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EFFECT OF BOTTOM ASH AS REPLACEMENT OF FINE AGGREGATES IN CONCRETE

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ABSTRACT

This paper presents the experimental investigations carried out to study the effect of use of bottom ash (the coarser material, which falls into furnace bottom in modern large thermal power plants and constitute about 20% of total ash content of the coal fed in the boilers) as a replacement of fine aggregates. The various strength properties studied consist of compressive strength, flexural strength and splitting tensile strength. The strength development for various percentages (0-50%) replacement of fine aggregates with bottom ash can easily be equated to the strength development of normal concrete at various ages.

Keywords: bottom ash, compressive strength, splitting tensile strength, normal concrete

1. INTRODUCTION

Concrete is a material synonymous with strength and longevity. It has emerged as the dominant construction material for the infrastructure needs of the twenty-first century. In addition to being durable, concrete is easily prepared and fabricated from readily available constituents and is therefore widely used in all types of structural systems. The challenge for the civil engineering community in the near future is to realize projects in harmony with the concept of sustainable development and this involves the use of high performance materials and products manufactured at reasonable cost with the lowest possible environmental impact.

Energy is the main backbone of modern civilization of the world over, and the electric power from thermal power stations is a major source of energy, in the form of electricity. In India, over 70% of electricity generated in India, is by combustion of fossil fuels, out of which nearly 61% is produced by coal-fired plants. This results in the production of roughly 100 ton of ash. Most of the ash has to be disposed off either dry, or wet to an open area available near the plant or by grounding both the fly ash and bottom ash and mixing it with water and pumping into artificial lagoon or dumping yards. This causes the pollution in water bodies and loss of productive land.

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The continuous reduction of natural resources and the environmental hazards posed by the disposal of coal ash has reached alarming proportion such that the use of coal ash in concrete manufacture is a necessity than a desire. The use of coal ash in normal strength concrete is a new dimension in concrete mix design and if applied on large scale would revolutionize the construction industry, by economizing the construction cost and decreasing the ash content. This paper presents the experimental investigation carried out to study the effect of use of bottom ash as a replacement of fine aggregates. Although, flyash is being generally used as replacement of cement, as an admixture in concrete, and in manufacturing of cement, the study on the use of bottom ash (the coarser material, which falls into furnace bottom in modern large thermal power plants and constitute about 20% of total ash content of the coal fed in the boilers) has been very limited.

2. LITERATURE REVIEW

Though a large number of significant results have been reported on the use of flyash in concrete [1-6], however, there is not much literature available on the use of fly ash as partial replacement of fine aggregates [7-9], with even less literature on the use of bottom ash [10-13] as partial replacement of fine aggregate.

Experimental investigations were carried out by replacing sand by equal weight of fly ash, with sand replacement levels of 0, 20 and 30 % and w/c ratio of 0.35, 0.40, 0.45 and 0.50, keeping cement content constant at 350 kg/m^3 in all mixes. Compressive Strength gain and corrosion resistance was higher for sand replaced with flyash mixtures. Also, the corrosion rate of reinforcing steel bars in concrete was lowest in 30% replacement level [7]. Mechanical properties like compressive strength, splitting tensile strength, Flexural strength and Modulus of Elasticity at age of 7, 14, 28, 56, 91 and 365 days were studied. The strength difference between flyash concrete specimens and plain concrete specimens become more distinct after 28 days. The maximum compressive strength, flexural strength, splitting tensile strength and Modulus of elasticity was observed to be with 50 % fly ash content at all ages. [8-9].

An experimental investigation of various fresh and hardened properties of concrete was reported. Tests were conducted on mixes of natural sand (known as control mix), bottom ash and mixes having equal volumes of natural sand and bottom ash. Also, mixes were developed using high range water reducing admixtures. The results indicated that the mixing water requirement increases rapidly when bottom ash is used in the concrete, also inclusion of bottom ash has no significant influence on the entrapped air content and setting times of fresh concrete. Due to the higher water requirement and yield, the compressive strength properties of the bottom ash and combined bottom ash and natural sand mixtures are lower than those of the control samples. [10].

