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EXPERIMENTAL STUDY ON USE OF FLY ASH AS A PARTIAL CEMENT REPLACEMENT IN CONCRETE

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Abstract

Fly ash is a by-product from the coal industry, which is widely available in the world. the use of fly ash in concrete as partial replacement of cement is gaining immense importance today. mainly on account of the improvement in the long-term durability of concrete combined with environmental benefits. The replacement of fly ash as a cementations component in concrete depends upon the design strength, water demand and relative cost of ash compared to cement. This paper reports the results of an experimental investigation carried out to study the effects of fly ash on strength development of concrete and the optimum use of fly ash in concrete. The concrete grade of M15 has been selected and designed as per IS 456-2000 Standard method.Cement was replaced by 10%, 20% and 30% of class F fly ash by the weight. After each mix preparation, nine cubes specimens are cast and cured. Necessary tests were carried out in fresh and hardened concrete. Workability was found from slump test. Tests for compressive strength were carried out on specimens at age 7,14 and 28 days.The test results were compared with the results of specimen prepared after control mix. Test results shows that, inclusion of fly ash generally improves the compressive strength up to certain percent of replacement.

Keywords: *fly ash*, *cement*, *compressive strength*, *workability*.

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دراسة تجريبية على استعمال الرماد المتطاير كبديل جزئي للأسمنت في الخرسانة

الملخص:

الرماد المتطاير هو منتج ثانوي من صناعة الفحم، والذي يتوفر على نطاق واسع في العالم. استخدام الرماد المتطاير في الخرسانة كبديل جزئي للأسمنت تكتسب أهمية كبيرة اليوم. أساسا بسبب التحسن الذي طرأ على متانة على المدى الطويل من الخرسانة جنبا إلى جنب مع الفوائد البيئية. استبدال الرماد المتطاير كمكون الالتحام في الخرسانة يعتمد على قوة التصميم، والطلب على المياه والتكلفة النسبية للرماد مقارنة بالإسمنت. هذه الورقة العلمية تعرض نتائج التحقيق التجريبي لدراسة آثار الرماد المتطاير على تطوير قوة الخرسانة والاستخدام الأمثل للرماد المتطاير fly ashفي الخرسانة. وقد تم اختيار خرسانة نوع M15 وتما التصميم بناء على IS 456 -2000. حيث ان الاسمنت تما استبداله بنسبة 10٪، 20٪ و30٪ من الرماد المتطاير فئة F مع الوزن. بعد اعداد الخلطات المطلوبة، تما صب تسع مكعبات قياسيةواجريت المعالجة المطلوبة. وكذلك أجريت الاختبارات اللازمة على الخرسانة الطازجة والمتصلدة.حيث قيست التشغلية للخلطة الخرسانة المحتوية على الرماد المتطاير باستخدام اختبار الهبوط (slump test).وأجريت اختبارات مقاومة الخرسانة للضغط لجميع العينات عند عمر 7،14 و 28 يوم . واظهرت النتائج للاختبارات أن التشغلية للخرسانة تزيد مع زيادة نسبة الرماد المتطاير المستبدل مكان الاسمنت وكذلك ان إدراج الرماد المتطاير عموما يحسن قوة الضغط تصل إلى نسبة معينة من الاستبدال وبعدها اي بعد هذه النسبة تبدأ مقاومة الخرسانة للضغط في التناقص.

كلمات البحث: الرماد المتطاير، والاسمنت، وقوة الضغط، التشغلية.

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1. Introduction

Concrete materials are the most galore manufactured materials in the world. Concrete is a desirable engineering material because of its high compressive strength, its ability to place in any form, its ability to withstand temperature to insulate the interior and its relative durability compared with other construction materials. It is used in dams, building, foundations, pavement, industrial plants, parking structures, pipes, fences – practically any engineered structure can be built using concrete.

The essential components of concrete are Portland cement, Gravel /stone, sand (aggregate) and water. Although the Portland cement content in concrete less than 20% of total volume of concrete, it is critical material system that, upon reacting with water, binds the other ingredients together. Unfortunately cement industry is using up high levels of energy as well as it is essential contributor in the emission of carbon dioxide (CO_2). Thus, the energy intensity of Portland cement production makes it the most expensive component of concrete.

