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A STUDY ON MECHANICAL PROPERTIES OF CEMENT CONCRETE BY PARTIAL REPLACEMENT OF FINE AGGREGATES WITH BOTTOM ASH

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Abstract

Bottom Ash is a new waste material and abundantly available. It is a solid residue which falls into furnace bottom in modern large thermal power plants and constitutes about 20% of total ash content of the coal fed in the boilers. Direct use of this material with a large quantity, will provide a solution to dispose of this material, and the possibility as alternative materials in construction. The main objective of this research is to study the behavior of concrete mix which comprises of partial replacement of fine aggregates with bottom ash against plain concrete. The study was carried out using coal bottom ash as a partial replacement with fine aggregates in the concrete mix by 20%, 30%, 40%, and 50% by weight. The various strength properties studied consist of compressive strength, flexural strength and splitting tensile strength. The results shows that the compressive strength, split tensile strength and flexural strength decreased as the percentage of replacement of bottom ash increased as compared to plain concrete. It was observed that up to 20% replacement the results of compressive test, flexural test and split tensile test are approximately same as that of the controlled concrete.

Key Words: coal bottom ash, compressive test, flexural test, split tensile test.

I. INTRODUCTION

Cement concrete is the most extensively used construction material in the world and is the second to water as the most heavily consumed substance with about six billion tones produced every year. It has emerged as the dominant construction material for the infrastructure needs of the 21stcentury. The challenge for civil engineers in the future is to design the project using high performance materials within reasonable cost and lower impact on environment. Large quantities of waste materials are produced from the manufacturing industry, service industry and municipal solid waste incinerators. The waste materials are gaining attention to use the materials as a substitute to natural aggregates or cement in concrete. The sense of using waste materials not only helps in getting them utilized in cement, concrete, and other construction materials, it helps in reducing the cost of cement and concrete manufacturing, but also has numerous indirect benefits such as reduction in land-fill cost, saving in energy, and protecting the environment from possible pollution effects. Coal is primarily used as a solid fuel to produce electricity and heat through combustion. It is one of the world's most important sources of energy, fuelling almost 41% of electricity worldwide. In India, over 70% of electricity generated is by combustion of fossil fuels, out of which nearly 61% is produced by coal-fired plants. The total coal production in the India at present is 557.45 Million Tons (MT) per year which rose 3.2% over the previous year, being the third largest producer in the world.

The increasing demand for electricity resulted in construction of coal fired power plants. As the consumption of coal increases, the production of coal and its by-products also increased. The ash has to be disposed off either dry, or wet to an open area near the plant or by mixing both the fly ash and bottom ash with water and pumping into artificial lagoon or dumping yards. The disposal of such large quantity of ash has occupied thousands hectares of land which includes agricultural and forest land and causes pollution of water bodies too. If these combustion by-products are not utilized properly, there will be no enough space and the disposal of these by-products will be a problem. To minimize all these effects, a best alternative is to promote large-scale utilization of coal ash. The utilization of large quantity of bottom ash can mitigate or solve the disposal and environmental problems associated to it. Coal ash is a residue resulting from combustion of pulverized coal or lignite in Thermal Power Plants and these residues or by-products are commonly known as Coal Combustion products or CCPs. In a dry bottom boiler, about 80 percent of the unburned material or coal ash is entrained in the combustion gases and is captured as fly ash. The remaining 20 percent of the ash is dry bottom ash collected at the bottom of the furnace. This study shows the effect of mechanical properties of concrete in which the fine aggregates are partially replaced with varying percentages.

II. LITERATURE REVIEW

The experimental investigations by **Bakoshi et al.**[1] used bottom ash for his study in the amounts of 10–40% as replacement for fine aggregate. Test results indicate that the compressive strength and tensile strength of bottom ash concrete generally increases with the increase in replacement ratio of fine aggregate and curing age. The freezing–thawing resistance of concrete using bottom ash is lower than that of ordinary concrete and abrasion resistance of bottom ash concrete is higher than that of ordinary concrete.