An investigation was also carried out on the behavior and long term durability of laboratory-made roller compacted concretes containing bottom ash as fine aggregate for the properties like fresh properties and strength, stiffness, and deformation characteristics [11-12]. It was observed that samples containing dry bottom ash offered excellent strength, stiffness, and deformation properties, considering the range of cement factors used.

Laboratory-made roller compacted concretes with various combinations of cement (Type I and Type V for sulfate-resistant concrete), lignite dry bottom ash, and crushed limestone coarse aggregate were tested to ascertain the suitability of this type of concrete for pavement applications. The analysis of the test results leads to the conclusions that durable concrete can be produced with the high-calcium dry bottom ash used in this investigation. Resistance to sulfate attack, rapid freezing and thawing, and wear improved with increases in cement and/or coarse aggregate contents. Length change due to external sulfate attack varied from 0.0203 to 0.0388 percent, whereas no mass loss or reduction in strength was found in any of the test samples. Abrasion testing under wet conditions was consistently worse than under dry conditions. After 300 rapid freezing and thawing cycles, the mixture proportions of this investigation displayed a maximum mass loss of 2.3 percent and a minimum durability factor of 91.2 percent.

A study on the potential of using bottom ash as pozzolanic material was done. The quality was improved by grinding until the particle size retained on sieve 325 mm was less than 5% by weight. The results showed that pastes of cement with replacement by original or ground bottom ash, between 10-30% resulted in longer initial setting time, depending on the fineness of the ashes, compared to setting time of the cement paste. Original bottom ash mortar had higher water requirement than that of the cement mortar and ground bottom ash mortar had lesser water requirement than that of the cement mortar. Bottom ash could be used as a pozzolanic material if it was ground having retention on 325-micron sieve less than 5%, Ref. [13].

The municipal solid waste bottom ash (MSWBA) was used as alternative aggregate for the production of building concrete presenting a characteristic strength at 28 days of 25 Mpa [14].

An attempt was made to develop 'Light Weight Concrete' in which flyash and bottom ash were used as partial replacement of cement and fine aggregate [15].

The effects of furnace bottom ash on workability, compressive strength, and permeability, depth of carbonation and chloride penetration of concrete were investigated [16]. 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/m^3. 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.

3. EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Cement

Ordinary Portland cement 43 grade conforming to IS: 8112-1939 was used [17]. Its properties are shown in Table 1.

Table 1. Cement test results

S.No	Characters	Experimental Value	As per IS: 8112 1989
1	Consistency of cement	31.0%	-
2	Specific Gravity	3.14	3.15
3	Initial Setting Time	55 Mins	>30 Mins
4	Final Setting Time	275 Mins	<600 Mins
5	Fineness of cement	10%	10%
6	Compressive Strength		
i	3 days	23.5 N/mm^2	<23
ii	7 days	35.8 N/mm^2	<33

3.1.2 Bottom Ash

Bottom ash obtained from thermal power plant at Panipat, Haryana in India was used in the investigation. The specific gravity of bottom ash was 1.68. Figure 1 gives the grading curve for bottom ash.

