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Cavitation resistance of concrete containing different material properties

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Abstract. In the present investigation, influence of various material parameters on the cavitation erosion resistance of concrete was investigated on the basis of laboratory experiments. As there is no well-established laboratory test method for evaluating the cavitation resistance of concrete, a test set up called 'cavitation jet' was specially established in the present study in order to simulate the cavitation phenomenon experienced in the hydraulic structures. Various mixtures of concrete were designed by varying the grade of concrete, type and quantity of pozzolana, type of aggregates and cement type to develop good cavitation resistant concrete constructed using marginal aggregates. Three types of aggregates having three different Los Angeles abrasion values (less than 30%, between 30% and 50% and more than 50%) were employed in this study. To evaluate the cavitation resistance a total of 60 cylindrical specimens and 60 companion cubes were tested in the laboratory respectively. The results indicate that cavitation resistance of concrete degrades significantly as the L.A. abrasion value of aggregates goes beyond the 30% value. Incorporation of pozzolanic admixtures was seemed to be beneficial to enhance the cavitation resistance of concrete. Influence of other material parameters on the cavitation resistance of concrete was also noted and important observations have been made in the paper.

Keywords: hydraulic structures; concrete; cavitation erosion; material properties

1. Introduction

Cavitation is a common phenomenon observed in many hydraulic structures. It is a process of formation of cavities in the form of air bubbles in the low-pressure region of flowing fluid. In the hydraulic structures when sudden change in the velocity or pressure takes place, cavities in the form of vapor bubbles are formed in the low-pressure zones. Further, these vapor bubbles travel from low pressure zone to high pressure zone (i.e., near to surface) and collapse. The sudden collapse of vapor bubbles generates intense shockwaves and imposes high bursting forces on the surface. This action of bubbles erodes the surface and leaves small pits and holes on the surface of concrete. This is a progressive phenomenon which goes on repeating and in each cycle, its impact

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on structure increases, which ultimately results in severe structural damages. Erosion resistance of concrete is strongly influenced by various material parameters like strength grade of concrete, type and quantity of pozzolana, type of aggregates and cement type.

Simulating cavitation erosion in the laboratory is always a challenge. Some laboratory methods in the due course of time have been developed by various researchers to simulate cavitation erosion in hydraulic structures and the performance of concrete against cavitation erosion was studied. Walter (1947) in his investigation used high velocity water jet method for determining the effect of mix proportion, absorptive form lining, curing, surface finish and air entrainment on the cavitation erosion on concrete. His results concluded that smooth high velocity flow and no abrupt changes in flow will not cause any kind of damage. Houghton *et al*. (1978) worked on fiber and polymer concrete and his research exhibited significantly higher cavitation erosion resistance as compared to conventional concrete. Superior erosion resistance was noticed by polymerization of steel fibrous reinforced concrete and by polymerization of monomer filled sand patches in conventional concrete.

Cheng *et al*. (1990) conducted a detailed experimental test to examine the efficiency of four surface coating systems against cavitation erosion. Full-scale field cavitation test and cavitating jet erosion apparatus test were employed for the testing purpose. It was noted in the results that cavitation jet method was suitable than ultrasonic vibratory cavitation erosion for simulating actual field results. Momma and Lichtarowicz (1995) investigated some new type of sensor to find the cavitation loading pressure. Donald (2000) probed that the cementations based material exhibited poor cavitation resistance. A ceramic filled epoxy, a metal filled fiber reinforced epoxy and polyurethane exhibited the best cavitation resistance. Goretta *et al*. (1999) determined that the material loss in concrete appears to have been caused by a combination of fracture mechanisms. Momber (2000) informed that the material’s behaviour during cavitation erosion significantly depends on its capability to transfer local stresses and to locally deform. The interfacial bond between aggregate and cement matrix is of decisive importance for the cavitation erosion resistance. Henrik and Bernd (2001) explained that in the erosion test, using an aluminum plate, the number of cavitation damage pits increases rapidly with the test time.

