Performance of Coal Washery Reject and Fly Ash Blended Concrete in Acidic Environment

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Abstract— Disposal of waste material has been a great problem and it becomes difficult to find natural resources due to their excessive exploitation. Use of waste materials as construction materials has numerous benefits such as reduction in cost, saving in energy, and protection of environment. Many investigations have been done on Fly Ash (FA) and Coal Washery Reject (CWR). The utility of FA as a partial replacement of cement in concrete mixes has become a traditional practice. CWR is a waste material disposed from Thermal power plants and it can be a substitute for coarse aggregate. The present investigation is mainly aimed to study the variation in compressive strength, weight and ultrasonic pulse velocity (UPV) before and after acid attack of three different concrete mixes after 28, 60 and 90 days of immersion in acid ambient room temperature after 28 days of initial curing in water. In this study, M 25 grade of concrete mixes were manufactured with three different mix proportions such as conventional concrete (CC); CWR_30 concrete with 30% of CWR as coarse aggregate replacement; and FCWR_30 concrete with 30% of CWR as coarse aggregate replacement and 30% of FA as cement replacement. These mixes were then subjected to three acid attacks i.e., 5% hydro chloric acid (HCl),5% magnesium sulphate($MgSo_4$) and 5% sulphuric acid (H_2SO_4). Results revealed that FCWR_30 concrete performs similar to CC and better than CWR_30 in the acid environments.

Key words: Concrete, Coal Washery Rejects, Ultrasonic Pulse Velocity, Fly Ash, Compressive Strength, Mass, Acid Attack

I. INTRODUCTION

About 67% of electricity produced in India is by combustion of coal. The total estimated reserves of coal in world are estimated to be 6,641,200 million tones and for India the same is estimated to be 106,260 million tones. The consumption of coal is expected to increase at faster rate than it had been in the past because of the increase in the price of crude and natural gas. The demand of coal has the highest forward linkage effect with thermal power, railways locomotives, fertilizers industry, cement, steel, electric power and a number of other industries. India continues to be the sixth largest producer of coal with its annual production of nearly 100 million tones. The reserves of high ranking coal i.e. anthracite and coking bituminous coals are less as compared to the low ranking bituminous and lignite coals. On the other hand, the demand of high rank coals is more for metallurgical use and for use as fuel. The coal as it comes from mines consist of many impurities such as magnesium sulphate, sulphur in form of pyrites, slate and fire clay. These substances have higher specific gravity than pure coal and hence, it requires coal washing technique to clean coal before using. Specific gravity of pure coal is 1.2 to 1.7 and for impure coal is 1.7 to 4.9. Therefore, coal must be screened to size and it must be cleaned by jigging or by heavy-media separation [1].

Indian coal is considered to be of low quality since it contains ash as high as 45%, high moisture content (4–20%), low sulfur content (0.2–0.7%), and low calorific values (between 2500–5000 kcal/kg) (IEA, 2002). High ash content in the coal supplied to the power plants not only poses environmental problems but also results in poor plant performance and high cost for Operation & Maintenance and ash disposal. Thus, coal washing is necessary from economic and environment point of view.

During the coal washing process, cleaned coal carried out by the water flow over a weir and the refuse sinks at the bottom. Refuse is removed time to time from the washer and stored in bunker storage. This refuse which is stored in bunker storage is called coal washery rejects (CWR) [2]. The generation of rejects from washeries in Coal India Limited (CIL) in 2004-05 was 2.44 Mt. Accumulated stock of washery rejects up to March'05 was 18.15Mt. The Coal Washery Rejects (CWR) are the major environmental hazard during the process of Coal Washing. Disposal of this huge quantity of rejects in an environment friendly manner poses a real problem. Recently, the reject from the washery has been reused by burning it again in fluidized bed based boiler to raise steam for Power generation. For solving the disposal of large amount of coal washery rejects, reuse of CWR in concrete industry can also be considered as the most feasible application [3]. Rajesh et. al. already studied the strength properties of concrete containing CWR at different replacements (0%-50%) and observed that the increase in CWR replacement level decreased the strength values. This decrease was marginal at 20% and 30% replacement levels, but beyond 30%, the decrease was very much significant. Results revealed that 30% CWR replacement can be considered as optimum level in the construction industry [4 & 5].

