Experimental Study on the Behaviour of High Strength Concrete with Silica Fume under Monotonic and Repeated Compressive Loads

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Abstract

The main objective of this paper is to determine the effect of silica fume on the compressive strength of concrete under two types of loading, monotonic and repeated compressive loads. Mixes were carried out by replacing cement with different percentages of silica fume of (0, 5,10,15,20) % by wt. of cement with a constant water-binder ratios 0.25. Tests on standard cylinders (300*150) mm for the different ratios of silica fume were carried out to study the behavior of concrete under monotonic and repeated loads, the load was applied for many cycles up to failure with rate of loading (0.3) N/mm^2/sec. The results indicated that the addition of silica fume improves the properties of concrete giving high compressive strength, high stress and strain, stresses carried by the concrete increased by (46.3,68.8,63.1,57.5)% also the strain increased by (58.5,97.8,52.8,22)% for silica fume percentages (5,10,15,20)% for monotonic loading, and stresses increased by (44.4,68.5,63.7,56.5)% and strain increased by (45.8,68.4,51.5,26.3)% for the same percentages under repeated loads. Compressive strength, dissipated energy, and modulus of elasticity also increased with increasing silica fume percentage.

Key Words : Silica fume, High Strength Concrete, Stress, Strain, Repeated and Monotonic Loads.

دراسة عملية لسلوكية الخرسانة عالية المقاومة الحاوية على مادة غبار السليكا تحت تأثير الاحمال التزايدية والتكرارية الانضغاطية

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الخلاصة

إن الهدف الأساسي من هذا البحث هو دراسة تأثير اضافة مادة غبار السليكا على مقاومة الانضغاط للخرسانة تحت تأثير نوعين من الاحمال, احمال تزايدية واحمال تكرارية. اذ تم استخدام مادة غبار السليكا بنسب (0و5و10و15و20) % من وزن الاسمنت وكانت نسبة الماء الى المادة الرابطة (0.25). تضمن البحث فحوصات عملية على نماذج اسطوانية خرسانية قياسية بأبعاد(300*150) ملم تحتوي على النسب الوزنية المختلفة لغبار السليكا ولكل نسبة من هذه النسب تم صب ثلاث اسطوانات وإيجاد المعدل لها وذلك لدراسة سلوك الخرسانة الحاوية على هذا النوع من المواد تحت تأثير الأحمال التزايدية والتكرارية. تم تسليط الاحمال الدورية لعدة دورات لغاية الفشل وبنسبة تحميل (0,3) نيوتن/ملم^2/ثا. ومن خلال النتائج التي تم الحصول عليها اثناء الفحص لوحظ ان اضافة مادة غبار السليكا ادى الى تحسين خواص الخرسانة من حيث مقاومة الانضغاط وايضا الاجهاد و الانفعال, أذ يلاحظ من النتائج أن الاجهادات التي تتحملها الخرسانة قد زاد بنسبة (57.5,63.1,68.8,46.3) كما ازداد الانفعال بنسبة (22,52.8,97.8,58.5) % لنسب غبار السليكا (20,15,10,5)% بالنسبة للاحمال التزايدية, وازدادت الاجهادات بنسبة (56.5,63.7,68.5,44.4) % والانفعال بنسبة (26.3,51.5,68.4,45.8) % لنفس نسب غبار السليكا تحت تأثير الاحمال التكرارية. كما بينت النتائج ازدياد كل من مقاومة الانضغاط ومعامل المرونة والطاقة المتبددة بزيادة نسبة غبار السليكا.

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Introduction

Silica fume is a bye product of silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume may have very high strength and may be very durable. Silica fume is available from suppliers of concrete admixtures and, when specified, is simply added during concrete production. Placing, finishing, and curing silica-fume concrete require special attention on the part of the concrete contractor.

Prior to the mid-1970s, nearly all silica fume was discharged into the atmosphere. After environmental concerns necessitated the collection and land filling of silica fume, it became economically viable to use silica fume in various applications, in particular high-performance concrete [1]. Silica fume has many effects on properties of fresh concrete: a) Workability: With the addition of silica fume, the slump loss with time is directly proportional to increase in the silica fume content due to the introduction of large surface area in the concrete mix by its addition. Although the slump decreases, the mix remains highly cohesive. b) Segregation and Bleeding: Silica fume reduces bleeding significantly because the capillary water is consumed in wetting of the large surface area of the silica fume and hence the capillary water left in the mix for bleeding also decreases. Silica fume also blocks the pores in the fresh concrete so capillary water within the concrete is not allowed to come to the surface.

