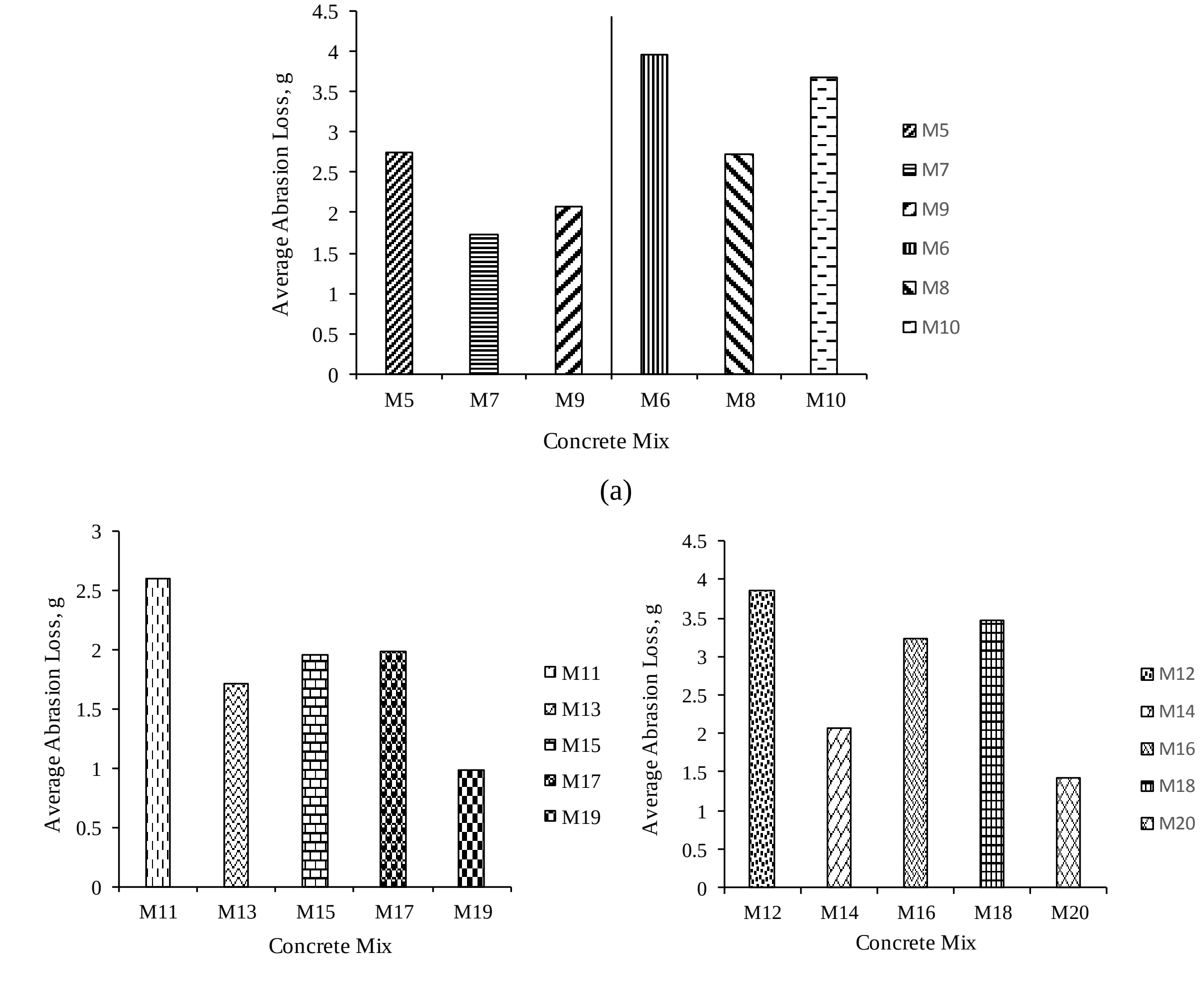


Fig. 6 – Effect of pozzolana on abrasion resistance at the age of 28 days

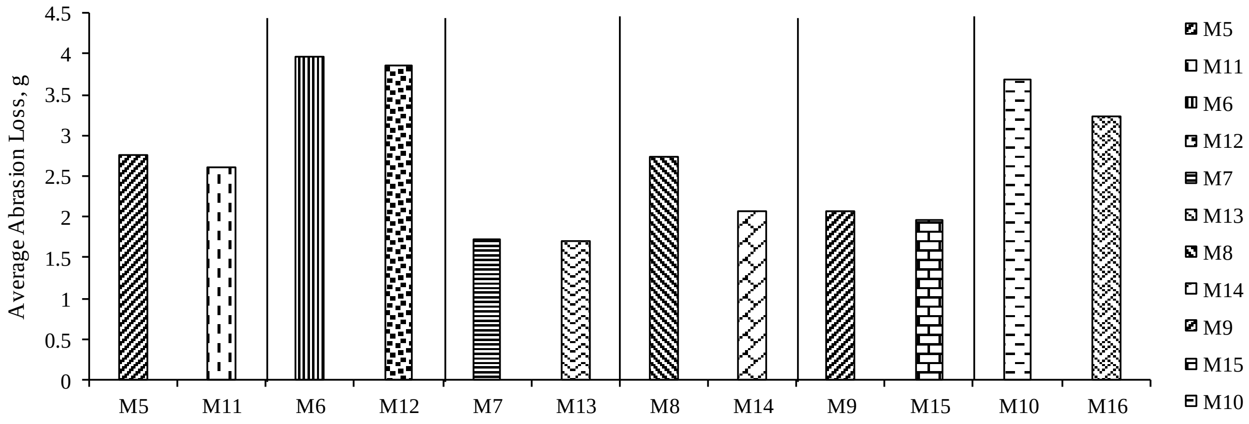


Fig. 7 – Effect of cement type on the abrasion resistance of concrete

The relevant test data from the previous studies from the literature were extracted in order to compare the trends of this study. The results of previous investigations related to the influence of strength grade of concrete on the dry abrasion resistance of concrete were converted to such a form so that a comparison could be made with the results of this study. The compressive strengths of concrete were converted to cube compressive strength and the dry abrasion loss was computed in terms of mass loss in grams. Ozturan et al. [20] used concrete mixes of cube compressive strengths ranging from 14 to 37 MPa and found that the Bohme disc dry abrasion loss reduces by 32% as the concrete strength increases. Yazici et al. [21] experienced a reduction in the abrasion loss by 32% when the concrete cube strength was varied from 68 to 82 MPa. Kilic et al. [6] reported 25% reduction in Bohme disc dry abrasion loss of concrete when concrete strength was increased from 50 to 121 MPa cube compressive strength. Rao et al. [22] conducted surface abrasion tests on concrete mixes with cube strength varying from 16 to 48 MPa and their results show a reduction in abrasion loss by 61% as the concrete strength increases. Cai et al. [23] used sand blasting dry abrasion test using concrete with cube strengths varying from 50 