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RESEARCH ARTICLE

STUDY OF PARTIAL REPLACEMENT OF CEMENT BY SILICA FUME.

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Abstract

The use of silica fume had major impact on industries, ability to routinely and commercially produce silica fume modified concrete of flow able in nature but yet remain cohesive, which in turn produces high early and later age strength including resistant to aggressive environments. This study is an experimental on the nature of silica fume and its influences on the properties of fresh concrete. The partially replacement of cement by silica fume the strength parameters of concrete have been studied. First the strength parameters of concrete without any partial replacement were studied then strength parameters by partial replacement with silica fume have been studied by placing cube and cylinder on compression testing machine (CTM).

Silica fume were used to replace 0% to 15% of cement, by weight at increment of 5% for both cube and cylinder. The results showed that partial replacement of cement with silica fume had significant effect on the compressive strength of cube and split tensile strength cylinder. The strength of concrete increases rapidly as we increases the silica fume content and the optimum value of compressive strength is obtained at 10% replacement. After 10% its start decreasing under uniform load condition of 4 KN and similarly the split tensile strength increases up to 10% and then start decreasing under the uniform load condition of 2KN.

Introduction:-

Silica fume, also known as micro silica is an amorphous (non-crystalline) polymorph of silicon dioxide. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production. It is extremely fine with particles size less than 1 micron and with an average diameter of about 0.1 microns, about 100 times smaller than average cement particles. Its behaviour is related to the high content of amorphous silica (> 90%). The reduction of high-purity quartz to silicon at temperatures up to 2,000°C produces SiO_2 vapours, which oxidizes and condense in the low temperature zone to tiny particles consisting of non-crystalline silica.

During the last three decades, great strides have been taken in improving the performance of concrete as a construction material. Particularly Silica Fume (SF) and fly ash individually or in combination are indispensable in production of high strength concrete for practical application. The use of silica fume as a pozzolana has increased worldwide attention over the recent years because when properly used it as certain percent, it can enhance various properties of concrete both in the fresh as well as in hardened states like cohesiveness, strength, permeability and durability. Silica fume concrete may be appropriate in places where high abrasion resistance and low permeability are of utmost importance or where very high cohesive mixes are required to avoid segregation and bleeding.

The history of silica is relatively short, the first recorded testing of silica fume in Portland cement based concretes was conducted in 1952 and it was not until the early 1970's that concretes containing silica fume came into even limited use. The early work done in Norway received most of the attention, since it had shown that Portland cement-based-concretes containing silica fumes had very high strengths and low porosities. Since then the research and development of silica fume made it one of the world‘s most valuable and versatile admixtures for concrete and cementious products.

The objective of this study is to find the effect of partial replacement of Silica fume on the strength characteristics of concrete. Three percentage levels of replacement i.e. 5, 10 and 15 percent are considered for partially replacing cement with silica fume. M30 concrete grade is initially designed without replacement and subsequently cement is partially replaced with silica fume.

Experimental work:-

To achieve the objectives of this study, an experimental programming was planned to investigate the effect of silica fume on compressive strength and split tensile strength of concrete. The various tests have been conducted on cement, fine aggregate, coarse aggregate, water, silica fume and on the hardened concrete specimen (cubical and cylindrical) after suitable time period of curing 7, 14 and 28 days with and without replacement of cement with silica fume.

Materials:-

The required strength or target strength of concrete can be obtained by careful selection of ingredients, correct grading of ingredients, accurate water measurements and adopting a good workmanship in mixing, transporting, placing, compacting, finishing and curing of concrete in the construction work. The properties of material used for making the concrete mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were cement, coarse aggregates, fine aggregates, water and silica fume. The aim of studying of various properties of materials is used to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular strength.

Ordinary portland cement:-

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. It constitutes only about 20 percent of the total volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days.

The cement as determined from various tests conforming to Indian Standard IS: 8112:1989 are listed in Table 1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength.

Table 1:- Properties of OPC 43 grade concrete:

S.No	Characteristics	Values obtained experimentally	Values specified by IS
1	Specific gravity	3.15	
2	Standard consistency(%)	33	
3	Initial setting time	105(minutes)	30(minutes)
4	Final setting time	430(minutes)	600(minutes)
5	Compressive strength 3 days 7 days 28 days	 25.2 N/mm^2 37.9 N/mm^2 47.8 N/mm^2	 23 N/mm^2(minimum) 33 N/mm^2(minimum) 43 N/mm2(minimum)

Aggregate:-

Aggregates constitute the bulk of a concrete mixture and give dimensional stability to concrete. The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean, hard, strong and well graded.

Coarse aggregate:-
The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types:-

1. Crushed graves or stone obtained by crushing of gravel or hard stone.
2. Uncrushed gravel or stone resulting from the natural disintegration of rock
3. Partially crushed gravel obtained as product of blending of above two types.

The normal maximum size is gradually 10-20 mm; however particle sizes up to 40 mm or more have been used in Self Compacting Concrete. Locally available coarse aggregate having the maximum size of 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. Specific gravity and other properties of coarse aggregates are given in **Table 2**. The sieve analysis of coarse aggregate was done. Table 2 the result of sieve analysis. Proportioning of coarse aggregates was done and fineness modulus was obtained.

Table 2: Properties of coarse aggregate

Characteristics	Value
Colour	Grey
Size	20mm
Shape	Angular
Specific gravity	2.74

Fine aggregate:-
The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:

1. Natural sand, i.e. fine aggregate resulting from natural disintegration of rocks.
2. Crushed stone sand, i.e. fine aggregate produced by crushing hard stone.
3. Crushed gravel sand, i.e. fine aggregate produced by crushing natural gravel.

According to size, the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. In this experimental program**,** fine aggregate was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and conforming to grading zone II. It was coarse sand light brown in colour. Sieve analysis and physical properties of fine aggregate are tested as per IS:383-1970 and results are shown in Table 3.

Table 3: Properties of fine aggregate

Characteristics	Value
Specific gravity	2.34
Bulk density(kg/m^3)	1.3
Fineness modulus	2.62
Water absortption	0.88

Cement:-
Cement is considered as the best binding material and is being commonly used as a binding material in the construction of various engineering structures these days. Portland cement is referred as ordinary Portland cement is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. Concrete is made by Portland cement, water and aggregates. Cement constitutes about 20 % of the total volume of concrete. Portland cement is hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name Portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England.

