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# Stress- Strain Behavior and Mechanical Properties of Silica Fume Lightweight Polymer Concrete

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**Keywords**

stress-strain behavior ,compressive strength, flexural strength, modulus of elasticity, lightweight concrete , polymer concrete, SBR.

**ABSTRACT**

This investigation aims to improve the stress-strain behavior and mechanical properties of lightweight concrete in order to use it in structural members. Special type of lightweight concrete was produced in this study prepared by mixing Ordinary Portland Cement(OPC type I) and white gravel of low specific gravity, sand with very low percentage of 10% from gravel weight, and w/c ranged from 0.42 to 0.46 , silica fume added as percentage from cement weight and STYRENE BUTADIENE RUBBER (SBR) was added also in different percentages(5%, 10% and 15%). The main mixes 1:5 (cement: gravel) and 1:4 were used in this study. The tests in this research include stress- strain tests for both ascending and descending portions, compressive strength test, tensile strength test, flexural strength test and density of specimens. The most significance effect done by adding 15% SBR resin and gives (110%) increment in compressive strength for 1:4 mixes and ( 142 %) increment for1:5 mixes. For mixes 1:5 and by adding 15% SBR, the tensile strength increased 100%, flexural strength increased also 62% and density of specimens increased 8.2% , but more significant effect is seen for mixes 1:4, the increased in tensile and flexural strength and density of specimens were 138%, 109% and 7.71% respectively. The values of modulus of elasticity increased also compared with reference mixes and have excellent values ,by adding 15%SBR the increment was ( 58 %) for 1:4 mixes, and ( 150 %) increment for 1:5 mixes, that increments are very important to reduce the deflection in concrete members such as slabs and beams, therefore, like this polymer concrete can be used as structural members.



## سلوك الاجهاد-الانفعال والخواص الميكانيكية للخرسانة الخفيفة الوزن والحاوية على السليكا فيوم

**الخلاصة**

هدف هذه الدراسة هو تحسين سلوك الاجهاد-انفعال والخواص الميكانيكية للخرسانة الخفيفة الوزن كي يمكن استخدامها في لأعضاء الإنشائية. في هذه الدراسة تم انتاج نوع خاص من الخرسانة الخفيفة الوزن من خلال خلط الاسمنت البورت لأندي العادي نوع I والحصى الابيض الخفيف الوزن ذات وزن نوعي قليل ونسبة واطئة من الرمل (10%) من وزن الحصى، ونسبة ماء/سمنت تتراوح من (0.42الى0.46) وأضافه سليكا فيوم بنسبة من وزن الاسمنت مع اضافة نسب مختلفة من (SBR) (5%، 10%، 15%) . نسبة خلط الاسمنت والحصى هي 1:4 (1 سمنت ، 4 حصى ). ألأختبارات التي اجريت في هذا البحث تتضمن اختبار اجهاد-أنفعال لكلا الجزئين الصاعد والنازل، واختبار الضغط، والشد، ومقاومة الأنثناء وكثافة النماذج. بأضافة 15% من SBR وجد ان هنالك زيادة مهمه في مقاومة الانضغاط ما يقارب 110%للخلطات الخرسانية 1:4 و 142% للخلطات الخرسانية 1:5. وكذلك يزداد معمل المرونة مقارنة مع خلطات المصدر بقيم ممتازة، حيث كانت الزيادة هي 58% للخلطات الخرسانية 1:4مع اضافة 15%من SBR و150% للخلطات الخرسانية 1:5، والزيادة في معامل المرونة مهمة جدا في تقليل الهطول في الأعضاء الخرسانية مثل السقوف والأعتاب.

**الكلمات المفتاحية**

تصرف أجهاد-أنفعال، مقاومة الانضغاط، مقاومة الانثناء، معامل المرونة، خرسانة خفيفة الوزن، الخرسانة البوليمرية، مضاف.

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## Introduction

Lightweight concrete (LWC) is widely used in structures , because it has good physical properties such as low density ( less than 2000 kg/m$^3$) that leads to reduce dead loads of total structure and less footing dimension and also low cost of construction [1] . when lightweight concrete has low values of compressive strength (less than 17 MPa) ,the use of LWC can only be in partitions or not suitable in used as structural members, structural lightweight concrete can be defined as the concrete of compressive strength not less than 17 MPa [2,3]. The LWC can be produced from the use of lightweight aggregates or by using no-fine concrete, the density of LWC should be less than 2000 kg/m$^3$ with comparison to normal concrete that has density between (2200 kg/m$^3$-2500 kg/m$^3$) [3,4].

