

## Effect of silica fume on the mechanical properties of crushed brick concrete

Ghanim Mohammed Kamil

Engineering College / University of Thi-Qar /Iraq

E-mail:ghanimmohammed80@yahoo.com

### Abstract:

This paper presents an experimental investigation on the effect of silica fume on the mechanical properties of concrete obtained by replacing 50% of weight of stone aggregate by crushed clay-brick. The only variable considered in this study was the dosage of silica which it is a percent of cement weight, the percent values of replacement silica fume are (0%, 2%, 4%, 6%, and 8%) of cement weight. The comparative study is focus on the effect of the silica fume on this type of concrete not the effect of replacement of crushed brick. The added silica fume has active effect on the strength of crushed brick concrete. The effect of using silica fume on compressive strength is different for the different replacement of silica fume and it is more active for the 2% replacement at 7 days age, while the replacement that yield best enhancement at 28 days is 4%. The compressive strength for 28 days age is about 27.5 MPa, 29.5 MPa, 38.5 MPa, 31.4 MPa, and 10 MPa, for (0%, 2%, 4%, 6%, and 8%) of replacement silica percent. Furthermore the best increasing in tensile strength is at 2% while there is a small gradually increasing in gain in modulus of rupture with using silica fume until 6%, which beyond the least value it starts to drop. The high level which is observed in this study beyond 6% reduce the gain in strength of compressive at 28 days and it gets a compressive strength less than the control value at 7 days. Furthermore it gets a reduction in tensile strength and modulus of rupture in at 28 days.

**Keywords:** Crushed brick; Silica fume; Strength.

### تأثير مسحوق السيليكا على الخصائص الميكانيكية لخرسانة الطابوق المكسر الخلاصة:

يقدم هذا البحث دراسة حول تأثير مسحوق السيليكا على الخصائص الميكانيكية للخرسانة الناتجة من استبدال 50% من وزن الركام الصخري بوزن مماثل من ركام الطابوق الطيني المكسر. المتغير الوحيد المعتبر في هذه الدراسة هو كمية مسحوق السيليكا المضاف كنسبة من السمنت، كميات الاستبدال للسيليكا هي (0%، 2%، 4%، 6%، 8%) من وزن السمنت. الدراسة مركزة حول تأثير السيليكا على هذا النوع من الخرسانة وليس على نسبة الاستبدال من ركام الطابوق المكسر. الكميات المضافة من مسحوق السيليكا تمتلك تأثيرا على مقاومة خرسانة الطابوق المكسر. التأثير مختلف باختلاف النسب لمسحوق السيليكا وهذا التأثير ذو فعالية اكثر عند 2% استبدال بعمر 7 ايام، بينما نسبة الاستبدال التي حققت افضل تحسين للمقاومة بعمر 28 يوم كانت 4%. مقاومة الانضغاط للنماذج بعمر 28 يوم هي كالآتي (27.5، 29.5، 38.5،

31.4 ، 10) ميكا باسكال لنسب الاستبدال (0%، 2%، 4%، 6%، 8%) على التوالي، كذلك الزيادة الافضل في مقاومة الشد كانت عند نسبة استبدال 2%، بينما كان هناك ازياج تدريجي في كسب المقاومة في معامل الانتشاء الى حد 6% ، و بعد هذه النسبة تبدأ المقاومة بالتناقص. المستوى العالي لنسبة استبدال مسحوق السيليكا الملاحظ بعد ال6% استبدال في هذه الدراسة قلل الكسب في المقاومة لمقاومة الانضغاط بعمر 28 يوم واعطى مقاومة انضغاط اقل مقارنة بالنموذج المرجعي بعمر 7 يوم . كذلك قلل ومقاومة الشد ومعامل الانتشاء بعمر 28 يوم.