Classification of OPC:-
Depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. Cement is classified as
a) 33 grade cement

b) 43 grade cement
c) 53 grade cement
If 28 days strength is not less than 33N/mm^2, it is called 33 grade of cement, if the strength is not less than 43N/mm^2, it is called 43 grade of cement, and if the strength is not less than 53N/mm^2, it is called 53 grade of cement. But actual strength obtained by these cements at the factory is much higher than the BIS specifications.

Water:-
Generally, water that is suitable for drinking is satisfactory for use in concrete. The potable water is generally considered satisfactory for use in concrete. The water was taken from Arni University Civil Engineering Department. This was free from any detrimental contaminants and was good potable quality.

Test methods:-
The methods used for testing cement, coarse aggregates, fine aggregate and concrete are given below:

Specific gravity:-
It is ratio of the weight of a given volume of a substance to the weight of an equal volume of some reference substance, or equivalently the ratio of the masses of equal volumes of two substances. Figure 1. shows estimation of specific gravity.

Figure 1:- Specific gravity of aggregate.

Compressive strength of concrete:-
The compressive strength of concrete is one of the most important and useful properties of concrete. Test specimens of size 150mm×150mm×150mm were prepared for testing the compressive strength concrete. The concrete mixes of varying percentages (0%, 5%, 10%, 15%) of silica fume as partial replacement of cement were cast into cubes for subsequent testing. In this work, to make the concrete coarse aggregate of size 20mm, fine aggregates sand of zone II, Ordinary Portland cement (OPC), and Silica fume were mixed properly with appropriate proportions for dry mix followed by addition of water and then mixed efficiently to achieve uniform and high workable mix. Before placing concrete in the moulds the interior surface of the moulds and the base plates were oiled with lubricant before the concrete has been placed than the concrete has been placed in 150 mm ×150 mm×150 mm cube. The concrete is filled up to 1/3rd height of the mould. Each layer is tamped at least 35 strokes of the tamping rod. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of 27 ± 2ºC. The specimen was cast were tested after 7, 14 and 28 days of curing measured from the time specimen placed for curing. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The uniform applied loading of 4KN is given to sample in compression testing machine (CTM).

Figure 2:- Casting of cube.

The load was applied axially without shock till the specimen was crushed. Results of the compressive strength test on concrete with and without varying proportions (5%, 10% and 15%) of silica fume replacement at the age of 7days, 14 days and 28 days were noted.

The cubes were tested using compression testing machine (CTM).

P/A = Compressive stress.

Where, P = Load (N) and A = Area (mm^2).

Split tensile strength:-

Concrete being a brittle material is not expected to resist direct tensile forces. However tension is of importance with regard to cracking, which is a tensile failure. Most of the cracking is due to the restraint of contraction induced by drying shrinkage or lowering of temperature the tensile strength of concrete varies from 7% to 11% of the compressive strength but on average it is taken as 10% of compressive strength. Further it has been observed that higher the compressive strength, lower the relative tensile strength.

The split tensile strength of concrete is determined by casting cylinders of size 100mm ×200mm (Figure 3). Sample is prepared similar to that for cubical specimen. The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading. For Cylinder specimen concrete mix were made as cubes specimen given above. The concrete was thoroughly mixed until it achieved homogenous and uniform consistency. The fresh concrete was casted in cylinder in three layers each layer is compacted by a tamping rod. All freshly cast specimens were left in moulds for 24 hours before being demoulded. The demoulded specimens were cured in water for 28 days at a temperature of 27±2ºC, were air dried and then tested for its split tensile strength as per Indian standards. Two specimens were prepared for each proportion of silica fume i.e, 5%, 10% and 15% for 28 days tests.

Split tensile strength test was carried out conforming to IS 516-1959 to obtain tensile strength of concrete at the age of 28 days. The cylinders of size 100mm in diameter and 200mm in length were tested using compression testing machine (CTM). The uniform applied loading of 2KN is given to sample in compression testing machine (CTM). The split tensile strength of concrete is most often evaluated using a split cylinder test, in which a cylindrical specimen is placed on its side and loaded in diametrical compression, so to induce transverse tension.

Practically, the load applied on the cylindrical concrete specimen induce tensile stresses on the plane containing the load and relatively high compressive stresses on the plane containing the load and high compressive stresses in the area immediately around it. The split tensile strength obtained by formula given below:

$$T = 0.637P/DL$$

Where,

T= split tensile strength in MPa.
P = Applied load.
D = Diameter of concrete cylinder sample in mm.
L = length of concrete cylinder sample in mm.

Figure 3:- Split tensile strength.

Concrete mixes:-

Mix design for M_{30} grade of concrete was carried out using the guidelines prescribed by IS: 10262- 1982. The designed concrete mix for M_{30} served as basic control mix (CM). Silica fume concrete mixes were obtained by adding silica fume to basic control mix in percentages varying from 0 to 15% at an increment of 5% by weight of cement. (SFC0, SFC5, SFC10, SFC15).

Batching, mixing, and curing:-

The concrete ingredients viz. cement, sand and coarse aggregate were weighed according to M_{30} and are dry mixed on a platform. To this the calculated quantity of silica fume was added and dry mixed thoroughly. The required quantity of water was added to the dry mix and homogenously mixed. The homogeneous concrete mix was placed layer by layer in moulds kept on the vibrating table. The specimens are given the required compaction both manually and through table vibrator. After through compaction the specimens were finished smooth. After 24 hours of casting, the specimen were demoulded and transferred to curing tank where in they were immersed in water for the desired period of curing.

MIX DESIGN (M30):-

A) Test data for materials

(i)	Specific gravity of cement	3.14
(ii)	Specific gravity of coarse aggregates	2.74
(iii)	Specific gravity of fine aggregates	2.34
(iv)	Zone of fine aggregates	II
(v)	Water absorption of coarse aggregates	0.43%
(vi)	Water absorption of fine aggregates	0.88%

Result and discussion:-

Thepresentation of results obtained from various tests conducted on concrete specimens cast with and without silica fume are shown here.