The experimental investigations by **Mohd Syahrul Hisyam bin Mohd Sani, Fadhluhartini bt Muftah , Zulkifli Muda (2010)** [2] presents the use of Washed Bottom Ash (WBA) as fine aggregate in special concrete. To substitute the amount of carbon usage in concrete the bottom ash was utilized and fully submerged in water for 3 days to produce as WBA with low carbon composition. The aim of the study is to investigate the feasibility and potential use of washed bottom ash in concreting and concrete applications. The results of the physical and chemical properties of WBA were discussed. Different concrete mixes with constant water to cement ratio of 0.55 were prepared with WBA in different proportions as well as one control mixed proportion. The mechanical properties of special concrete with 30% WBA replacement by weight of natural sand is found to be an optimum usage in concrete in order to get a favorable strength and good strength development pattern over the increment ages.

Siddique, R (2003) [3] conducted experimental work on the effects of furnace bottom ash on workability, compressive strength, and permeability, depth of carbonation and chloride penetration of concrete. The natural sand was replaced with furnace bottom ash by 30, 50, 70 and 100 % by mass at fixed free w/c ratio of 0.45 and 0.55 and cement content of 382 kg/m3. The results showed increase in the workability of concrete, and decreased compressive strength, at fixed cement content and w/c ratio. No adverse influence on the long-term strength was observed. Air permeability, sorptivity and carbonation rate for bottom ash concrete was higher as compared to control concrete. However the chloride transport coefficient decreased with the increase of the replacement level up to 50%, beyond which it increased. A lightweight concrete using flyash (FA), furnace bottom ash (FBA) and Lytage (LG) as a replacement of OPC, natural sand and coarse aggregate respectively was manufactured.

III. EXPERIMENTAL INVESTIGATIONS

A. Materials

a. Cement

Ordinary Portland Cement of 53 grade was used in the study. Testing of cement was done as per IS: 8112-1989. The various tests results conducted on the cement are tabulated in Table 1.

Table 1: Properties of cement

Sl. No.	Characteristics	Values obtained	As per IS : 8112-1989
1	Normal consistency (%)	32	-
2	Initial setting time (minutes)	40	Not less than 30
3	Final Setting time (minutes)	380	Less than 600
4	Fineness (%)	3.5	<10
5	Specific gravity	3.06	3.15

b. Coarse Aggregate

Locally available coarse aggregates having the maximum size of 10 mm and 20mm were used in the present study. The testing of coarse aggregates was done as per IS: 383-1970. The results of various tests conducted on coarse aggregates and sieve analysis of 20mm and 10mm aggregates are tabulated in Table 2 and Table 3 respectively.

Table 2: Sieve analysis of 20 mm aggregates

Sl. No.	Sieve No. (mm)	Mass Retained (g)	Percentage retained	Cumulative %age Retained	Percentage Passing
1.	40	-	-	-	-

2.	20	-	-	-	-
3.	12.5	980	49.49	49.49	50.51
4.	10	670	33.83	83.32	16.68
5.	4.75	330	16.66	99.98	0.02
6.	Pan	0	-	-	-

Table 3: Sieve analysis of 10 mm aggregates

Sl. No.	Sieve No.	Mass Retained (kg)	Percentage Retained, %	Percentage Passing, %	Cumulative %age Retained
1	40	-	-	-	-
2	20	-	-	-	-
3	10	482	24.12	75.88	24.12
4	4.75	1452	72.67	27.33	96.79
5	Pan	64	3.2	96.8	99.99

c. Fine Aggregates

The sand used for the study was locally procured and conformed to grading zone II as per IS: 383-1970 having specific gravity of 2.67 and fineness modulus 3.66. The maximum size of fine aggregate was taken to be 4.75 mm. The sieve analysis results are shown in Table 4.