Silica fume may improve concrete in two ways the basic pozzolanic reaction, and a micro filler effect. Addition of silica fume improves bonding within the concrete and helps reduce permeability, it also combines with the calcium hydroxide produced in the hydration of Portland cement to improve concrete durability.

In (2005) Mostofinejad and Nozhati [2] made many attempts to propose some experimental models to predict the modulus of elasticity of high strength concrete based on some known characteristics of the concrete mix. To do so, 45 mix proportions including 5 different ratios of silica fume, i.e., SF/CM = 0,5,10,15 and 20 percent, 3 water to cementitious materials ratios, i.e., w/cm = 0.24,0.3 and 0.4, and 3 types of coarse aggregates, i.e., limestone, quartzite and andesine were selected. 540 cylindrical specimens were cast, cured and tested after 7, 28 and 91 days. Regarding different ratios of silica fume and different ratios of w/cm, the relationship of modulus of elasticity of concrete at different ages was discussed and some empirical equations were proposed. The maximum compressive strength of HS concrete was achieved by a 10% substitution of silica fume for cement when w/c was 0.4, and by a 15% substitution of silica fume for cement when W/C was 0.3 or 0.24. The optimum silica fume percentage does not seem to be constant, and increases when the ratio of w/c decreases. To achieve the maximum modulus of elasticity of HS concrete, the optimum silica fume percentage is not necessarily equal to that for achieving the maximum compressive strength.

In (2006) Ali Bashah [3] studied the effect of silica fume on the properties of high performance ground granulated blast furnace slag concrete to reveal the potential furthest. It was found by compressive strength test, that high strength concrete can be achieved. At the age of 28 days, concretes containing 5,7.5, and 10% silica fume gave compressive strengths of 65.6, 64.6, and 67.1 Mpa, respectively. At aged 56 days concrete containing 10% silica fume had the highest strength. However the concrete containing 5% of silica fume had low permeability thus may enhance the durability.

In (2007) George et al. [4], carried out for two grades of concrete ie. M20 and M30. For the grades of concrete the cement content, sand, grit, coarse aggregate and w/c ratio are kept constant. Only the percentage of silica fume has been changed ie. 0%, 5%, 10% and 12.5%. The results have shown the considerable improvement in compressive strength, modulus of elasticity and durability with respect to sulphate. Splitting tensile strength is observed to be nearly same with or without the use of silica fume for both the grades.

During cyclic loading, the concrete, is subjected to loading, unloading, and reloading processes. This will cause initiation of micro-cracks and will sometimes lead to the fatigue limit of the materials. This, thus resulting in reduction in the stiffness. Hence, it is necessary to evaluate degradation of stiffness in the concrete subjected to cyclic or repeated loading.

In (2002) Daniel and Loukili [5] investigated the behavior of high-strength fiber-reinforced concrete (HSFRC) beams under cyclic loads. They illustrated that HSFRC with tensile reinforcement ratio of 0.55% exhibited behavior similar to that of a HSC beam with a tensile reinforcement ratio of 0.97% and the fibers have no influence on strength deterioration during loading cycles at a given displacement.

In (2010) Al-Sulayfani at all. [6] studied behavior of concrete adding steel fibers under repeated loads, by testing simply supported beam with dimension (150,160,1000) mm, reinforced with different percentages of steel fibers (0.0,0.5,0.75,and1.0%). The compressive strength of the concrete used was found by casting standard cylinders (300*150) mm for the different percentage of fibers. All the results show improvement in behavior of fiber reinforced concrete under repeated loads.

In (2010) Abdulla,M,M. [7] tested standard concrete cylinders (300*150)mm, containing different percentage of glass fiber under two types of loading, monotonic and repeated load, the results showed that the behavior of concrete improved due to addition of glass fiber, and this improved increased with increasing the percentage of the fiber added.

Research Significance:

The objective of this study was to determine the effect of silica fume on compressive strength, stress and strain of concrete under monotonic and repeated loads.

