International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

Hardened Behavior of Fly Ash Incorporated Concrete with Bottom Ash (FACB) as Partial Replacement of Fine Aggregate

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Abstract**: *The utilization of thermal power plant waste ashes (fly ash and bottom ash) in concrete as partial replacement of cement and sand could be an important step toward development of sustainable, user-friendly and economical infrastructure. For this purpose, different concrete mixes were considered at constant binder content of 300kg/m³ and differ water-to-binder ratio (w / (c + f) mainly as 0.5 , 0.55 and 0.6. Also six wide range of fly ash replacement levels (f/c ratio) namely 0, 0.11, 0.25, 0.43, 0.67 and 1.0 were introduced in the experimental scheme. The 3-days to 180 days compressive strengths of FACB was measured at interval of 3, 7, 28, 56 and 90 days. This study also presents a relationship between the ratios of split tensile (ft) strength to compressive strength (fc). It is applicable to lean concrete having consideration of curing period at early age (3day) to long term (180days). The results of this investigation are principally important, because the comprehensive information on the dependability of the relationships has not been available for (w/c+f) and bottom ash combination. The investigational results of this work are indicated that waste-Bottom ash with the regular sizes can be used successfully as a fine aggregate in fly ash concrete (FAC). The Study also reflected in finding constant "k" by ACI code equation for fly ash and bottom ash mix concrete. It has obtained between 0.337 - 0.504. This could be useful in finding splitting tensile strength when concrete carrying fly ash and bottom ash.***

Keywords* : *fly ash, bottom ash, lean concrete, split tensile, compressive strength, fine aggregate.

I. INTRODUCTION

Sustainable construction exercise means establishment and controlling of a healthy built environment considering resource productivity and ecosystem [Plessis, 2007]. Sustainable development has been well-defined by the World Business Council for Sustainable Development (WBCSD) as: "Practices of progress that come across the needs of the present without negotiating the ability of future demand to meet their needs" [Humphreys and Mahasenan, 2002].

Revised Manuscript Received on February 28, 2020.
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Concrete became leading construction material over the world as versatile quality [Penttala, 1997], however, it has badly impacts on the environment economy [Naik, 2008] .Cement is a most important source of greenhouse gas emissions and cement is a main ingredient used for concrete structure [Imbabi et al., 2012]. The supplementary cementitious materials (SCMs) is a promising method for reducing cement utility from concrete production and fly ash have been used successfully as SCMs. [Imbabi et al., 2012]. Concrete is fundamentally a mixture of cementitious paste and aggregate. The cementitious paste, encompassed of cementitious material like cement, fly ash, silica fume, metakaolin and water, binds the aggregate into a solid mass; the paste hardens due to chemical reaction of the cementitious content and water called hydration. In concrete mix design with quality control, the uni-axial compressive strength of concrete is reflected as the most valuable property, which in chance is subjective by a number of factors. The strength of the concrete is firm by the characteristics of the cementitious material, mortar, coarse aggregate characteristics and the interface. For the same feature of mortar, diverse types of coarse aggregate with different shape, texture may result in diverse concrete strengths. For making concrete bottom ash and fly ash effectively play role of sand and cement in certain replacement levels.

Bottom ash is primarily composed of silica, alumina, and iron with minor amounts of calcium, magnesium, sulfate, etc. Its chemical composition is depended by the source of the coal. After the burning of coal in furnace of coal fired TPS, the non-combustible substantial present in it results in manufacture of coal ash. The finer and lighter atoms of coal ash outflow with the flue gases and are extracted in the Electrostatic Precipitators (ESP) before getting the environment. The coal ash collected from the Electrostatic Precipitators is known as fly ash. Fly ash particles are usually spherical, ranging in diameter from 1 µm up to 150 µm. the chemical composition and the mineralogical composition of fly ashes varied over a wide range [Carette and Malhotra, 1986]. The available research study indicates that bottom ash is a feasible material as sand replacement in concrete. Therefore it's suitable and usable ash and replacement material in concrete. The bottom ash effects can be calculated by considering the fresh, hardened properties of concrete. Aggregates are a skeleton of concrete.

Approximately three-fourth of the volume of regular concrete is occupied by aggregate. Aggregate is usually regarded as an inert dispersion in the cement paste. However, rigorously speaking, aggregate is not actually inert because physical, thermal, and, sometimes, chemical properties can effects on the performance of concrete [Neville and Brooks, 1990].