## 1. Introduction:

Concrete is the most widely used man-made construction material. It is obtained by mixing cement, water and aggregates (and sometimes admixture) in required proportions. Aggregates impart higher volume stability and better durability than hydrated cement paste in concrete and provide around 75 percent of the body of concrete<sup>[1]</sup>. The aggregates are usually derived from natural sources but in regions such as Bangladesh and parts of West Bengal, India where natural rock deposits are scarce, burnt-clay bricks are used as an alternative source of coarse aggregate. Here, construction of rigid pavement, small-to medium-span bridges and culverts and buildings up to six stories high using crushed brick (brick aggregate) concrete is quite common<sup>[2]</sup>. However, the use of mixed aggregate (a combination of brick aggregate and stone aggregate) may improve the strength and stiffness of concrete in comparison with those of purely brick aggregate concrete.

Silica fume is known to improve both the mechanical properties and durability of concrete. The principle physical effect of silica fume in concrete is that of filler besides the pozzolanic activity, which because of its fineness can fit into space between cement grains in the same way that sand fills the space between particles of coarse aggregates and cement grains fill the space between sand grains. As for chemical reaction of silica fume, because of high surface area and high content of amorphous silica in silica fume, this highly active pozzolan reacts more quickly than ordinary pozzolans. The use of silica fume will not significantly change the unit weight of concrete. Silica fume will produce a much less permeable and high strength concrete, but it will not produce a concrete with a higher mass per unit volume. Against these backdrops, this review is focused on the effect of silica fume on mechanical properties of concrete<sup>[3]</sup>.

Many of researchers focus their searches on the effect of using addition of silica fume on the mechanical properties of concrete and the results somewhat is consistent ,that is in general, the properties are increased with increasing silica fume to limit values and after beyond these limits they start to decrease<sup>[4,5,6]</sup>. N. Siva Linga Rao, et. al. investigate the properties of lightweight of aggregate concrete with cinder and silica fume , they conclude that 60 percent

replacement of conventional aggregate with cinder by volume along with cement replaced by 10 percent of silica fume by weight yields the target mean strength. It worth noted that there is a slight increase in strength and other properties due to extended curing periods and the unit weight of the cinder concrete is varying from 1980Kg/m<sup>3</sup> to 2000Kg/m<sup>3</sup> with different percentages of cinder. It is also noted that there is a decrease in density after extended curing periods<sup>[7]</sup>.

Due to the excessive of using the natural sources of the aggregate in the infrastructure and in the building in many of the countries, there is a need to find a substitution source for the coarse aggregate, and the demolition of the building construction gets a row material for coarse aggregate.

## **2. Experimental program:**

### **2.1. Cement:**

Ordinary Portland cement (ASTM Type-I) was used as binding material in this study. A mixture of locally available coarse and fine sands were mixed in the ratio of 1:1 (by volume) to be used as fine aggregate. The test values of specific gravity, water absorption, and fineness modulus of fine aggregate indicate that the cement conforms to the Iraqi standard No. 5/1984<sup>[8]</sup>.

### **2.2. Fine Aggregate (Sand)**

Natural sand brought from Al-Zubair region was used as a fine aggregate in this research. The sieve analysis test was conducted according to BS EN 12620+A1<sup>[9]</sup>.

### **2.3. Water**

Ordinary tap water was used for casting and curing the specimens.

### **2.4. Coarse aggregate:**

The coarse aggregates used in the study are normal coarse and crushed brick coarse aggregate with maximum size of 10 mm, the sieve analysis for the two type of coarse aggregate are done according to BS EN 12620+A1<sup>[9]</sup>.

### **2.5. Crushed brick aggregate:**

Crushed stones available in the local market were collected to be used as natural aggregates. Well-burnt bricks of well-shaped and reddish in color were collected and then crushed in the laboratory for making brick aggregates. The nominal dimension of each brick was (241mm×114mm×70mm) and their average compressive strength was found as (23MPa).

The bricks were crushed manually and then sieved into various size fractions, and the flaky particles were separated for rejection. Both types of coarse aggregates were size-screened to a maximum of (10 mm), the sieve analysis is worked according BS EN 12620+A1<sup>[9]</sup>.