Materials and Test Procedures:

Materials:

Materials used in this research for ordinary concrete were as follow:

1. Cement: locally manufactured cement was used. The physical and chemical analysis for this type of cement showed in table (1) and (2) according to IQS:5/1984 [8].
2. Water: tap water (potable) was used for mixing and curing purpose.
3. Fine aggregate: river sand was used and graded according to the (B.S882:1992) [9] , the sieve analysis showed in table (3).
4. Coarse aggregate: river aggregate with M.A.S. 5 mm was used. The sieve analysis showed in table (4). according to the (B.S 882:1992) [9]

The properties of aggregate are shown in table (5)

Table (1), physical properties of used cement

Test	Result	IQS:5/1984
Consistency	0.29	0.24-0.32
Initial setting time (min.)	210	Min. 45 min.
Final setting time (min.)	330	Max 600 min.
Fineness (%)	5	Max. 10 %
Compressive Strength(MPa)		
3 days	21	Min. 16 MPa
7 days	28.5	Min. 24 MPa

5. Super plasticizer used was (181k) with 2% of cement weight, The properties of super plasticizer are shown in table (6), from O.BASF the chemical company.
6. Silica fume :The properties of silica fume are shown in table (7)

Table (2), chemical properties of used cement

Chemical Composition	Value %	Limits %	Chemical Composition	Value %	Limits %
SiO	20.30	----	CaO	62.00	----
AL_2O_3	3.82	----	MgO	2.45	6
Fe_2O_3	4.49	----	SO_3	0.68	2.3
C_3S	64.10	----	C_4AF	13.66	----
C_2S	9.84	----	C_3A	2.53	----

Table (3), fine aggregate sieves analysis

Sieves (mm)	Passing%	Specification Limit (B.S 882-1992)
14mm (1/2in)	97.4	90-100
10mm (3/8 in)	57.4	50-85
5 mm (No.4)	2.1	0-10
2.36mm (No.8)	1	----

Table (4), coarse aggregate sieves analysis

Properties	Fine Aggregate	Coarse Aggregate
Absorption	2.8%	1.11%
Specific Gravity	2.24	2.66
Density	1650 kg/m^3	1750 kg/m^3
Sulfate Content	0.75%	0.08%

Table (5), properties of aggregate

Sieves (mm)	Passing %	Specification Limit (B.S 882-1992)	Additional limits B.S 882-1992		
			Coarse	Medium	Fine
5 mm(No.4)	100	89-100	-----	------	-----
2.36mm(No.8)	86	60-100	60-100	65-100	80-100
1.18mm(No.16)	70	30-100	30-100	45-100	70-100
0.6mm(No.30)	49	15-100	15-54	25-80	55-100
0.3mm(No.50)	17	5-70	5-40	5-48	5-70
0.15mm(No.100)	4	0-15	------	------	------

Table (6), properties of super plasticizer

Structure of the Material	Naphthalene Sulphonate Based
Color	Brown
Density	1.153-1.213 kg/liter
Chloride Content %(EN480-10)	< 0.1
Alkaline Content %(EN480-12)	< 10

Table (7), properties of silica fume

Chemical properties of silica fume	Physical properties of silica fume
Amorphous	Particle size (typical) <1 micron
Silicon dioxide >85%	Bulk density As- produced : 130 to 430 kg/m^3 Densified: 480to 720 kg/m^3
Trace elements depending upon type of fume	Specific gravity :2.2
-------------------------	Specific surface 15,000 to 30,000 m^2/kg

Casting and test procedure:

The mixed proportion was (1:2:3/0.25), Concrete cylinders were prepared, the materials were placed in mixer the placement order was coarse aggregate, fine aggregate , cement, silica fume (mixed in dry condition), then the mixing water was added with the Super plasticizer , and then the samples were cast in the molds and after casting the samples were left for 24 hours and then cured in the water (standard curing). After 28 days the samples were taken out of water, then were tested in compression as shown in Fig. (1).

Fig. (1) Compression testing Machine

Results:

It is observed that when silica fume is added in concrete as an admixture, it modifies most of the properties of concrete such as workability, compressive strength, modulus of elasticity.

WORKABILITY:

The slump test is used for the indication of consistency of fresh concrete. The test is an empirical test that measures the consistency of fresh concrete. More specifically, it measures water contents between batches. Fig.(2) given below show that consistency (workability) varies with the different silica fume percentages with added a super plasticizer, The effectiveness of super plasticizer is enhanced in the presence of silica fume. With increase in silica fume content in concrete, the value of slump decreases. which can be attributed to high specific surface of silica fume.