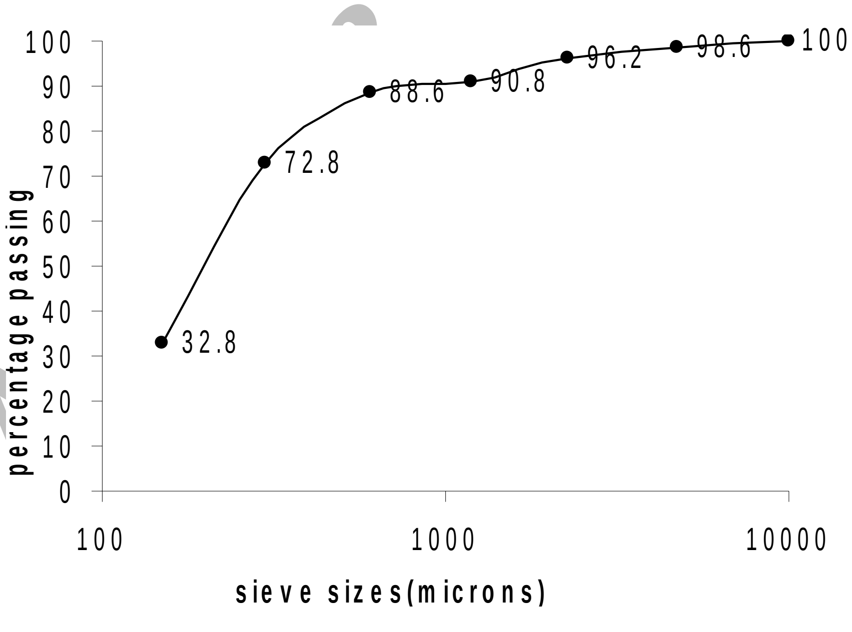

Figure 1. Grading curve for the bottom ash

3.1.3 Fine Aggregate

Natural sand conforming to Zone III with specific gravity 2.65, fineness modulus as 2.36 was used. The maximum size of fine aggregate was taken to be 4.75 mm. The testing of sand

was done as per Indian Standard Specifications IS: 383-1970 [18].
The sieve analysis results are shown in Table 2.

Table 2. Sieve analysis of fine aggregates

IS Sieve designation	Wt. retained on Sieve (gm)	% age passing	Requirement IS: 383-1970 [15]
10mm	0	100	100
4.75mm	16	98.4	90-100
2.36mm	82	90.2	85-100
1.18mm	150	75.2	75-100
600µm	133	61.9	60-79
300	298	32.1	12-40
150µm	257	6.2	0-10

3.1.4 Coarse Aggregate

Coarse aggregate was used with 20 mm nominal size and specific gravity 2.67, and fineness modulus 6.9 and were tested as per Indian Standard specifications IS: 383-1970 [18]. The sieve analysis results are shown in Table 3.

Table 3. Sieve analysis for coarse aggregates

IS Sieve designation	Wt. retained on Sieve (Kg)	% age passing	Requirement IS: 383-1970 [15]
80mm	-	100	100
40mm	-	100	100
20mm	-	100	95-100
10mm	4.6	8	0-20
4.75mm	0.34	1.2	0-5

3.1.5 Superplasticizer

A commercially available superplasticizer, Aqueous Solution of modified polycarboxylate with density as 1.10 (approx) and pH as 5.0 (approx) was used in the study.

3.2 Mix Proportions

Five mixture proportions were made. First was control mix (without bottom ash), and the other four mixes contained bottom ash. Fine aggregate (sand) was replaced with bottom ash by weight. The proportions of fine aggregate replaced ranged from 20% to 50%. Mix proportions are given in Table 4. The controls mix without bottom ash was proportioned as per Indian standard Specifications IS: 10262-1982 [19], to obtain a 28-days cube compressive strength of 33.3 MPa. Hand mixing was done for the concrete mixes.

3.3 Preparation and casting of test specimens.

The 150mm concrete cubes were cast for compressive strength, 150×300 mm cylinders for splitting tensile strength and 101.4×101.4×508 mm beams for flexural strength. After casting, all the test specimens were finished with a steel trowel. All the test specimens were stored at temperature of about 30^{o}C in the casting room. They were demolded after 24 hours, and were put into a water-curing tank.

3.4 Concrete Properties

Fresh concrete properties such as compaction factor, unit weight etc. was determined according to an Indian Standard specification IS: 1199-1959 [20]. The compressive strength, splitting tensile strength and flexural strength tests were performed at 7, 28, 56, 90 days in accordance with the provisions of the Indian Standard Specification IS: 516-1959 [21].

Table 4. Mix proportions

Mixture no.	M1	M2	M3	M4	M5
Cement (kg/m^3)	426.7	426.7	426.7	426.7	426.7
Bottom ash (%)	0 %	20 %	30 %	40 %	50 %
Bottom ash (kg/m^3)	0.0	106	160	213	266.35
Water (lts)	185	185	185	185	185
Sand (kg/m^3)	532.7	426.7	372.7	319.7	266.3
Coarse aggregate (kg/m^3)	1225	1225	1225	1225	1225
Superplasticizer (l/ m^3)	2	2.7	2.8	2.95	3.2
Air temperature(^{o}C)	32	33	32	34	33
Concrete density (kg/m^3)	2480	2467	2437	2408	2400

4. RESULTS AND DISCUSSION

The various aspects studied include (i) the effect of bottom ash on workability (Compaction Factor) of fresh concrete; (ii) the effect on compressive, flexural and splitting tensile strength using bottom ash in varying percentages as a partial replacement of fine aggregates.

