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Effect of Gradation of Manufactured Sand in Acid Attack of Concrete

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Common river sand is expensive due to excessive cost of transportation from natural sources. Also large-scale depletion of these sources creates serious environmental problems. In such a situation the manufactured sand can be an economical alternative to river sand. Manufactured sand is defined as the residue, tailing or other non-valuable material after the extraction and the processing of rocks to form fine particles less than 4.75 mm (0.19 inch). Use of manufactured sand as fine aggregate in concrete and mortar draws serious attention of researchers and investigators. Durability problems of concrete are associated with the severity of the environment. In this paper, mix design has been developed for M 20, M 30 and M 40 grade concrete using various proportions of manufactured sand and natural sand as fine aggregate incorporating the parameters of particle size and specific gravity. The deteriorating effects of sulfuric acid solution on concrete have been ascertained through the strength reduction tests.

Keywords: Manufactured sand, Natural sand, Particle size, Specific gravity, Acid attack.

INTRODUCTION

Concrete is an alkaline material, with a pH above 12.5 necessary for proper strength and protection. The pH of the acidic fluid and how much of it is in contact with the concrete are the primary determining factors in how corrosive the acid attack is. Although this pH level makes concrete open to react with acidic compounds, the pH must be kept high in order to prevent corrosion from occurring. Acids are substances with a pH value lower than 7. Most soils contain some sulfate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Decay of organic matters in marshy land, shallow lakes often leads to the formation of hydrogen sulfide, which can be transformed into sulfuric acid by bacterial action. Water used in concrete cooling towers can also be a potential source of sulfate attack on concrete. Therefore sulfate attack is a common occurrence in natural or industrial situations. The composition of the aggregate, cement type, w/c ratio and air void system are the important parameters which affect the concrete deterioration in acid solution.

Sawich and Heng[1] observed the durability of concrete with the addition of limestone powder. The results showed that a beneficial influence of a powdered limestone on concrete durability was observed when w/c < 0.6. Above this value, the powdered limestone has almost no essential effect. Babu[2] investigated the performance of quarry waste as fine aggregate in concrete and he reported that quarry waste could be used as fine aggregate in concrete. Nagaraj and Banu[3] investigated the efficient utilization of rock dust and pebbles as aggregate in Portland cement concrete. They concluded that the rock dust due to its higher surface consumes more cement than sand and the pebbles due to their smooth surface texture reduce the concrete strength. Ueda *et al.*[4] pointed out that sulphuric acid is hard to penetrate into hardened cement. The reaction between cement hydrates and sulphuric acid occurs only in the surface portion of specimens. The surface portion, therefore, is a main field of the reaction of sulphuric acid. St. John *et al.*[5] examined the composition of the aggregate, cement type, w/c ratio, air void system, identification of admixtures and surface flaws in the paste. In this study the investigator showed that in concrete that had been attacked by soft water (low pH), the texture of the outer layer would consist of silica gel over a carbonated zone. The outer gelatinous layer may or may not be fully intact because it can easily break off during the transportation and the testing process. This pattern is always observed in concrete that has been attacked by acidic water. Ilangovan[6] reported that quarry dust could be used as alternative replacement of natural sand in concrete. He observed that using quarry dust reduces the cost without affecting the strength of concrete. Kosmatka *et al.*[7] stated that keeping a low w/c would increase the resistance of the concrete deterioration by acid. Low permeability, a result of the low water cement ratio, will help keep the acidic solution out of the concrete pore structure. Kurashige[8] described that sulphuric acid penetrating into the mortar or concrete reacts with calcium hydroxide of cement hydrates, which causes expansion resulting in erosion. Perumal and Sundarajan[9] reported that the quarry rock dust could be used as alternative replacement of natural sand in concrete. They observed that using quarry rock dust reduces the cost without affecting the strength. They concluded that the weight loss and strength of concrete with quarry rock dust is considerably less. Kawai *et al.*[10] found that the rate of concrete deterioration caused by sulphuric acid attack depended on the pH value of acid solutions and the depth of erosion of concrete. It was nearly proportional to the exposure time of flowing acid solution to which the concrete was exposed. Raman *et al.*[11] investigated the utilization of quarry waste fine aggregate in concrete mixtures. They concluded that the use of rock dust enhancing the durability of concrete. Ilangovan *et al.*[12] studied the strength and durability properties of concrete containing quarry rock dust as fine aggregate, it was found that the compressive, flexural strength and durability studies of concrete made of quarry rock dust are nearly 10 % more than the conventional concrete. Shanmugavadivu and Malathy[13] investigated the effect of fines of fine aggregate in mechanical properties of concrete. It was concluded that the compressive strength, split tensile strength and flexural strength values of concrete are increased up to 80 % of manufactured sand. Shanmugavadivu and Malathy[14] studied the durability properties of concrete with manufactured sand. They found that the water absorption of the concrete with manufactured sand is less when compared to the conventional concrete. The weight loss and strength loss due to acid attack, chloride attack and sulphate attack is reduced as 40 % while increasing the proportions of manufactured sand.