The experimental program was planned to investigate the effect of silica fume on compressive strength and split tensile strength concrete. The experimental program consists of casting, curing and testing of controlled and silica fume concrete specimen at different ages.

The experimental program included the following:

- Testing of properties of materials used for making concrete.
- Design mix (M20).
- Casting and curing of specimens.
- Tests to determine the compressive strength and split tensile strength of concrete.

Compressive strength:-

General:-

In most structural applications, concrete is employed primarily to resist compressive stresses. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains.

Test Procedure and ResultsL:-

Test specimens of size 150 *150* 150 mm were prepared for testing the compressive strength concrete. The concrete mixes with varying percentages (0%, 5%, 10% and 15%) of silica fume as partial replacement of cement were cast into cubes and cylinders for subsequent testing. In this study, to make concrete, cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine aggregates. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of 27^0 C. The specimens so cast were tested after 7, 14 and 28 days of curing measured from the time water is added to the dry mix. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Results of the compressive strength test on concrete with varying proportions of silica fume replacement at the age of 7, 14 and 28 days are given in the Table 4, 5 and 6.

Table 4:- Compressive strength of cube for 7 days.

Mix(%)	Compressive strength(N/mm^2) after 7days		Average compressive strength after 7 days
	Specimen 1	Specimen 2	
0	18.62	17.60	18.11
5	19.70	18.98	19.34
10	20.80	21.20	21
15	18.60	18	18.3

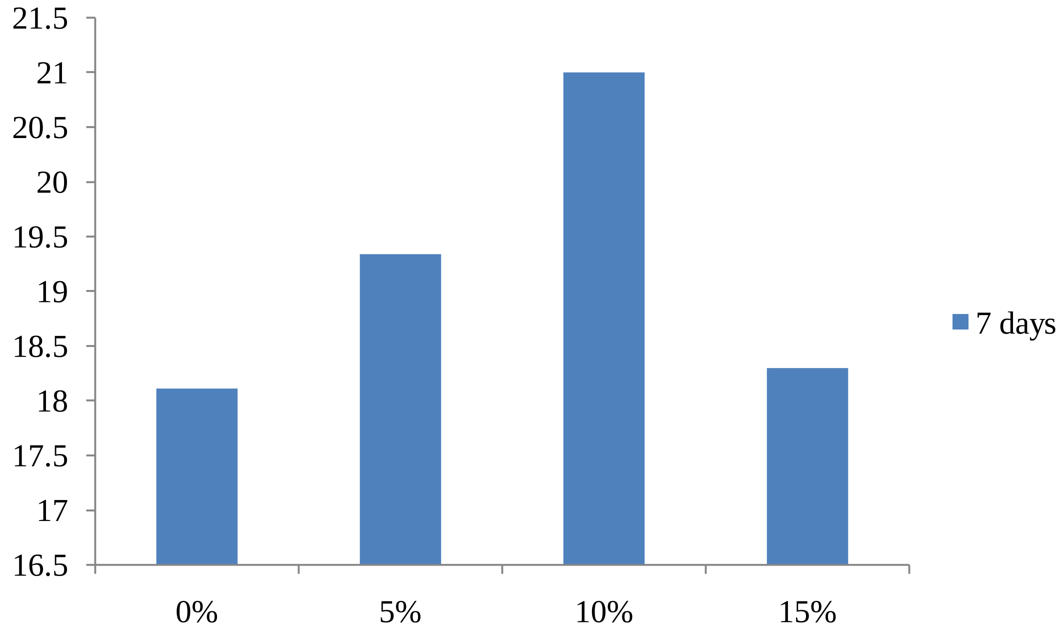

Figure 4:- Graph representation of cube for 7 days.

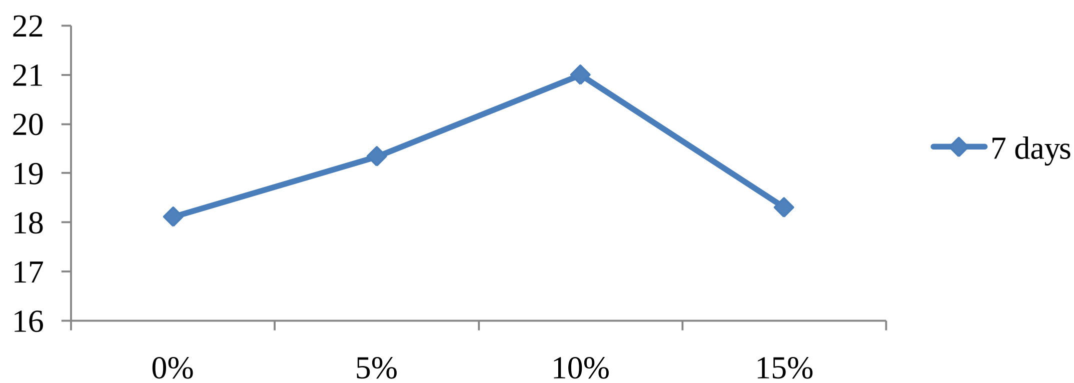

Figure 5:- Linear representation of cube for 7 days.

The cube strength results of concrete mix are also shown graphically in Figure 4. The compressive strength increases as compared to control mix as the percentage of silica fume is increased. As we increase the percentage of silica fume its compressive strength increases continuously from 5% to 10% respectively and after 10% its start decreasing. Figure 5. shows the variation of percentage increase in compressive strength with replacement percentage of silica fume. The results also indicate that early age strength gain i.e. at 7, 14 and 28 days, is higher when compared to the control mix if 10% of cement is replaced by silica fume.

Table 5:- Compressive strength of cube for 14 days.