Compressive strength:

Is the capacity of a material or structure to withstand axially directed compressive forces. When the limit of compressive strength is reached, materials are crushed. Concrete can be made to have high compressive strength. In this research compressive strength was obtained from testing standard cylinders (300*150) mm, of concrete for the different silica fume ratios (0,5,10,15,20) %, the results are shown in Figs.(3) and (4) under monotonic and repeated loads. It is observed from the figures that there is an improvement in compressive strength for all the percentages of silica fume. When a super plasticizer of 2% of cement weight was added to the mix, the maximum strength obtained is for 10% of silica fume. It can be noticed that the percent increase in compressive strength is (46.3,68.8,63.1,57.5)% for the silica fume (5,10,15,20)% under monotonic load, and the percent increase in compressive strength is

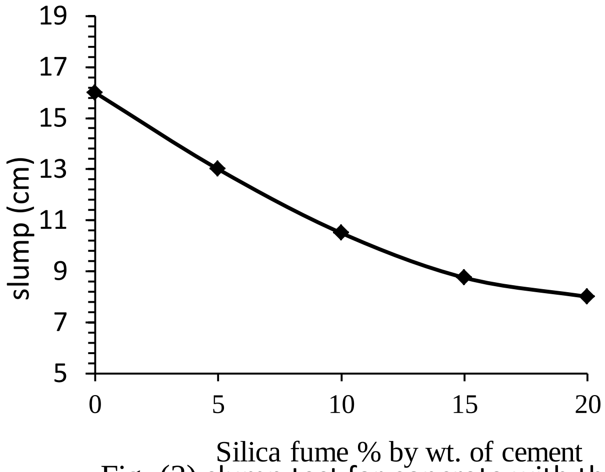


Fig. (2) slump test for concrete with the different silica fume percentage with a superplasticizer

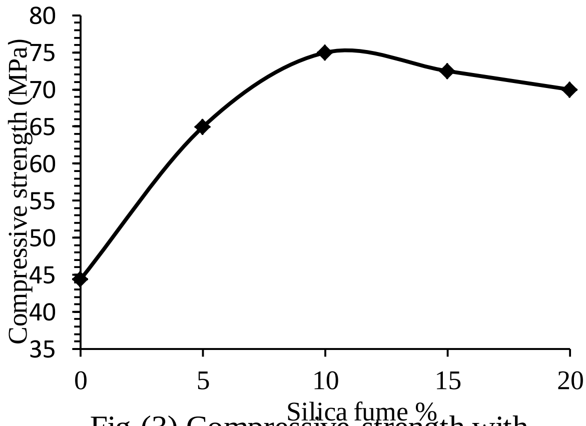


Fig (3) Compressive strength with silica fume ratio under monotonic loads

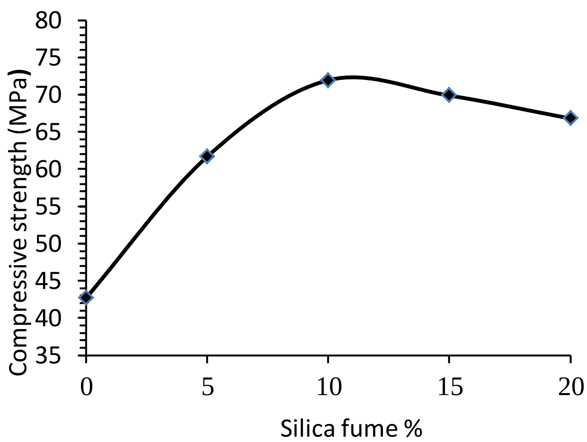


Fig (4) Compressive strength with silica fime under repeated loads

(44.4, 68.5, 63.7, 56.5)% for the same percentages of silica fume under repeated load. So the percentage (10) of silica fume gave the optimum value of compressive strength under monotonic and repeated loads. This was because of the hydration of Portland cement which produces many compounds including Calcium Silicate Hydrates (CSH) and Calcium Hydroxide (CH). When silica fume is added to fresh concrete, it reacts with the CH to produce additional CSH which improves the bond between the cement and the surface of the aggregate [10].

The relationship between stress and strain that a material displays is known as a Stress-Strain curve. It is unique for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading. These curves reveal many of the properties of a material (including data to establish the Modulus of Elasticity, E). Fig.(5) show the stress -strain relationship for concrete with the different silica fume percentages under monotonic loads. The stress increased by (46.3,68.8,63.1,57.5) for the silica fume (5,10,15,20)% and the strain increased by (58.5,97.8,52.8,22) for the same percentages of silica fume under monotonic loads.