Some melted ash collected on the boiler walls and alongside steam tubes and solidifies to form solid masses called clinkers. The clinkers form up and fall to the bottom of furnace and are cooled in the water body before passing through clinker grinder. This coal ash finally collected at bottom of furnace/boiler is named as bottom ash. Bottom ash elements are physically coarse, porous, smooth, granular and grayish in color. Bottom ash is developed to 25% of the total ash, while fly ash extracted remaining 75% [Ahmaruzzaman, 2010]. In Asian continents, coal based TPS are the main source of power generation and about 70% to 75% electricity generations are fulfilled by them. Nearly 360 million tons of coal is fired by the coal based TPS annually. Indian coals have high amount of inorganic inclusions up to 46%. About 160 million tonnes of fly ash and 30-40 million tone of bottom ash is produced by Indian TPS every year. Out of the generation quantity, only 56 million-tons has been utilized in production of cement, concrete and bricks. The remaining fly ash is still acting a filling material and while the size of ash-dumps pond continues to expand. Annual formation of TPS bottom ash will bombard up to 50 million tones. Bottom ash is also used as land fill material and some places in road construction. In India up till date a minor volume of fly ash is consumed in production of cement but bottom ash is not used in any practice. Bottom ash laterally with unutilized fly ash is disposed off in ponds on thousand acres of land and this disposal of bottom ash in various ponds lands poses risk to human-environmental fitness. Few places hazardous constituents of bottom ash migrated and can pollute contaminate ground water with living things. It's also dangerous according to environment concerns as ash drains and escape on surrounding area of ash pond. Hence it becomes crucial to initiate the strength to utilize the bottom ash in any suitable place. Bottom ash has been particle size distribution similar to that of natural river sand. Due to such advantageous properties it appealed to be used as sand replacement in concrete partially or fully. Recent decades researchers have been engrossed on usage of bottom ash as partial sand replacement in concrete. Aramraks [2006] verified that the compressive strength of bottom ash concrete (replacement 50% and 100%) and suggested that was to be about 20–40% lower than that of natural sand concrete. The fresh and hardened properties of concrete are closely related with the characteristics and appropriate proportioning of its constituent materials. The researcher [Singh and Siddique, 2013] investigated that inclusion of bottom ash as sand replacement in concrete impacts on the workability, setting times, porosity, water loss through bleeding, bleeding frequency, plastic shrinkage of fresh concrete and strength, durability of hardened concrete. The decrease in strength of concrete is largely due to higher porosity and higher water requirement on bottom ash. The compressive strength can been enhanced by reducing the water demand by using super plasticizers agents. The authors are strongly recommended that possibility of coal bottom ash being used as substitute of fine aggregate. Kim and Lee [2011] suggested that the modulus of elasticity decreased with the increase in replacement of fine and coarse aggregates by bottom ash. For 100% sand replacement with fine bottom ash, the modulus of elasticity of concrete found decreased by 15.1%. The split tensile strength of bottom ash concrete has been evolutions in the related manner as in the case of normal concrete. Arumugam et al. [2011] detected that Split tensile strength of concrete of specimens containing 20% bottom ash as sand replacement was higher than the control concrete specimens. Split tensile strength decreased with increase in bottom ash level from 20% where as Yuksel and Genc [2007] witnessed that up to 10% natural sand replacement, there was no change in split tensile strength specimens. Gebler and Klieger, 1986 assessed the effect of Class F and Class C ASTM fly ashes from different sources on the compressive-strength improvement of concretes under different curing conditions. Their tests indicated that concrete incorporating flyash had the potential to produce reasonable compressive-strength development. The influence of the class of TPS fly ash on the long-term compressive strength of concrete was not major. Internationally fly ash is used in big volume in manufacturing of cement as mineral additive and in construction field as partial cement replacement in concrete. Mortars containing fly ash normally gain less strength at early ages as the pozzolanic reaction of fly ash is generally slower than the hydration of cement in the beginning [Chatterjee 2011; Cyr et al.2006]. Un and Baradan, [2011] investigated compressive and flexural strengths of mortars containing fly ash and have found the results enhanced by curing at higher temperatures. The addition of fly ash has been commonly observed to improve pores, prominent to a more durable concrete [Nath and Sarker 2011; Uysal and Akyuncu 2012]. Finer fly ashes improves the workability of the mortar since the spherical shape of ash particles provide better packing, lubricate the paste and reduce water demand [Grzeszczyk and Lipowski 1997], this is known as ball bearing effect [Neville 1995]. Compressive strength be subjected with the water-binder ratio. The compressive strength increases with lowering water-binder ratio [Aitcin and Mehta,1990].

The split tensile strength has related to several parameters such as compressive strength, water to binder ratio and concrete age but most of the researchers estimated the tensile strength directly from compressive strength readings. The mechanical properties of concrete mainly used for structural design are Compressive and tensile strengths. Split tensile strength is important for non-reinforced concrete structures. The split tensile strength has been frequently consider for designing dam under earthquake excitations, pavement slabs and airfield runway as bending Strength subjected to tensile forces. Ultimately tensile test is comparative more important than compressive strength. Many researchers have recommended tensile strength formulae for high-strength concrete, the popular of which related with square root function, similar to that recommended by ACI. Existing researcher relationships in the literature are based mainly on data found from concretes with compressive strength. The trustworthiness of the proposed equation is evaluated on the basis of integral absolute error (IAE, %) [Nihal et al, 2006]. The numerical value of tensile strength of concrete is much poorer than the compressive strength, fundamentally because of the cracks can propagate under tensile loadings.

The tensile strength analysis is still needed because cracking in concrete inclines to be of tensile behaviour. Concrete is to be considered a brittle material and in brittle material propagates flaw, hair cracks or micro cracks which caused the tensile strength. This work aimed to examine carrying out of using bottom ash waste as partial replacement of fine aggregate, on the hardened characteristics of fly ash incorporated concrete (FACB).Million tons of TPS bottom ash is being generated annually all over the world.

This study presents a relationship between the ratios of split tensile (ft) strength to compressive strength (fc). It is applicable to concrete at 3day to 180days for standard and medium strength concrete. The results of this investigation are principally important because no comprehensive information on the dependability of the relationships has been available for (w / c + f) and bottom ash combination. The approach is a realistic one, using experimental data recorded that ware used in this study into account the incorporation of cementitious material (cement +fly ash) and reduction of natural sand by replacement with bottom ash. This parameters that were not taken into consideration authentically by existing literature. Therefore here study of split to compressive strength (ft/fc) relation prolong to proposed satisfactory equations, which based on added cementitious and filler material, curing age.

