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VARIATION OF THE PHYSICAL, MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE USING ALUMINIUM SLAG, FLY ASH AND SILICA FUME

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ABSTRACT

The objective of present work is to utilize the aluminium slag, fly ash and silica fume in the natural cycle (closed loop) by using it as an engineered material and to investigate the mechanical properties and durability properties of new concrete type obtained by adding aluminium slag which is an impure aluminium mixture that results from melting of metals and mixing with flux. The main advantage of this type of concrete over the conventional ones is the reduction in the quantity of raw materials and to decrease the CO_2 release during the process of the production of cement.

Aluminium slag, fly ash and silica fume have been used at different proportions to replace cement by 5%, 10%and 20 % by weight and also different combinations like keeping the aluminium slag content constant at 5% and 10% and fly ash at 10%and 20%. The cubes cast with those mixtures are tested for compressive strength for 3 days, 14days, 28 days, 56 days and 90 days. Fly ash and silica fume were also added to the concrete mix of aluminium slag which can reduce the expanding properties of the aluminium slag concrete and also increases the mechanical and durability properties of the concrete. Hence, 5% of aluminium slag replacement is preferable.

The results of this study indicate that aluminium slag can be used as an ingredient in the concrete mix along with the admixtures like fly ash and silica fume which increases the mechanical and durability properties.

Keywords: Aluminium slag, Flyash, Silica Fume, Partial Replacement, Acid Attack and Strength of Concrete.

I. INTRODUCTION

Sustainable construction mainly aims at reduction of negative environmental impact resulted by construction industry which is the largest consumer of natural resources. The total amount of by-products generated by the industries worldwide every year exceeds 1000 million tonnes. Over a period of time, waste management had become one of the most complex and challenging problem in the world which is affecting the environment. The rapid growth of industrialization gave birth to numerous kinds of waste by-products like Aluminium slag, fly

ash, silica fume and slags which are by-products formed in smelting, and other metallurgical and combustion processes from impurities in the metals or ores being treated ,which are environmentally hazardous and create problems of storage. Always, construction industry had been at vanguard in consuming these waste products in large quantities.

II. OBJECTIVE

The main objective of the present experimental investigation is to obtain the influence of the combined application of aluminium slag, flyash, silica fume on various strength and durability properties of M20 grade of concrete. 5%, 10%, 20% of Aluminium slag and 10% and 20% of Flyash and Silica fume by weight of cement replacement is adopted. Compressive strength, and Acid attack test of the M20 grade of concrete prepared using different proportions aluminium slag, fly ash, silica fume are to be obtained and the results are to be compared with that of controlled concrete.

III. EXPERIMENTAL INVESTIGATION

3.1 Properties of Materials

3.1.1 Cement

In the present investigation Ordinary Portland Cement (OPC) of 53 Grade confirming to IS specifications was used. The properties of cement are shown in Table.1.

Table 1. Properties of Cement

S.No	Property	Value
1	Specific Gravity	3.11
2	Normal Consistency	33 %
3	Setting Time i) Initial Setting time ii) Final setting time	 50 Min 320 Min
4	Fineness value	325 m^2/kg

3.1.2 Fine Aggregate

Naturally available sand is used as fine aggregate in the present work. The most common constituent of sand is silica, usually in the form of quartz, which is chemically inert and hard. The sand is free from clayey matter, silt and organic impurities etc. Hence it is used as a fine aggregate in concrete. The size of sand is that passing through 4.75mm sieve and retained on 150 micron IS sieve, in accordance with IS: 2386-1963.The properties of fine aggregate are shown in Table.2.

Table 2. Properties of Fine Aggregate

S.No	Property	Value
1	Specific Gravity	2.7
2	Fineness Modulus	3.12
3	Bulking of sand	4 %
4	Grading of Sand	Zone – I

The particle size distribution of sand was determined and the results are tabulated in Table 2.1 and Fig. 2.1 shows the grading curve for upper and lower limit of zone-I sand and the fine aggregate used for Concrete preparation.