Soyama *et al*. (2001) experimentally investigated threshold level of cavitation impact value which can cause cavitation erosion to materials with certain cavitation resistance. In that study cavitation jet erosion test suggested by ASTM G-134 were employed to determine the erosion rates for various materials. Momber (2003) found that the cavitation erosion rate decreases as the compressive strength of concrete increases. Momber (2004) found that cavitation erosion with an exposure time as low as 10 seconds generated measurable damage. Filho and Genovez (2009) developed a cavitating jet apparatus with the use of a direct displacement pump. In order to simulate combined effect of cavitation and high-velocity flow, interchangeable nozzle was used at the exit of the pipe. The experimental study indicated that this apparatus proved to be appropriate to test cavitation erosion resistance in concrete. This apparatus has the advantage of requiring a small assembly area and expenses with energy are reduced due to the short exposure operation time, especially when compared to the venturi device. Zeman *et al*. (2010) employed a laboratory setup developed by University of Illinois at Urbana-Champaign (UIUC) to test the theory that positive and negative water hammers occur in a saturated rail seat during load cycles, causing cavitation erosion and hydraulic pressure cracking at the concrete surface. The test setup includes a laboratory concrete specimen that represents the rail seat, which is submerged in a water tank while being subjected to load cycles of varying magnitudes and frequencies. Martinovic *et al*. (2013) investigated possible application of refractory concrete in conditions of cavitation effect and analysed the influence of different sintering temperatures on cavitation resistance of refractory concrete. Modified vibratory cavitation test method was used for conducting the laboratory testing of the cavitation resistance. The results show that the samples sintered at 1100℃ are not suitable for application in conditions of cavitation while the samples sintered at 1300° and 1600℃ exhibited very good cavitation resistance. Fairfield (2014) used high-pressure water-jet, codified in WIS 4-35-01 to measure the cavitation damage in potential sewer and drain pipe materials. Concrete, clay, 30% (v/v) glass-filled nylon, polysulphone, and polyetherimide were reported as best five materials on the basis of measured erosion rates and loss of material thickness under the action of the cavitating high-pressure water-jet. Matikainen *et al*. (2014) performed cavitation erosion tests on coatings with an ultrasonic transducer (VCX-750, Sonics & Materials, USA) according to the ASTM G32-10 standard. Zhang *et al*. (2017) used MCF-30 rotary erosion test machine to measure the cavitation resistance of synthesised hydrophobic fluorinated polyurethanes (FPU) coatings.

Most of the previous studies on the cavitation performance of concrete investigated mainly hydraulic parameters and to some limited extent concrete material parameters. There is no well-established laboratory test method for evaluating the cavitation resistance of concrete. Thus, there is an urgent need of developing a testing method in this regard. In view of this, the present investigation has been planned to investigate the influence of various material parameters on the cavitation erosion resistance of concrete.

Table 1 Description of concrete mixtures

Mix	Grade of concrete	LA value of aggregate	Type of cement	Pozzolana type and % of 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

2. Experimental program

An experimental program was designed to achieve the objectives of this research. Strength grade of concrete, type and quantity of pozzolana, type of aggregates and cement type are different variables which were taken into consideration during the designing of various concrete mixes. In the present investigation, two strength grades of concrete, i.e., M40 and M60 were used. To evaluate the cavitation resistance of concrete, a total of 60 cylindrical specimens were cast from 20 batches of concrete and 60 companion cubes were tested to assess the cube compressive strength of various concrete mixes. The description of various concrete mixtures and proportions of mixes are provided in Tables 1-2 respectively.

2.1 Material properties

All the materials used in the present study conformed to the relevant Indian Standard Codes (IS 12089 1987, IS 1489 Part 1 1991, IS 15388 2003, IS 3812 Part 1 2003, IS 650 1966, IS 8112 1989). Ordinary Portland Cement (OPC) and Pozzolana Portland Cement (PPC) were the two types of cement employed in various concrete mixes. To enhance the properties of paste, three types of pozzolanas, i.e., silica fume, fly ash and Ground Granulated Blast Furnace Slag (GGBS) were used in the mixes as part replacement of cement. Two different types of aggregates with low

Table 3 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		Limestone

abrasive properties and one sound aggregate with satisfactory abrasion value were employed in different concrete mixes. Low quality aggregates are further classified into two categories based on the L.A abrasion value, i.e., aggregates with L.A. value less than 50% (but more than 30%), designated as A2 and aggregates with L.A. value more than 50%, designated as A5. To obtain a grading for 20 mm graded aggregates as per IS 383 (1970), two types of fractions of these low-quality aggregates i.e., 10 mm and 31.5 mm were mixed appropriately. Aggregates type with L.A value less than 30% and graded as per 20 mm grading, were designated as sound aggregates and used as benchmark for control testing. Sand conforming to zone II of IS 383 (1970) was used as a fine aggregate throughout the study. Physical properties of fine as well as coarse aggregates are represented in Table 3.