Due to the above reasons, in this paper, the chemical attack such as acid attack is conducted on concrete with the replacement of natural river sand by manufactured sand and also studied the effect of fines (particle size less than 75 microns) and w/c ratio in acid attack of the concrete.

EXPERIMENTAL

The materials used are Portland pozzolana cement, Natural River sand, Manufactured sand and 20 mm down size Coarse aggregate. The properties of materials are tested in the laboratory.

Mix design: Mix design has been prepared for M 20, M 30 and M 40 grade concrete with various proportions of natural sand and manufactured sand based on their gradation and specific gravity.

Testing details

Compressive strength: The compressive strength of concrete cube was determined based on IS: 516 -1959. Three cubes of size 150 × 150 × 150 mm were tested for each trial mix combination at the age of 7, 28, 56, 90 and 365 days of curing using a compression testing machine[15-18].

Acid attack: For performing the tests namely acid attack, the cubes of size 150 × 150 × 150 mm were cast and have been cured for 28 days in normal water. The weights and compressive strengths at the end of 28 days were taken and they were placed in sulfuric acid solution of 0.1 normality. The weight and compressive strength of the cubes are taken for 28, 56, 90, 180 & 365 days.

RESULTS AND DISCUSSION

Initial properties of materials: Table-1 shows that the properties of cement. From Table-1, it is observed that the properties of cement are within the allowable limits. Table-2 shows the properties of coarse aggregate. It is noticed that the properties of coarse aggregate values satisfy the standards. Table-3 gives the properties of various proportions of natural river sand (N.S) and manufactured sand (M.S). It is also observed that the fineness modulus values of fine aggregate are increased with the increase in percentage of manufactured sand. Because of this increased in values, the fine aggregate content changes from Zone-III to Zone-I. This represents the fine aggregate content changes from fine to coarse while increasing the quantity of manufactured sand. The coarser particles have less specific surface area which requires less amount of water. It is also observed that the surface moisture content of fine aggregate is increased while increasing the proportions of manufactured sand. This may be due to the manufactured sand is washed with water. Fig. 1 shows the grading curves (particle size distribution curve) of natural sand and the various proportions of manufactured sand. Fig. 1 showed that the fine particles less than 600 microns are increased with the increase in percentage of manufactured sand. When the manufactured sand is blended with the natural sand, the micro fines are reduced and also the fines are within the allowable limits as specified by IS 383-1970[16]. The blending of 80 % manufactured sand and 20 % natural sand coincides with the upper limit. The blending of 90 % M.S & 10 % N.S and 100 % M.S exceed the upper limit. Figs. 2 and 3 show the energy dispersive spectroscopy (EDS) results of natural sand and manufactured sand. Fig. 2 indicates that the natural sand has the major amount of silica and oxides. Fig. 3 indicates that the manufactured sand contains silica, alumina and oxides.

Mix design: Table-4 gives the mix ratios for M20, M30 and M40 grade concrete. From Table-4, it is found that the quantity of fine aggregate increases with the increase in percentage of manufactured sand up to 70 %. Beyond 70 % of manufactured sand, the fine aggregate quantity is reduced. It is also

TABLE -1
PROPERTIES OF CEMENT

Properties	Values
Specific gravity	3.15
Fineness (by sieve analysis)	4.6 %
Consistency	29 %
Initial setting time	110 min
Final setting time	230 min