Table 2.1. Sieve Analysis of Fine Aggregate

Sieve Size	Weight Retained (gm)	Cumulative % Retained	Cumulative % Passing	Zone - Specifications as per IS:383-1970 for % Passing			
				I	II	III	IV
4.75 mm	12	1.2	98.8	90-100	90-100	90-100	95-100
2.36 mm	103	11.5	88.5	60-95	75-100	85-100	95-100
1.18 mm	316	43.1	56.9	30-70	55-90	75-100	90-100
600 µ	205.5	63.65	36.35	15-34	35-59	60-79	80-100
300 µ	296.5	93.3	6.7	5-20	8-30	12-40	15-50
150 µ	62	99.5	0.5	0-10	0-10	0-10	0-10
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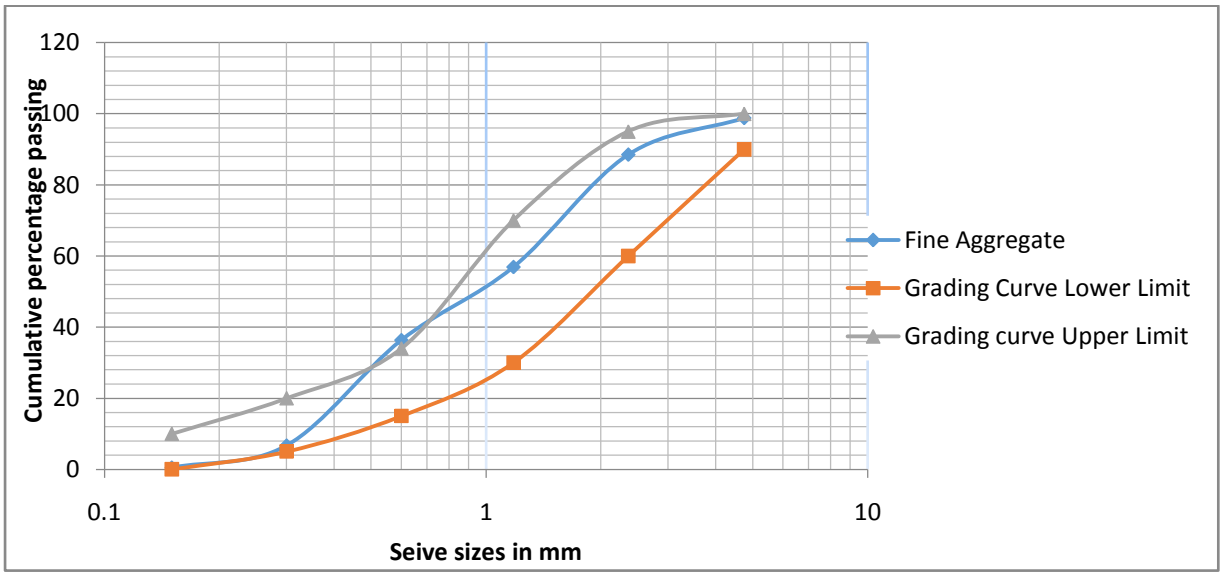

Fig 2.1 Particle Size Distribution of Fine Aggregate

3.1.3 Coarse Aggregate

Crushed granite metal of nominal size 20 mm and 10 mm obtained from the local quarry and confirming to IS specifications were used. The properties of coarse aggregate are shown in Table.3. The coarse aggregate used for the preparation of concrete is a combination of 20 mm and 10 mm size aggregates in ratio 1.5: 1.0.

Table3. Properties of Coarse Aggregate

S.No	Property	Result
1	Specific Gravity	2.8
2	Bulk Density (Loose)	14.13 kN/m^3
3	Water Absorption	0.4%
4	Fineness Modulus	8.0

3.1.4 Aluminum Slag

Aluminium slag is a mixture of free metal and nonmetal substances (e.g., aluminium oxide and salts).Slags as well as salt slags (or: salt cakes) are residues from aluminium industry. Aluminium slag is formed during refining and by air-oxidation of the liquid metal during melting, holding and casting operations. It consists of a complex conglomerate, including metallic oxides (e.g.: Al_2O_3, Al_2O_3 • MgO, Al_2O_3 •SiO_2, Al_2O_3 • FeO etc.), nitrides (e.g.: AlN), chlorides (e.g.: $AlCl_3$, NaCl, KCl), fluorides (e.g.: CaF_2, NaF, AlF_3, Na_3AlF_6 etc.), carbides (e.g.: Al_4C_3), sulphides (e.g.: Al_2S_3), phosphides (e.g.: AlP), dirt and impurities appart from metallic aluminium (between 80-20%). The properties of Aluminium slag are shown in Table 4.