There are many portland cement replacement materials that can be used to reduce the quantity of portland cement in concrete such as fly ash , slag and silica fume. These supplementary industrial by-product (IBP) materials are among the most feasible means of reducing the embodied energy and associated greenhouse gas (GHG) emissions. The concrete construction industry has been using (IBP) materials in concrete for more than half a century. The first major breakthrough was the construction of Hungry Horse Dam in 1948, which used 120,000 metric tons of fly ash.

When these materials are added to concrete mixes, the amount of cement that is necessary must be reduced, thus saving the raw materials such as limestone, coal etc. required for manufacture of cement. In addition to the energy and emissions benefits a number of these materials are byproducts of an industrial process that are often prepared for disposal in a landfill, thus can be obtained at a lower cost than Portland cement. On the other hand, replacement of a portion of the Portland cement by (IBP) material like fly ash can also result in a concrete having improved performance characteristics over the corresponding plain Portland cement concrete mixture. In addition, these materials greatly improve the durability of concrete through control of high thermal gradients, pore refinement and resistance to chloride and sulphate penetration. Moreover, improve compressive strength of concrete at early age. Strength development contributed by fly ash occurs through chemical combination of reactive fly ash glass with calcium hydroxide generated by hydration of Portland cement. This process is called pozzolanic activity.

Several researchers in the past investigated the effect of use fly ash as replacement material on the properties of the concrete adopting different theories. Some of the major research works are listed below.

According to a Marthong and Agrawal (2012), effect of fly ash additive on concrete properties result that, as workability of concrete increased with the inclusion of fly ash in comparison to that of concrete with pure cement. This is due to the increase of the paste volume that leads to the increase of plasticity and cohesion.

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The research carried out by Bentz et al(1997), indicated that curing conditions have considerable effect on degree of hydration of cement.thier work showed that by cured specimens at 100% relative humidity for 6 or 12 hours exposed to 90%RH, hydration process discontinued as all remaining capillary water was lost due to evaporation.

Al-Feel and AL-Saffar (2009) studied effect of curing methods on splitting, flexural and compressive strength of self – compacting concrete showed that specimens with water curing gave the highest results of concrete compressive strength, splitting tensile strength and flexural strength compared with specimens cured in air.

According to Amit Mittal (2010) experimental study on the use of fly ash in mix concrete, the results showed as fly ash content increase there is reduction in the strength of concrete. This is expected, as the secondary hydration due to pozzolanic action is slower at initial stage for fly ash concrete. The reduction is more at earlier ages as compared to later ages of concrete.

2. Experimental Program

2.1 Properties of fly ash:

In this experimental investigation, an attempt has made to study utilization of fly ash in concrete as a partial replacement of cement. Fly ash is finely divided residue, resulting from the combustion of ground or powdered coal and transported by the flue gases of boilers fired by the pulverized coal. It is available in large amounts as west product from thermal power stations and industrial plants. Fly ash is in two-type class C and F, in class C fly ash normally produced by burning sub-bituminous coal or lignite, usually has more than 20% lime CaO. While in class F fly ash produced by burning anthracite or bituminous coal. This fly ash is pozzolanic in nature and contains less than 20% CaO. The separation of fly ash into two classes reflects differences in composition, that affect cementations pozzolanic properties. fly ash Class C usually has pozzolanic properties, in addition to has some self-cementing properties. In the presence of water fly ash class, C will harden and gain strength over time greater than class F (Jatale, 2013). The physical and chemical properties of fly ash are given in Table 1.

Table 1: Properties of fly ash

Properties	**Description**	**Requirement as Is : 3812-2003**
Physical properties	Fineness– specific surface area m^2/kg	> 320
	Comp.strength at 28 days as % of Cement mortar cubes MPa	> 80
	Lime reactivity MPa	> 4.0
	Drying shrinkage	< 0.15
	Soundness by autoclaving Expansion	< 0.8

	Method	
	Retention on 45 micron sieve %	< 34
Chemical properties	Loss on ignition % by wt	< 12
	Silica, Iron Oxide and Alumina as(Sio_2, Fe_2O_3,Al_2O_3) total % by wt	> 70
	Silica as Sio_2 % by wt	> 35
	Magnesium oxide MgO % by wt	< 5.0
	Sulfur as SO_3 % by wt	< 2.75
	Alkalies as Na_2O by wt %	< 1.50

2.2 Materials:

Coarse aggregate:

Coarse aggregates are particles of gravel or crushed stone retained on the 10 mm sieve and ranging up to 150 mm. The most commonly used maximum aggregate size is 20 mm.