to 68 MPa and it was reported that the abrasion loss gets reduced by 15% when the concrete strength increases. The above results, though, show different amount of reduction in the dry abrasion loss or varying quantum of improvement in the dry abrasion resistance of concrete when the strength of concrete is increased, one thing is common in all the previous studies and this study: i.e. the abrasion performance of concrete improves as the strength of concrete is increased. The new dimension which this study adds is that how the improvement in strength and thereby in the abrasion resistance of concrete containing marginal aggregates can be achieved through the use of secondary cementitious materials.

3.4 Effect of cement type

Two types of cement, i.e. Portland Pozzolana Cement (PPC) and Ordinary Portland Cement (OPC) were used in the study. The abrasion values of concretes made with the above-mentioned cements have been compared in Fig. 7. The PPC based silica fume concrete mixes showed an increase of 57% abrasion loss when the aggregates with L.A. abrasion value > 50% were used. The same was found to be only 21% in case of OPC based silica fume concrete mixes. When PPC was used with GGBS, an increment of 77% in the abrasion loss was found with the aggregates with L.A. abrasion value > 50%. The same was 64% with OPC based GGBS concrete mixes. It was observed that OPC-based mixes showed better abrasion resistance than the comparable PPC based mixes. The comparison of various mixes with the benchmark mix M1 has been shown in Fig.8.