2.2 Mixing, casting and curing

Required proportions of various ingredients used in the concrete mixes i.e. cement, sand, coarse aggregates, water, pozzolana and super plasticizer were kept ready before each casting. 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. A tilting type mixer was employed for mixing these ingredients in the laboratory. During the casting, cleaned, brushed and oiled moulds were placed on the vibrating table with a speed range of 12,000±400 rpm and an amplitude range of 0.055 mm. To determine the slump of fresh concrete, slump cone test was conducted after completing the mixing procedure. A slump value of 100-150 mm was maintained in all the mixes. All the mixes were checked for bleeding and segregation was not observed in any of the mixes. After 24 hours, specimens were removed from the moulds and were cured in water until the day of testing.

2.3 Testing

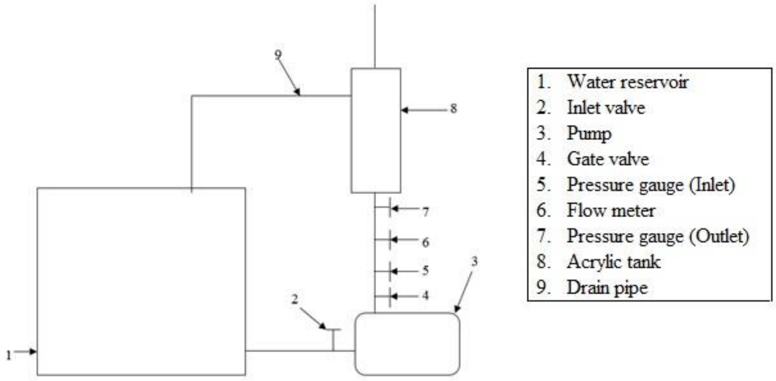


Fig. 1 A schematic diagram of cavitation jet apparatus

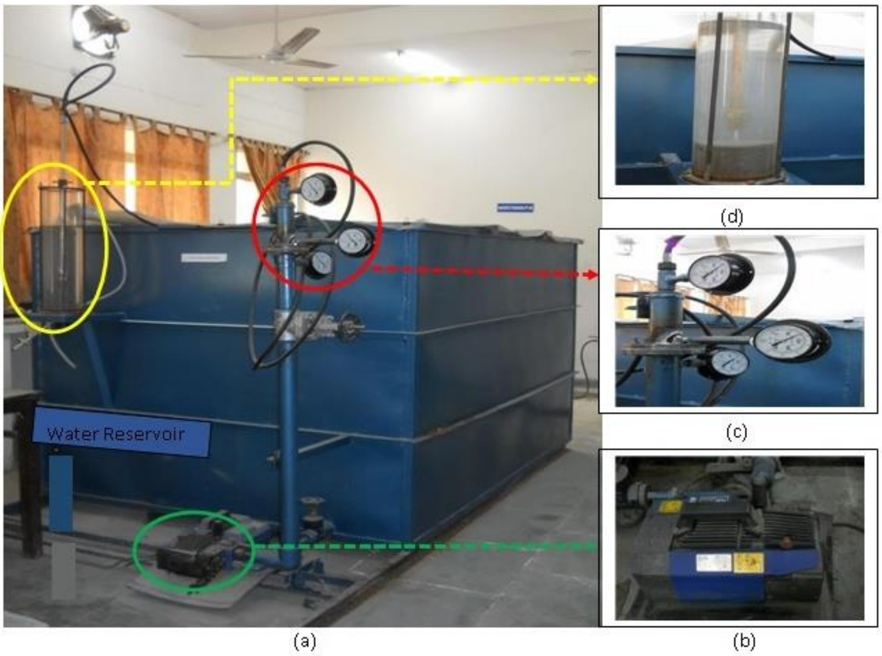


Fig. 2 A view of cavitation jet apparatus

All the specimens were removed from the curing tank after a curing of 28 days and left under the laboratory ambient conditions till the cavitation resistance test and the compressive strength test was carried out. In order to simulate the cavitation phenomenon and to determine the erosion of concrete specimens, a test set up called ‘cavitation jet’ was specially developed indigenously. The apparatus was designed first and then fabricated in the laboratory. The cavitation jet test apparatus consisted of a reservoir connected with pump, pressure gauges, orifice, jet nozzle and acrylic chamber. A schematic diagram of cavitation jet apparatus is shown in Fig. 1 and the fabricated experimental test set up is shown in Fig. 2. Cavitation apparatus was attached with a water reservoir (Fig. 2(a)) to ensure uninterrupted availability of water. Motor pump (Fig. 2(b)) with adjustable water flow pressure was attached to the reservoir and water was supplied to acrylic tank with a predefined pressure and flow velocity. The apparatus was so designed to create a case of submerged nozzle. Acrylic tank was filled with water to simulate the bubbles impulsion due to cavitation. The cavitation jet downstream of the nozzle hit the surface of the specimen. A pump was used to ensure flow of water to the facilities and then to the acrylic chamber for visualization of the test (Fig. 2(d)). A pressure gauge with measurement range of 0 to 14 MPa was located at the pump exit (Fig. 2(c)). Water temperature in the test was 28℃, the vapour pressure (P_v) was 3800 Pa and the density of water (ρ) was 996 Kg/m$^{3.}$ In order to produce the combined effect of high-speed flows and cavitation, nozzle was placed at the exit of the pipe. Nozzle with an opening angle of 20° and conical geometry was set with orifice of 3mm diameter. Orifice meter and pressure tapings were used to accomplish the test conditions.