Mix(%)	Compressive strength(N/mm^2) after 14 days		Average compressive strength after 14 days
	Specimen 1	Specimen 2	
0	22.96	22.78	22.87
5	23.28	23.52	23.40
10	29.06	30.24	29.65
15	26.39	26.98	26.68

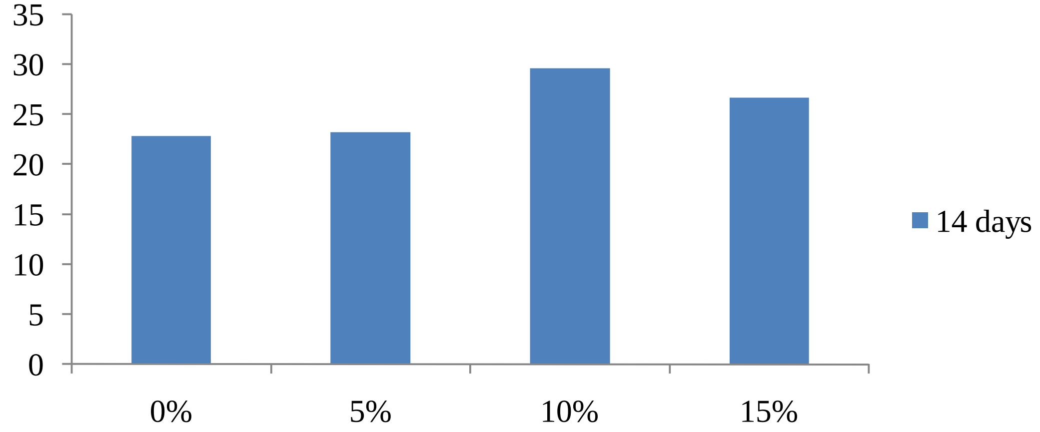

Figure 6:- Graph representation of cube for 14 days

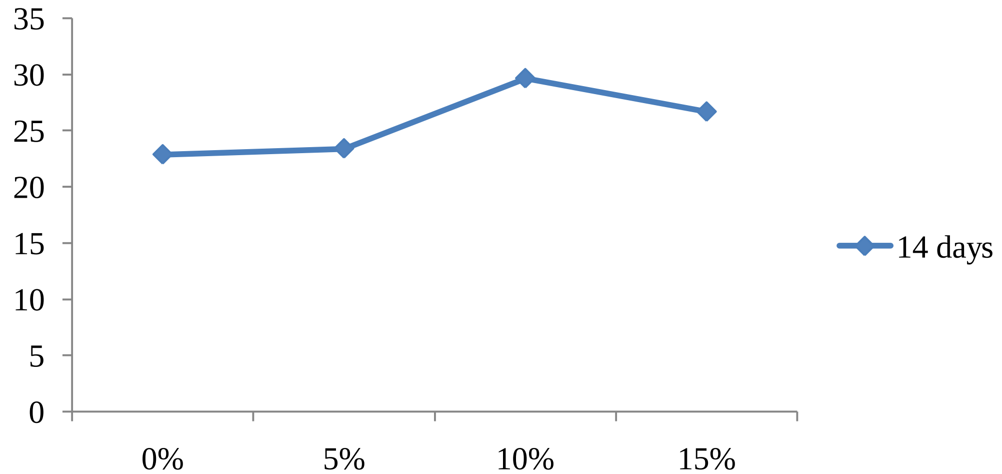

Figure 7:- Linear representation of cube for 14 days.

Table 6:- Compressive strength of cube for 28 days.

Mix(%)	Compressive strength(N/mm^2) after 28 days		Average compressive strength after 28 days
	Specimen 1	Specimen 2	
0	25.80	26.60	26.20
5	31.80	31.08	31.44
10	34.80	35.06	34.93
15	30.30	30.10	30.20

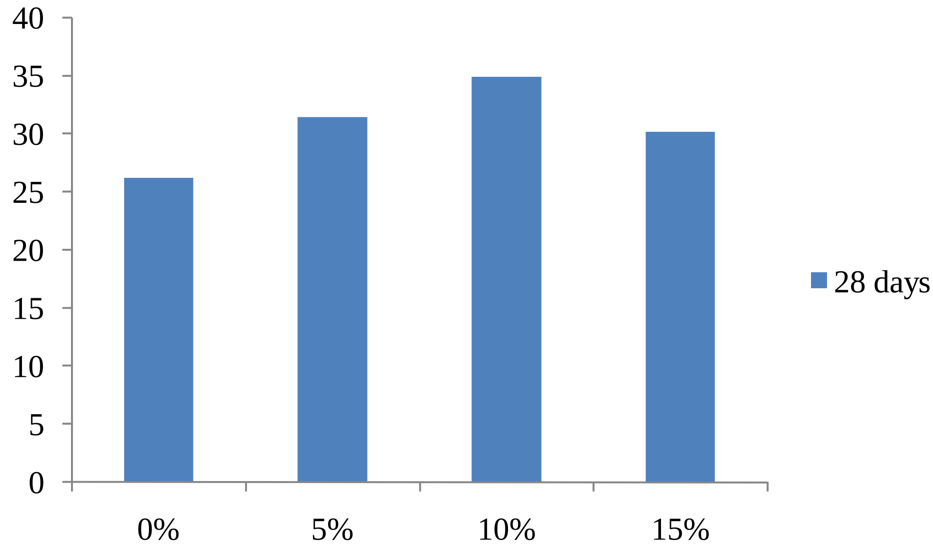

Figure 8:- Graph representation of cube for 28 days.

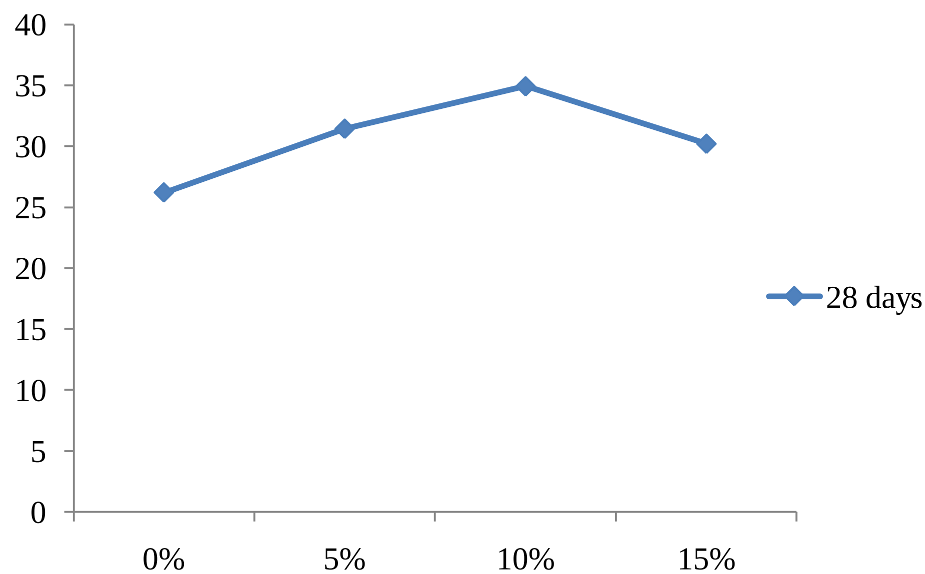

Figure 9:- Linear representation of cube for 28 days.