TABLE-3
PROPERTIES OF FINE AGGREGATE

S. No	Proportions	Specific gravity (g)	Fineness modulus (F.M.)	Surface moisture (S.M.) (%)	Water absorption (W.A.) (%)	Zone
1	A(100 % N.S-0 % M.S)	2.59	2.21	0.11	0.09	III
2	B(90 % N.S-10 % M.S)	2.57	2.23	0.35	0.07	III
3	C(80 % N.S- 20 % M.S)	2.50	2.27	0.67	0.05	II
4	D(70 % N.S-30 % M.S)	2.50	2.41	0.91	0.04	I
5	E(60 % N.S-40 % M.S)	2.50	2.39	1.06	0.03	I
6	F(50 % N.S-50 % M.S)	2.51	2.38	1.31	0.02	I
7	G(40 % N.S-60 % M.S)	2.61	2.60	1.66	0.01	I
8	H(30 % N.S-70 % M.S)	2.60	2.50	1.80	0.01	I
9	I(20 % N.S-80 % M.S)	2.59	2.63	2.26	0.02	I
10	J(10 % N.S-90 % M.S)	2.52	2.52	2.41	0.05	I
11	K(0 % N.S-100 % M.S)	2.56	2.51	4.44	0.11	I

TABLE -2
PROPERTIES OF COARSE AGGREGATE

Properties	Values
Specific gravity	2.73
Bulk density	1653.06 kg/m^3
Surface moisture	0.086 %
Water absorption	1.00 %
Fineness modulus	6.98

TABLE-4
MIX RATIOS OF M20, M30 AND M40 GRADE CONCRETE

Proportions	M 20 grade	M 30 grade	M 40 grade
A	1:1.48:3.34/0.53	1:1.31:3.09/0.49	1:0.82:2.73: 0.39
B	1:1.48:3.37/0.53	1:1.30:3.09/0.48	1:0.82:2.73:0.39
C	1:1.48:3.29/0.53	1:1.33:3.02/0.48	1:0.85:2.68:0.39
D	1:1.58:3.22/0.52	1:1.40:2.95/0.47	1:0.90:2.62:0.39
E	1:1.58:3.22/0.51	1:1.40:2.95/0.47	1:0.9:2.62:0.39
F	1:1.59:3.22/0.51	1:1.41:2.95/0.47	1:0.91:2.62:0.38
G	1:1.66:3.22/0.50	1:1.47:2.95/0.46	1:0.95:2.62:0.38
H	1:1.66:3.22/0.50	1:1.47:2.95/0.46	1:0.94:2.62:0.38
I	1:1.65:3.22/0.49	1:1.47:2.95/0.46	1:0.95:2.62:0.37
J	1:1.62:3.22/0.49	1:1.47:2.95/0.45	1:0.94:2.62:0.37
K	1:1.60:3.22/0.49	1:1.43:2.95/0.44	1:0.92:2.62:0.37

observed that the w/c ratio is reduced with the increase in percentage of manufactured sand. This may be due to the coarser particles requires less amount of water and the higher surface moisture content of manufactured sand.

Compressive strength: Figs. 4-6 show the compressive strength of M 20, M 30 and M 40 grades of concrete. It is

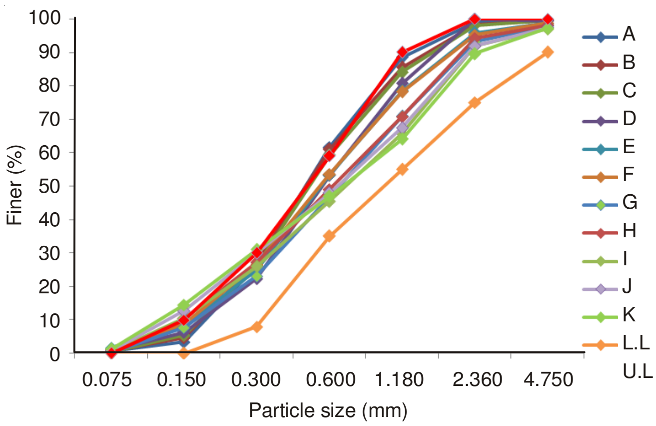

Fig. 1. Particle size distribution curve for various proportions of fine aggregate