II. MATERIALS AND METHODS

For the purpose of experimental investigation, we had used commercially available Ordinary Portland Portland Cement (OPC) conforming IS 12269-2004, Bureau of Indian Standard, New Delhi, river bed sand conforming IS 383 [1970, Reaffirmed 2002], siliceous pulverized TPS fuel ash (fly ash and bottom ash) obtained from thermal power plant, Eklahare at Nashik district conforming IS 3812 Part 2 [2003], and potable quality tap water satisfying the requirements as per IS456 -2000. No admixtures were used in this study. The Fly ash is classified mainly as class C and class F according to [ASTM C 618]. The sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ should not be less than 50% for class C and must be more than 70% for class F. for this research work fly ash of F Class ($SiO_2 + Al_2O_3 + Fe_2O_3$ = 92.73) used at all mixes. The details of chemical characteristics mention in Table 1.

Table- I: Chemical Characteristics of Fly ash

Sr. No	Particular	Fly Ash Used: Class F	Requirement as per IS: 3812-1981 (1999) and 2003 (Part – I)
1	SiO2 + Al2O3 + Fe2O3 (%)	92.73	70 min by mass
2	Cao(%)	1.55	-
3	SiO2 (%)	59.57	35 min by mass
4	Al2O3 (%)	28.71	-
5	Fe2O3 (%)	4.45	-
6	MgO(%)	2.17	5.0 max by mass
7	SO3 (%)	0.80	3.0 max by mass
8	Na2O (%)	0.55	1.5 max by mass
9	Total Chlorides(%)	0.030	0.05 max by mass
10	LOI (Loss of Ignition) %	1.13	Less than 5

The specific gravity of fly ash was 2.15 and fineness specific surface by Blaine's permeability method was 366 m^2/kg. For cement specific gravity and fineness specific surface was 3.15 and 320m^2/kg respectively. The bottom ash is coarser than the fly ash and cement. The river sand was obtained the fineness modulus, specific gravity and water absorption as about 2.55, 2.75 and 1.08% respectively. The coarse aggregates were washed by clean potable water and allowed to place in a dry, open space in the laboratory premises until the surface moisture got evaporated and the aggregates reaches to a saturated surface dry condition. 20 mm nominal size of coarse aggregate having specific gravity 2.73 and bulk density 1610kg/m^3 were used for concrete specimens. The strength of any concretes depends on a constituents and related parameters. The aim of the present study is not only for a particular strength or workability but also to evaluate the effect of fly ash on standard concrete of low to medium strength. The study is planned to decide the contribution of fly ash on concrete, as an outcome of mix variables like superiority of ingredients, mix proportions and curing conditioned have been kept constant for experimentation. At decided binder content, the variables of key interest are w/(c+f) ratio and efficiency of fly ash replacement levels. For this purpose, different concrete mixes were considered at constant binder content of 300kg/m^3 and differ water-to-binder ratio(w/(c + f) of 0.5 , 0.55 and 0.6. Six wide range of fly ash replacement levels (f/c ratio) namely 0, 0.11, 0.25, 0.43, 0.67 and 1.0 were introduced in the experimental scheme. The fly ash replacement percentages, water binder ratios as per binder contents have been primarily fixing to produce a wide database of workability observations and strength results of fly ash incorporated concrete. The bottom ash in concrete mixes as replacement level 15% and 30% has been kept constant for all mixes and strength evaluation was performed according to compressive strength results.

III. RESULTS AND DISCUSSION

The compressive strength of a concrete is the uni-axial compressive stress reached when the concrete fails completely. A set of three cubes were tasted for every mix proportioning and the average value of these three was recorded. Ultimate load is noted for every cube specimens. Compressive strength test on concrete were done as per guidelines discussed in IS 14858:2000 and IS 516:1959 (Reaffirmed 2004). The experimental set up for compression tests of concrete are shown in Fig. 1 and specimens of size 150 mm x150 mm x150 mm were used for Compressive testing machine (CTM) are shown in Fig 2.

Fig. 1. The experimental set up of CTM for compression tests

Fig. 2. Concrete Specimen cubes (150mm x 150 mm x 150 mm) before testing

Fly ash replacement (f/c ratio 0, 0.11, 0.25, 0.43, 0.67, 1.0) effects on Compressive strength for various curing periods at w/(c+f) ratio 0.5,0.55 and 0.6 with fine aggregate combinations of Natural sand (85% and 70%) : Bottom ash sand (15% and 30%) are graphically represented in fig 3 to fig. 5 and Percentage reduction in compressive strength for w/(c+f) ratio 0.5, 0.55, 0.6 with respect to Control concrete mixes: 15% and 30% bottom ash added for sand replacement and (f/c ratio 0, 0.11, 0.25, 0.43, 0.67, 1.0) are shown in Fig. 6 to Fig. 8 respectively.