## 2.6. Silica Fume

The silica fume was in powder form containing 91.4% silicon dioxide (SiO<sub>2</sub>) and having a specific surface area of about 18,000 m<sup>2</sup>/kg was used. The chemical properties of silica fume are given in Table (1). A high range water reducing admixture (superplasticizer) was used in preparing all the specimens in this investigation. Chemically it is Naphthalene formaldehyde sulphonate. It was used in its liquid state as a percentage of cement content (by weight). The dosage of superplasticizer is added to keep the slump in the range 60-80 mm.

**Table (1) Chemical properties of silica fume.**

SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Loss of ignition
91.4	1.25	1.74	1.28	1.5	0.29	3.8

## 3. Concrete Mix:

The concrete mix ratio for the study is (cement: sand: coarse) (1:1.5:2) by weight with 50% replacement of crushed brick as coarse aggregate, the water cement ratio is 0.4. The silica fume replacement levels used in this investigation were (2, 4, 6, and 8%) of cement weight. Superplasticizer does is somewhat different to keep the slump in range of 60-80 mm.

## 4. Experimental procedure:

The work is compose of casting 5 batches of concrete samples, one of them is the control reference and four of them to demonstrate the effect of silica fume on the crushed concrete, each batch includes casting 6 cubes 100 × 100 × 100 mm and cylinder of 150 × 300 mm, and prism of 100 × 100 × 500 mm.

The coarse aggregates and the fine aggregates were made saturated surface dry condition before mixing with other ingredients. At first, the amounts of the mixed aggregates were put in the batch and 0.75 of water were added and then the silica fume were added to the mix and rotate for 2 minutes and then the cement and sand were added and the dosage of the super plasticizer was added to the rest of water, and rotate for 3 minutes. The workability of fresh concrete was measured with standard slump cone test immediately after mixing. The values of slump of fresh concretes for different mixes ranged from 60 mm to 80 mm.

The casting specimens were put on the vibratortable and filled with fresh concrete in three equal layers, and the vibration was done in each layer. The top surface of fresh concrete for both the cylinder and prism specimens was finished off with a trowel. The specimens were demoded after 24 hours of casting. They were cured by immersing in a curing tank in the lab. The specimens were taken out of water at the date and time of testing the sample was removed from water and by cleaning with piece of cloth and testing it for the desired test.

The concrete specimens for different test series were tested (using 130 kN capacity universal testing machine) for compressive strength, splitting tensile strength, and modulus of elasticity at the age of 28 days. Figure 7 shows the test setup of cube and some of the failure cubes. The prisms were tested under single point loading to determine the modulus of rupture. The concrete specimens were tested following appropriate BS ENStandards.

## 5. Results and discussion:

The results of the tests of the samples which are tested for the work study were plotted as shown from figure1 to figure5 to illustrate the function of the mechanical properties.

### 5.1 .Testing of Specimens

All the tests were done according to the BS EN 12390<sup>[10, 11, 12, and 13]</sup> Testing hardened concrete Part 6: Tensile splitting strength of test specimens. The cube specimens, the cylinder and the prisms were subjected to water curing. The cubes were tested at 7 days and 28 days to determine the compressive strength. The other samples were tested to determine the tensile strength and the rupture of failure at 28 days.

### 5.2. Compressive strength:

Figs. 1 and4 show the variation of compressive strength with the concrete mixes having different SF contents. At 7 days age, an increase in all levels of replacement is observed while the reference mix exhibit higher strengths than the corresponding mixes containing silica fume beyond 6%. At 28 days, there is an increasing in compressive strength and gain higher the reference mixes. Concrete mixes incorporating 2 to 6 % silica fume will continue to gain higher strengths as compared to reference mixes. The variation in compressive strengths of Silica fume concretes expressed as a percentage of the corresponding strength of reference mix has been given infig.4.As compared to the reference mix, the replacement of silica fume at range 2% to 4% gives somewhat a steady constant gain in strength and it is the maximum

gain. After 4% there is a decreasing in gain of strength and it is a more reduction in concrete at 7 days than 28 days, may be this occurs due to the required enough curing to get the silica more effective as stated by other researches<sup>[7]</sup>. Also may be the lower improvement in strength in could be attributed to inherently lower capillary porosity in the reference mix as a result of lower water/binder ratio. Inherent lower capillary porosity leaves less room for improvement by incorporating SF.