4.1 Workability

The workability measured in terms of compaction factor, decreases with the increase of the replacement level of the fine aggregates with the bottom ash as given in Table 5 and Figure 2. It can be due to the extra fineness of bottom ash as the replacement level of fine aggregates is increased. Thus, increase in the specific surface due to increased fineness and a greater amount of water needed for the mix ingredients to get closer packing, results in decrease in workability of mix.

Table 5. Workability in term of compaction factor

Mix Type	M1	M2	M3	M4	M5
C.F	0.90	0.87	0.85	0.84	0.82

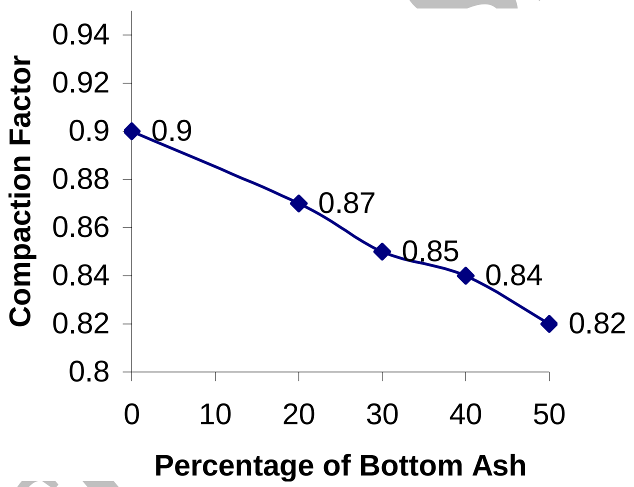

Figure 2. Compaction factor for the fresh concrete

4.2 Compressive Strength

Compressive strength of concrete mixes made with and without bottom ash was determined at 7, 28, 56, 90 days. The test results are given in Table 6,7 and Figures 3,4. The gain of compressive strength by different types of bottom ash concrete with respect to their compressive strength at the age of 90 days varies from 56-65% at 7 days 75-85% at 28 days and varies between 86-90% at 56 days. The bottom ash concrete gains strength at a slower rate in the initial period and acquires strength at faster rate beyond 28 days, due to pozzolanic action of bottom ash. Also, at early age bottom ash reacts slowly with calcium hydroxide liberated during hydration of cement and does not contribute significantly to the densification of concrete matrix at early ages.

Table 6. Compression behavior of bottom ash concrete with age

Mix Type	Compressive strength (f_c) N/mm^2			
	7 days	28 days	56 days	90 days
M1	24.74	33.33	35.40	37.18
M2	23.26	30.43	32.15	36.07
M3	22.48	29.55	31.78	36.74
M4	21.70	28.00	30.60	35.26
M5	20.15	26.37	30.44	35.18

Table 7. Compression behavior of bottom ash concrete v/s plain concrete

Mix Type	$\text{Strength gain} = \frac{\text{Strength of Bottom Ash}}{\text{Strength of Plain concrete}} \times 100$			
	7 days	28 days	56 days	90 days
M2	69.79	91.30	96.46	108.22
M3	67.45	88.66	95.35	110.23
M4	65.11	84.01	91.81	105.80
M5	60.46	79.12	91.33	105.55