The different governing parameters were adjusted to achieve a significant amount of cavitation typically encountered in the field situations. The important parameters identified were pressure at the inlet of the orifice (P_1), pressure at outlet of the orifice (P_2), standoff distance (distance between outlet of nozzle to specimen surface), amplitude (diameter of exposed area of specimen), angle of nozzle outlet and duration of exposure. In order to get the desired results, trial and error method was adopted by adjusting different parameters and for each combination, cavitation index was calculated. Cavitation index is a parameter used to express the critical combination of quantities like velocity of flow, pressure of flow, and water vapor pressure which are responsible for cavitation of hydraulic system. Cavitation is also known as an index used to measure the susceptibility of a system to the cavity. Cavitation index is a dimensionless quantity and expressed as

$$\sigma_j = \frac{(P_j - P_v)}{(\rho V_j^2)/2} \tag{1}$$

Where, σ_j=Cavitation index for a submerged jet, P_j=Pressure in the core of jet, P_v =Vapour pressure, V_j=Velocity in the core of the jet, ρ=Density of water.

Parameters like nozzle outlet angle (20°), duration of exposure (900 seconds) were kept constant and pressure P_1 was regulated using in-built controller in motor pump. According to the value of P_1, the value of P_2 was changed based on the geometry of orifice. Standoff distance was varied by adjusting the distance between exposed surface and nozzle. Amplitude of exposed area changed according to the standoff distance as the nozzle outlet angle was constant. In order to achieve the desired cavitation conditions on the surface of the concrete specimen, P_1 was taken as 5 MPa, standoff distance as 5 cm, and corresponding values of other parameters being P_2 as 5.25 MPa, jet velocity as 118.4 m/s and cavitation index (σ) as 0.72 based on many trials. According to Falvey (1982), cavitation index values ranging from 0.3 to 1.8 represent the desired cavitation similar to field conditions.

After finalizing the operational parameters, the scheduled cavitation test program was executed on selected cylindrical specimens after water curing of 28 days. The concrete specimen was placed perpendicular to the direction of cavitating jet nozzle. After 900 seconds of testing, specimen was removed and number of pits on the specimen's surface was counted with the help of magnifying glass, and then again, the same specimen was placed in the apparatus for further 900 seconds against the same exposure. Three such cycles were repeated for each specimen (total 2700 seconds). Cavitation erosion rate can be analyzed in terms of number of pits by time in order to obtain quantitative and qualitative information of the erosion intensity variation with various material parameters employed in this study.