The results show that up to the 6% is there are gains in strength in compressive strength for both 7 days and 28 days to the reference mixes. This indicates that the pozzolanic effect of silica fume is become slower in high percent. However, beyond 7 days, silica fume mixes gain higher strengths due to the reaction mechanism of silica fume. It is observed that silica fume mixes show highest strengths at 28days, indicating that the pozzolanic reaction dominates from 7 to 28 days<sup>[14]</sup>. It is also observed that silica fumecontent of 4% gives maximum improvement in compressive strength values. This could be attributed to the lime content. In concrete mixes having silica fume contents lower than 4%, silica fume does not consume all of CH and thus improvement in strength is not high<sup>[5,15]</sup>. The figures of 1 and 4 show the affecting of the replacement of silica fume on the compressive strength of cubes. From the figure it can be conclude that there is a rational effect of adding silica fume, the behavior of samples at 7 days are similar of the 28 days in strength of compressive of cubes. The 2% replacement of silica fume is the more active in increasing of strength at 7 days, while the 4% is the more active at 28 days.

### 5.3. Tensile strength:

Fig. 3 and Fig. 6 show the variation of split tensile strength with silica fume replacement percentage. It is observed that silica fume incorporation increases the split tensile strength of concrete until 2% replacement of silica fume. A close observation of Fig. 2 exhibits that beyond 2% of replacement start the tensile with dropping with increasing in replacement ratio of silica fume and does not significantly increase the split tensile strengths and the maximum increase at 2% is 48%. Replacements considerably improve the split tensile strength with respect to control. The initial filling of the voids by silica fume significantly improves the tensile strengths, but at higher levels, the improvements decrease. On computing the percentage gains in split tensile strengths of silica fume concrete with respect to control, the best values of the average gains are at 2% and 4%, replacement levels are obtained as 48% and 20 respectively. The trend in strength gain is almost similar with that of compressive

strength at 7 days and 28 days, the optimum 28-day split tensile strength at 2% of replacement level of silica fume.

#### 5.4. Modulus of Rupture:

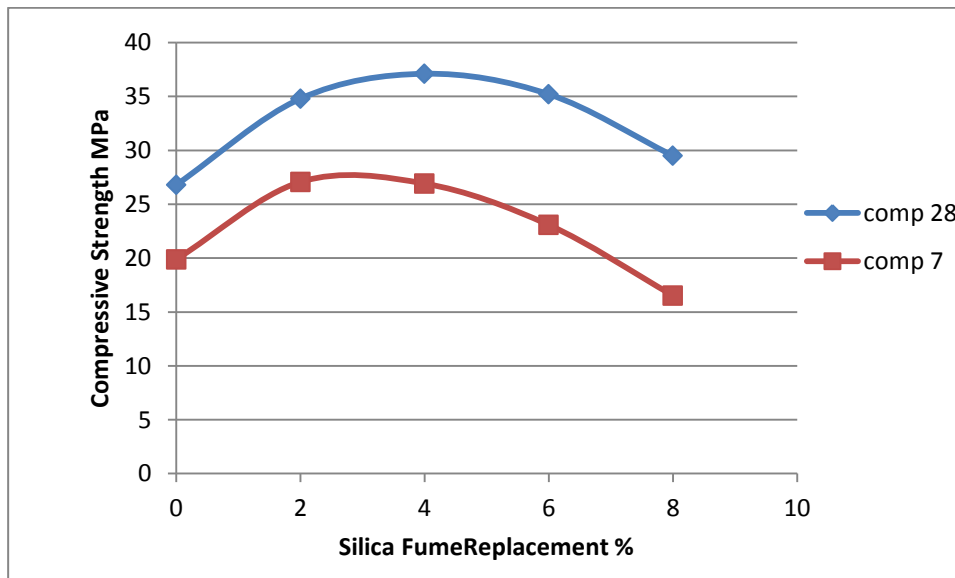
Fig. 2 and Fig.5 shows the variation of flexural tensile strength with silica fume replacement percentage. Fig.2 does reflect a rational consistent view with the tensile and compressive strength, it shows that there is a gradually increasing in the strength of modulus of rupture with replacement of silica fume until 6%, it is may be similar in general behavior with compressive strength and somewhat with tensile strength but in a less limit. The using of higher than 6% of silica fume seems to have the same pronounced effect on the split tensile strength and compressive strength, leads to dropping in strength as in Fig.5. The gains in split tensile strengths are higher than the flexural strengths at lower replacement levels. The flexural strengths almost follow the same trend as the 28-day compressive strength does. The results of the present investigation indicate that the optimum silica fume replacement percentage for 28-day flexural tensile strength is at 6%.