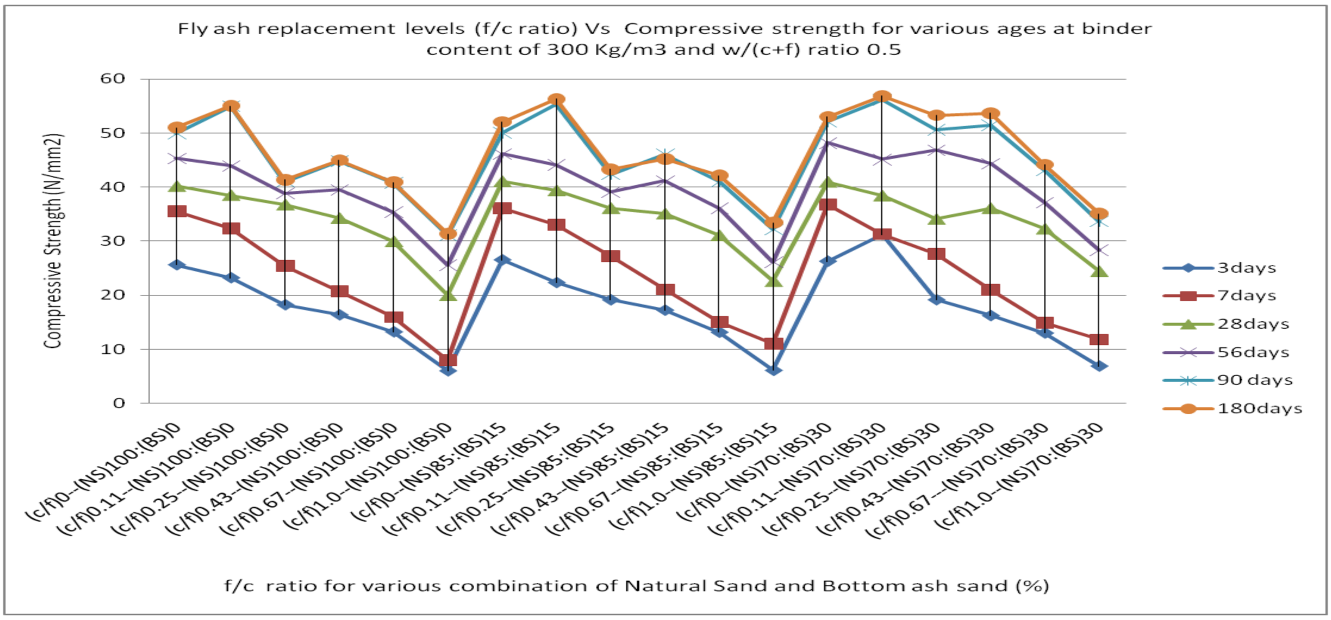

Fig. 3. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0) Vs Compressive strength for various curing periods at w/(c+f) ratio 0.5 with fine aggregate combinations of Natural sand-Bottom ash sand

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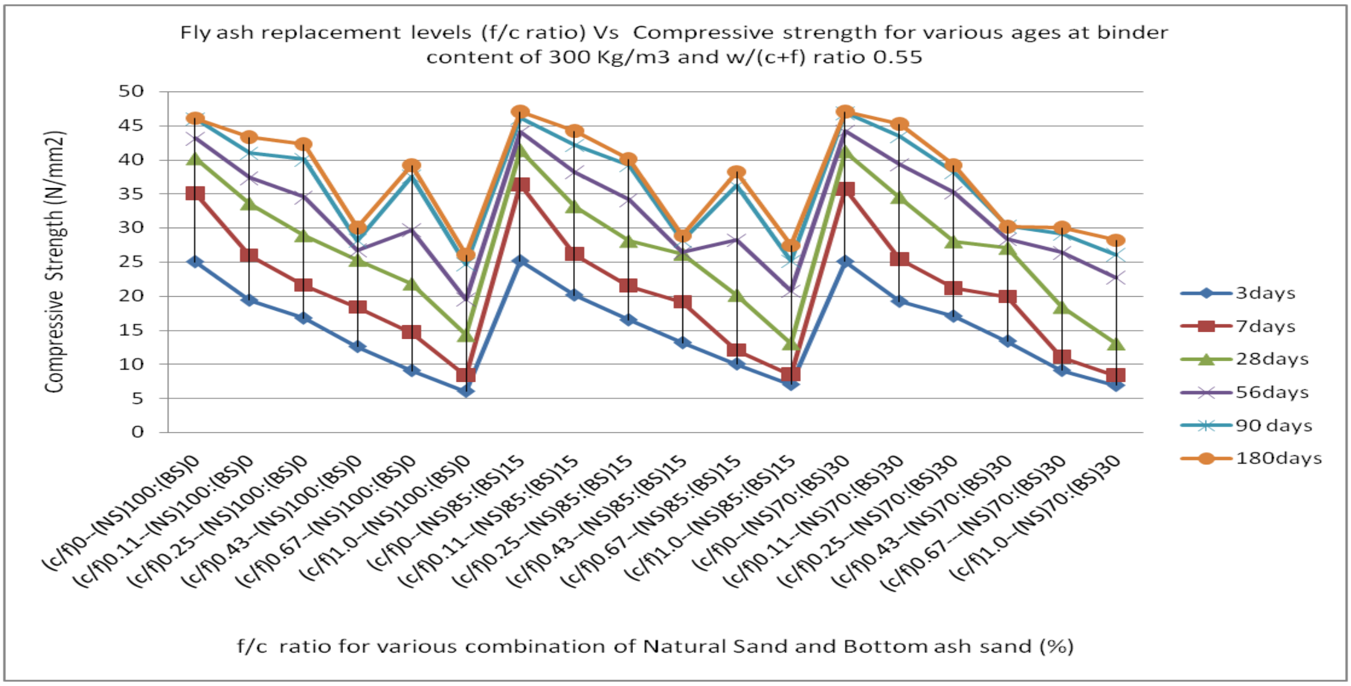

Fig. 4. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0) Vs Compressive strength for various curing periods at w/(c+f) ratio 0.55 with fine aggregate combinations of Natural sand-Bottom ash sand.