Table 4: Sieve analysis of Conventional Sand

Sl. No.	Sieve size (mm)	Mass Retained (g)	Percentage Retained, %	Cumulative Percentage Retained	% Passing
1	4.75	28.27	2.84	2.84	97.16
2	2.38	31.55	3.17	6.01	93.99
3	1.18	137.5	13.85	19.86	80.14
4	0.600	296	29.82	49.68	50.32

5	0.300	390	39.30	88.98	11.62
6	0.150	105.14	10.59	99.57	0.43
7	0.075	2.35	0.235	99.80	0.2
8	Pan	1.51	0.151	-	-

d. Bottom Ash

The bottom ash was procured from the Bellary Thermal Power Station, Kuditini village, Bellary, Karnataka. The specific gravity of bottom ash is 1.86. The testing was done as per IS: 383-1970. The sieve analysis results are shown in Table 5

Table 5: Sieve analysis of bottom ash

Sl. No.	Sieve size (mm)	Mass Retained (g)	Percentage retained	Cumulative %age	Percentage finer
1.	4.75	0	0	0	-
2.	2.38	12.96	2.5	2.5	97.5
3.	1.18	41	8.2	10.7	89.3
4.	0.600	91.11	18.24	28.94	75.06
5.	0.300	150.28	30.09	59.03	40.97
6.	0.150	106.32	21.28	80.31	19.69
7.	0.075	84.84	16.99	97.3	2.7
8.	Pan	12.84	2.5	99.8	0.2

e. Water

Potable water which is free from salts and impurities was used for washing aggregates, mixing and curing purposes.

B. Mix Design and Proportions

The control mix containing cement, natural sand and coarse aggregates was designed as per Indian Standard Recommended Guidelines IS: 10262-2009. Natural sand was partially replaced with bottom ash in the range of 0%, 20%, 30%, 40% and 50% by weight. The designed mix proportion for normal concrete is 1:1.38:1.83 with water cement ratio of 0.42. In this study five mix proportions were made. First was control mix and the other four mixes contained bottom ash which was partially replaced with fine aggregates. Nine cubes were casted for each percentage of bottom ash replaced with fine aggregate. The mix proportions are given in Table 6

Table 6: Mix proportion of M40 grade concrete

Mix Designation	Cement Kg/m^3	Fine Aggregate kg/m^3	Course Aggregate (10mm) Kg/m^3	Course Aggregate (20mm) Kg/m^3	Bottom Ash Kg/m^3	Water (lts)
NC (0%)	519	718	380	570	0	197
Mix-1 (20%)	519	575	380	570	143	197
Mix-2 (30%)	519	503	380	570	215	197
Mix-3 (40%)	519	431	380	570	287	197
Mix-4 (50%)	519	359	380	570	359	197

C. Preparation and Casting of Test Specimen

The concrete cubes of standard size of 150mm were cast for compressive strength test, the concrete beam of 100mm×100mm×500mm for tensile test, cylinders of size 150 mm diameter and 150 mm lengths for splitting tensile test . Concrete of specified proportions was prepared and filled in the mould and compacted preferably on a vibrating table. After compaction the specimen was leveled. The specimens were demoulded and immersed in water at a temperature of 27±2ºC for 24hrs from the time of addition of water to the ingredients. At the age of testing, the specimens were taken out of the water, wiped and tested. All the specimens were prepared in accordance with Indian Standard Specifications IS: 516-1964.

D. Concrete Properties

The fresh concrete properties such as slump was conducted and the hardened properties such as compressive strength, flexural strength and tensile strength were performed for 7, 28 and 56 days at varying percentages of bottom ash in accordance with the provisions of the Indian Standard Specification IS: 516-1959.

IV. RESULTS AND DISCUSSIONS

A. Workability

Slump was conducted on the plain concrete and the concrete mix containing various percentages of bottom ash. The test results are shown in Table 7. It is observed that the slump decreases with the increasing percentage of replacement of fine aggregates with bottom ash. As the replacement level increases, a greater amount of water is required for the mix to get closer. This is due to the extra fineness of the bottom ash.