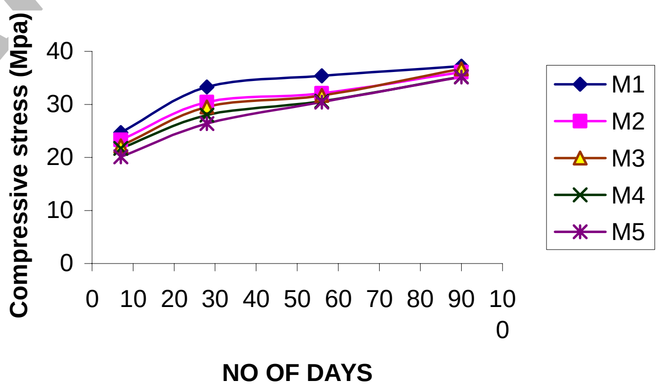

Figure 3. Compressive strength of concrete with age

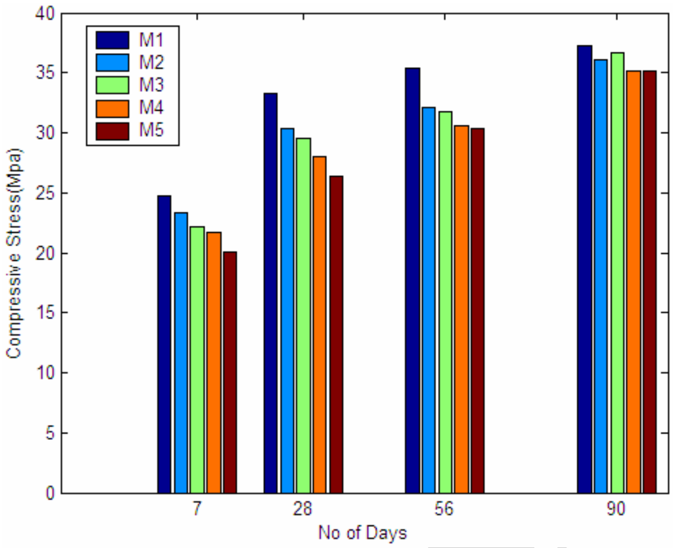

Figure 4. Compressive strength of concrete for various mixes

4.3 Flexural Strength

The flexural strength test results of bottom ash concrete are given in Table 8 and shown in Figures 5 and 6, respectively. Figure 5 shows the flexural strength development with age, and Figure 6 shows the variation of flexural strength for various percentages of bottom ash. It is observed that 'M4' mix type gives comparable flexural strength at the age of 90 days that can be used for pavement application. The flexural strength is affected to more extent with the increase in bottom ash concrete. The bottom ash concrete gains flexural strength with the age that is comparable but less than that of plain concrete. It is believed to be due to poor interlocking between the aggregates, as bottom ash particles are spherical in nature.

Table 8. Flexural behavior of bottom ash concrete with age

Mix Type	**Flexural strength (f_t) N/mm^2**			
	7 days	**28 days**	**56 days**	**90 days**
M1	2.48	3.32	3.64	4.40
M2	2.40	3.20	3.52	3.92
M3	2.28	2.92	3.56	3.76
M4	2.20	2.52	3.44	3.80
M5	2.04	2.40	3.44	3.76