#### 6. Conclusions:

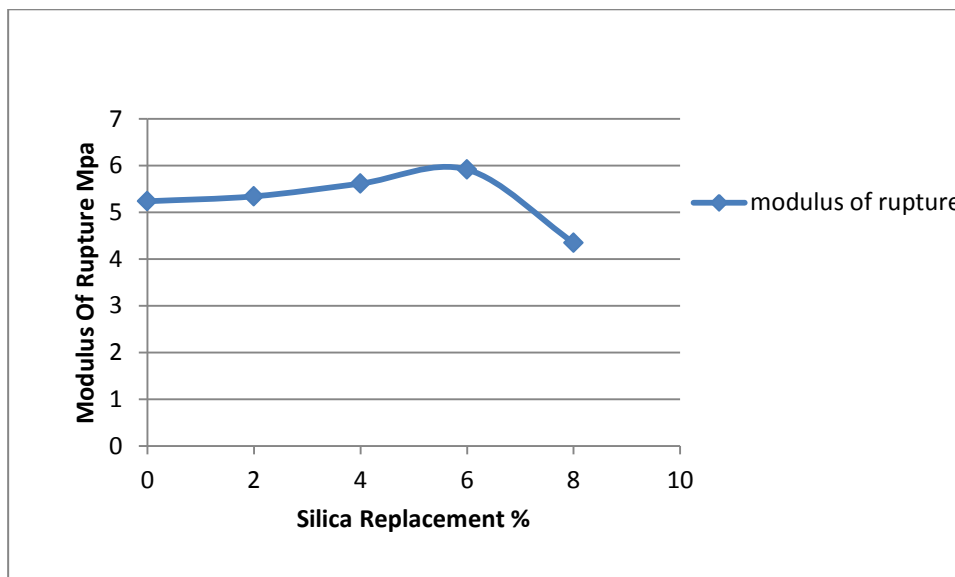
This study is worked to establish the effect of the silica fume on the mechanical properties of the concrete with crushed brick at 50% replacement. The percentage of silica fume is the main factor in this study which is mentioned to establish the enhancement in the compressive strength, tensile strength, and the rupture strength of concrete. From the diagrams which are executed based on the values, it can be concluded the following:

1. There is a somewhat similar behavior of the increasing in the compressive strength, tensile strength, and rupture failure strength.
2. The increasing is somewhat larger for the compressive in 6 %.
3. The increasing percent is linear with increasing of the silica fume for a limit and it is similar in general with the previous studies<sup>[4, 5, 6, and7]</sup>.
4. The best percent of silica fume adding for compressive is at 4% at 28 days while is at 2% for both compressive at 7 days and tensile strength at 28 days while for modulus of rupture is at 6%.
5. There is a need to further study in method of adding of the silica fume and for more replacement levels of silica fume.

6. Using of high percent of silica fume does not significantly increase the split tensile strengths, and the 2% of replacement gives best increasing ratio, 48%.