Table 7: Measure of workability

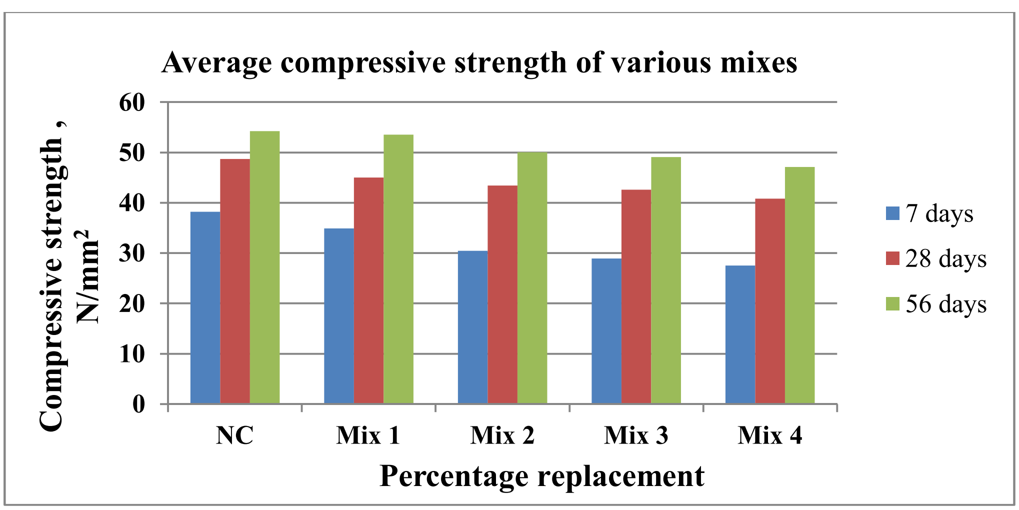
Sl.No.	Name of the test	Designation of the Specimen				
		NC	Mix-1	Mix-2	Mix-3	Mix-4
1	Slump Flow(mm)	75	71	68	72	67
2	Vee-Bee consistometer (sec)	5	5.8	6.1	6	6.7

B. Compressive strength

The compressive strength of concrete mixes made with various percentages of coal bottom ash as fine aggregate replacement and the conventional mix were tested at the age of 7 , 28 and 56 days of curing. The test results are shown in the table 8. From the obtained results it can be seen that the strength decreases as the percentage of the bottom ash is increased. The bottom ash gained the strength at a slower rate in the initial period and acquires strength at a faster rate after 28days (above the targeted strength).

Table 8: Compressive strength of various mixes with age

Mix Type	Average compressive strength (N/mm^2)		
	7 days	28 days	56 days
NC (0%)	38.22	48.7	54.22
Mix-1 (20%)	34.88	45	53.54
Mix-2 (30%)	30.44	43.40	50.05
Mix-3 (40%)	28.90	42.58	49.10
Mix-4 (50%)	27.50	40.79	47.13