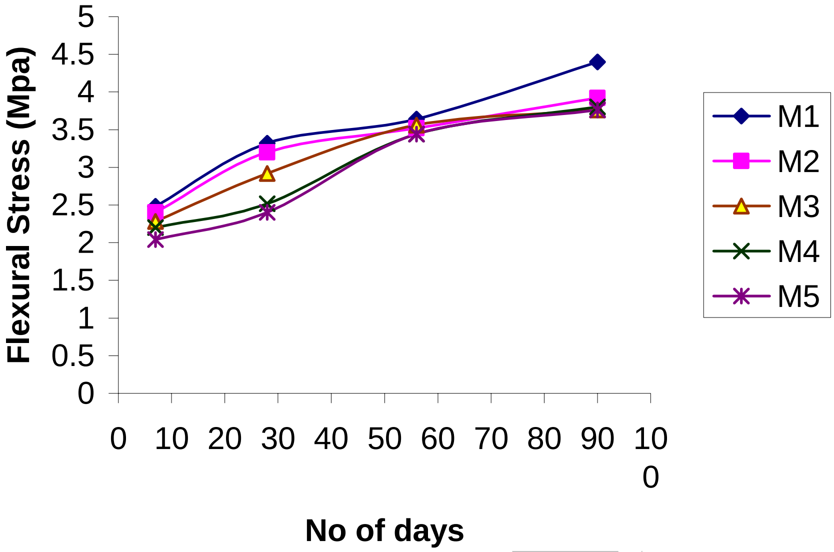

Figure 5. Flexural strength of the concrete with age

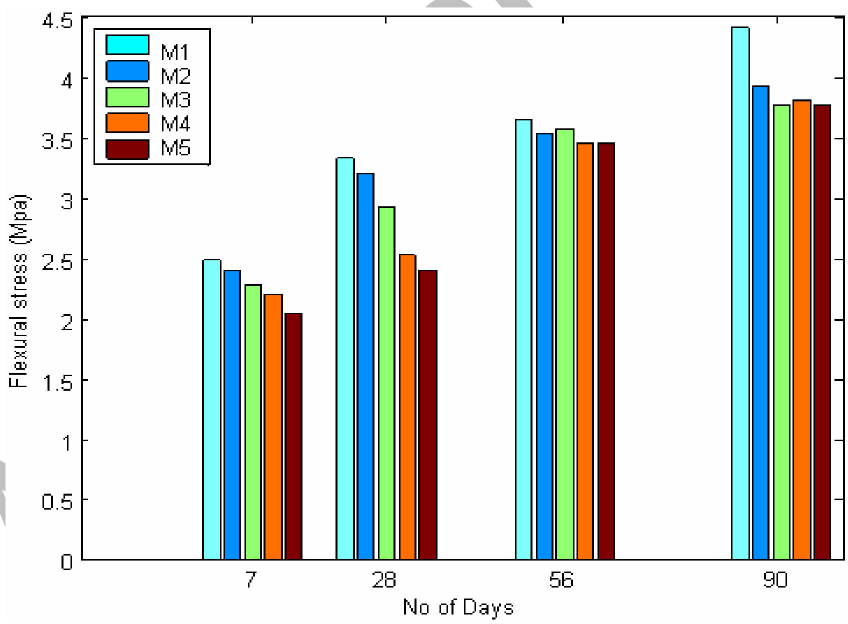

Figure 6. Flexural strength of the concrete for various mixes

4.4 Splitting Tensile Strength

The results of splitting tensile strength of concrete mixes with and without bottom ash measured at 7,28,56,90 days are given in Table 9 and shown in Figures 7,8. Figure 7 shows the variation of splitting tensile strength with age for different bottom ash percentages. It is observed from the tables that the splitting tensile strength of concrete decreases with the increase in the percentage of fine aggregates replacement with the bottom ash, but the splitting tensile strength increases with the age of curing. The rate of increase of splitting tensile strength decreases with the age. The splitting tensile strength gain is more at 20% replacement of fine aggregates with bottom ash. At higher percentages the strength gain decreases and it is minimum at 50% replacement level. Plain concrete attains 64%, 77% and 88% strength at 7 days, 28 days and 56 days of its splitting tensile strength at 90 days respectively, whereas the bottom ash concrete attains splitting tensile strength between 62-86%, 60-83%, 56-83% and 53-84% for mixes M2, M3, M4 and M5 respectively.

Table 9. Splitting tensile behavior of bottom ash concrete with age

Mix Type	**Flexural strength (f_{st}) N/mm^2**			
	7 days	**28 days**	**56 days**	**90 days**
M1	2.19	2.62	3.01	3.40
M2	2.05	2.52	2.83	3.30
M3	1.98	2.37	2.72	3.26
M4	1.80	2.26	2.69	3.22
M5	1.70	2.23	2.69	3.18