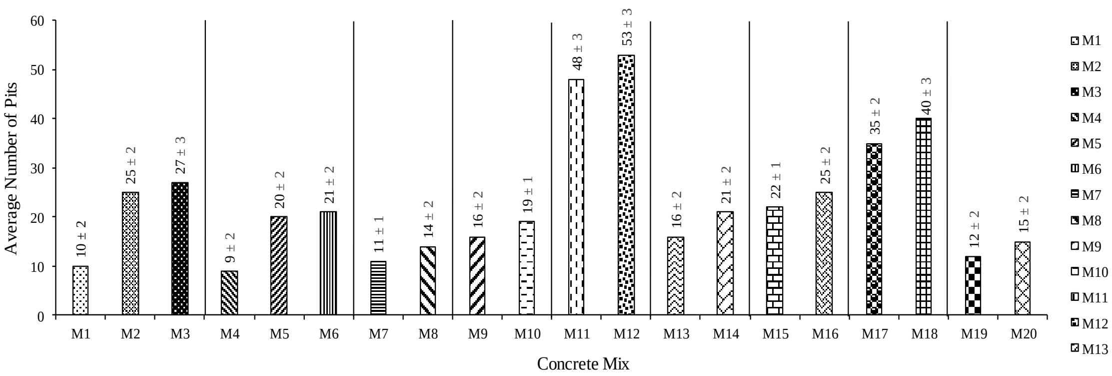


Fig. 3 Results of cavitation jet test

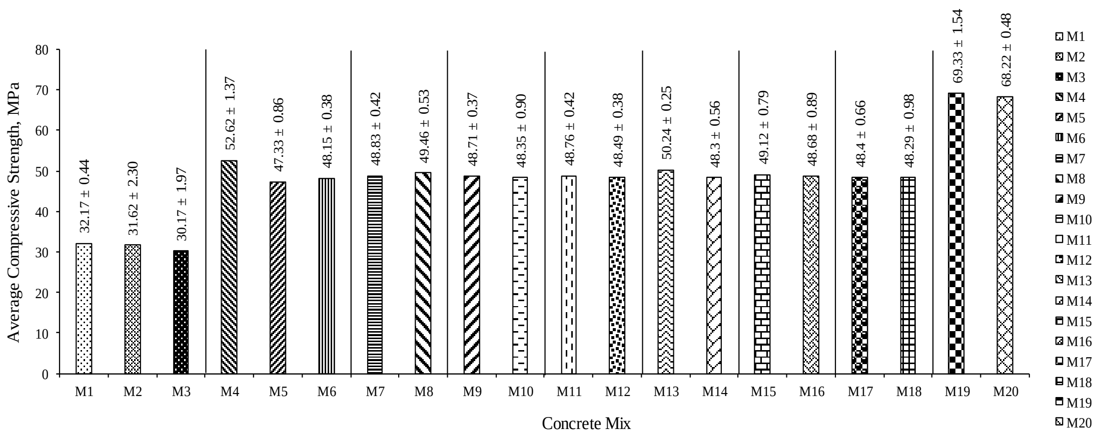


Fig. 4 Average cube compressive strength of concrete mixes at the age of 28 days

3. Results and discussion

The results of the cavitation jet test and cube compressive strength are given in Figs. 3-4 respectively. The influence of various parameters, considered in this investigation, on the cavitation resistance of concrete has been presented in the following sections. From compressive strength test results (Fig. 4), it can be observed that in each mix, target cube compressive strength of the requisite grade was achieved. It can be noted that compressive strength of a given mix remained more or less same irrespective of the Los Angeles abrasion value of the aggregates used in that mix. There is only marginal difference between cube compressive strength of concrete constructed with aggregates of high LA value and those constructed with sound aggregates. So, it can be concluded that cube compressive strength of concrete is not influenced much as the abrasion value of aggregates changes. The typical appearance of the specimens for cavitation tests has been shown in Fig. 5.

3.1 Effect of aggregate

The effect of aggregates on the cavitation performance of concrete can be gauged from Fig. 6.

(a)

(b)

(c)

Fig. 5 Typical appearance of a specimen before and after the cavitation jet test

The results show that the concrete containing weak aggregates with high L.A. value had more cavitation damage than the concrete containing sound aggregates with low L.A. value. Comparing the results of mix M1 with M2 and M3, each having M 25 grade of concrete, it can be noted that the type of aggregate has a significant effect on the cavitation erosion of concrete. With 10 and 27 pits formed in M1 and M3 type mixes respectively, the cavitation loss was found to be least in the specimens with the aggregates having L.A value<30%. As the L.A value of aggregates increased, the cavitation loss also increased. The average volume loss for M3 concrete mix containing aggregates of L.A. value>50% was 2.7 times higher than that of the mix M1 made with aggregates of L.A. value<30%. The mix M3 showed an abrasion cavitation loss of 1.1 times more than mix M2, which was made with aggregates of L.A. value 30-50%. 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 cavitation erosion of concrete. The comparisons of the cavitation erosion values of concretes made with the two weaker aggregates i.e., mixes M2 and M3, M5 and M6, M7 and M8, M9 and M10, M11 and M12, and M 13 and M14, M15 and M16, M17 and M18, M19 and M20 indicate that the cavitation loss of concretes made with aggregates having L.A. value>50% was about 1.05 to 1.35 times higher than the cavitation erosion of concretes with aggregates having L.A. value<50%.