Comparison of strength of cube according to days:-

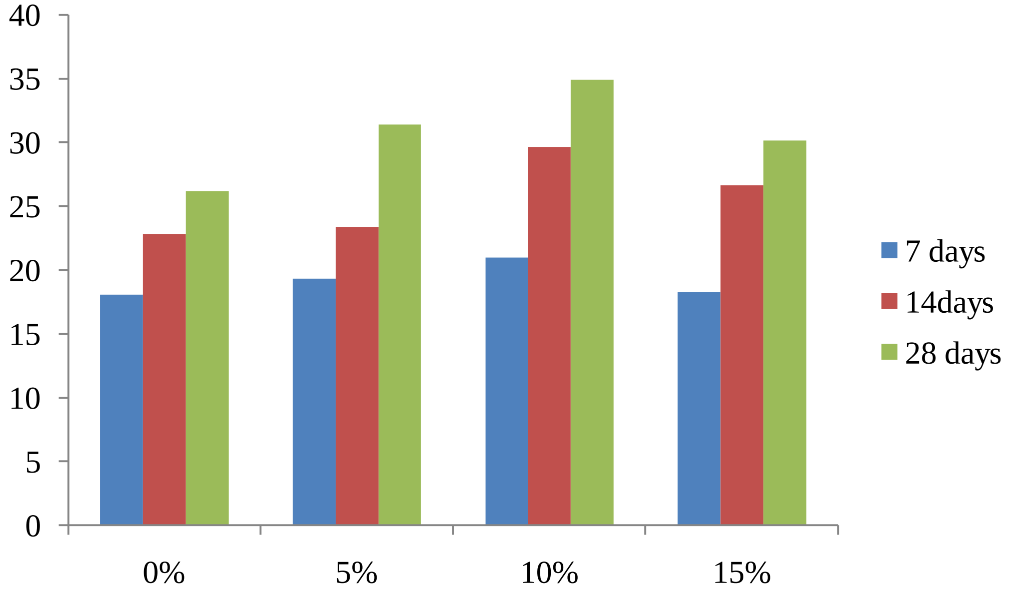

Figure 10:- Comparison of cubes according to days.

Linear camparision of cubes according to days:-

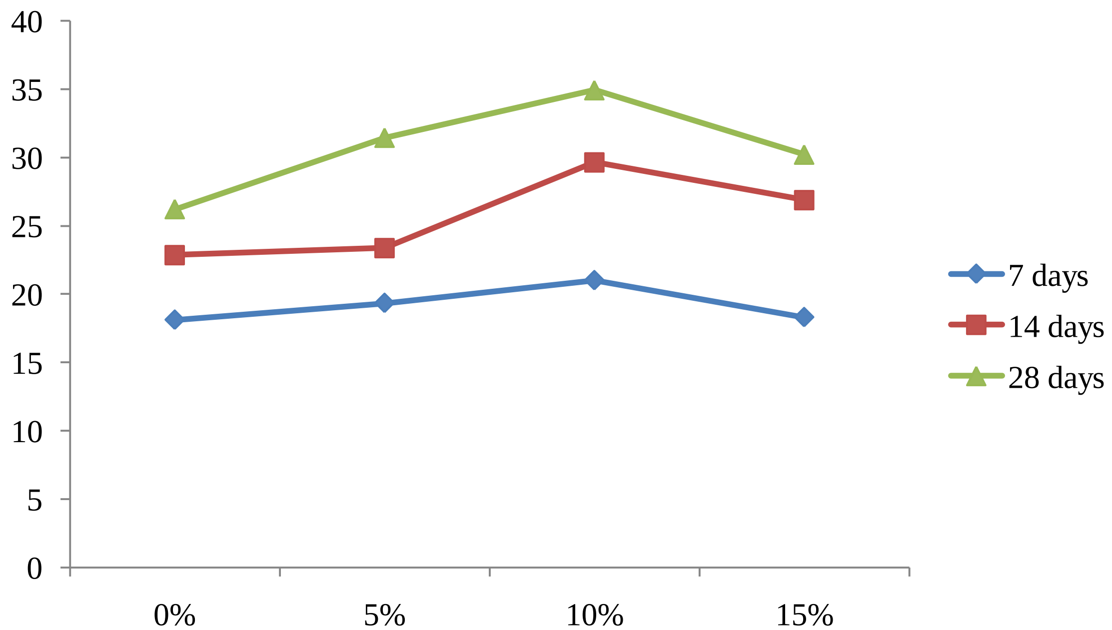

Figure 11:- Linear comparison of cubes according to days.

Split tensile strength:-

Test specimens of size 100* 200 mm were prepared for testing the split tensile strength of concrete. The concrete mixes with varying percentages (0%, 5%, 10% and 15%) of silica fume as partial replacement of cement were cast into cylinders for subsequent testing. In this study, to make concrete, cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine aggregates. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of 27^0 C. The specimens so cast were tested after 7, 14 and 28 days of curing measured from the time water is added to the dry mix. For testing in tension, no cushioning material was placed between the specimen and the plates of the machine. The load of 2KN was applied axially without shock till the specimen was crushed. Results of the split tensile strength test on concrete with varying proportions of silica fume replacement at the age of 7, 14 and 28 days are given in the Table 7, 8, 9. The cylinder strength results of concrete mix are also shown graphically in Figure 12, 14 and 16. The tensile strength increases as compared to control mix as the percentage of silica fume is increased.

Table 7:- Split tensile strength of cylinder for 7 days.