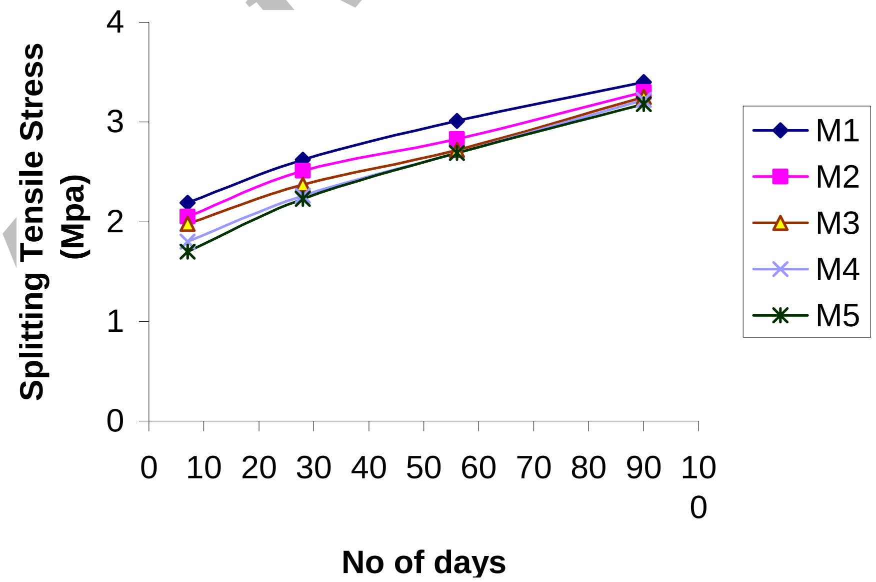

Figure 7. Splitting Tensile Strength of the Concrete with age.

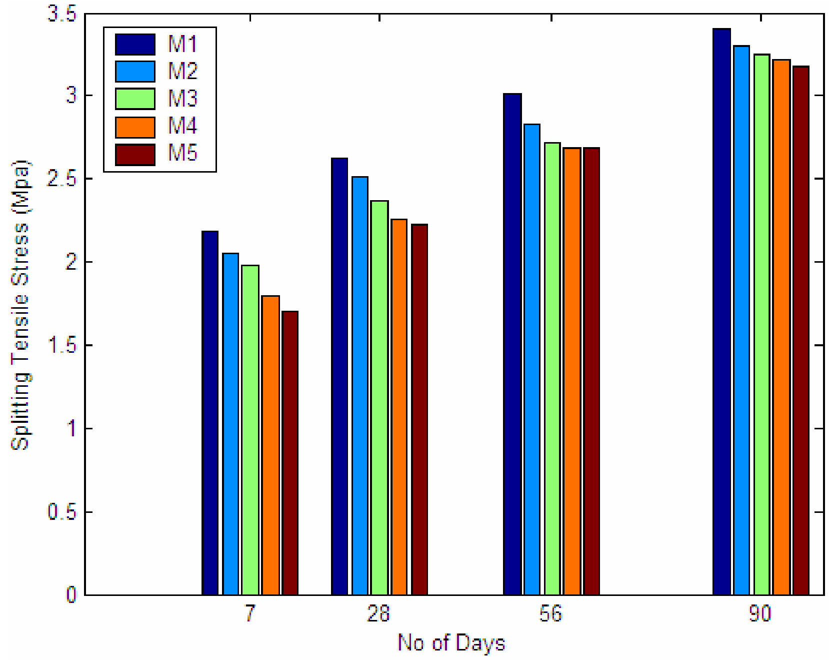

Figure 8. Splitting tensile strength of concrete for various mixes

5. CONCLUSIONS

The following conclusions could be arrived at from the study:

- The workability of concrete decreased with the increase in bottom ash content due to the increase in water demand, which is incorporated by increasing the content of superplasticizer.
- The density of concrete decreased with the increase in bottom ash content due to the low specific gravity of bottom ash as compared to fine aggregates.
- Compressive strength, Splitting tensile strength and Flexural strength of fine aggregates replaced bottom ash concrete specimens were lower than control concrete specimens at all the ages. The strength difference between bottom ash concrete specimens and control concrete specimens became less distinct after 28 days.
- Compressive strength, Splitting tensile strength and Flexural strength of fine aggregate replaced bottom ash concrete continue to increase with age for all the bottom ash contents.
- Mix containing 30% and 40% bottom ash, at 90 days, attains the compressive strength equivalent to 108% and 105% of compressive strength of normal concrete at 28 days and attains flexural strength in the range of 113-118% at 90 days of flexural strength of normal concrete at 28 days. The time required to attain the required strength is more for bottom ash concrete.
- Bottom ash concrete attains splitting tensile strength in the range of 121-126% at 90 days of splitting tensile strength of normal concrete at 28 days.

- Compressive strength of bottom ash concrete containing 50% bottom ash is acceptable for most structural applications since the observed compressive strength is more than 20 MPa at 28 days.
- Even though the strength development is less for bottom ash concrete, it can be equated to lower grade of normal concrete and making utilization of waste material justifies the concrete mix-development.
- Bottom ash used as fine aggregates replacement enables the large utilization of waste product.

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