Cavitation resistance of concrete decreases significantly once the L.A value of aggregates becomes higher than 30%. However, the performance of concrete against cavitation with L.A. value>50% was only marginally less than that of with aggregates having L.A. value<50% (but

>30%). It shows that a limit of 30% of L.A. abrasion value of aggregates, recommended by Indian Standard IS 383 (1970) is a reasonable upper limit. The results show that there is no direct relation between the L.A. value of aggregates and abrasion resistance of concrete. But, the influence of aggregate type on abrasion performance is more pronounced in lower strength grades than in higher strength grades of concrete. The higher-grade concretes and silica fume based concretes may provide satisfactory cavitation erosion resistance even though the aggregates used are of higher L.A values.

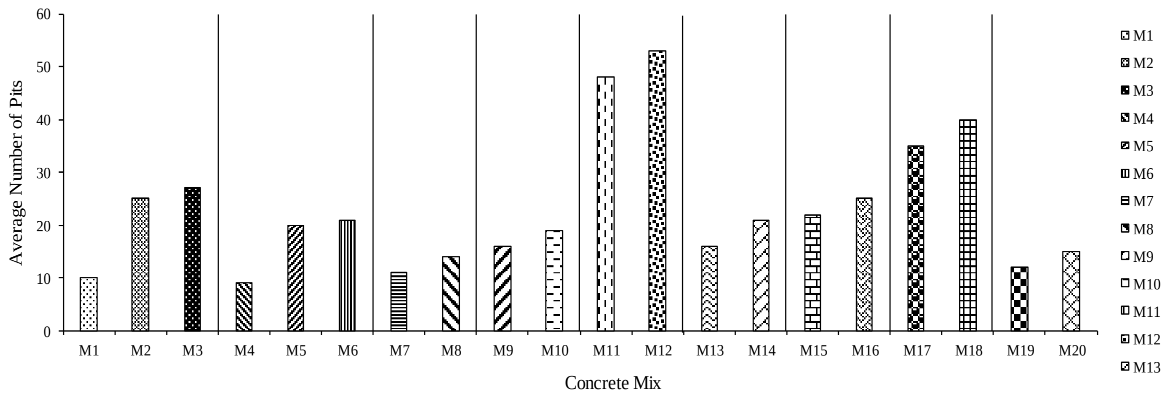
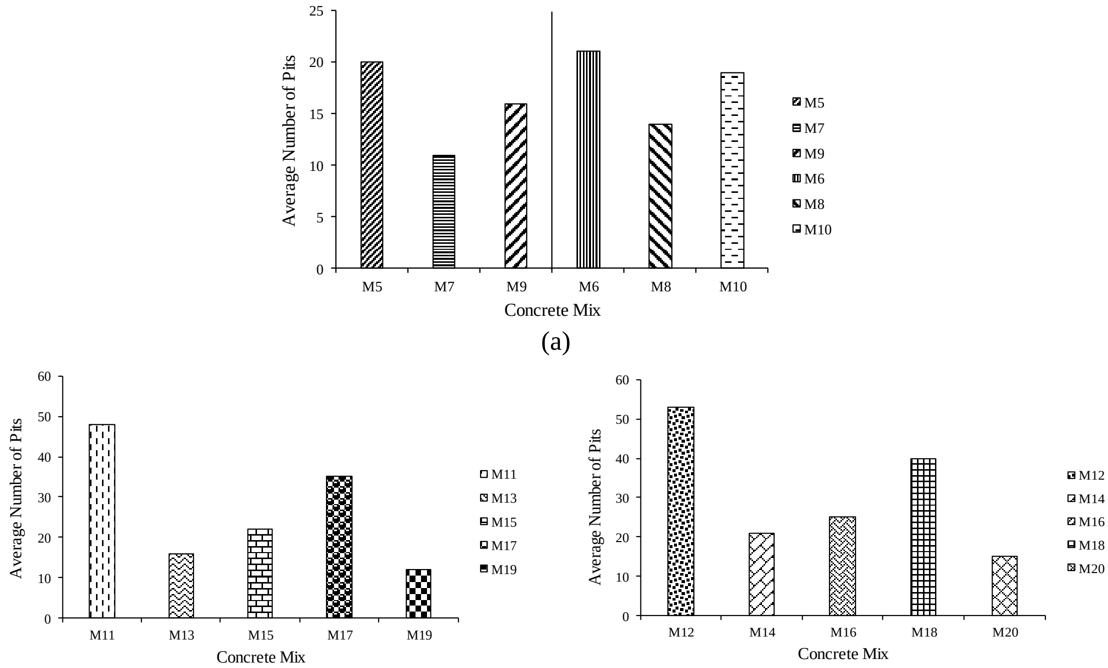