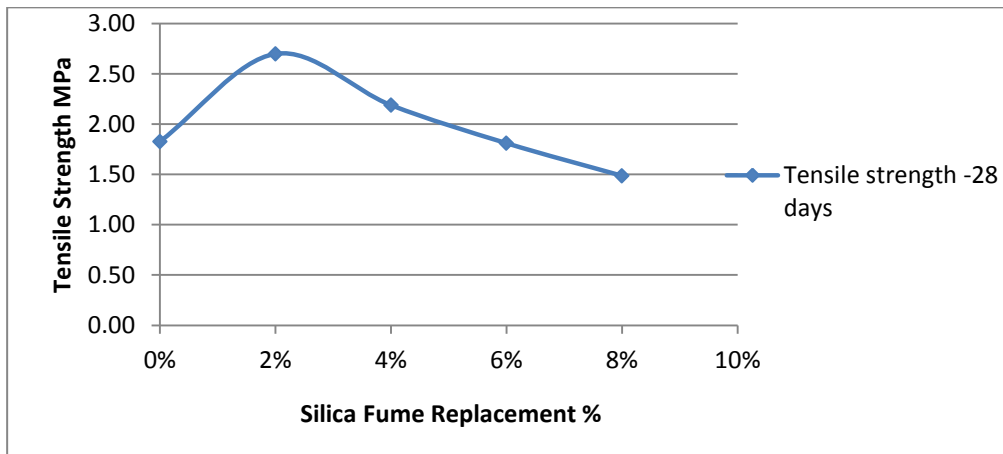


**Figure1: Relationship between 28 days and 7 days compressive strength and percent of silica fume replacement**

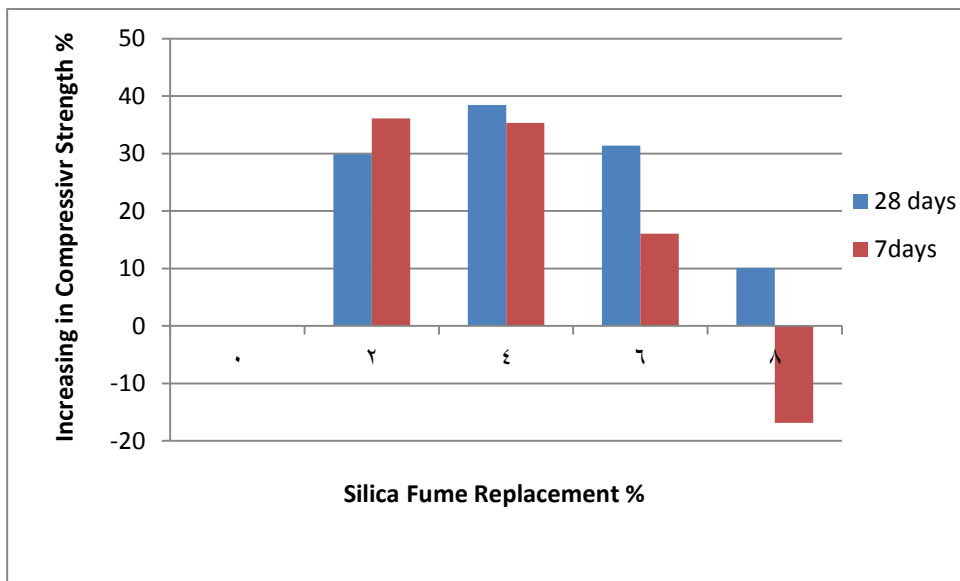


**Figure 2: Relationship between 28 days modulus of rupture and percent of silica fume replacement**





**Figure 3: Relationship between 28 days tensile strength and percent of silica fume replacement**



**Figure 4: Bar chart shows variation in increasing of compressive strength of concrete at 7 days and 28 days with different percent of replacement of silica fume.**