Fine aggregate:

Fine aggregates are particles of natural or synthetic sand passing the 5 mm sieve and free from impurities.

Water:

The water used for the study was free of organic matter, acids, suspended solids, alkalis and impurities which when present may have adverse effect on the compressive strength of concrete.

Portland cements:

Ordinary Portland Cement (OPC) 42.5 grade was used in all test specimens, all properties of materials are given in tables 2 and 3.

Table 2: Physical properties of Portland cement.

Sr.No.	Characteristics	Values	Value specified by IS:1489 (part1)-1991
1	Specific gravity	3.13	-----
2	compressive strength (28 days)MPa	$\leq$ 62.5	-----
3	Initial setting time ,minutes	$\geq$ 60	Minimum30
4	Soundness mm	$\leq$ 10	-----

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Table 3: Physical properties of coarse and fine aggregate.

Sr.No.	Characteristics	Test Value		
		Coarse aggregate		Fine aggregate
		CA-I	CA-II	
1	Type	crushed	crushed	----
2	Maximum nominal size mm	10	20	-----
3	Specific gravity	2.63	2.66	2.63
4	Total water absorption	1.70	1.75	2.30
5	Fineness modulus	7.01	6.66	2.51

2.3 Concrete mix design:

In the present study, M15 grade with nominal max as per IS 456-2000 was used. The concrete mix proportion (cement: fine aggregate: coarse aggregate) is 1:2:4 by weight and water cement ratio of 0.50 is taken without any admixture. The fly ash is blended at rate 0%, 10%, 20% and 30% by weight of cement in steps of 10%.

2.4 Compressive strength determination:

In this test sample of concrete is filled the mould of size 150 mm×150 mm × 150 mm and top of mould is strike off. A total number of 36 cubes were casted (figure 1). The fly ash added in place of cement in concrete in four different percentages starting from 10% and raised the mixing of fly ash up to 30% at interval of 10%. For each percent of fly ash, nine cubes were casted. The specimens are covered with wet gunny bags and are stored in place free from vibration ,in most air at least 90% relative humidity and at a temperature of 27degree ± 2degree for 24 hours from the addition of water to the dry ingredients. After this period, the specimen is removed and cured. At the end of curing period, the specimen is taken and tested immediately at different age’s i.e. 7, 14 and 28 days. The testing is done under the Testing Machine model no.CO55P113 figure 2. The crushing loads are noted and average compressive strength for three specimens is determined for each.

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Figure 1: the test specimens

Figure 2: Cube inside Compressive Strength Machine

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3. Results and Discussion

3.1 Workability

Workability of concrete increased with the increase quantity of fly ash content when comparison with pure cement. The reason may be due to the increase of the paste volume that leads to the increase of plasticity and cohesion. Fly ash particles tend to coat and lubricate the aggregate particles. The spherical shape of the fly ash particles contributes to the workability of concrete by reducing the friction at the aggregate paste interface, producing a ball bearing effect at the point of aggregate contact. The workability (slump) of concrete for different proportion of fly ash is presented in table 5 and showed in figure 3.