4. Regression model

An attempt has been made to develop an empirical relationship to estimate the abrasion loss of concrete using the compressive strength of concrete and L.A. abrasion value of aggregates. Efforts were made to include the relevant data from previous researchers also to arrive at some meaningful regression equation. As mentioned earlier, many different types of dry abrasion tests have been employed by many researchers in the past in evaluating the abrasion resistance of concrete. The test results have already been discussed and an attempt has been made to develop a regression model for abrasion loss based on the dry abrasion tests. The data of previous investigations from the literature was suitably brought to a consistent representation in conformity with the current investigation. Figure 9 shows a scatter of existing data in the literature along with present investigation between the abrasion loss and the compressive strength of concrete. It can be noted that the abrasion loss decreases as the concrete strength increases. An equation which relates abrasion loss with concrete strength and L.A. abrasion value of aggregates shall be of more significance. However, it was not possible to develop the same using the data of other researchers along with the data of this study due to the unavailability of L.A. abrasion values of aggregates in most of the previous studies. Therefore, such best fit empirical equation was developed using the data from this study only. Figure 10 shows this multivariable plot and based on this following equation is being proposed whose correlation coefficient is reasonably acceptable:

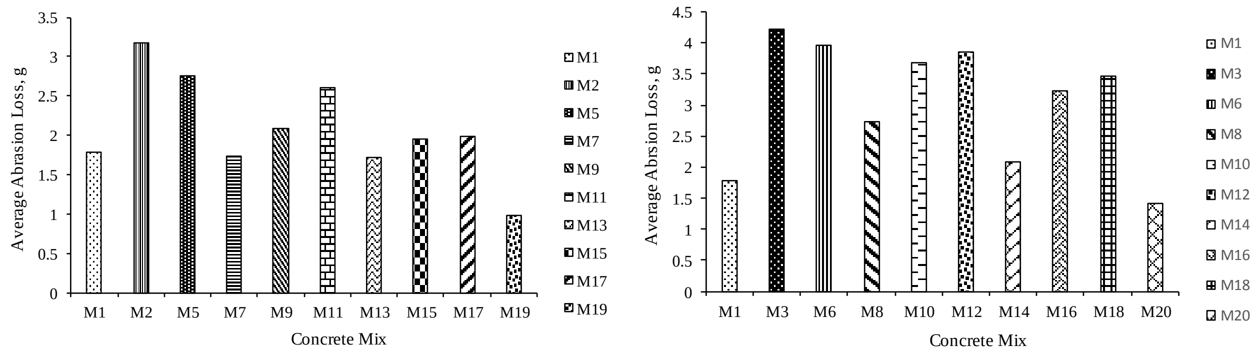


Fig. 8 – Comparison of various mixes with the bench mark mix M1

$$AL = a + bf_{ck} + cLA + df_{ck}^2 + eLAf_{ck} + gf_{ck}^3 + hf_{ck}^2.LA \quad (2)$$

Where, *a*, *b*, *c*, *d*, *e*, *g*, *h* = coefficients, *AL* = abrasion loss in g, f_{ck} = compressive strength of concrete in MPa, *LA* = L.A. abrasion value of aggregates (%).

The coefficients with goodness of fit are as follows:

a = - 0.7085
b = 0.1465
c = 0.03055
d = -0.00407
e = 0.001343
g = 3.253e-05
h = -2.419e-05

Goodness of fit:
SSE: 3.923
R-square: 0.7712
Adjusted R-square: 0.6656
RMSE: 0.5493