Table 4. Properties of Aluminium slag

Properties	**Granular slag**	**Compact slag**
Alloy content(%)melt	2.44-11.77	1.34-10.03
Alloy content(%)recover metal	1.03-5.51	0.33-6.80
Distribution(q)(mm^{-1})	0.08(coarse)-0.452(fine)	-
Density(t/m^3)	0.0828-1.118(bulk)	2.396-2.528(apparent)
Metal content (%)	46.9-69.1	71-93
Lixiviate(pH)	9.52-10.14	9.03-9.48

3.1.5 Silica Fume

Silica Fume a is very fine non-crystalline silica, produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon. The typical particle size is less than $1\mu m$, hence can be considered as an excellent material fills the space between the cement particles. Silica Fume can also be considered as a supplementary cementitious material. In this experimental investigation, 10% and 20% of Silica-Fume was used as cement replacement by weight. The properties of Silica-Fume are shown in Table 5.

Table 5. Properties of Silica Fume

S.No.	Property	Value
1	Specific gravity	2.60
2	Physical form	Powder
3	Color	Pale white

3.1.6 Fly Ash

The combustion of pulverized coal at high temperatures and pressures in power stations produces different types of ash. The 'fine' ash fraction is carried upwards with the flue gases and captured before reaching the atmosphere by highly efficient electro static precipitators. This material is known as Pulverized Fuel Ash (PFA) or 'fly ash'. The properties of fly ash are shown in Table 6.

Table. 6. Properties of Fly-Ash

S.No.	Property	Actual Analysis
1	Specific gravity	2.50
2	Physical form	Powder
3	Color	Dark green

3.1.7 Water

Water used for casting and curing of concrete test specimens is free from impurities which when present can adversely influence the various properties of concrete.

3.2 Concrete Mix Proportion

In the present experimental investigation the influence of application of aluminium slag, flyash and silica fume as partial replacement of cement on M20 grade of concrete is studied.

M20 grade of concrete were designed as per the Indian Standard code of practice. The various ingredients for one cubic meter of M20 grade of concrete is shown in Table 7.

Table. 7 Quantities of Ingredients per cum of M20 Grade Concrete

Concrete	Cement (kg)	Aluminium slag (Kg)	Flyash (Kg)	Silica Fume (Kg)	Water (lit)	w/c	Fine Aggregate (kg)	Coarse Aggregate (kg)
Control	372	0	0	0	186	0.50	644	1155
AS 5%	353.4	18.6	0	0	186	0.50	644	1155
AS 10 %	334.8	37.2	0	0	186	0.50	644	1155
AS 20 %	297.6	74.4	0	0	186	0.50	644	1155
AS 5% + FA 10 %	316.2	18.6	37.2	0	186	0.50	644	1155
AS 5% + FA 20 %	279	18.6	74.4	0	186	0.50	644	1155
AS 10% + FA 10 %	297.6	37.2	37.2	0	186	0.50	644	1155
AS 10% + FA 20 %	260.4	37.2	74.4	0	186	0.50	644	1155
AS 5% + SF 10 %	316.2	18.6	0	37.2	186	0.50	644	1155
AS 5% + SF 20 %	279	18.6	0	74.4	186	0.50	644	1155

AS 10% + SF 10 %	297.6	37.2	0	37.2	186	0.50	644	1155
AS 10% + SF 20 %	260.4	37.2	0	74.4	186	0.50	644	1155

3.3 Test Specimens

Concrete test specimens consist of 150 mm × 150 mm × 150 mm cubes. Concrete cube specimens were tested at 3, 14, 28, 56 and 90 days of curing to obtain the compressive strength of concrete. Cube specimens were tested at the age of 28 days to obtain the durability of concrete by acid attack test. The rate of loading is as per the Indian Standard specifications.

IV. RESULTS AND DISCUSSION

4.1 Compressive Strength

4.1.1 Compressive strength of concrete containing 5% Aluminium slag and 10%,20% of fly ash

The replacement of Aluminium slag in cement, it is clearly observed that when the percentage of Aluminium slag is increases above 5% in concrete, the compressive strength of concrete gradually decreases. The strength of concrete at 5% AS replacement in cement after 28 days is observed as 32.44N/mm^2 and strength of concrete of 10 % AS in cement after 28 days is 20.22N/mm^2 and strength of concrete of 20% AS in cement after 28 days is 15.12N/mm^2. The compressive strength attained by the Aluminium slag replaced concrete cube at 5% AS, strength increases gradually up to 90 days. Further increase in aluminium slag in concrete leads to decrease in compressive strength compared to control concrete. Variation of compressive strength of different replacement of AS is tabulated in table 8.