Mix(%)	**Split tensile strength strength(N/mm^2) after 7 days**		**Average compressive strength after 7 days**
	Specimen 1	**Specimen 2**	
0	2.42	2.82	2.62
5	2.72	2.96	2.84
10	3.92	3.98	3.95
15	3.67	3.23	3.45

As we increase the percentage of silica fume its compressive strength increases continuously from 5% to 10% respectively and after 10% its start decreasing. Figure 4.9 shows the variation of percentage increase in tensile strength with replacement percentage of silica fume. The results also indicate that early age strength gain i.e. at 7, 14 and 28 days, is higher when compared to the control mix if 10% of cement is replaced by silica fume.

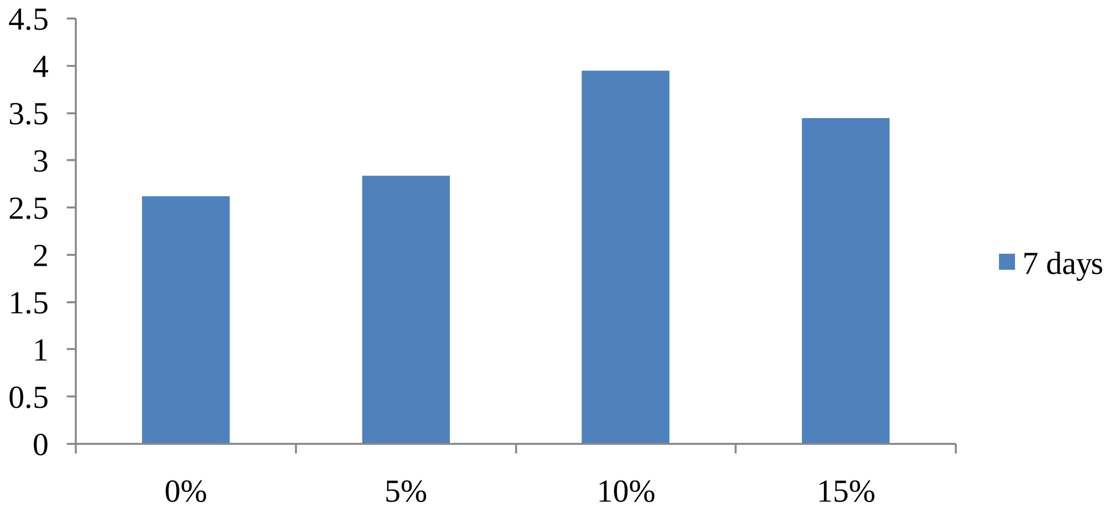

Figure 12:- Graphical representation of cylinder 7 days.

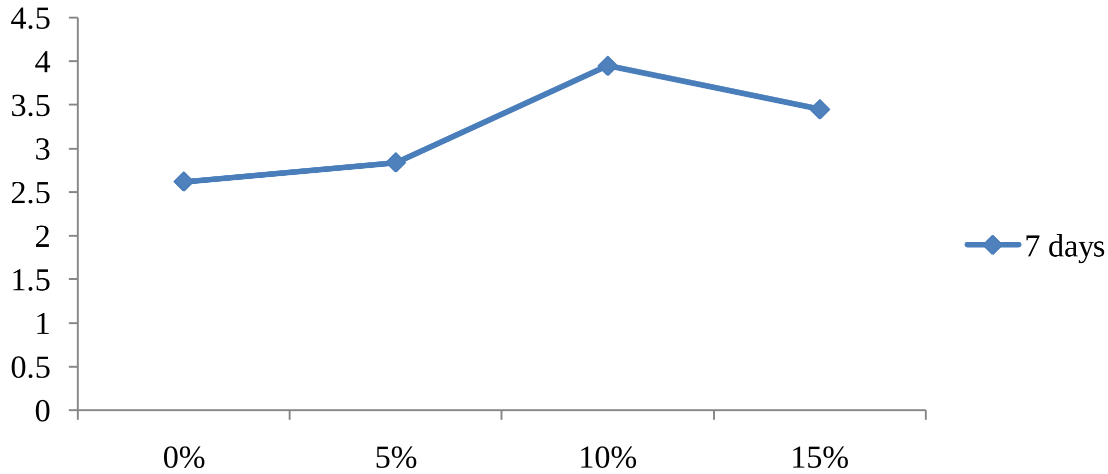

Figure 13:- Linear representation of cylinder for 7 days.

Table 8:- Split tensile strength of cylinder for 14 days.

Mix(%)	Split tensile strength strength(N/mm^2) after 14 days		Average compressive strength after 14 days
	Specimen 1	Specimen 2	
0	3.11	3.52	3.31
5	3.98	3.74	3.86
10	4.29	3.97	4.13
15	3.92	3.91	3.91

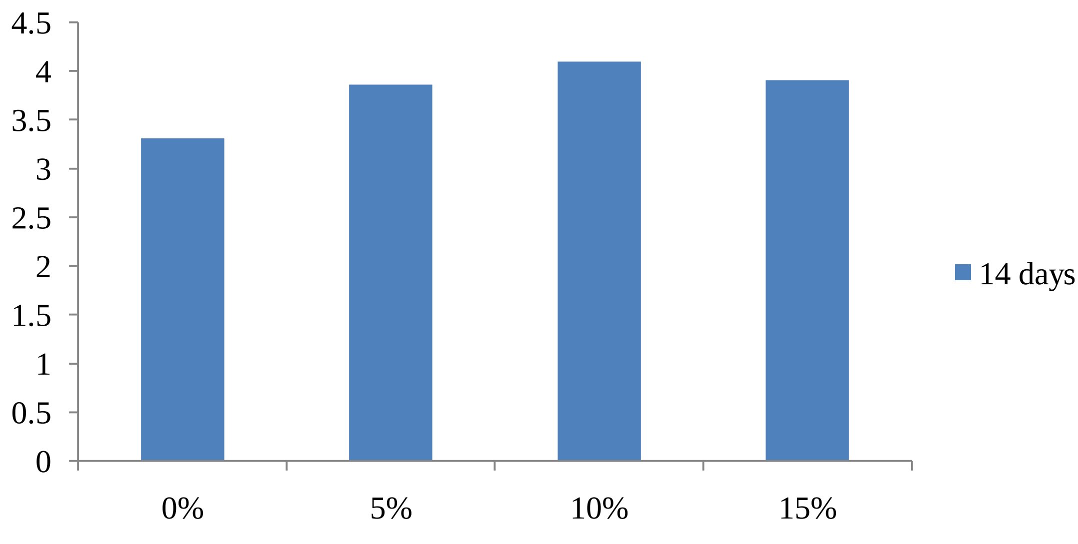

Figure 14:- Graphical representation of cylinder for 14 days.