Table 5: Slump with different proportion of fly ash

% of fly ash	0%	10%	20%	30%
Slump(mm)	10	30	30	40

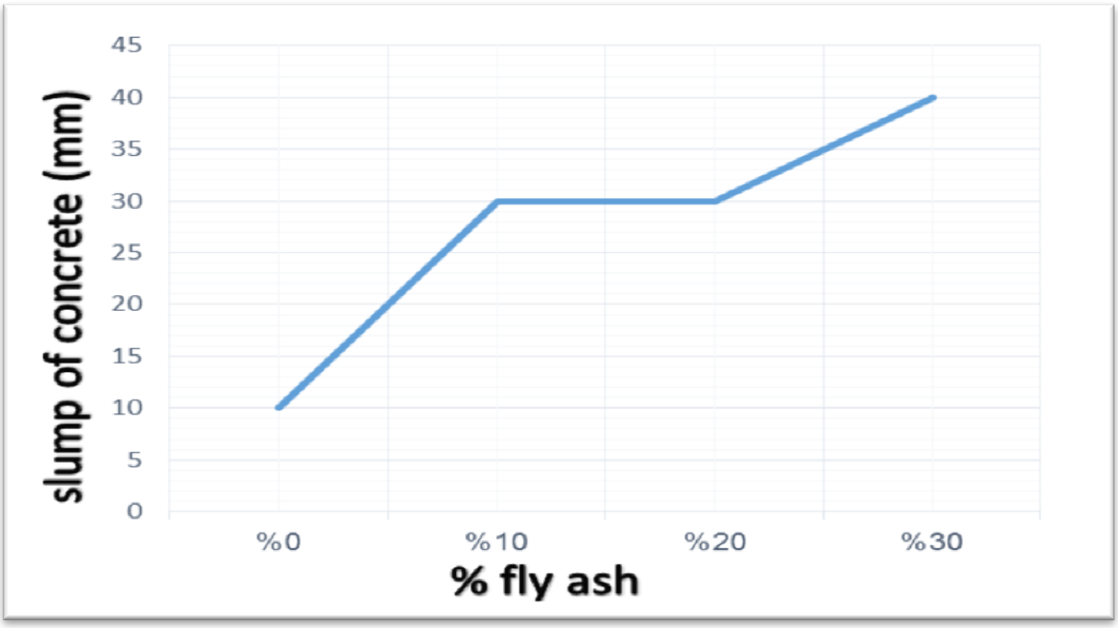

Figure 3: slump with different percentage of fly ash

3.2 Compressive Strength of Fly ash Concrete

The compressive strength of OPC and fly ash concrete are presented in Table 6 to 8, have been graphically represented in figure 4 to 6. Also for the ease of comparison, the relative compressive strengths are shown in figure 7.

Table 6*: Compressive strength for different Proportion of fly ash after 7 days curing*

Sr.No	**% fly ash**	**Compressive Strength N/Sq.mm**	**Avg. Comp. Strength N/Sq.mm**
1	0%	29.03	28.04
2		27.04	
3		28.05	
4	10%	21.20	19.73
5		17.44	
6		20.54	
7	20%	20.52	21.65
8		22.25	
9		22.18	
10	30%	18.82	19.27
11		19.00	
12		20.00	

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Table 7: *Compressive strength for different proportion of fly ash after 14 days curing*

Sr.No	% fly ash	Compressive Strength N/Sq.mm	Avg. Comp. Strength N/Sq.mm
1	0%	24.94	27.49
2		26.33	
3		31.22	
4	10%	20.49	21.77
5		23.63	
6		21.19	
7	20%	24.09	23.84
8		24.10	
9		23.32	
10	30%	22.04	21.39
11		21.26	
12		20.87	

Table 8: *Compressive strength for different proportion of fly ash after 28 days curing*

Sr.No	% fly ash	Compressive Strength N/Sq.mm	Avg. Comp. Strength N/Sq.mm
1	0%	35.89	33.65
2		33.04	
3		32.01	
4	10%	22.86	24.21
5		27.06	
6		22.72	
7	20%	26.95	26.75
8		25.39	
9		27.92	

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10	30%	23.59	24.88
11		23.64	
12		27.41	

- From the results obtained it can be clearly seen that for 10% to 20% replacement of fly ash with weight of cement ultimate compressive strength is increases and then if we further increases percentage of fly ash, ultimate compressive strength decreases.
- 0% fly ash i.e. concrete with no replacement of cement with fly ash, has maximum ultimate compressive strength development.
- Among all the mixes, for 7, 14 and 28 days compressive strength, no fly ash concrete achieved maximum strength. Test result showed that the 7 days compressive strength for OPC concrete is 31 %,23% and 32% higher than fly ash concrete of replacement level 10%, 20% and 30% respectively. 14 days compressive strength data obtained for 10%, 20%and 30% fly ash replacement level concrete strength were lower than no fly ash concrete by 21%, 13% and 22 % respectively. At this age, the reduction in strength is lower as compared to that of 7 and 28 days. Where for 28 days compressive strength test result for the same replacement level were lower by 29%, 21% and 26% when compared with plain concrete (no fly ash).
- Concrete with 20% of fly ash as a replacement cement content gives higher values of concrete compressive strength than concrete with 10% and 30% of fly ash.
- For fly ash blends greater than 20% fly ash, the rates of strength development as well as final strengths both reduce with addition of fly ash. In long terms, concrete with higher level of fly ash gains comparable with that of concrete with pure cement.

