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EFFECT OF SILICA FUME ON COMPRESSIVE STRENGTH OF CONCRETE UNDER DIFFERENT CURING CONDITIONS

Wrida .O. ALasefir [1] , Mohamad Gabar [2]

[1]&[2]Lecturer, Department of civil Engineering, Faculty of Engineering, Tobruk University, Libya

Abstract

The utilization of silica fume in concrete as partial replacement of cement is gaining immense importance these days , mainly on account of the improvements in the long term durability of concrete combined with ecological benefits. The main objective of this paper has been made to investigate mechanical properties like compressive strength, slump of concrete incorporating silica fume. In this present paper four mixes of concrete incorporating silica fume are prepared and cast to perform experiments. These experiments were carried out by replacing cement with different percentages of silica fume at a single constant water-cementitious materials ratio keeping other mix design variables constant. The silica fume was replaced by 0%, 10%, 20% and 30% for water-cementitious materials (w/cm) ratio for 0.50. In all a total of 72 cube specimens were cast and cured under different conditions (water curing and air curing) before testing. For all mixes compressive strengths were determined at 7, 14 and 28 days for 150 mm cubes. Test results were compared with the corresponding values of conventional concrete. Other properties like workability were found from slump test. Experimental results showed that use of silica fume in concrete has improved the performance of concrete in strength at a certain percentage replacement. It can be seen that at all ages and replacement levels compressive strengths of curing water are higher than that for air curing. The highest value of compressive strength for all test cases is obtained from specimens cured in water for 28 days followed by those cured in water for 14 days, and air cured specimens are given the lowest value of compressive strength.

***Keywords**: silica fume, cement, compressive strength, curing condition*

تأثير غبار السليكا على مقاومة الخرسانة للضغط تحت ظروف معالجة مختلفة

الملخص:

يكتسب استخدام غبار السليكا في الخرسانة كبديل جزئي للإسمنت أهمية كبيرة في هذه الأيام ، ويرجع ذلك أساسًا إلى التحسينات في متانة الخرسانة على المدى الطويل مع الفوائد البيئية. الهدف الرئيسي من هذه الورقة هو التحقق من الخصائص الميكانيكية مثل قوة الانضغاط ، وركود الخرسانة المدمجة في غبار السليكا. حث تما تجهيز اربعة خلطات من الخرسانة التي تحتوي على غبار السليكا لإجراء التجارب. وقد أجريت هذه التجارب من خلال استبدال الإسمنت بنسب مختلفة من غبار السليكا بمعدل واحد ثابت من المياه الإسمنتية مع الاحتفاظ بمتغيرات تصميم الخلط الأخرى ثابتة. استبدلت الغبار بنسبة 0 ٪ ، 10 ٪ ، 20 ٪ و 30 ٪ لنسبة المواد الإسمنتية المائية 0.50. في كل مجموعه 72 عينة مكعب تم صبها وعلاجها في ظروف مختلفة (معالجة المياه ومعالجة الهواء) قبل الاختبار. بالنسبة لجميع الخلطات تم تحديد مقاومة الانضغاط في 7 و 14 و 28 يومًا لمكعبات 150 مم. تمت مقارنة نتائج الاختبار مع القيم المقابلة للخرسانة التقليدية. تم العثور على خصائص أخرى مثل قابلية التشغيل من اختبار المخروط. أظهرت النتائج التجريبية أن استخدام غبار السليكا في الخرسانة قد أدى إلى تحسين أداء الخرسانة في القوة عند استبدال نسبة معينة. ويمكن ملاحظة أنه في جميع الأعمار ومستويات الاستبدال تكون نقاط مقاومة الانضغاط لمياه المعالجة أعلى من تلك المستخدمة في معالجة الهواء. يتم الحصول على أعلى قيمة من مقاومة الانضغاط لجميع حالات الاختبار من العينات التي تم معالجتها في الماء لمدة 28 يومًا يليها تلك المعالجة في الماء لمدة 14 يومًا ، ويتم إعطاء العينات المُعالجة بالهواء أقل قيمة من مقاومة الانضغاط.