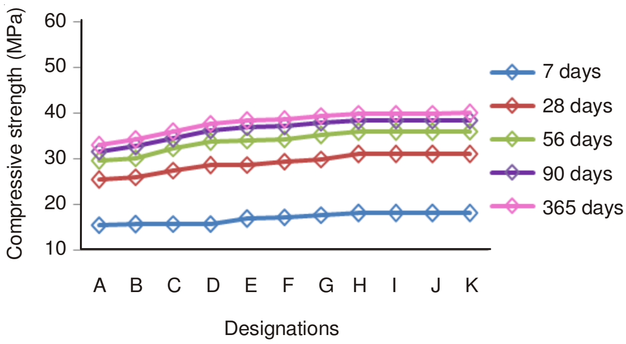

Fig. 4. Compressive strength of M 20 Grade

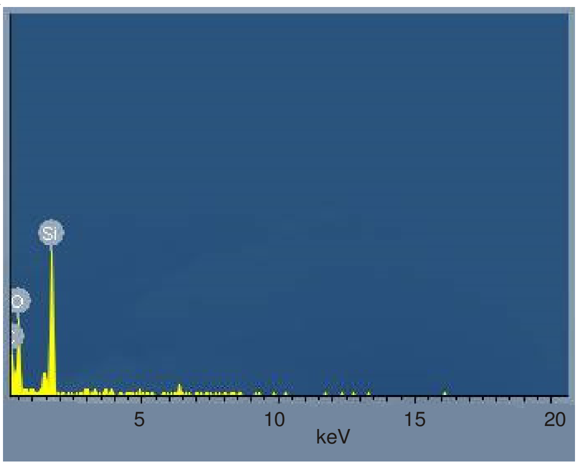

Fig. 2. Natural sand

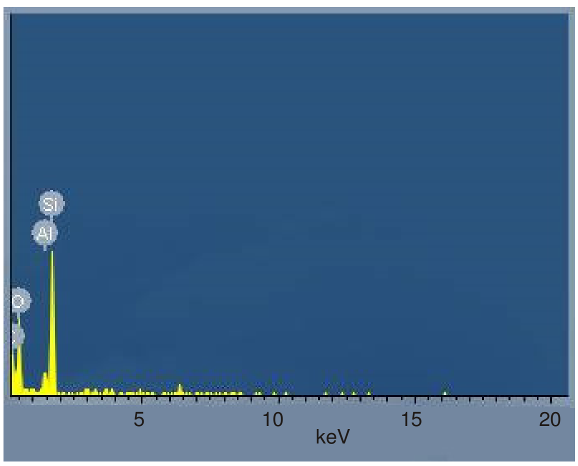

Fig. 3. Manufactured sand

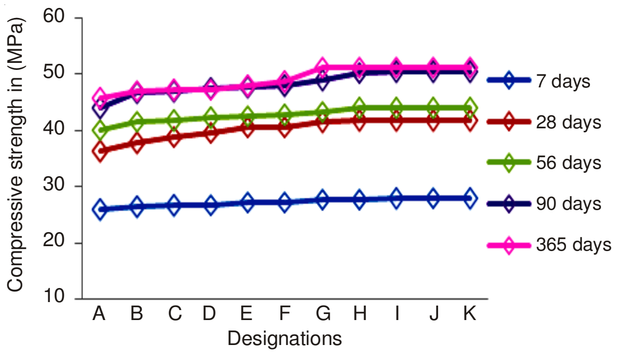

Fig. 5. Compressive strength of M 30 Grade

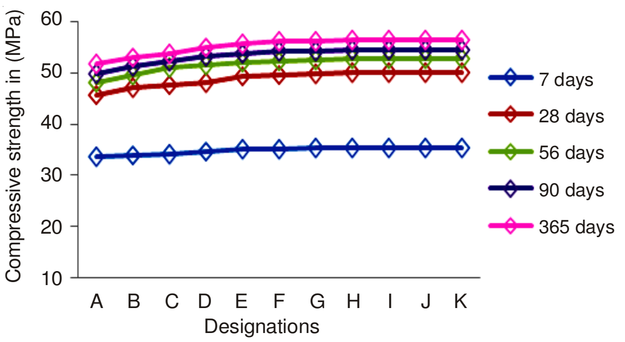

Fig. 6. Compressive strength of M 40 Grade

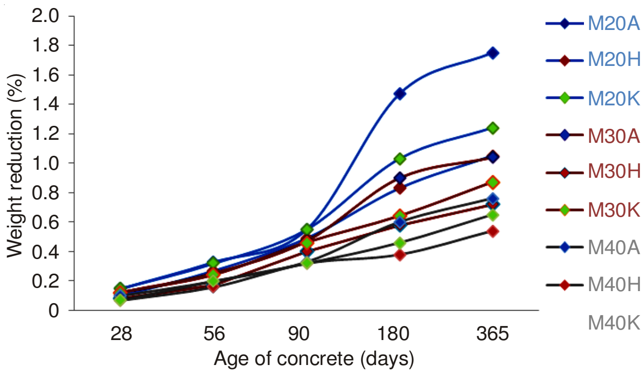

Fig. 7. Percentage weight reductions of concrete in acid attack

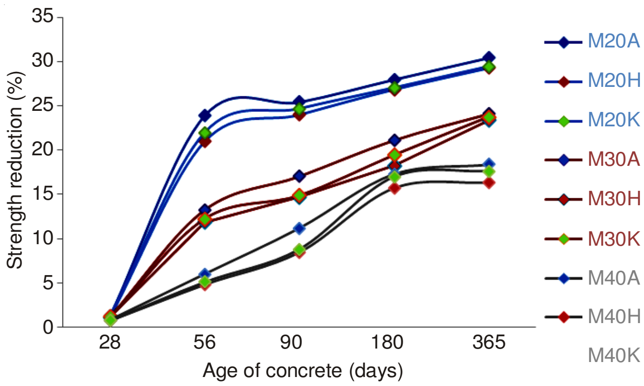

Fig. 8. Percentage strength reductions of concrete in acid attack

observed that the compressive strengths are increased with the increase in percentage of manufactured sand for all the three grades of concrete. This is due to the rough surface and angular particles of the manufactured sand create better interlocking between the aggregate and the hydrated cement paste. Another reason for the strength increment is that the manufactured sand is free from clay particles. The clay present in the natural river sand interferes with the bond between the aggregate and the cement paste which in turn reduces the compressive strength of the concrete. It also indicates that there is no significant change for the proportions H and K. It states that even though the strength is increased for 100 % (K) manufactured sand, there is no significant improvement in the strength achievement beyond 70 % (H) of manufactured sand due to the large amount of fine particles present in 80, 90 and 100 % of manufactured sand.

Acid attack: The loss in weight and the compressive strength of M 20, M 30 and M 40 grade concrete specimens with proportions A, H and K in sulphuric acid solution are illustrated in Figs. 7 and 8. It clear that the weights are decreased in acid solution. Since concrete is an alkaline substance, many of its components readily react with acids. The reaction between the acid and the calcium compounds form calcium salts, which can be soluble in water. These salts are then leached away, causing a loss of volume and cohesion of the paste. It was also found that the percentage weight reduction was less in concrete with proportion K and it is the least for the proportion H, when compared to the concrete with natural river sand. This may be due to the presence of fewer pores in concrete with 70 % manufactured sand. It was also noted that the percentage weight reduction was less for M 30 and M 40 grade concrete than for M 20 grade concrete due to less w/c ratio and less porosity, which reduce the leaching of calcium salts through these small number of pores. Fig. 8 represents that the strength is reduced in acid solution. The mechanism of concrete