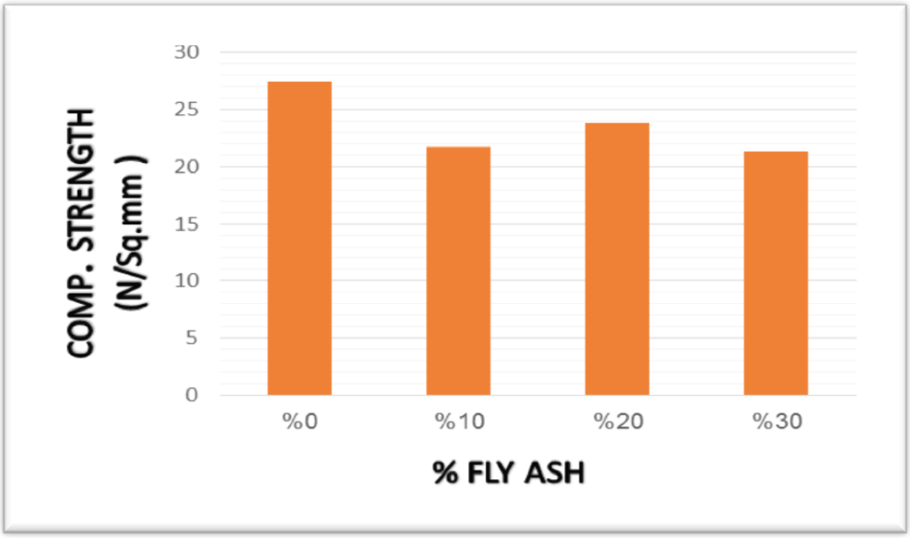

Figure 4: Compressive Strength for Different Proportion of Fly Ash After 7 Days Curing

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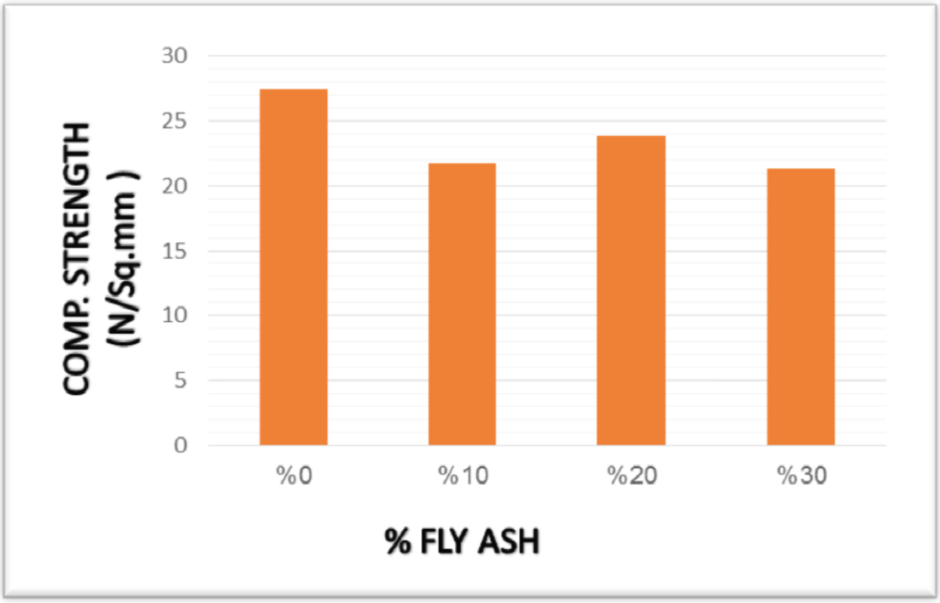

Figure 5: Compressive Strength for Different Proportion of Fly Ash After 14 Days Curing