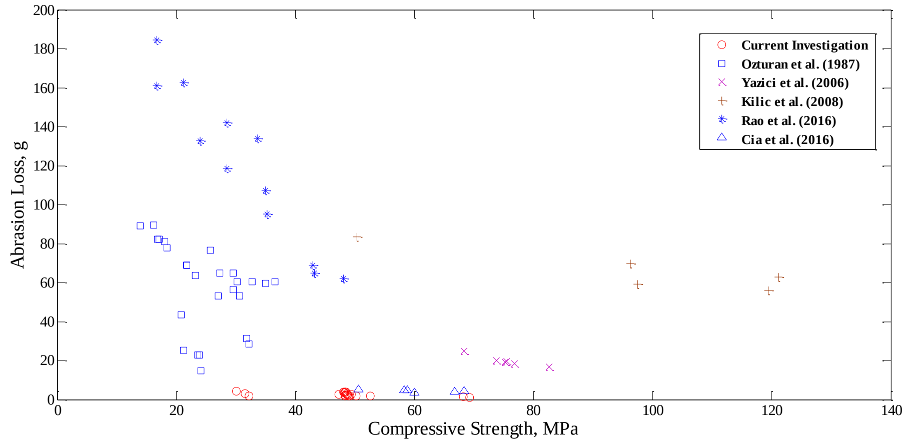


Fig. 9 – Compressive strength versus abrasion loss based on dry abrasion tests

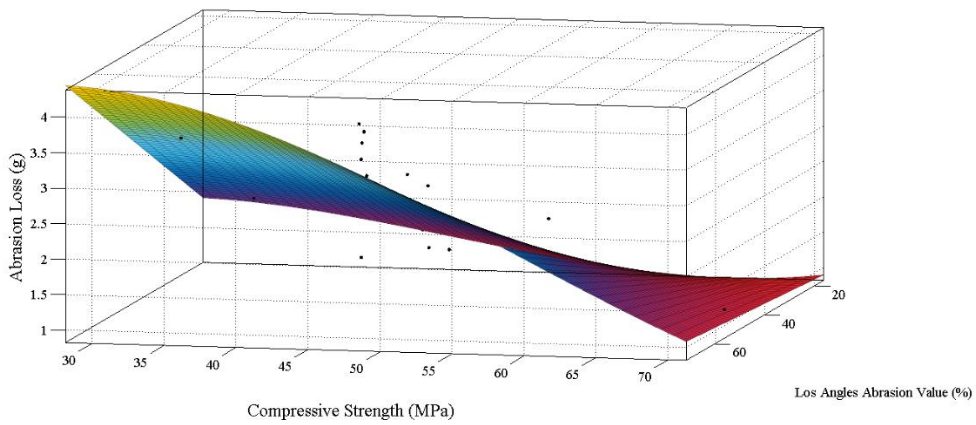


Fig. 10 – Correlations between average abrasion loss, compressive strength and L.A. value of aggregates

5. Conclusions

In this investigation, a total of 60 cubes were tested as per IS 9284 -1979 procedure to evaluate the abrasion resistance of concrete containing marginal aggregates. The parameters of the study were aggregate abrasion value, strength grade of concrete, cement type, and pozzolanic additions. Within the scope of the present study, the following conclusions may be drawn.

(1) The abrasion resistance of concrete depends significantly upon the abrasion properties of aggregates. The aggregates having higher L.A.

abrasion value show lower abrasion resistance of resulting concrete compared with aggregates having lower L.A. abrasion value. The abrasion performance of aggregates having L.A. abrasion value in the range of 30-50% and that of aggregates having L.A. abrasion value more than 50% was observed to be more or less similar and equally unsatisfactory. Thus, it can be concluded that once the L.A. abrasion value of aggregates goes beyond 30%, the abrasion performance of resulting concrete gets influenced significantly.

(2) The abrasion resistance of concrete improves as the compressive strength of concrete increases. In higher strength grade of concretes, the paste content of concrete assumes dominating role and the influence of aggregates becomes relatively less pronounced. Further, the influence of aggregate L.A. abrasion value is observed to be less predominant in higher strength grades of concrete than in lower strength grades.

(3) The results of this study show that the incorporation of pozzolanic materials in the mix of high strength grade of concrete further improves the abrasion resistance of concrete. However, the results show that silica fume based concrete provides significant improvement in abrasion resistance. Fly ash and GGBS additions do not show very encouraging results.

(4) Ordinary Portland cement (OPC) based concrete shows better abrasion performance than the concrete made with Portland Pozzolana Cement (PPC).

(5) The results show that for the range of variables investigated in the present study, the abrasion value of the aggregate does not influence much the cube compressive strength of concrete.

(6) An empirical equation has been proposed to estimate the abrasion resistance of concrete using the compressive strength of concrete and the L.A. abrasion value of aggregates.

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