كلمات البحث: غبار السليكا، والاسمنت،وقوة الضغط ، ظروف المعالجة.

1. INTRODUCTION

During the last three decades, concrete is not a material that consist only cement, fine aggregate, coarse aggregate and water but it is an engineered material that consists of many new materials which performs satisfactorily under all conditions. these new materials like Fly ash, silica fume, Rice husk ash and Ground Granulated Blast furnace Slag used for cement as partial replacement and that it can be lead to global sustainable development and reducing the quantity of cement required for making concrete which shows to a reduction in construction cost. Moreover some of these materials are byproduct materials. The use of these materials shows the reduction in waste, freeing up valuable land, save in energy consumption to produce cement .One of these materials is silica fume (SF. The American concrete institute (ACI) defines silica fume as a ‘‘very fine non crystalline silica produced in electric arc furnaces as a byproduct of production of elemental silicon or alloys containing silicon’’. Silica fume is also known as micro silica, condensed silica fume, volatized silica or silica dust. It is usually a grey colored powder, somewhat similar to Portland cement or some fly ashes. It can exhibit both pozzolanic and cementitious properties. Silica fume has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties to a great extent. Addition of silica fume to concrete improves the durability of concrete and also in protecting the embedded steel from corrosion. When fine pozzolana particles are dispersed in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore this mechanism makes the paste more homogeneous and dense as for the distribution of the fine pores. This is due to the reaction between the amorphous silica of the pozzolanic and the calcium hydroxide produced by the cement hydration reactions .Silica fume is a byproduct and it is the most beneficial uses in concrete. Because of its chemical and physical properties. Fresh concrete content silica fume (SF) is more cohesive and therefore less prone to segregation than concrete without silica fume. The main benefit from increased cohesion can be seen for new construction, repair of existing structures or ground support in tunneling operations. Because of the very high surface area of the silica fume and the usually very low water content of silica fume concrete, there will be very little, if any bleeding. Silica fume gained initial attention in the concrete market place because of its ability to produce concrete with very high compressive strength. Improvements in other mechanical properties such as modulus of elasticity or flexural strength are also seen.

Several researchers in the past investigated the effect of use silica fume (SF) as replacement material on the properties of the concrete adopting different theories. Some of the major research works are listed below.

According to Khedr and Abou Zaid (1994) ,The advantages like increase in strength , durability and reduction in cement production are obtained due use of silica fume in concrete and the optimum percentage replacement of silica fume ranging from 10% to 20 % to obtain maximum strength of concrete at age 28 days .

During the extensive research work carried out by Lewis [2001], it has been observed that there is a considerable reduction in rebound from (35-15)% by addition of SF which also increased the pumpability of high workability mix having slump value above 250mm.

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.

From the research work done by Amudhavalli and Mathew [2012], it has been observed that The normal consistency increases about 40% when silica fume percentage increases from 0% to 20%. Silica fume seems to have a more pronounced effect on the flexural strength than the split tensile strength.

Roy and Sil [2012], experimental study on the use of SF in mix of concrete, the results showed, maximum compressive strength for (both cube and cylinder) with 10% replacement of cement by SF are higher (by 19.6% and 16.82% respectively) than those of the normal concrete without SF, whereas split tensile strength and flexural strength of the SF concrete are increased by about 38.58% and 21.13% respectively over those of the normal concrete.

A study has been carried out by Pradhan and Dutta[2013], it has been observed that when the cubes at 28 days are tested the failure plane of cubes cut the aggregates but not along the inter facial zone which is concluded that the interfacial zone attained much higher strength than control concrete i.e. concrete without silica fume.

According to a Ghutke and Bhandari [2014] ,effect of silica fume additive on concrete properties result that, as Workability of concrete decreased as increased with percent of silica fume. Compressive strength decreased when the cement replacement was above 15% of silica fume.

Based on the investigation curried out by Kumar and Imam[2017], the results showed the optimum percentage of replacement with SF lies at 8% for compressive strength. Nevertheless, the variation of blending goes up to 8% in case of flexure strength as well and the percentage goes down up to 7% in case of split tensile strength.