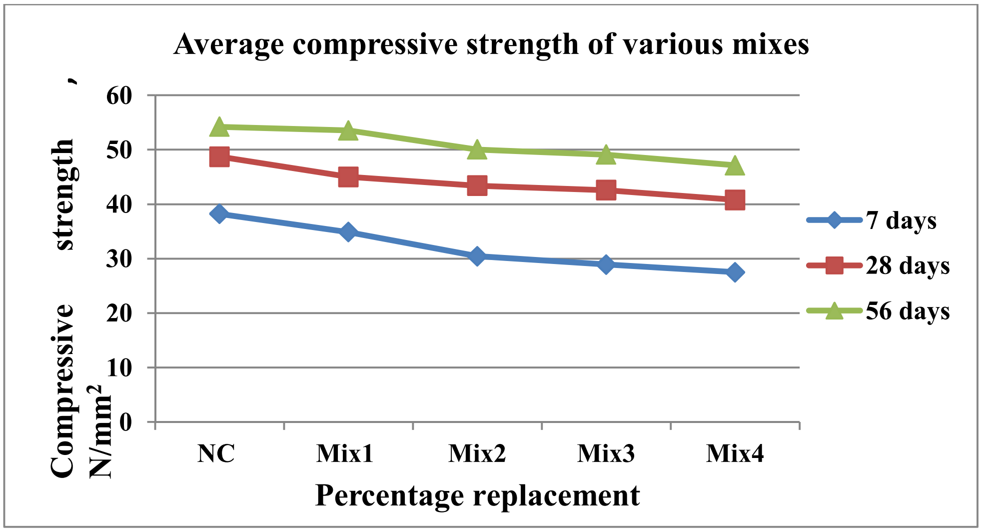


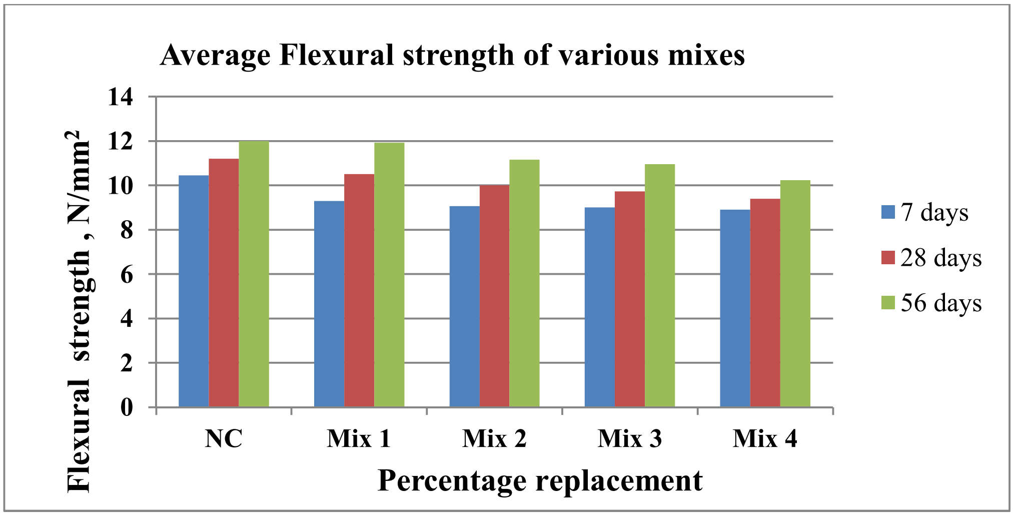
Fig 1. Graph showing Compressive Strength of Different Mixes

C. Flexural Strength

The flexural strength of concrete mixes made with various percentages of coal bottom ash as fine aggregate replacement and the conventional mix were tested at the age of 7 , 28 and 56 days of curing. The test results are shown in the table 9. From the obtained results it was observed that the flexural strength of concrete decreases with increasing percentage of bottom ash. It may be due to the poor interlocking between the aggregates. However, the strength gains with the age.

Table 9: Flexural strength of various mixes with age

Mix Type	Average flexural strength (N/mm^2)		
	7 days	28 days	56 days
NC (0%)	10.45	11.20	12
Mix-1 (20%)	9.30	10.50	11.92
Mix-2 (30%)	9.06	10	11.16
Mix-3 (40%)	9.01	9.72	10.96
Mix-4 (50%)	8.9	9.4	10.23