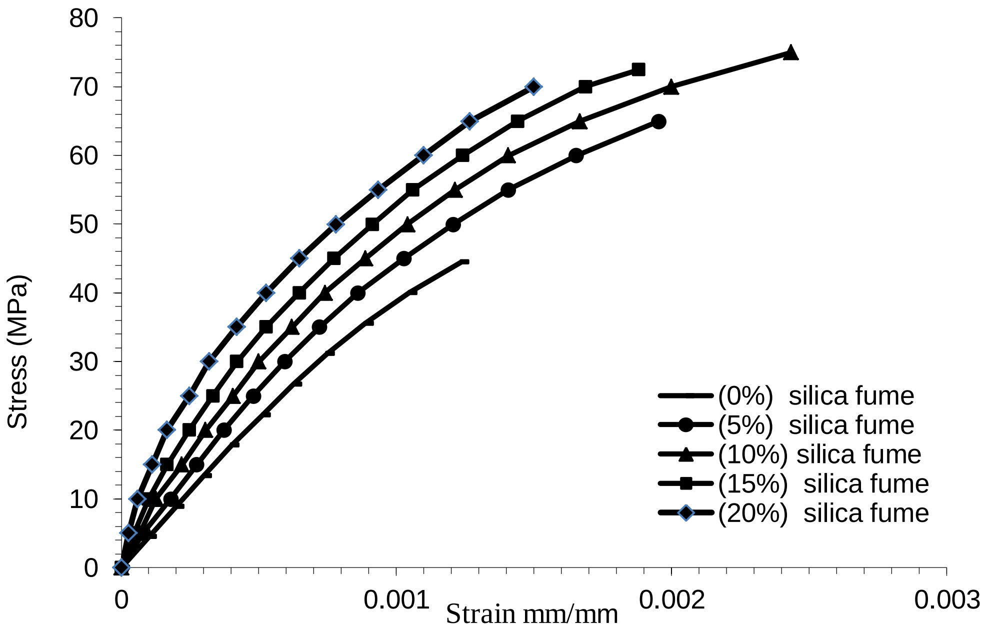
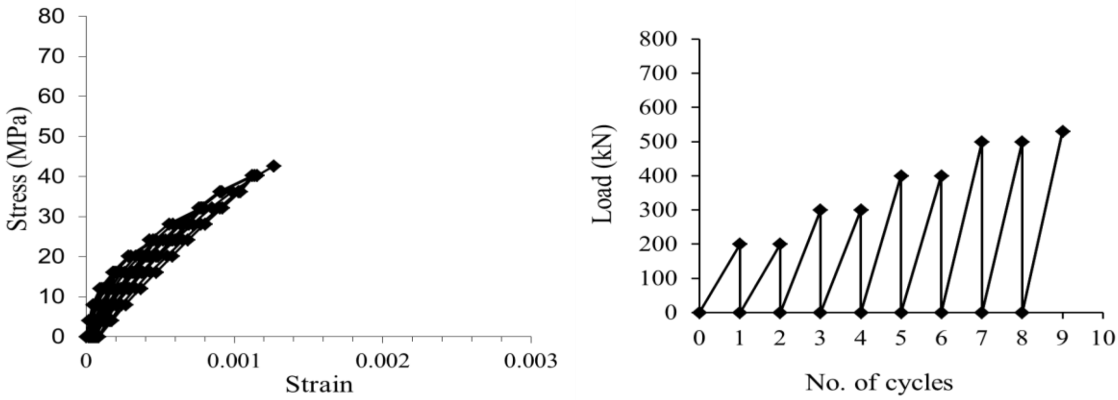
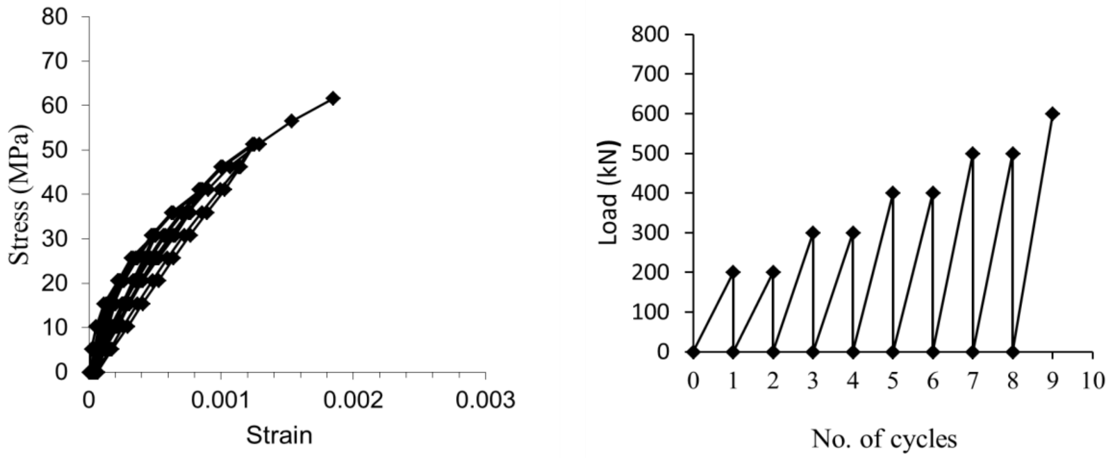