Keeping in view of the above aspects, an attempt has been made to replace cement by SF to develop a cost effective modified concrete, i.e, SF concrete. Considering this aspect, the present paper reports a study on the effect partial replacement of cement by SF (from 10% to 30% with a step of 10%) on M15 grade concrete designed with 42.5 grade Ordinary Portland Cement, sand and coarse aggregate . As cement is costlier than SF , addition to cement will further enhance the cost, which may not be economically viable. The present study has, therefore, made an attempt to use SF as cement replacement materials for low/medium grade concrete (M15) used for general construction purposes with a view to achieve the desired strength parameters of the concrete higher grade.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials:

2.1.1 Ordinary Portland cements (OPC): Portland Cement 42.5 grade was used in the present study which surpasses BIS Specifications (IS 1489-1991) on compressive strength levels. The properties of Ordinary Portland Cement are shown in table 1.

Table 1: Physical properties of Portland cement*

Sl.no.	**Characteristics**	**Values**	**Value specified by IS:1489 (part1)-1991**
1	Specific gravity	3.13	……
2	Stander consistency, percent	≤ 62.5	…….
3	Initial setting time ,minutes	≥ 60	Minimum 30
4	final setting time ,minutes	≥ 10	…….

*As per manufacturers manual

2.1.2 Coarse aggregate(CAg): Crushed angular stones of maximum particle size 20 mm were used as coarse aggregate. The material were collected and cleaned for impurities. Particles of nominal size 20 mm were used and tested in the laboratory as per specifications recommended by IS:383-1970.The specific gravity and fineness modulus of coarse aggregate were determined and they were 2.67 and 6.66 respectively.

2.1.3 Fine aggregate (FAg): for this work the locally available Natural sand was used. sand particles passing through the 4.75 mm sieve were used and it free from impurities. It was tested in the laboratory as per specifications recommended by IS: 383-1970. The specific gravity, fineness modulus and Total water absorption of fine aggregate were determined and they were 2.81, 2.51 and 1.63% respectively.

2.1.4 Water: The water used for mixing as well as curing of concrete specimens. was free of organic matter, acids, suspended solids, alkalis and impurities which when present may have adverse effect on the compressive strength of concrete.

2.1.5 Silica fume (SF): Silica fume is formally known as, micro silica is an ultrafine powder of spherical particles of amorphous (non-crystalline) polymorph of silicon dioxide, (SiO_2) with an average particle diameter of 150 nm. It is a by- product of the manufacture of silicon alloys such as ferro-chromium, ferro-manganese and calcium silicon etc. Amorphous silica is highly reactive and the smallness of the particles speeds up the reaction with free calcium hydroxide produced by the hydration of Portland cement paste. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength bond strength, and abrasion resistance. Addition of silica fume to concrete mix also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions and those of humid continental(Neville 1995). The silica fume HR in dry densified form obtained from "SIKE EGYPT for Construction Chemicals confirming to ASTM - C (12402000) was used in this work for the preparation concrete specimens. The properties of silica fume are shown in table 2.

Table 2: Properties of silica fume

SI.NO	CHEMICAL ANALYSIS	ANALYSIS
1.	Specific Gravity	2.2
2.	Bulk Density (20^o) * Kg/m^3	650 ± 100
3.	Size ,(Micron)	0.1
4.	Surface Area (m^2/Kg)	20,000
5.	SiO2	(90-96) %
6.	Al_2O_3	(0.5-0.8) %

*As per manufacturers manual

2.2 Mix Proportioning:

In the present study, M15 grade with nominal max as per IS 456-2000 was used. The constituents were weighed and the materials were mixed by hand mixing. The concrete mix proportion (cement: fine aggregate: coarse aggregate) is 1:2:4 by weight and The water binder ratio (W/B) (Binder = Cement + Partial replacement of silica fume) adopted was 0.5

without any admixture. The silica fume is blended at rate 0%, 10%, 20% and 30% by weight of cement in steps of 10%.Four types of concrete mix are prepared, the first one (M0) was conventional concrete (0% Silica Fume), the second one (M1) was concrete with 10% Silica Fume, the third (M2) was combination of Portland cement and 20% of silica fume ,the fourth one (M3) was combination of Portland cement and 30 % of silica fume. The quantities for unit volume of all mixes proportion of concrete (Kg/m^3) were taken as given in table 3:

Table 3: Mix Proportioning of concrete

W/cm	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
0.5	120	240	480	72

3. EXPERIMENTAL PROCEDURE :

In this study the specimen of concrete is filled the mould cube size of 150 mm ×150 mm ×150 mm in different layers and each layer was compacted and top of mould is strike off. Then were 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**.** The silica fume added in place of cement of concrete for different percentages starting from 10% and rose the mixing of silica fume up to 30% at interval of 10%. A total 72 cubes were casted and cured under different conditions (water curing and air curing) for compressive strength test. For each percent of silica fume eighteen cubes were casted, nine cubes were cured in water, nine cubes were left in air .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 1. The crushing loads are noted and average compressive.

Figure 2: Cube test inside Compressive Strength Machine

4. TEST RESULTS AND DISCUSSIONS

4.1 Fresh State

Workability of Fresh Concrete

Workability is defined as the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. In general workability represents the amount of work which is to be done to compact the concrete in a given mould. A workable mix should not segregate. In this study workability was measured by conducting slump cone test and the results are presented in table 4 and showed in figure 2. From table 4 ,the workability of concrete reduces with increase in silica fume percent of concrete. The reason may be due to the silica fume particles are ultra-fine and hence fill the voids between the cement particles making the silica fume concrete more cohesive which is further enhance by thixotropic nature of silica fume cement paste. The spherical shape of the silica fume particles give ball bearing action when energy is applied to silica fume concrete mix causing the mix flow easily. For equal workability silica fume concrete will tends to show less slump than conventional concrete.

Table 4: Slump cone test value

Mix No	Details of Material	Slump Value (mm)
M0	100% cement + 0% Silica fume	30
M1	90% cement + 10% Silica fume	10
M2	80% cement + 20% Silica fume	20
M3	70% cement + 30% Silica fume	10

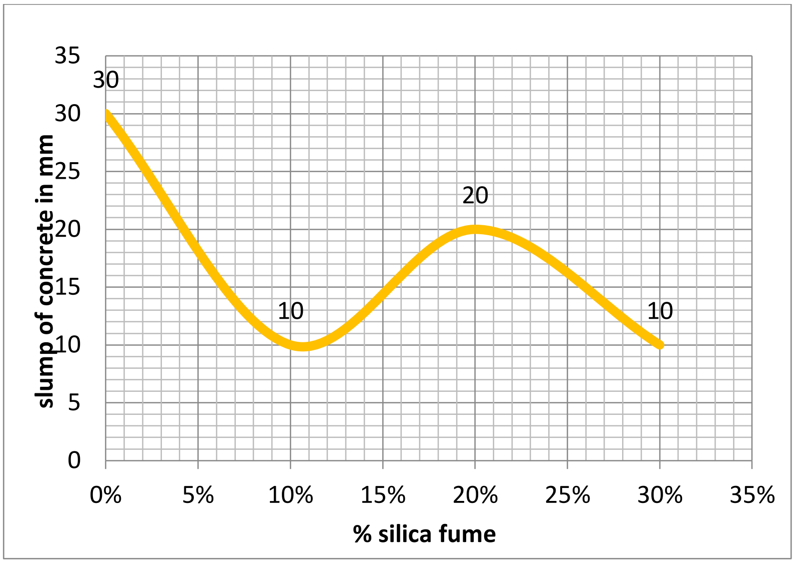

Figure 2: slump with different percentage of silica fume

4.2 Hardened State

❖Effect of Silica fume on Compressive Strength of Concrete

The results of the compressive strength test for all concrete mixes after 7, 14, and 28 days curing were determined and presented in tables 5 ,6.