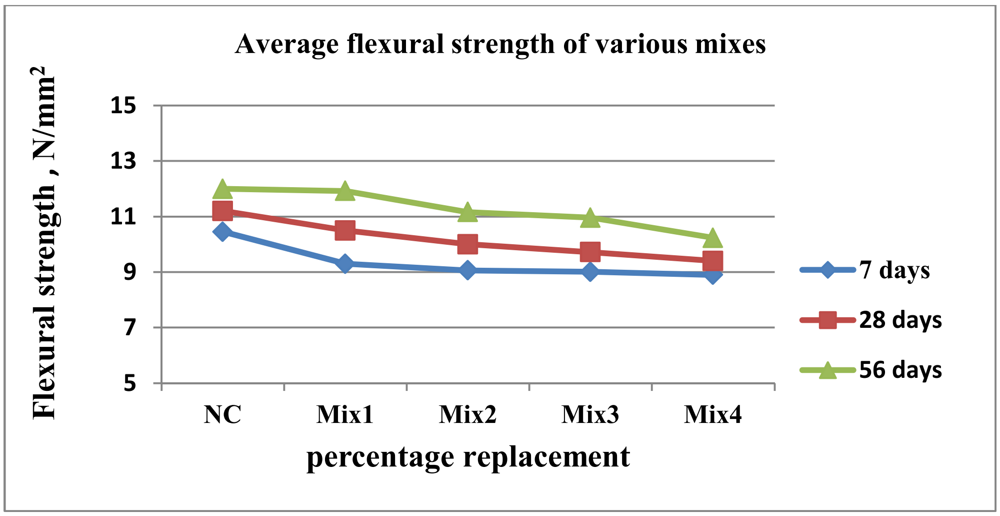


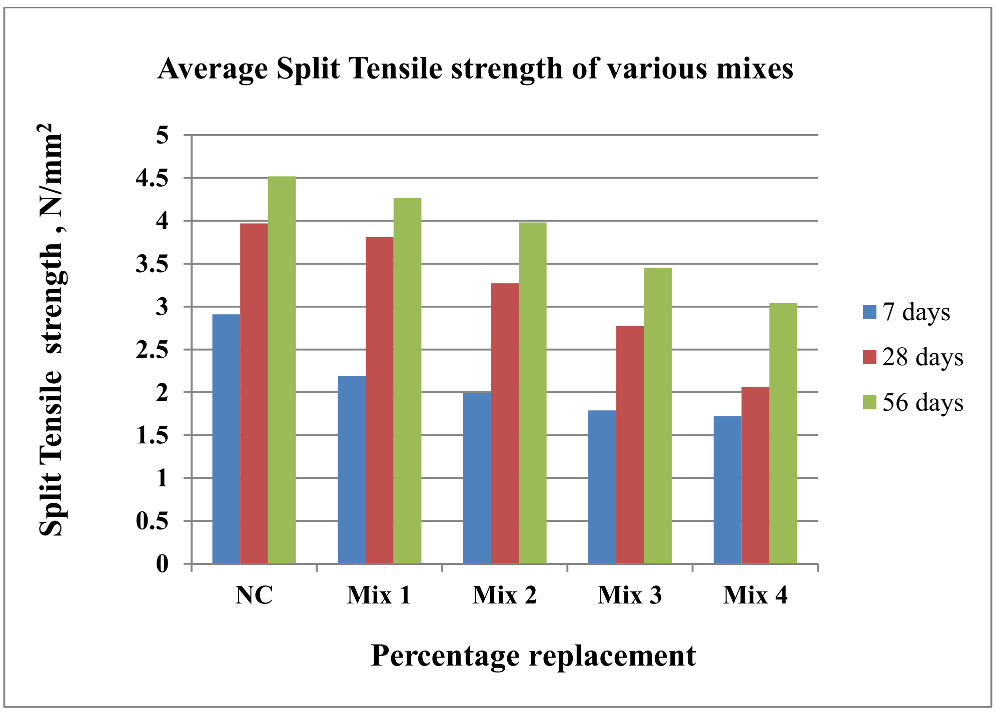
Fig 2. Graph showing flexural Strength of Different Mixes

D. Splitting Tensile Strength

The tensile strength of concrete mixes made with various percentages of coal bottom ash as fine aggregate replacement and the conventional mix were tested at the age of 7, 28 and 56 days of curing. The test results are shown in the table 10. From the obtained results it is observed that the tensile strength of concrete decreases with the increasing percentage of bottom ash. However, the strength increases with the age of the curing. The strength gain is more at higher age of curing but the strength gain decreases at higher percentage of replacement.