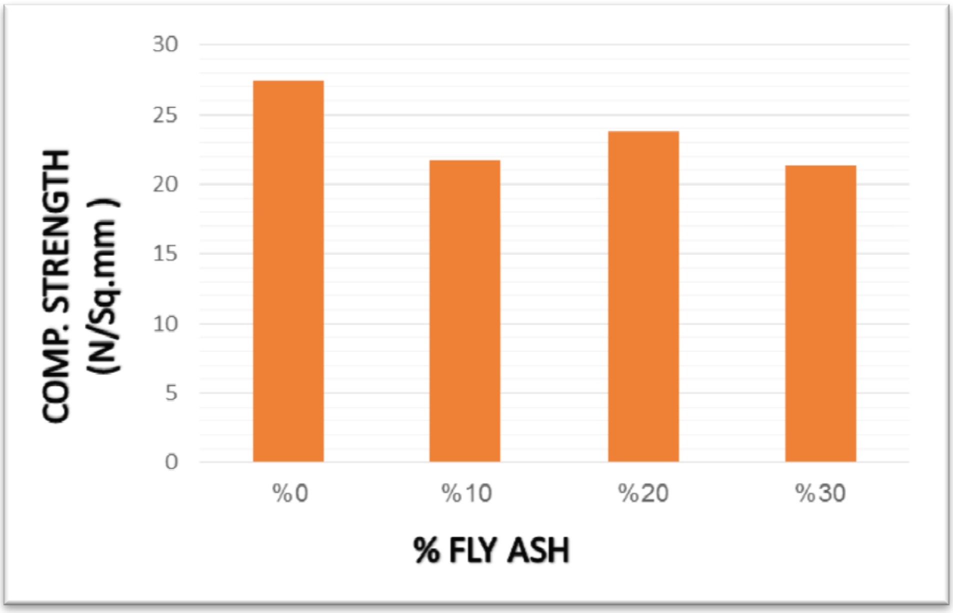

Figure 6: Compressive Strength for Different Proportion of Fly Ash After 28Days Curing

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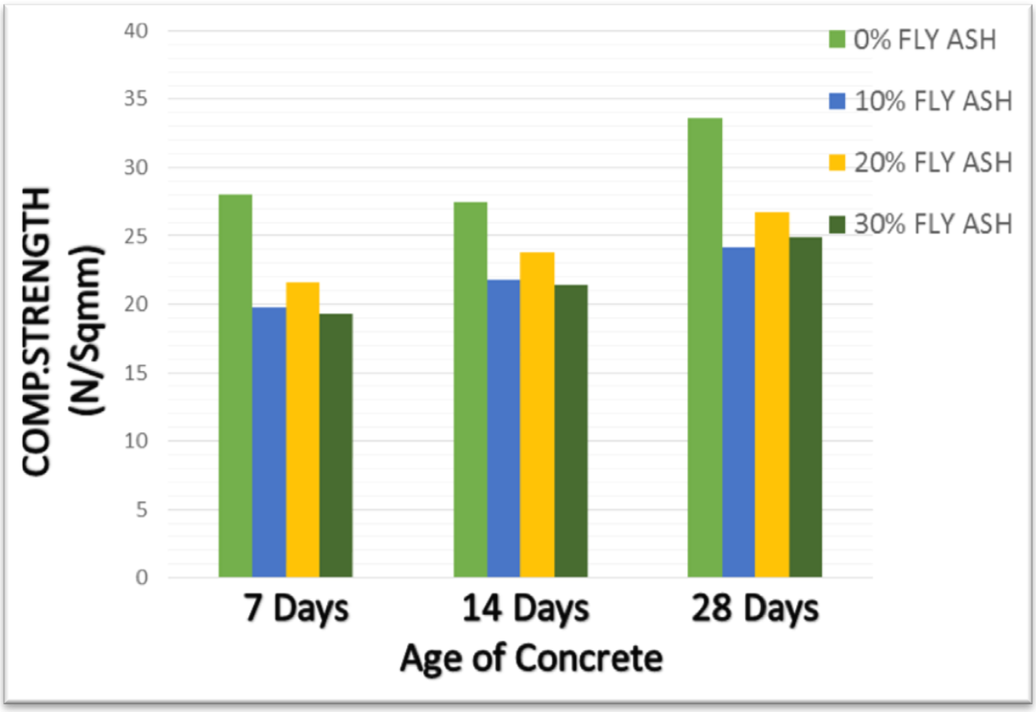

Figure 7: Compressive Strength for Different Proportion of Fly Ash and for different age of concrete

4. Conclusion

From the experimental work carried out and the analysis of the results following conclusions seem to be valid with respect to the utilization of fly ash:

- ❖ Use of fly ash improves the workability of concrete.
- ❖ Till the addition of fly ash up to 20% there is negligible change in the compressive strength of concrete.
- ❖ The rate of gain in strength of fly ash concrete specimens is observed to be lower than the corresponding OPC concrete.
- ❖ Utilization of fly ash in any construction work as a replacement of cement, provides lower impact on environment (reduce CO_2 emission) and judicious use of resources (energy conservation, use of by-product).
- ❖ Use of fly ash reduces the amount of cement as well as heat of hydration in a concrete mix. Thus, the construction work with fly ash concrete becomes environmentally safe.
- ❖ The use of fly ash in concrete will possibly reduce cost of concrete.

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