Table 5 :Compressive test result for water curing

Mix No	% of Silica Fume added	Compressive strength (N/mm^2)		
		7days	14days	28 days
M 0	0%	28.040	27.49	33.65
M 1	10%	27.73	37.23	35.70
M2	20%	32.11	37.51	36.53
M3	30%	30.96	38.61	40.96

Table 6 :Compressive test result for air curing

Mix No	% of Silica Fume added	Compressive strength (N/mm^2)		
		7days	14days	28 days
M 0	0%	29.610	32.52	32.59
M 1	10%	27.27	29.79	34.44
M2	20%	30.45	35.14	35.62
M3	30%	31.50	36.88	32.04

The obtained values of concrete compressive strength according to the different used percentage of SF for both curing conditions have been graphically represented in figures 3 and 4. Also for the ease of comparison, the relative compressive strengths are shown in figure 5 to 7. These figures indicate that, 30% replacement of cement by silica fume gives highest compressive strength as compare to other replacement at 28days for both curing condition (water curing and air curing). The compressive strength for specimens are cured in water for control mix (M0) at 28 days was found as 33.65 N/mm^2.Almost 22 % of increment in strength values (i.e. 40.96 N/mm^2) has been observed for replacement cement with 30% Silica fume . Slight increase in strength (i.e. 35.70 N/mm^2 to 36.53 N/mm^2) has been seen when the replacement level goes from 10 % to 20 %. There was a significant improvement in the compressive strength of SF concrete even with specimens are left in air at the same age, it was because its high pozzolanic activity and void filling ability.

The maximum 14 days water curing compressive strength observed as 38.61 N/mm^2 at level 30% of replacement (40.45 % higher over normal concrete M0) and the maximum 7 days strength obtained as 32.11 N/mm^{2}at level 20 % of replacement (14.51% higher over normal concrete M0). The maximum 14 days and 7 days air curing compressive strength are found to be 36.88N/mm^2 (13.41% higher) and 31.50 N/mm^2 (6.38% higher) respectively, when cement is replaced by SF at the same level 30 % as shown in figure 4.From the properties exhibited by concrete using silica fume replacing cement, it is observed that, there improves effectively both with the age and incorporation of SF in place of cement. The increase in strength development is due to the fact that silica fume dissolves in saturated solution of Ca(OH)2 within few minutes. As soon as enough Portland cement has hydrated to result in saturation of the pore water with Ca(OH)2, Calcium Silicate Hydrate (C-S-H) gel is formed on the surface of silica fume particles.This C-S-H gel produced by SF concrete has a lower C : S ratio than that resulting from the hydration of Portland cement concrete without silica fume.