Table 10. Split tensile strength of various mixes with age

Mix Type	Average split tensile strength (N/mm^2)		
	7 days	28 days	56 days
NC (0%)	2.91	3.97	4.52
Mix-1 (20%)	2.19	3.81	4.27
Mix-2 (30%)	1.99	3.27	3.98
Mix-3 (40%)	1.79	2.77	3.45
Mix-4 (50%)	1.72	2.06	3.04



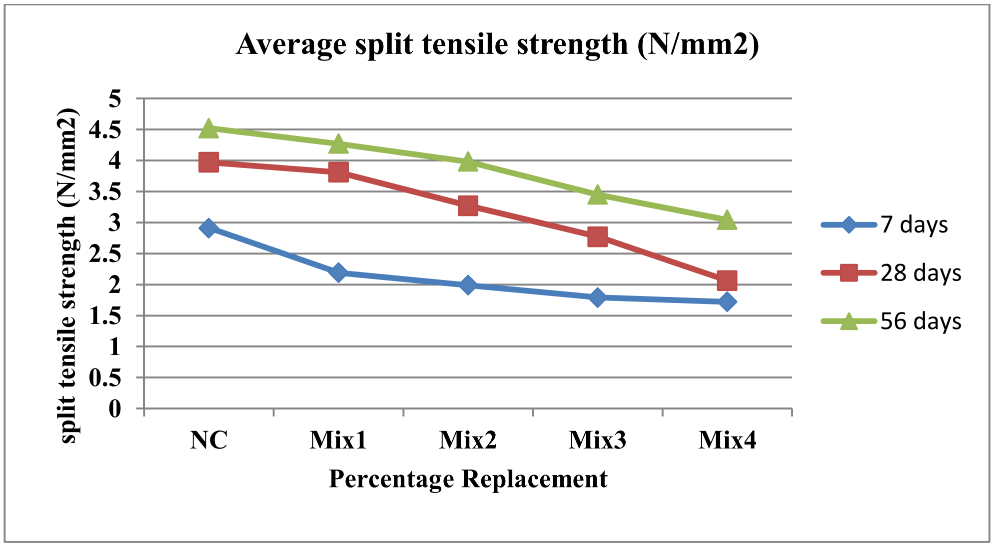


Fig 3. Graph showing tensile strength of Different Mixes

V. CONCLUSIONS

- The compressive strength of the plain concrete specimen for 7days, 28days and 56days was found to be 38.22 N/mm^2, 48.7 N/mm^2 and 54.22 N/mm^2 respectively. The 28days strength of the mix is 48.7 N/mm^2 which concludes that the mix has reached the targeted strength (M40).
- The 28days flexural strength of concrete with bottom ash has a reducing strength of 10.5, 10, 9.72, and 9.4 N/mm^2 for 20%, 30%, 40% and 50% of replacement of bottom ash with fine aggregates. This concludes that the 28days flexural strength of plain concrete has higher value of 11.2 N/mm^2 when compared with the concrete specimens replaced with bottom ash.
- The 28days Split Tensile strength of concrete with bottom ash has a reducing strength of 3.81 N/mm^2, 3.27 N/mm^2, 2.77 N/mm^2 and 2.06 N/mm^2 for 20%, 30%, 40% and 50% of replacement of bottom ash with fine aggregates. This concludes that the 28days split tensile strength of plain concrete has higher value of 3.97 N/mm^2 when compared with the concrete specimens replaced with bottom ash
- The workability of the fresh concrete decreases with the increasing percentage of bottom ash.

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Bellary Thermal Power Plant

Dissertation work.

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