Fig.(5) stress-strain relationship for concrete under monotonic loads

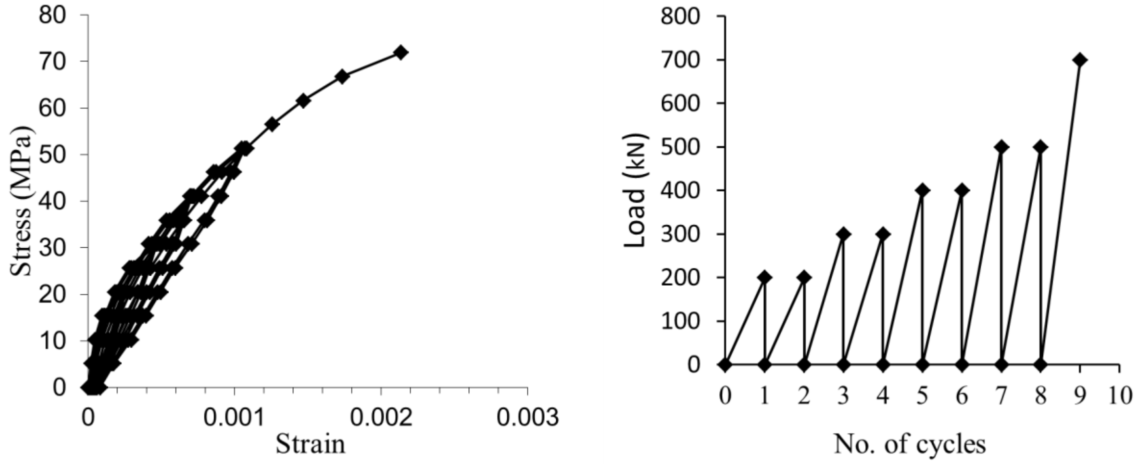


Fig(6) stress-strain relation ship for concrete without silica fume under repeated load

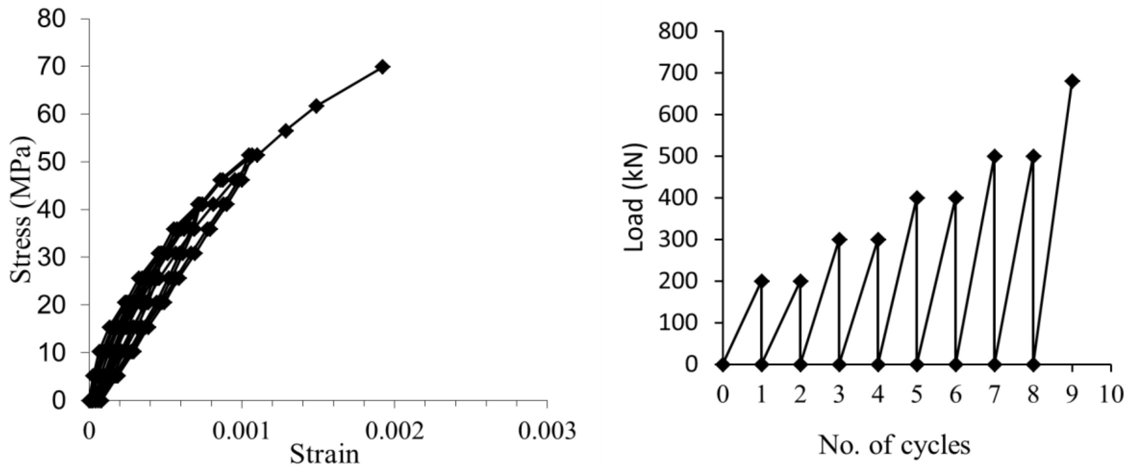
Similarly when testing standard cylinder (300*150) mm, of concrete for the same ratio of silica fume under repeated loads, the results show from figs.(6,7,8,9,10) that the stress increased by (44.4,68.5,63.7,56.5) for the silica fume (5,10,15,20)% and the strain increased by (45.8,68.4,51.3,26.3) for the same percentage of silica fume under repeated loads.