Fly ash is one of the residues generated in coal combustion facilities, and comprises the fine particles that rise with the flue gases. Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately gets ignites, generates heat and produces a molten mineral residue. Boiler tubes extract heat from the boiler, cool the flue gases and cause the molten mineral residue to harden and form ash. Coarse ash particles, called as Bottom Ash or Slag, fall to the bottom of the combustion chamber, and the lighter fine ash particles, termed as Fly Ash, and remain suspended in the flue gas. Before exhausting the flue gas, fly ash is removed by particulate emission control devices, such as filter fabric bag houses or electrostatic precipitators. As per ASTM C 618 [6] fly ash can be classified as class C and class F. Studies already examined that fly ash based concrete mixes perform better than conventional concrete [7 & 8].

II. EXPERIMENTAL STUDY

Though several waste products are being investigated as aggregate alternative and cement alternative, this investigation is mainly aimed to use 30% CWR as coarse aggregate replacement and 30% FA a cement replacement and study the performance of concrete against acid attack.

A. *Materials*

Ordinary Portland Cement 53 grade corresponding to IS 12269:1987 [9] having Fineness of 311.5 m^2/Kg, Standard consistency of 32%, Specific Gravity of cement 3.15, initial and final setting time of 100 min and 170 min respectively was used in the investigation. Class F fly ash having specific gravity of 2.29 was used. Natural river sand was used as fine aggregate. The bulk specific gravity in oven dry condition, bulk density and water absorption of the sand were 2.6, 1652 kg/m^3 and 1% respectively [10].

Crushed granite stones is used as coarse aggregate of sizes 20 mm and 10 mm in the ratio of 60:40. CWR of size 20 mm were used as partial replacement of 20 mm coarse aggregate. The physical properties of coarse aggregate are shown in Table 1. Three types of acids i.e., HCl, $MgSo_4$and H_2SO_4 were used.

Property	Crushed granite stone as Coarse Aggregate	Coal washery Rejects as Coarse Aggregate (CWR)
Specific gravity	2.6	2.06
Water absorption (%)	0.3	0.48
Bulk density (kg/m^3)	1580	1431
Impact strength (%)	17.9	19.5
Crushing strength values (%)	22.8	26.8

Table 1. Physical properties of coarse aggregate

B. *Experimental Investigation*

In this study, M 25 grade of concrete mixes were manufactured as per IS 10262:2009 [11] and IS 456:2000 [12] with three different mix proportions such as conventional concrete (CC); CWR_30 concrete with 30% of CWR as coarse aggregate replacement; and FCWR_30 concrete with 30% of CWR as coarse aggregate replacement and 30% of FA as cement replacement. These mixes were then immersed in two acids i.e., 5% hydro chloric acid (HCl), 5% magnesium sulphate and 5% sulphuric acid (H_2SO_4) after 28 days of curing. The variation in compressive strength and mass values were determined at different immersion periods of 30, 60 and 90. Compressive strength test was conducted on the cubical specimens for all the mixes at different periods as per IS 516 [13]. The mass of all concrete specimens was determined prior to compressive strength. Three cubical specimens of size 150 mm x 150 mm x 150 mm were cast and tested for each age and each mix. The specimens were cast and cured for 24 hours. After 24 hours, all the specimens are demoulded and kept in curing tank for 28 days. After 28 days all specimens were kept in atmosphere for 1day for constant weight. Subsequently, the specimens were weighed and immersed separately in 5% of sulphuric acid (H_2SO_4) solution and 5% of hydrochloric acid (HCl) solution for 30, 60, 90 days. After completion of age of immersing in acid solution, the specimens were taken out and were washed in running water and kept in atmosphere for 1day for constant weight. Then the specimens were weighed and loss in compressive strength, mass and ultrasonic pulse velocity (UPV) values was determined. Mix proportions of constituent materials are shown in Table 2.