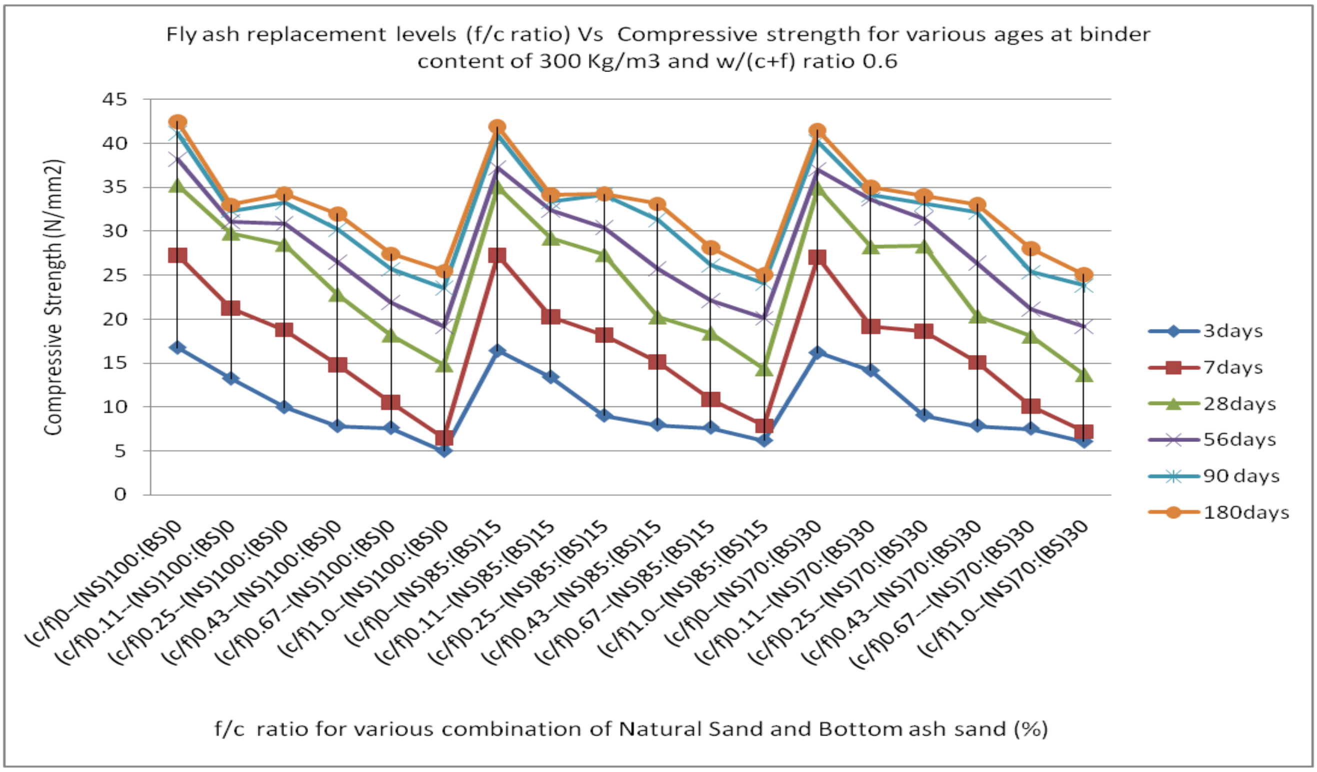

Fig. 5. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0)Vs Compressive strength for various curing periods at w/(c+f) ratio 0.6 with fine aggregate combinations of Natural sand-Bottom ash sand

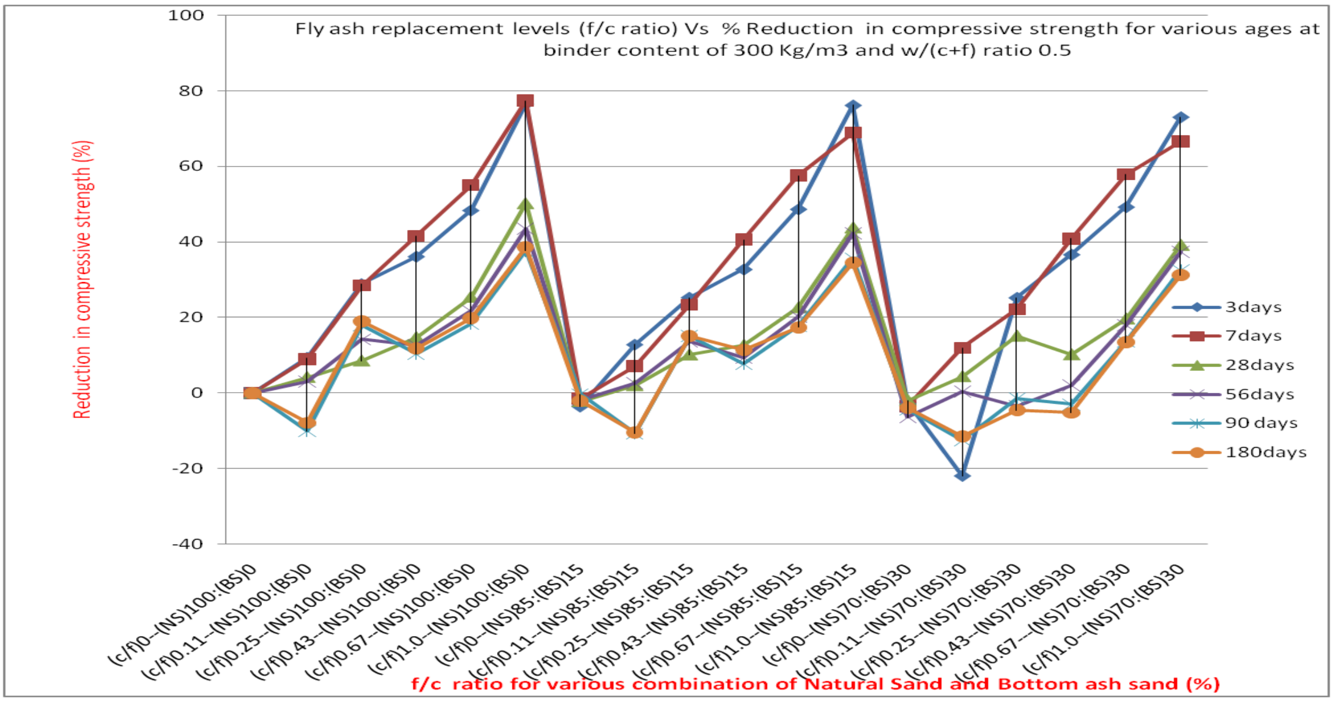

Fig. 6. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0) Vs Percentage reduction in Compressive strength for various curing periods at w/(c+f) ratio 0.5 with fine aggregate combinations of Natural sand-Bottom ash sand.