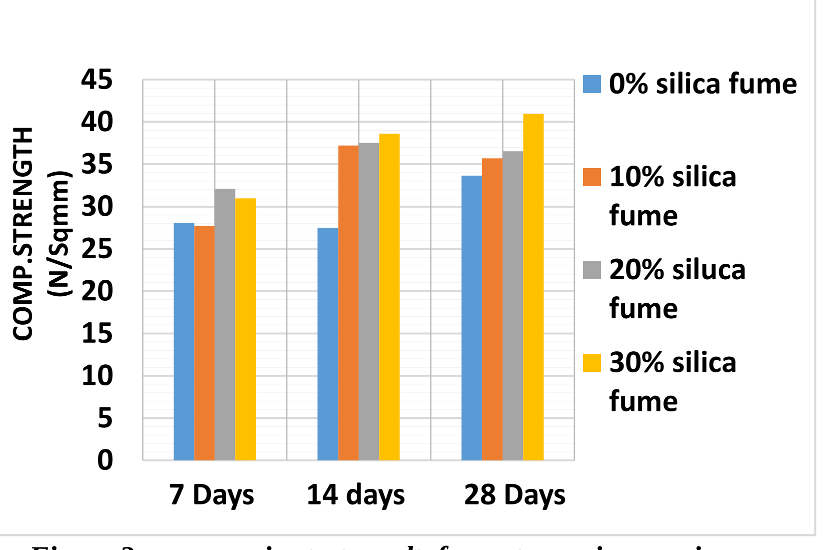

Figure 3: compressive test result for water curing specimens

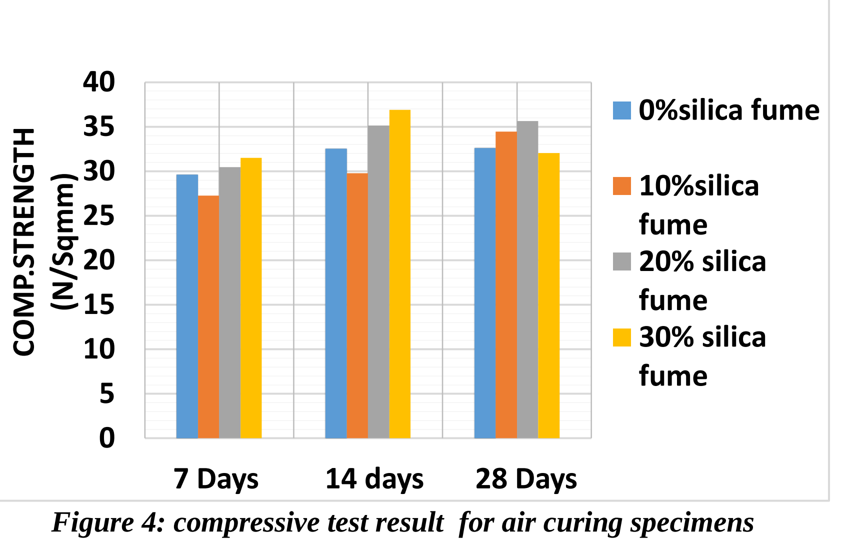

Figure 4: compressive test result for air curing specimens

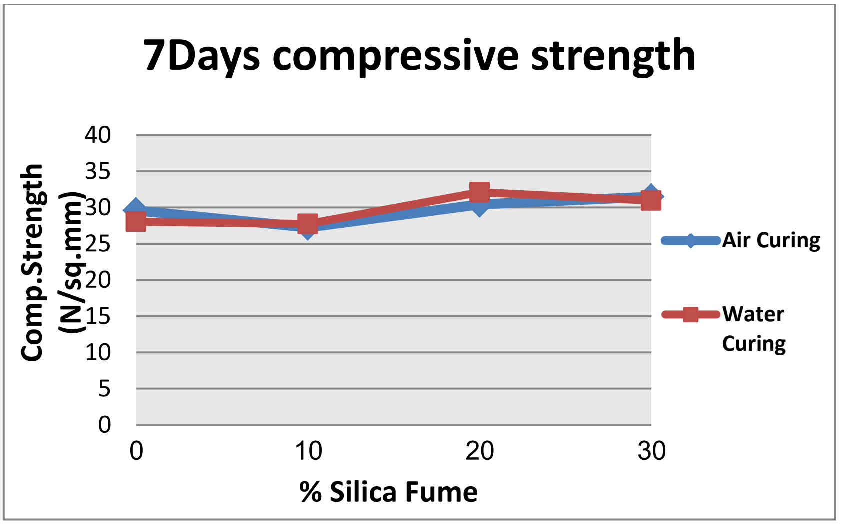

Figure 5: 7 days compressive test result

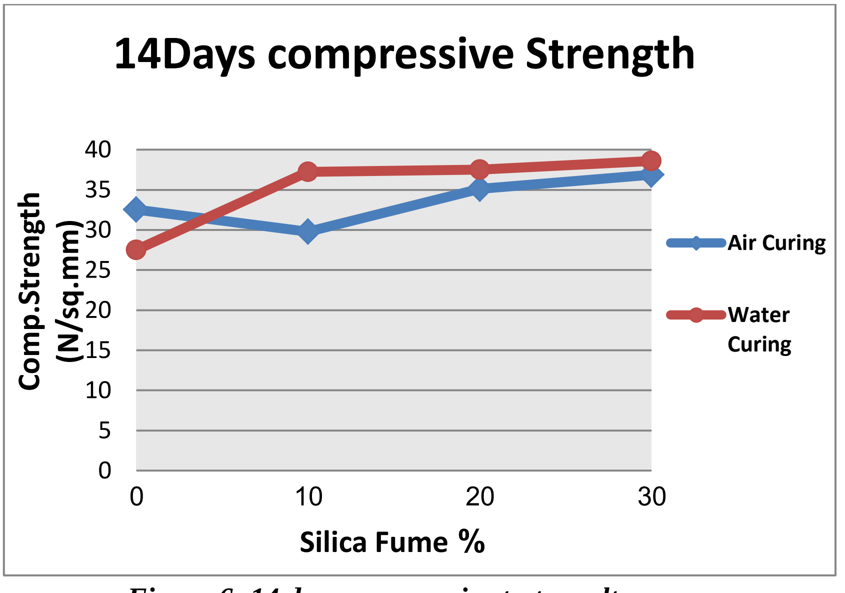

Figure 6: 14 days compressive test result

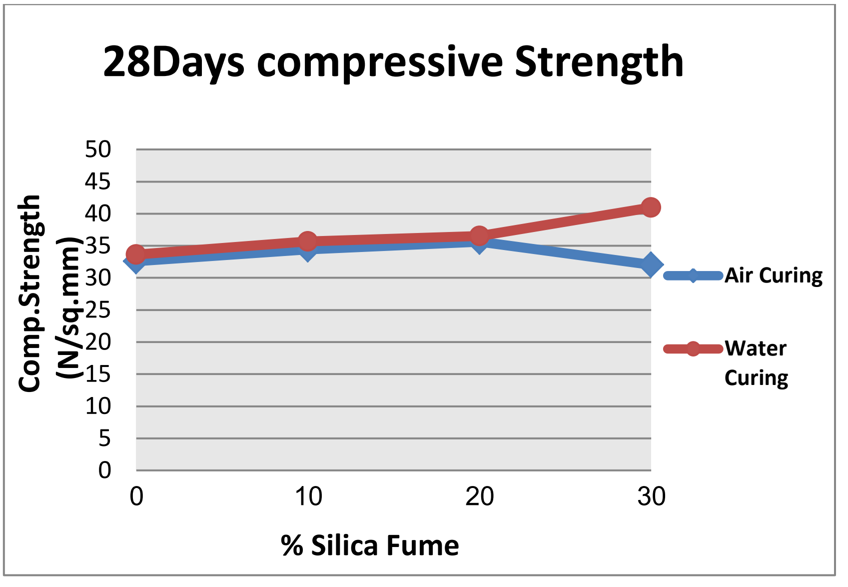

Figure 7: 28 days compressive test result

5. Conclusion

From the experimental work carried out and the analysis of the results the following generalized conclusions can be drawn on properties of concrete.

- Silica fume is considered as a highly reactive pozzolanic material which provides an increased cohesiveness in concrete due to its high fineness modulus. However, the requirement of water may be offset by adding super plasticizer.
- Workability of concrete decreases as increase with percent of silica fume.
- for water curing The compressive strength of concrete increases with increase in replacement level of silica and The optimum value of replacement of silica fume is found at 30 %.

- The highest value of compressive strength of SF concrete for all test cases is obtained from specimens cured in water for 28 days and the lowest value is obtained from air cured specimens
- Compressive strength decreases when the cement replacement is above 20% of silica fume for specimens were cured in air .
- As compressive strength of 10% replacement of cement by silica fume is more than normal concrete for both curing cases (water and air curing).
- Silica Fume has proved to be the most promising blending material to provide a good quality concrete.
- Lastly for various structural constructions such as high-rise buildings, bridges, chimneys, machine foundations, run ways etc., that require gain high early strength can be achieved in silica fume concrete with quality control (such as water curing and addition super plasticizer) that the timeframe of completion vis-à-vis the economy is an important driven factor for the targeted purpose as well as for the contractors and owners alike as this concrete will provides quick stage by stage or floor to floor construction.

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