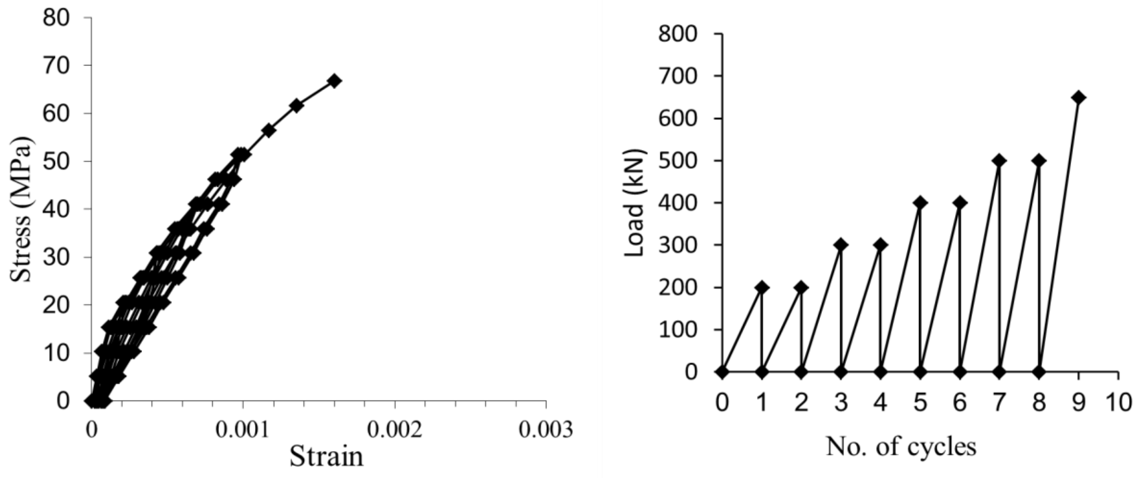
Fig(7) stress-strain relation ship for concrete with 5% silica fume under repeated load



Fig(8) stress-strain relation ship for concrete with 10% silica fume under repeated load



Fig(9) stress-strain relation ship fr concrete with 15% silica fume under repeated load



Fig(10) stress-strain relation ship for concrete with 20% silica fume under repeated load

Modulus of elasticity, or elastic modulus, It is defined as the ratio of the uniaxial stress over the uniaxial elastic strain in the range of stress in which Hooke's Law holds [11]. It can be experimentally determined from the slope of a stress-strain curve created during compressive tests conducted on a sample of the material. Fig. (11) shows that the Modulus of elasticity of the concrete under monotonic loads is maximum between 10% and 15% of silica fume. with the knowledge that the Modulus of elasticity is calculated at 40% of maximum stress, according to ASTM C469-02 [12]. Similarly the Modulus of elasticity of the concrete was determined under repeated loads as shown in fig. (12) at 5 and 8 cycles. The figure show that the maximum of the Modulus of elasticity at 10% of silica fume for both 5th and 8th cycle.

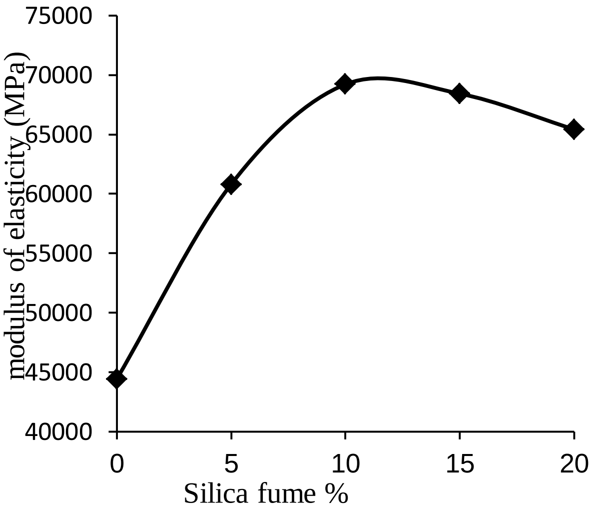


Fig.(11) effect of silica fume on the modulus of elasticity under monotonic loads