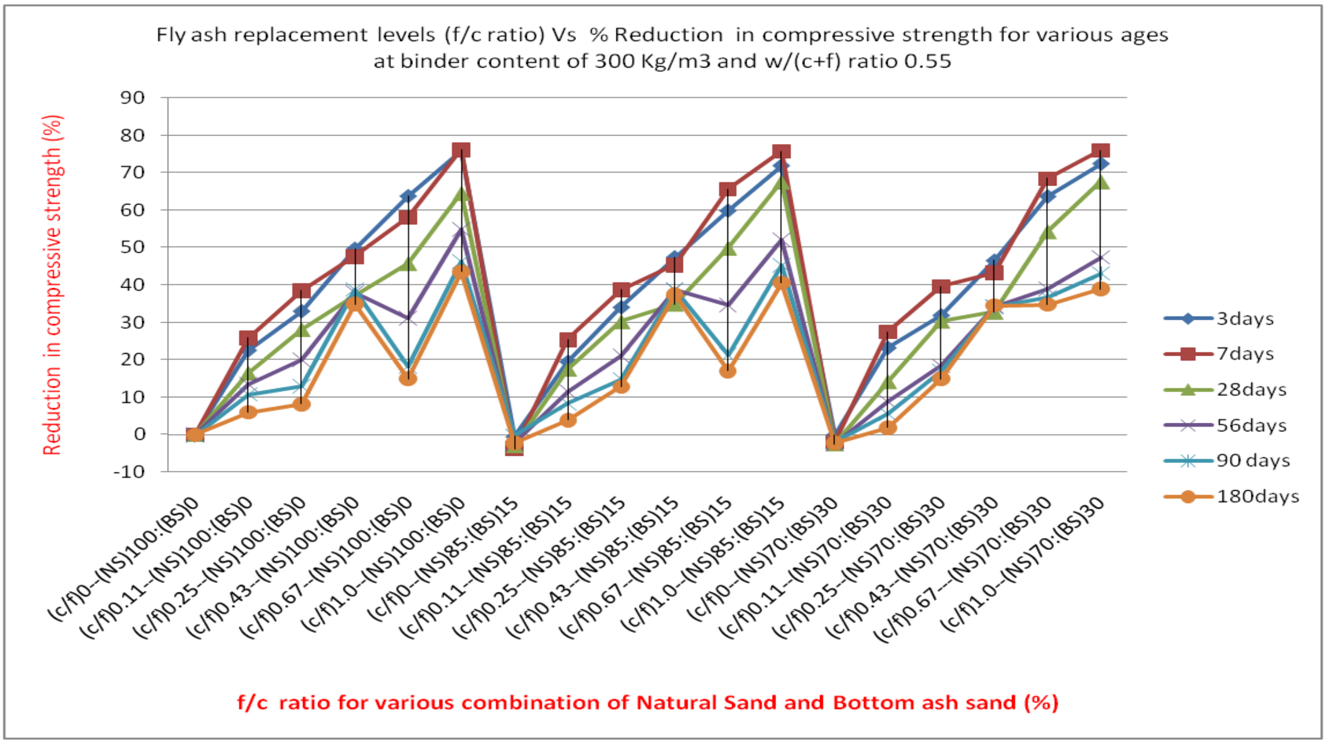

Fig.7. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0) Vs Percentage reduction in Compressive strength for various curing periods at w/(c+f) ratio 0.55 with fine aggregate combinations of Natural sand-Bottom ash sand.