Fig. 6 Effect of L.A. value of aggregates on the abrasion resistance of concrete at the age of 28 days

3.2 Effect of pozzolana

The addition of pozzolanic additives in the concrete mixes increased the cavitation resistance in both the PPC as well as the OPC based concrete mixes. From Fig. 3, it can be seen that the number of pits formed in M5 and M6 mixes, which are without any pozzolana additive, are 20 and 21 respectively. The same values in case of M7 and M8 mixes which are silica fume based, the number of pits gets decreased to 11 and 14 respectively showing the better resistance of the silica fume based concrete mixes against cavitation. With the addition of GGBS, the number of pits formed in the cavitation test increases by 45% with respect to silica fume based concrete with aggregates of L.A value<50% and an increment by 36% with respect to the mix having aggregates of L.A value>50%. This observation establishes the better performance of silica fume in resisting the cavitation loss. Similar trends are observed in PPC based concrete mixes. M11 registered 48 pits while 53 pits were formed in M12 mix. On adding silica fume in concrete mix, the cavitation loss decreased by 66% in mixes made with aggregates with L.A value<50% and decreased by 60% in the concrete mixes made with aggregates with L.A value>50%. However, the GGBS based concrete mix showed an increment of 37.5% cavitation loss than the silica fume based concrete mix, which again demonstrates the higher efficiency of silica fume in mitigating the cavitation loss in concrete. Nevertheless, the cavitation performance of GGBS based mixes was definitely better than the non-pozzolanic mixes. As compared to silica fume and GGBS based mixes, performance of fly ash based mixes against cavitation erosion was not that marked but in was better than non-pozzolanic mix (Fig. 7). This can be attributed to the stronger and denser paste resulting from pozzolanic additions.



(a)

(b) (c)

Fig. 7 Effect of pozzolana on cavitation resistance of concrete at the age of 28 days

3.3 Effect of strength grade of concrete

Effects of strength grade of concrete on the cavitation erosion of concrete can be observed from Figs. 7(b)-(c). A comparison of loss of concrete due to cavitation erosion between the mixes M13 and M19 and M14 and M20 shows that cavitation erosion resistance of concrete generally tends to improve with an increase in the strength grade of concrete. In case of M25 concrete mix, the number of cavitation pits registered was 25 in the mix made with aggregates with L.A value<50% and the number of pits in the mix made with aggregates with L.A value>50% was found to be 27. On increasing the strength grade of concrete to M40, a decrease of 25% in cavitation loss was found in the mixes made with aggregates with L.A value<50% and a decrease of 28% was found in the mixes made with aggregates with L.A value>50%. When the mix was upgraded to M60, a decrease of 33.3 % and 61.5% was registered in the cavitation loss in the mixes with aggregate L.A value<50% and>50% respectively. The above results show that an increase in the concrete strength grade improves the cavitation resistance of concrete irrespective of the abrasion properties of its aggregates. Thus, higher concrete strength grades having stronger paste phase can overcome the deficiencies in aggregates, if any.

3.4 Effect of cement type

The mixes made with PPC showed better resistance to the cavitation loss than the OPC based mixes. The cavitation jet test results of concrete mixes made with the above-mentioned cements have been compared in Fig. 8. The number of pits formed in M7 (PPC) mix was 11, while, it