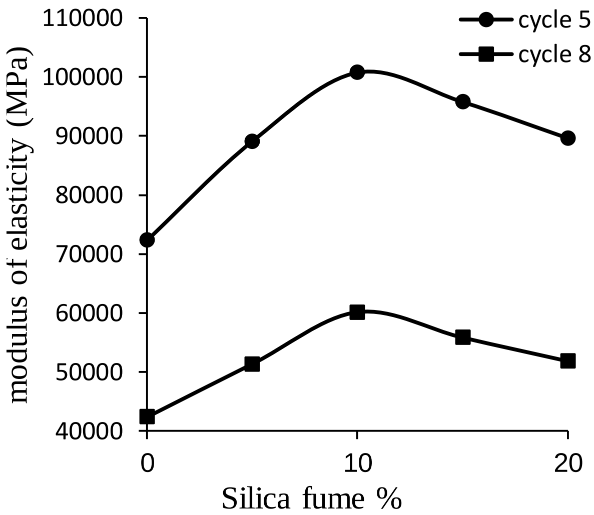


Fig. (12) effect of silica fume on the modulus of elasticity under repeated loads

One of the principal challenges in structural engineering concerns the development of modern design concepts to a better protecting of structures, with the occupants and contents, from the damaging effects of destructive environmental forces including those due to winds, waves and earthquakes. Passive energy dissipation devices, when incorporated into a structure, absorb or consume a portion of the input energy, thereby reducing energy dissipation demand on primary structural members and minimizing possible structural damage[13]. Fig. (13) show the result of Energy absorption which is defined as (area under the stress-strain curve). The Energy absorption increased for all silica fume percentages and giving the optimum percentage at (10)% under monotonic and repeated loads.

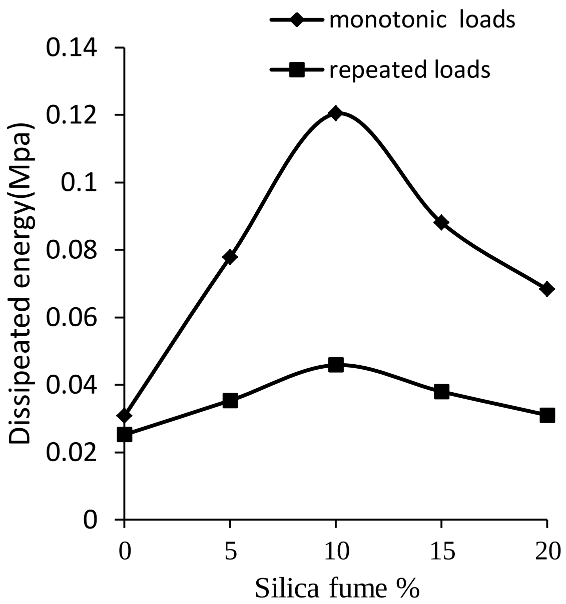


Fig. (13) effect of silica fume on dissipeated energy for concrete under monotonic and repeated loads

Summary for the obtained results are shown in table (8):

Table (8), Summary for the obtained results

Monotonic loads				
Silica fume %	Compressive strength (MPa)	Slump (cm)	Modulus of Elasticity (MPa)	energy dissipation (MPa)
0	44.4	15	44433	0.030674
5	65	15	60804	0.077797
10	75	10	69213	0.120386
15	72.5	10	68427	0.088036
20	70	10	65427	0.068199

Repeated loads					
Silica fume %	Compressive strength (MPa)	Slump (cm)	Modulus of Elasticity (MPa) Cycle 5	Modulus of Elasticity (MPa) Cycle 8	energy dissipation (MPa) Cycle 7
0	42.7	15	72337	42387	0.025194
5	61.7	15	89091	51376	0.035329
10	71.9	10	100737	60159	0.045827
15	69.9	10	95759	55843	0.037984
20	66.8	10	89627	51843	0.031

Conclusions:

The following conclusions can be stated:

1. The compressive strength increased by (46.3,68.8,63.1,57.5)% for the silica fume (5,10,15,20)% under monotonic loads, The compressive strength increased by

(44.4,68.5,63.7,56.5)% for the same percentages of silica fume under repeated loads. At a percentage of (10)% of silica fume the optimum result under both loading was obtained.
2. The stress increased by (46.3,68.8,63.1,57.5) % for the silica fume (5,10,15,20)% and the strain increased by (58.5,97.8,52.8,22)% for the same percentage of silica fume under monotonic loads. and stress increased by (44.4,68.5,63.7,56.5) % and strain increased by (45.8,68.4,51.3,26.3) % for the same percentages under repeated loads.
3. Modulus of elasticity of the concrete under monotonic loads is maximum between 10% and 15% of silica fume, and for repeated loads the Modulus of elasticity is maximum at 10% of silica fume for both 5th and 8th cycle.
4. Energy absorption increased for all silica fume percentage and give the optimum percentage at (10)% under monotonic and repeated loads.

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The work was carried out at the college of Engineering. University of Mosul