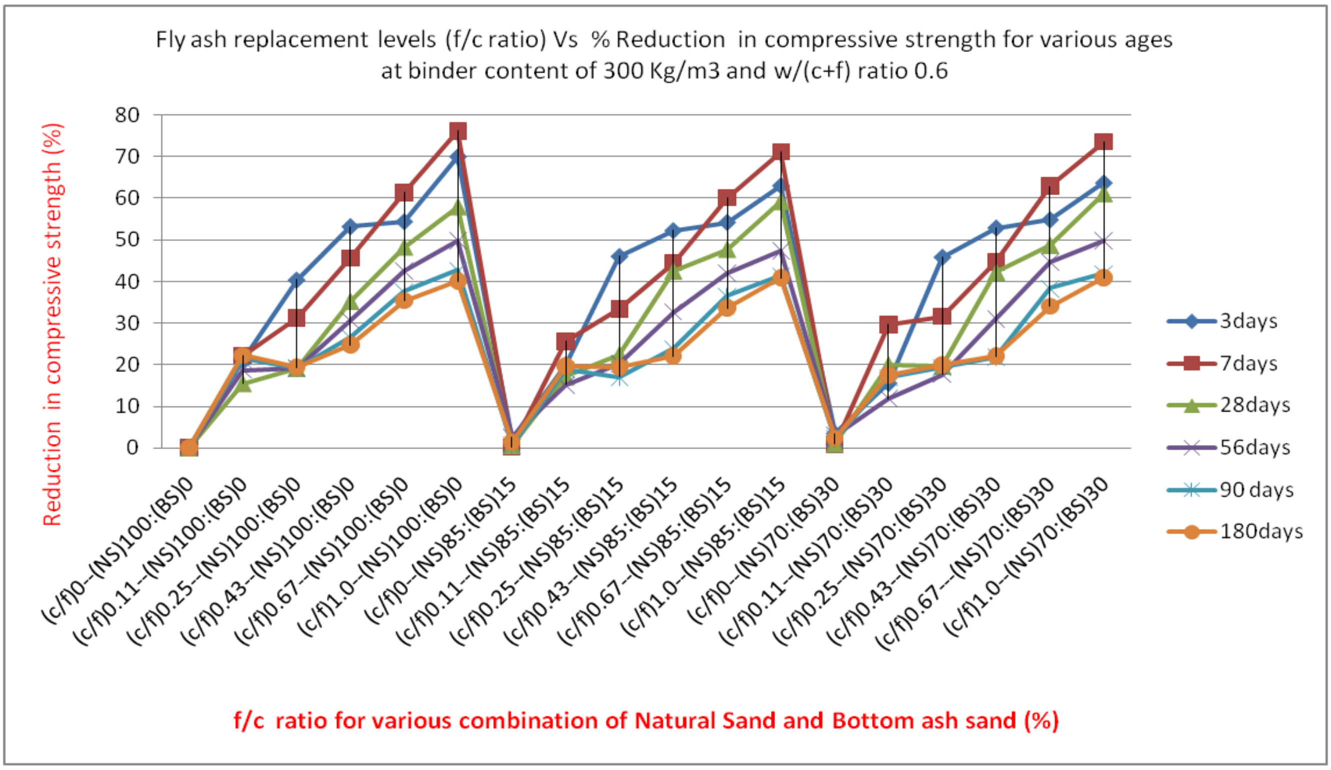

Fig. 8. Fly ash replacement (f/c ratio 0,0.11,0.25,0.43,0.67,1.0) Vs Percentage reduction in Compressive strength for various curing periods at w/(c+f) ratio 0.6 with fine aggregate combinations of Natural sand-Bottom ash sand

The cylindrical mold of 150mm diameter and 300mm length were used for splitting test and samples of specimen are shown in fig. 9. Fig. 10 shows the specimen failure pattern for splitting tensile test (after testing).

Fig. 9 cylinder specimen mould for splitting tensile test

Fig. 10 Specimen failure pattern for splitting tensile test (after testing)

Mindes and Young [1981] clarified that the relationship between split tensile and compressive strength is not a simple one to evaluate. The relation has been differs according to strength of concrete, aggregate type, degree of compaction, the log age and curing condition. There are several empirical formulae presented by many researchers for determining split strength (ft) and compressive strength (fc) and most cases scholars opted the following type formula : $ft=k(fc)^n$, the same expression formed by Neville (1995), where k and n both are the empirical constants.

American Concrete Institute has been proposed equation for the prediction of split tensile strength of normal weight concrete, where the constant value of k is determined as 0.59, where the exponent n considered 0.5, similar result was found for self-compacting concrete by Akinpelu, M.A. et al, 2017 but the Neville [1995] has determined 0.52 for constant k. Oluokun [1991] has not found the same result and his remark is suggestion of ACI relationship is not appropriate, he was found proportional exponent power n= 0.69, similar range varies between 0.6 and 0.8 [SeshaPhani et al., 2013]. Choi and Yuan [2005] studied experimental and analytical results for constant k and n in relationship between the tensile strength and compressive strength for the glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC). However, the value of constant k recommended 0.6 and 0.5 in the proposed equations for GFRC and PFRC respectively with n constant was taken 0.5. Many theoretical and empirical models based on concrete compressive strength have been developed to predict the splitting tensile strength of concrete [Yan et al., 2013]. ACI model also suggested square root relationship between the splitting tensile strength and (cylinder) compressive strength. Few studies have also indicated that the relationship is not furthermost appropriate [SeshaPhani et al., 2013; Krishna et al.,2010; Arioglu et al.,2006; Lavanya and Jegan, 2015; Gajendran et al., 2015]. Wiegrink et al. [1996] established that the strength development pattern for split tensile strength results is similar to that of compressive strength.

Apart from all bias between many popular researchers, the recent study did with considering the exponent 0.5 and evaluated the difference of constant-k between the ACI reporting for normal concrete and recent mixes of incorporated fly ash-bottom ash concrete. It is commendable to highlight that most of the relationships have been established based on studies on the conventional concrete. However, the intention of this research was to assess the relationship between the hardened properties of fly ash+ bottom ash incorporated concrete and to validate the applicability of the existing empirical values of constant k.

According to ACI, the empirical value ok constant n lies between 0.5 – 0.75 therefore the power of exponent to be taken as 0.5 for determining the value of constant-k. The compressive test has been conducted on 150mm X 150 mm X 150 mm cubes and by considering n-constant 0.5, the relation with splitting test has been proposed (equation [i to xiii] for 28days, 90days and 180days.