Table. 8. Variation of compressive strength of different replacement of AS

Sl. No	Cementitious material	W/C or W/B	Compressive strength (N/mm^2)				
			3 days	14 days	28 days	56 days	90 days
1	100% OPC + 0% AS	0.5	17.10	21.78	30.60	35.47	36.22
2	95% OPC + 5% AS	0.5	20.44	26.5	32.44	37.33	38.32
3	90% OPC + 10% AS	0.5	18.44	20.2	20.22	28.55	29.44
4	80% OPC + 20%AS	0.5	15.90	16.76	15.12	25.44	26.72

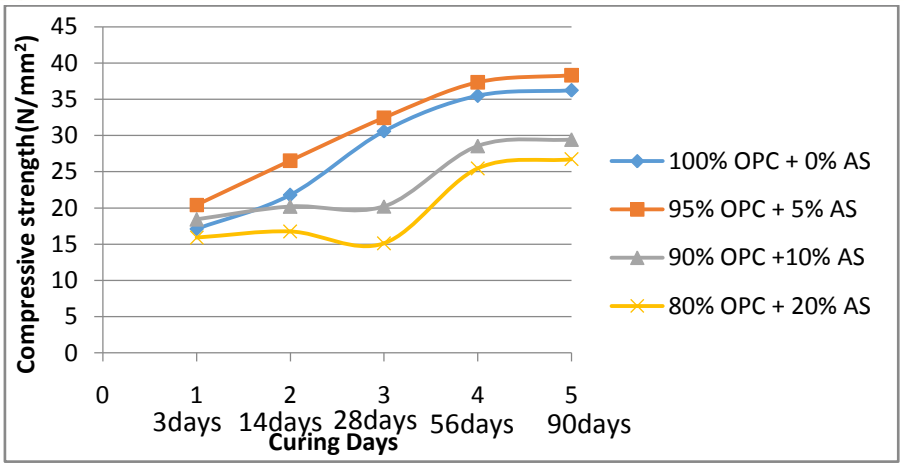

Fig. 4.0. Variation of Cube Compressive Strength of M20 Grade Concrete with age for different percentages of Aluminium slag.

4.1.1 Compressive strength of concrete containing 5% Aluminium slag and 10%,20% of fly ash

The strength of concrete at 5 % AS+20%FA in cement after 28 days is 32.44 N/mm^2. The compressive strength attained maximum value at 5%AS+20%FA. There after the strength gradually decreased compared to control concrete.

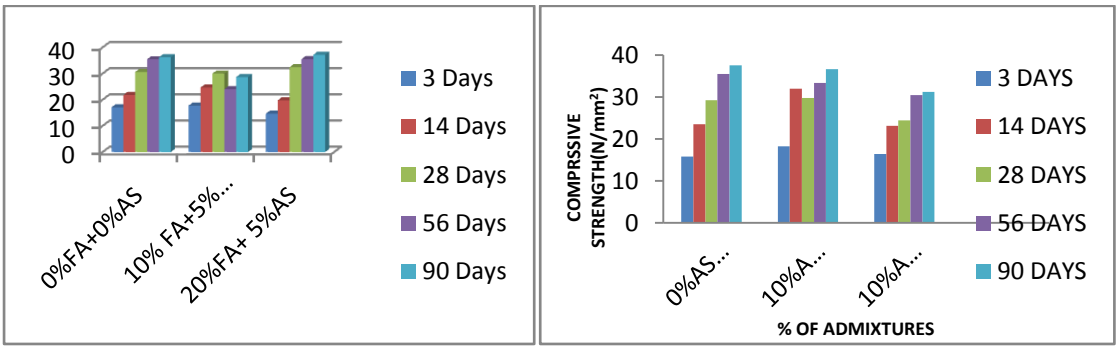

Fig 4.2 Compressive strength of concrete containing 5% Aluminium slag and 10%,20% of fly ash

4.1.3 Compressive strength of concrete containing 5%, 10% Aluminium slag and 10%, 20% of silica fume

The strength of control concrete at 28 days is 30.6 N/mm^2 and the strength of concrete at 5%AS+10%SF in cement after 28 days is 34.34 N/mm^2.From this observation it is clear that the compressive strength attained maximum value at 5% AS+10% SF when compared with the control concrete.