deterioration caused by sulfuric acid can be explained by the fact that the sulphuric acid penetrating into the concrete reacts with calcium hydroxide of cement hydrates and produces gypsum. At this time, the volume of solid substances increases largely, which causes expansion of reaction of products resulting in erosion. The decomposition of the concrete depends on the porosity of the cement paste, on the concentration of the acid, the solubility of the acid calcium salts (CaX_2) and on the fluid transport through the concrete. The disintegration of hardened cement paste, as a result of interaction with the environment, causes a reduction in the compressive strength of concrete. It also testifies that the percentage strength reduction rose higher for M 20 grade concrete, when compared to the M 30 and M 40 grade concrete. This is due to the concrete having a high water cement ratio and also because it has larger and more pores than that with a low water cement ratio. The acid solution enters through these large pores and erodes the concrete specimens. A visual inspection of concrete that has been attacked by acid reveals the corrosion of the paste that holds the aggregate in place. Acids attack and leach away the calcium compounds of cement paste formed in concrete through the hydration process, as well as the calcium in calcareous aggregate. The reaction is primarily between the offending acid and calcium hydroxide. Acid attack weakens the concrete structurally and reduces its durability and service life. The low water/cement ratio increases the resistance of the concrete deterioration by acid. Low permeability, a result of the low water/cement ratio, helps to keep the acidic solution out of the concrete pore structure.

Conclusions

• Mix design has been developed for M 20, M 30 and M 40 grade concrete incorporating the parameters of gradation and specific gravity.

• The strength achievements are increased up to the replacement level of 70 % manufactured sand. Beyond that proportion, there is no improvement in the strength achievement due to the large amount of fine particles in it.

• The compressive strength of the concrete with 70 % of manufactured sand is increased by about 20 % when compared to the natural sand.

• When compared to the conventional concrete, the weight loss in sulfuric acid solution at 365 days is reduced as 25 to 40 % while using the manufactured sand.

• When compared to the conventional concrete, the strength reduction due to acid attack is reduced as 10 to 20 % while using the manufactured sand.

• The concrete with manufactured sand shows high resistance to acid attack.

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