For water-to-binder ratio 0.5, the relation between ft and fc as mention below:

$$ft_{(7days)} = 0.337(fc_{7days})^{0.5} \quad \text{--------(i)}$$
$$ft_{(28days)} = 0.476\ (fc_{28days})^{0.5} \quad \text{--------(ii)}$$
$$ft_{(90days)} = 0.449\ (fc_{90days})^{0.5} \quad \text{--------(iii)}$$
$$ft_{(180days)} = 0.470\ (fc_{180days})^{0.5} \quad \text{--------(iv)}$$

For water-to-binder ratio 0.55, the relation between ft and fc as mention below:

$$ft_{(7days)} = 0.366(fc_{7days})^{0.5} \quad \text{-------(vi)}$$
$$ft_{(28days)} = 0.539(fc_{28days})^{0.5} \quad \text{-------(vii)}$$
$$ft_{(90days)} = 0.495(fc_{90days})^{0.5} \quad \text{-------(viii)}$$
$$ft_{(180days)} = 0.504(fc_{180days})^{0.5} \quad \text{--------(ix)}$$

For water-to-binder ratio 0.6, the relation between ft and fc as mention below:

$$ft_{(7days)} = 0.364(fc_{7days})^{0.5} \quad \text{-------(x)}$$
$$ft_{(28days)} = 0.494(fc_{28days})^{0.5} \quad \text{-------(xi)}$$
$$ft_{(90days)} = 0.479(fc_{90days})^{0.5} \quad \text{------(xii)}$$
$$ft_{(180days)} = 0.493(fc_{180days})^{0.5} \quad \text{------(xiii)}$$

The details of constant “k” finding are hereby evaluated in the following Table III.

Table- III: Values of k relating split tensile strengths and compressive strengths of 150x150x150 mm cubes [ft=k (fc)0.5]

(f/c) ratio	Mixes Designation	Value of k by considering formula $ft=k(fc)^n$, n=0.5											
		w/ (c+f) ratio W1= 0.5				*w/ (c+f) ratioW2= 0.55*				*w/ (c+f) ratio W3= 0.6*			
		7 days	*28 days*	*90 days*	*180 days*	*7 days*	*28 days*	*90 days*	*180 days*	*7 days*	*28 days*	*90 days*	*180 days*
0	F0	0.304	0.479	0.463	0.476	0.284	0.474	0.472	0.479	0.299	0.442	0.440	0.451
0.11	F10	0.269	0.443	0.415	0.445	0.322	0.494	0.475	0.462	0.306	0.456	0.480	0.498
0.25	F20	0.280	0.432	0.464	0.496	0.343	0.493	0.447	0.454	0.302	0.446	0.460	0.475
0.43	F30	0.298	0.425	0.420	0.450	0.357	0.489	0.500	0.528	0.325	0.473	0.453	0.460
0.67	F40	0.320	0.440	0.419	0.433	0.381	0.506	0.411	0.430	0.357	0.497	0.472	0.490
1.0	F50	0.346	0.398	0.407	0.445	0.350	0.461	0.415	0.457	0.420	0.518	0.464	0.477
0	S15F0	0.305	0.485	0.471	0.470	0.284	0.477	0.476	0.480	0.310	0.448	0.444	0.459
0.11	S15F10	0.322	0.492	0.458	0.461	0.338	0.537	0.498	0.498	0.366	0.494	0.497	0.519
0.25	S15F20	0.364	0.526	0.530	0.530	0.378	0.591	0.524	0.534	0.401	0.525	0.505	0.531
0.43	S15F30	0.392	0.508	0.474	0.509	0.389	0.593	0.598	0.600	0.406	0.580	0.502	0.511
0.67	S15F40	0.409	0.514	0.473	0.482	0.464	0.644	0.500	0.503	0.442	0.562	0.515	0.522
1.0	S15F50	0.388	0.528	0.488	0.517	0.497	0.762	0.569	0.575	0.460	0.616	0.521	0.537
0	S30F0	0.295	0.467	0.431	0.457	0.280	0.463	0.460	0.470	0.298	0.439	0.443	0.452
0.11	S30F10	0.324	0.500	0.420	0.452	0.335	0.511	0.479	0.482	0.358	0.495	0.484	0.500
0.25	S30F20	0.340	0.510	0.437	0.463	0.363	0.560	0.507	0.518	0.357	0.489	0.486	0.499
0.43	S30F30	0.356	0.447	0.415	0.426	0.343	0.541	0.542	0.563	0.345	0.317	0.460	0.478
0.67	S30F40	0.400	0.470	0.437	0.460	0.440	0.401	0.517	0.528	0.380	0.523	0.506	0.506
1.0	S30F50	0.354	0.497	0.467	0.494	0.442	0.708	0.520	0.517	0.413	0.574	0.493	0.501
	Average	**0.337**	**0.476**	**0.449**	**0.470**	**0.366**	**0.539**	**0.495**	**0.504**	**0.364**	**0.494**	**0.479**	**0.493**

Where,

F represents fly ash percentage (0-50%), S15 represents Bottom ash sand content 15% and Natural sand 85%. S30 represents Bottom ash sand content 30% and Natural sand 70%

IV. CONCLUSION

The ratio of tensile to compressive strength decreases as the compressive strength increases for fly ash + bottom ash incorporated concreted. The early age strength observed slower rate than the controlled concrete. The 15% bottom ash replacement by sand quietly good compressive and tensile strength. Most of the compressive strength results upto 20-30% replacement results similar to result obtained by natural sand fully acting as fine aggregate. The superior results are obtained from binder-to- water content w/(c+f) 0.5 rather than 0.55 and 0.6 at all ages (7-180days).

The ACI recommended the empirical value of constant "k" is validate only for normal concrete, the inferior result of constant k obtained for fly ash and bottom ash incorporated concrete. ACI recommendations is also applicable for cylindrical specimens in compressive and spitting test. If the compressive test has been conducted on 150mm X 150 mm X 150 mm cubes and by considering n-constant 0.5, the relation with splitting test has been proposed for 7days, 28days, 90days and 180days in equations (i) to (xi) . the value of constant k has been found between 0.337 to 0.539 for binder content 300kg/m3 having w/(c+f) considering 0.5, 0.55 and 0.6.

From the investigation, we recommended that possibility of coal bottom ash being used as substitute of fine aggregate and fly ash also used for cement replacement partially.

A. Abbreviations

c: cement
f: flyash
w: water
fc: compresseive strength
ft: splitting *strength*

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