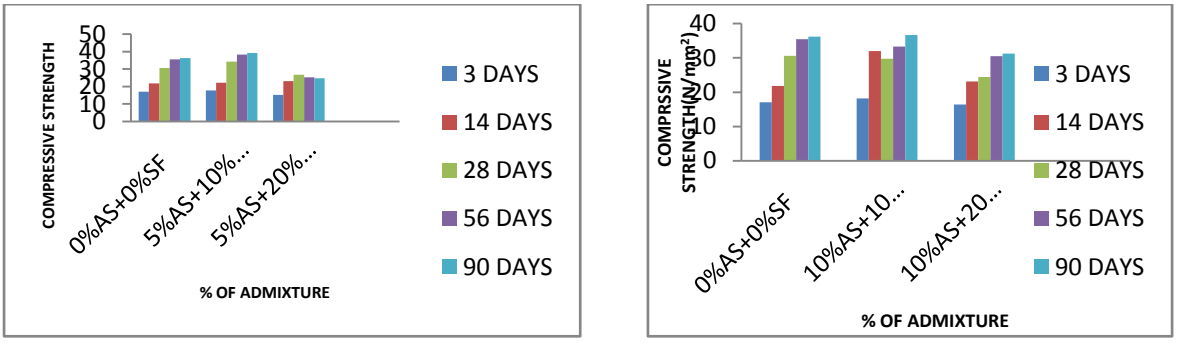

Fig 4.3 Compressive strength of concrete containing 5%, 10% Aluminium slag and 10%, 20% of Silica fume.

4.2 Acid Attack Test

The action of acids on concrete is the conversion of calcium compounds into calcium salts of the attacking acid. These reactions destroy the concrete structure. The percentage of loss in weight was given in the following tables respectively. The loss of compressive strength also given briefly in the following table .As per IS 516, cubes of sizes 150mm were cast and cured for 28 days. After 28 days curing cubes were taken out and allowed for drying for 24 hours and weights were taken. For acid attack 5% dilute hydrochloric acid is used. The cubes were to be immersed in acid solution for a period of 30 days. The concentration is to be maintained throughout this period. After 30 days the specimens were taken from acid solution. The surface of specimen was cleaned and weights were measured.

Table 9. Strength comparison of concrete specimens having different admixtures before and after the acidic attack

%of Admixtures(AS)	Compressive strength without subjecting to acid attack(normal concrete) N/mm^2	Acid attack with P^H 3.1		
		Percentage weight loss (Kg)	Compressive strength subjected to acid attack (N/mm^2)	Percentage decrease of compressive strength as compared to the normal concrete (%)
100%OPC+0% AS	30.60	3.99	28.22	7.78
95%OPC+5%AS	32.44	0.15	26.66	17.82
90%OPC+10%AS	20.22	3.89	15.22	24.73
80%OPC+20%AS	15.12	1.23	11.33	25.07
85%OPC+5%AS+10%FA	29.99	0.2	25.55	14.80
75%OPC+5%AS+20%FA	32.44	0.72	25.77	20.56
80%OPC+10%AS+10%FA	18.22	0.49	16.88	7.35
70%OPC+10%AS+20%FA	21.33	2.16	17.22	19.27
85%OPC+5%AS+10%SF	34.34	3.51	30.11	12.32
75%OPC+5%AS+20%SF	26.66	1.90	22.77	14.59
80%OPC+10%AS+10%SF	29.77	0.659	26.66	10.45
70%OPC+10%AS+20%SF	24.44	0.357	20.22	17.27

V. CONCLUSIONS

Compressive Strength and Acid attack tests were performed on concrete specimens prepared with Aluminium slag 5%,10%,20%and varying Fly Ash and Silica Fume with 10% and 20% . Using the test results, it can be concluded that for Aluminium Slag 5% the strength increased and further there is a rapid decrease with additional increase in Aluminium Slag (i.e 10%,20%)

The compressive strength for combination of 5%AS and 20%FA has shown considerable increase in strength. All other combinations with Fly Ash has no increase. It is observed that combination of AS 5% and 10%SF the compressive strength increased but for further increase in aluminium slag and Silica Fume content compressive strength reduced when compared to control concrete.

The compressive strength of cubes after Acid attack for controlled concrete is observed to lose 7.78% of strength and with replacement of AS with 5%,10%,20% , the percentage of strength loss further increase to 17.82,24.73and 25.07 respectively.

The combination of 10% AS and 10% FA is observed to have better resistance against Acid attack and the combination of 10% AS and 10% SF is also observed to have better resistance against Acid attack. All other combinations of FA and SF had relatively less compressive strength after Acid attack.

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