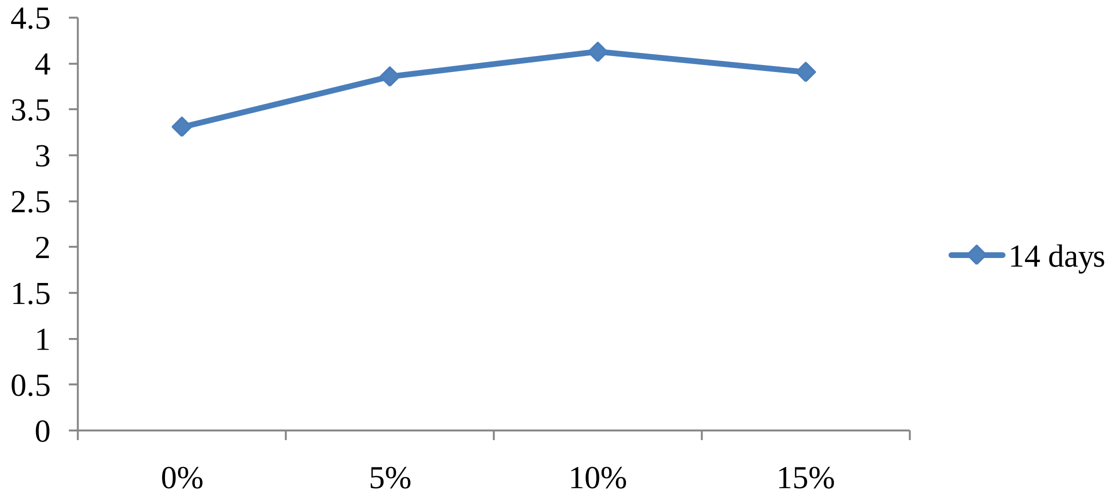

Figure 15:- Linear representation of cylinder for 14 days.

Table 9:- Split tensile strength of cylinder for 28 days.

Mix(%)	Split tensile strength strength(N/mm^2) after 28 days		Average compressive strength after 28 days
	Specimen 1	Specimen 2	
0	4.47	4.76	4.71
5	4.81	4.68	4.75
10	4.92	4.89	4.91
15	4.74	4.56	4.65

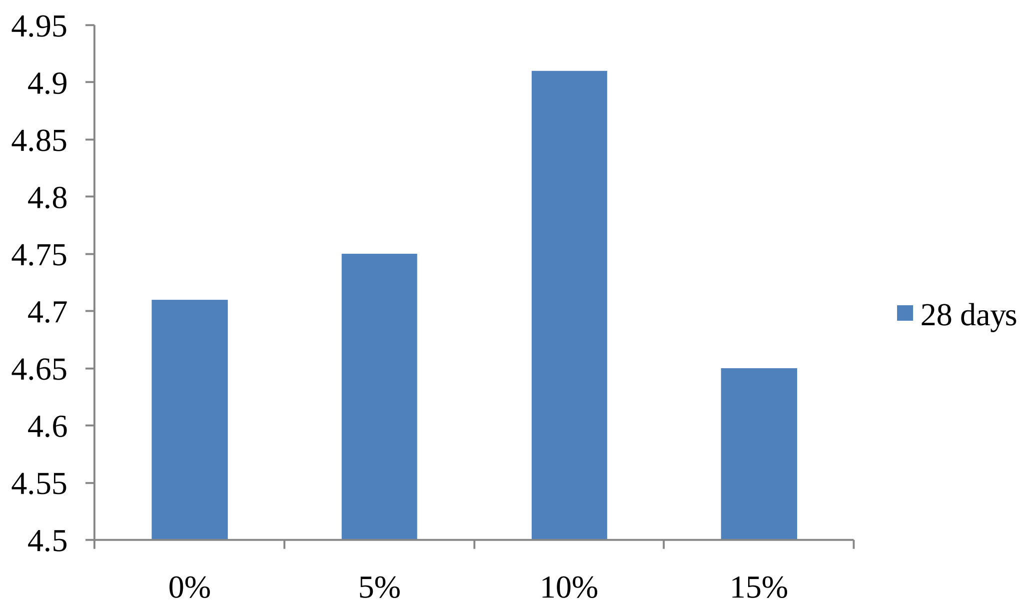

Figure 16:- Graphical representation of cylinder for 28 days.

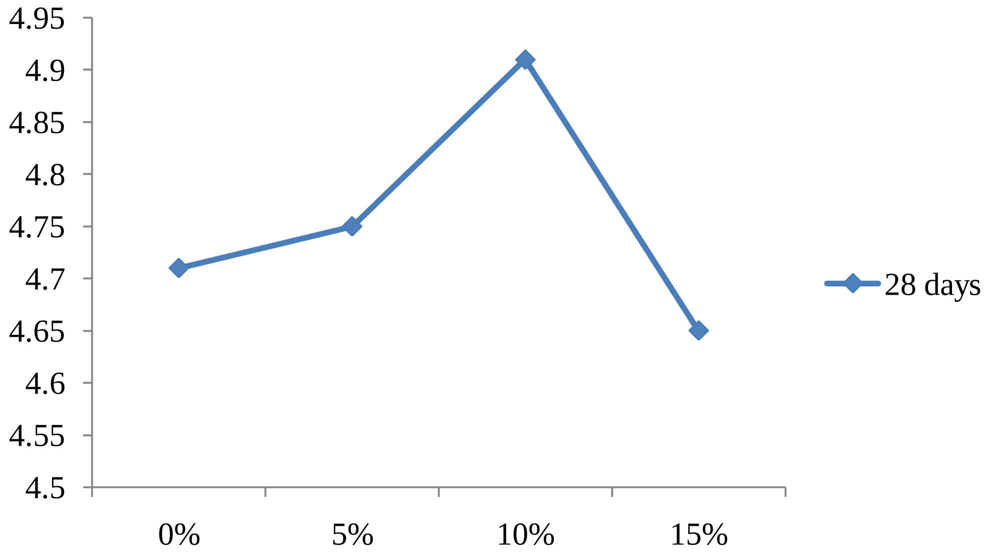

Figure 17:- Linear representation of cylinder 28 days.