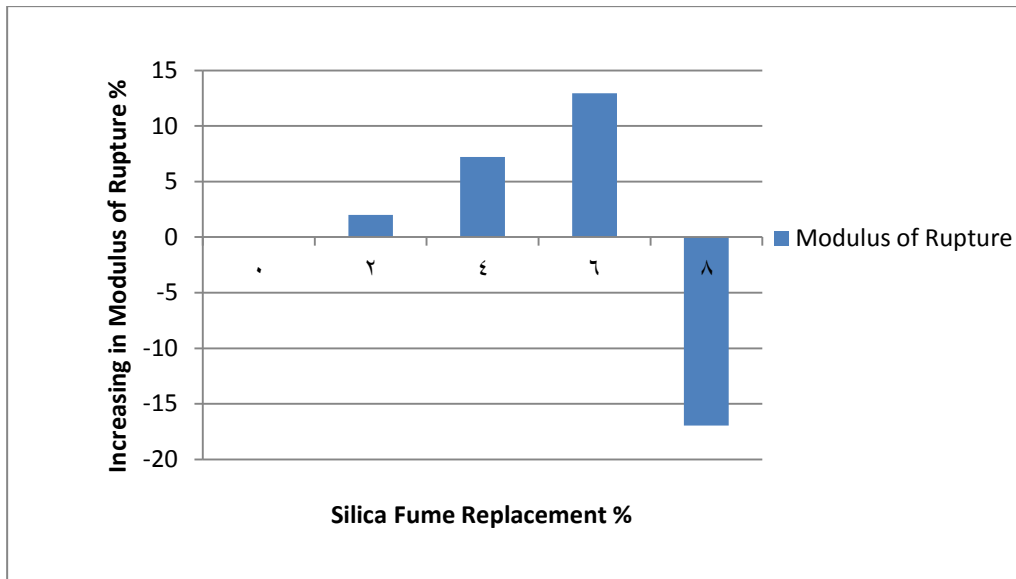


Figure 5: Bar chart shows variation in increasing of Modulus of Rupture of concrete 28 days with different percent of replacement of silica fume.

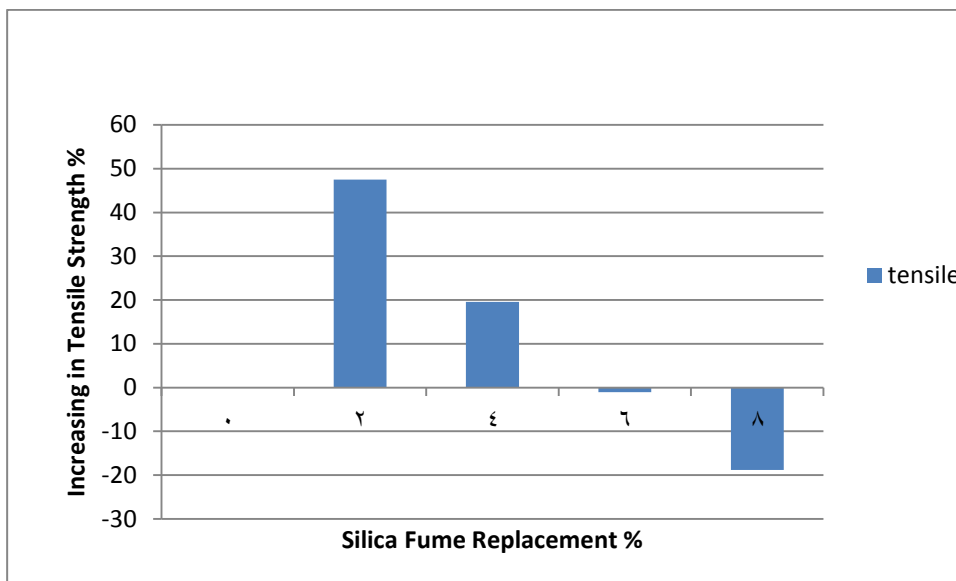


Figure 6: Bar chart shows variation in increasing of Tensile Strength of concrete 28 days with different percent of replacement of silica fume.



Figure (7) shows cubes under test and failure samples

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