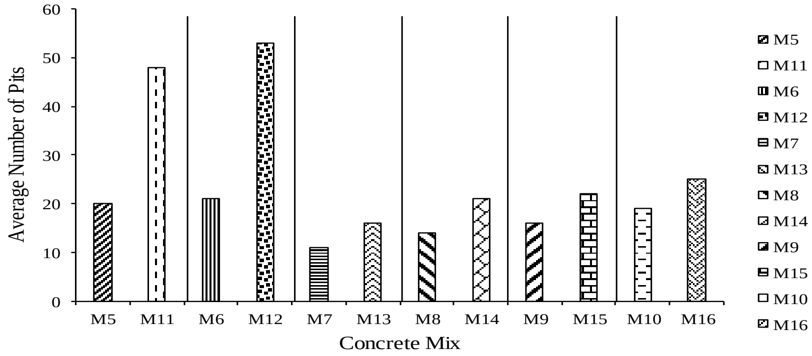
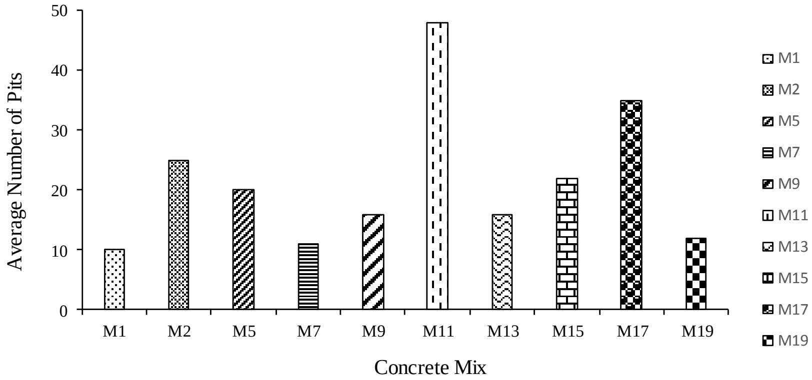
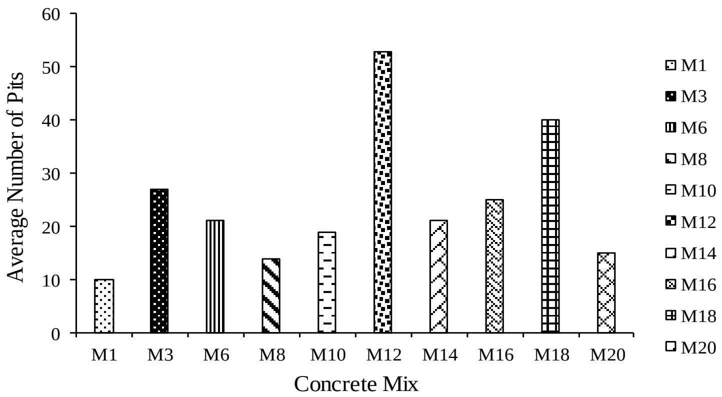


Fig. 8 Effect of cement type on the cavitation resistance of concrete



(a)



(b)

Fig. 9 Comparison of various mixes with the bench mark mix M1

increased to 16 in M13 (OPC) showing a decrease of 45% in cavitation resistance in OPC based mixes. Similarly, the cavitation resistance in GGBS based OPC mix decreased by 31% as compared to PPC based mix. The better cavitation resistance properties of the PPC based mixes are due to the denser micro-structure of concrete due to pozzolanic additions. The comparison of various mixes with the benchmark mix M1 has been shown in Fig. 9.

4. Conclusions

To evaluate the cavitation resistance of various concrete mixes constructed using varying material parameters, a total of 60 cylindrical specimens were tested in cavitation jet apparatus which was designed especially under the present study. Within the scope the present study, the following conclusions may be drawn:

- Properties of aggregates used in the concrete mix influences the performance of concrete against cavitation erosion significantly. The cavitation resistance of concrete deceases as the L.A. value of aggregates increases. However, no direct correlation exists between the L.A. abrasion value of aggregates and the cavitation erosion resistance of resulting concrete mix. There was a marginal difference between the performance of concrete against cavitation erosion with L.A. abrasion value in the range of 30-50% and that of aggregates with L.A abrasion value more than 50%. Thus, the cavitation resistance of concrete was found to decrease significantly as the L.A. abrasion value of aggregates goes beyond 30%.
- The cube compressive strength of concrete is not influenced much by the L.A. abrasion value of aggregates for the range of aggregates investigated in the present study.
- The results show that higher strength grade of concrete possess higher cavitation resistance. The influence of aggregates on cavitation resistance of resulting concrete subsides as the paste content of concrete becomes stronger and dominant.
- Cavitation resistance of concrete can be further improved by the incorporation of pozzolanic materials in the mix as a part replacement of cement. Silica fume shows the maximum benefit in enhancing cavitation resistance of concrete, while GGBS and fly-ash additions also provide encouraging results.
- The concrete prepared with PPC cement shows better resistance against cavitation erosion compared to that made with OPC cement.

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