Difference between cylinder strength according to days:-

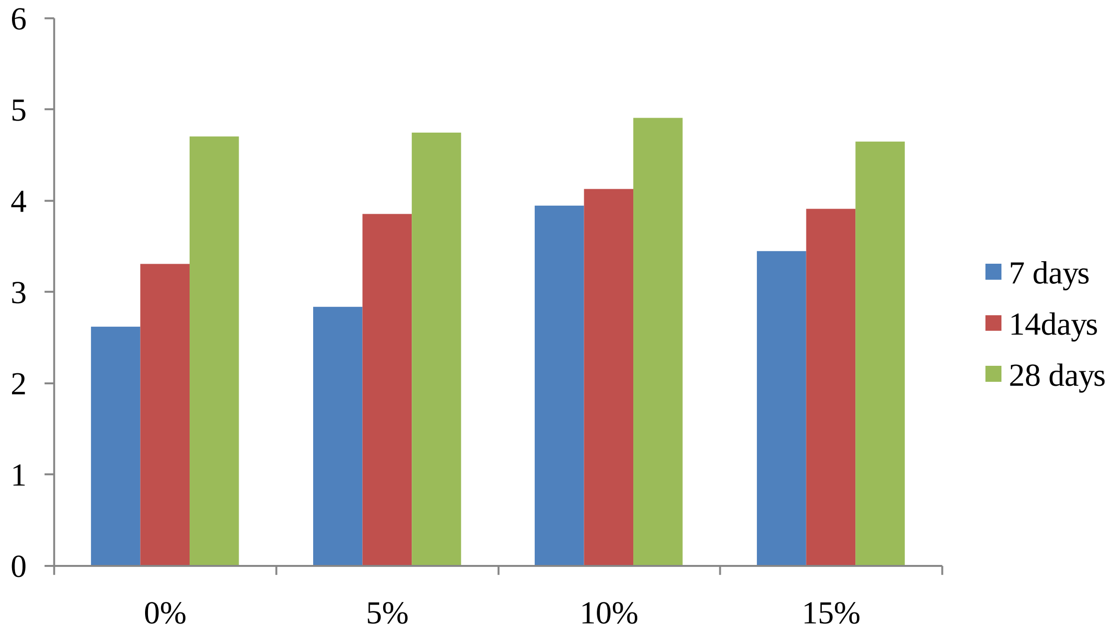

Figure 18:- Graphical representation of cylinder according to days.

Linear representation of cylinder according to days:-

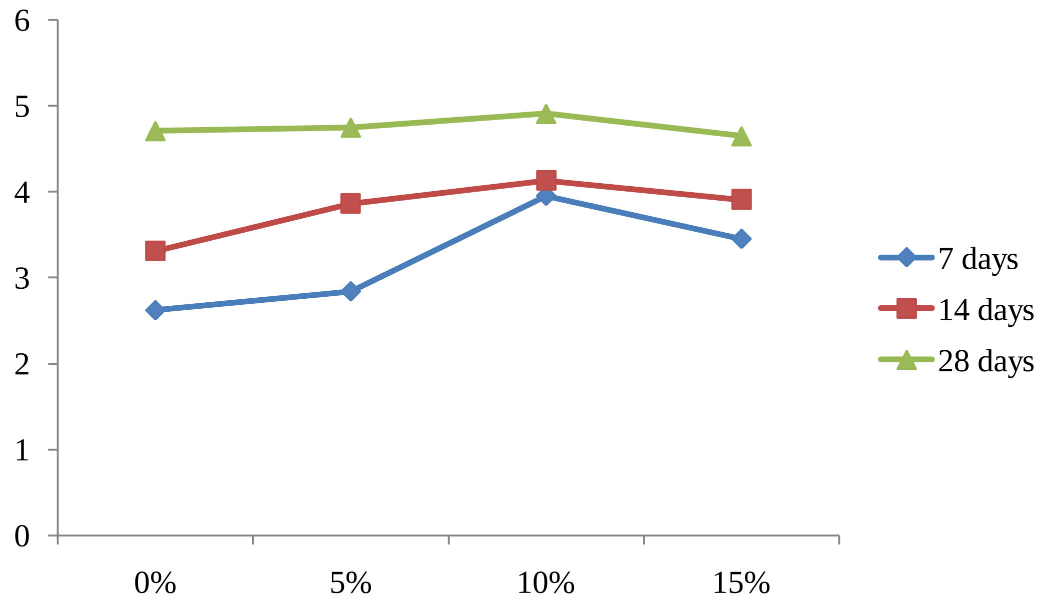

Figure 19:- Linear representation of cylinder according to days.

Conclusion:-

The strength and durability characteristics of concrete mixtures have been computed in the present work by replacing 5%, 10% and 15% silica fume with the cement. On the basis of present study, following conclusions are drawn:

Compressive strength:-

- After adding 5% silica fume in the mix, there is an increase in the strength of cube after 7 days as compared to concrete without replacement. And after 14 days and 28 days there is enormous increase in strength as compared to the control mix.
- By adding 10% silica fume, there is large amount of increase in strength after 7, 14 and 28 days respectively. The Compressive strength tends to increase with increase percentages of silica fume in the mix and decreases after 10% replacement.
- The optimum strength of cube is gain at 10% replacement for all 7, 14 and 28 days respectively.

Split tensile strength:-

- After adding 5% silica fume in the mix, there is an increase in the strength of cylinder after 7 days as compared to concrete without replacement and after 14 days and 28 days there is enormous increase in strength as compared to the control mix.
- By adding 10% silica fume, there is large amount of increase in strength after 7, 14 and 28 days respectively. The split tensile strength tends to increase with increase percentages of silica fume in the mix and decreases after 10% replacement.
- The optimum strength of cylinder is gain at 10% replacement for all 7, 14 and 28 days respectively.

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