Mix Type	Cement kg/m^3	Fly Ash Kg/m^3	Water l/m^3	20 mm kg/m^3	10 mm kg/m^3	CWR 20 mm kg/m^3	Sand kg/m^3
CC	384	0	192	683	456	0	636
CWR_30	384	0	192	478	456	163	636
FCWR_30	269	84	192	478	456	163	636

Table 2: Concrete mix proportions

III. RESULTS AND DISCUSSION

The variations in compressive strength values and percentage loss of compressive strength after acid attack are represented in Table 3 and Table 4 respectively.

Mix Type	Compressive strength (MPa)									
	Normal curing period (28 days)	Acid immersion period (days)								
		30			60			90		
		HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4
CC	33.06	31.12	32.69	30.08	28.78	31.25	25.11	25.33	30.93	22.08
CWR_30	31.14	28.29	29.95	27.67	25.45	28.56	22.43	22.52	28.40	18.82
FCWR_30	32.82	30.60	32.05	29.68	28.56	30.47	24.91	24.92	30.25	21.61

Table 3: Compressive strength of concrete mixes

Mix type	Loss of compressive strength (%)								
	Acid immersion period (days)								
	30			60			90		
	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4

CC	5.87	3.52	9.01	12.95	4.21	24.04	23.38	6.36	33.21
CWR_30	9.15	4.82	11.14	18.27	5.68	29.97	27.68	7.59	39.56
FCWR_30	6.76	3.95	9.57	12.98	4.53	24.10	24.07	5.46	34.16

Table 4: Percentage loss of compressive strength of concrete mixes

From the Tables 3 and 4, it is seen that the compressive strength of all concrete mixes have been decreased with the increase in the immersing period in each acid environment. The percentage loss of compressive strength is higher in CWR_30 when compared to CC at all acid immersion periods. It may be due to more deterioration of CWR aggregate in acid environment.

But it is noted that the incorporation of FA in FCWR_30 reduced this percentage loss when compared to CWR_30. It may be due to the pozzolanic action of fly ash which densifies the pore structure of the mix that leads to the enhancement of microlevel and macrolevel properties. This pozzolanic action compensates the deterioration caused by CWR [8]. As it can be seen from the results, the percentage loss of compressive strength is marginally similar in both the CC and FCWR_30 concrete mixes. The percentage loss of compressive strength is observed to be more in H_2SO_4 than HCl. Similar trend has been observed in the mass values of concrete mixes as shown in Tables 5 and 6.

Mix Type	Mass(kg)										
	Normal curing period (28 days)	ultrasonic pulse velocity (UPV) m/s	Acid immersion period (days)								
			30			60			90		
			HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4
CC	8.80	4278	8.51	8.72	8.49	8.38	8.68	8.36	8.19	8.65	8.17
CWR_30	8.67	4131	8.23	8.60	8.15	8.11	8.56	8.01	7.93	8.51	7.87
FCWR_30	8.74	4189	8.42	8.64	8.41	8.32	8.63	8.29	8.13	8.59	8.09

Table 5: Mass of concrete mixes

Mix Type	Loss of compressive strength (%)								
	Acid immersion period (days)								
	30			60			90		
	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4	HCl	$MgSo_4$	H_2SO_4
CC	3.29	0.9	3.52	4.77	0.95	5.00	6.93	1.1	7.15
CWR_30	5.07	0.86	5.99	6.46	0.89	7.61	8.53	0.94	9.23
FCWR_30	3.66	0.79	3.78	4.80	0.82	5.15	8.13	0.89	7.44

Table 6: Percentage loss of mass of concrete mixes

IV. Conclusions

The following conclusions have been drawn from the present investigation.

1) The loss of compressive strength and mass values are more in CWR_30 when compared to CC at all immersion periods due to more deterioration of CWR.
2) It is noted that the incorporation of FA in FCWR_30 reduced the percentage loss when compared to CWR_30. It may be due to the pozzolanic action of fly ash which densifies the pore structure of the mix that leads to the enhancement of microlevel and macrolevel properties. This pozzolanic action compensates the deterioration caused by CWR
3) It is seen that the percentage loss of compressive strength and mass of all concrete mixes have been decreased with the increase in the immersing period in each acid environment.
4) The loss of compressive strength and mass value of all concrete mixes is more in H2SO4 when compared to HCland MgSo4immersion.

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