Using no fine concrete, the concrete in this case has high number of voids which lead to very low compressive strength values(less than 12 MPa) [5], therefor it is not suitable for structural applications.

N. Sivalinga Rao et al.(2013) have studied on Fiber Reinforced Light Weight Aggregate (Natural Pumice Stone) Concrete. In their study, the mix design was M20 and the test results are as follows: More than the target means strength of M20 concrete is achieved with 20 percent replacement of natural coarse aggregate by pumice aggregate and with 1.5 percent of fibber. Also with 40% pumice and with 0.5% of fibbers average target mean strength of M 20 concrete is achieved[6].

Lakshmi Kumar Minapu1 et al.(2014) have presented experimental investigation on the mechanical properties of a structural grade light weight concrete M30 using the light weight aggregate pumice stone as a partial replacement to coarse aggregate and mineral admixture materials like Fly Ash and Silica Fume. They concluded that By using 20% of light weight aggregate as a partial replacement to natural coarse aggregate the compressive strength is promising. The density of concrete is found to decrease with the increase in percentage replacement of natural aggregate by pumice aggregate. The compressive strength of concrete is found to decrease with the increase in pumice content[7].

Therefore, there is a need for improving the mechanical properties of LWC by using supplementary materials without high increment in density which is very important. This research aims to improve stress-strain behavior which is very important to give us an idea of improvement of toughness, stiffness and modulus of elasticity, and also improving other mechanical properties which achieved in this research.

## Experimental Program

### 1. General

The experimental program include production of special LWC using small amount of sand. The reason for using this amount of sand is to reduce voids in concrete with keeping the lightweight property of its.

### 2. Materials and mix proportions used in study

Ordinary Portland Cement(OPC type I) was used, natural white gravel brought from (Al-Ruttba) region was used as lightweight coarse aggregate in concrete mixes. It has low density and specific gravity of (2.4) with maximum size aggregate of 10 mm and graded as shown in table 1, the sand was used as 10% by weight of gravel and meeting B.S requirements of grading (zone 4) [8], as shown in table 2, SBR resin added as percentages from cement weight with different values of 0%( reference mix), 5% , 10%, and 15% . silica fume of 2.2 specific gravity was used to improve properties of this concrete and added for all mixes except for reference mixes as percentage of cement weight as 10% . Two main types of mixes were used as 1:4 ( cement :gravel) and 1:5. The LWC was produced and casted at (Structural Laboratory – Engineering College – Kufa University).

The properties of SBR resin is shown in table 3. Ordinary drinking water used in all mixes, w/c ratio ranged from 0.42-0.46 in mixes.

**Table 1 : Sieve Analysis of Coarse Aggregate According to B.S 882 Standards Used in Study.**

| Sieve size (mm) | % passing by weight | B.S . SPECIFICATI ON(882:73) |
|---|---|---|
| 20 mm | 100% | 100% |
| 10mm | 100% | 85-100 |
| 5 mm | 20% | 0 - 25 |
| 2.36 mm | 4.2 % | 0- 5 |

**Table 2 : Sieve Analysis of Sand Used in Study.**

| Sieve size mm | % passing | % PASSING (B.S 882 STANDARDS-ZONE 4) |
|---|---|---|
| 10 mm | 100 % | 100 |
| 5mm | 100% | 95-100 |
| 2.36 mm | 98.4 % | 95-100 |
| 1.18 mm | 95.6 % | 90-100 |
| 600 micron (0.6 mm) | 92.7 % | 80-100 |
| 300 micron | 45.3 % | 15-50 |
| 150 micron | 11.9 % | 0-15 |

**Table 3 :Physical and Chemical Properties of SBR Resin Used in Study.**

| Specific density | color | Chemical composition of SBR particles | PH |
|---|---|---|---|
| 1.1 | white | Ch-ch2-ch2-ch—chains bond with C6H6 particles | 8.2 |

**Specimens and Testing Procedure**

- **Compressive strength :**

The compressive strength was done by using ELE testing machine, and the specimens was used by casting concrete in molds of dimensions of 100x100x100 mm, the tests done after water curing and tested at 28 days for all specimens.

- **Tensile strength**

Done by using splitting test of 100x200 mm cylinders.

- **Flexural strength test**

Done by ELE flexural strength testing machine, the concrete specimens was100*100*400 mm beams and using third point loading test, Fig.1 shows the dimensions and loading of beam for flexural strength.

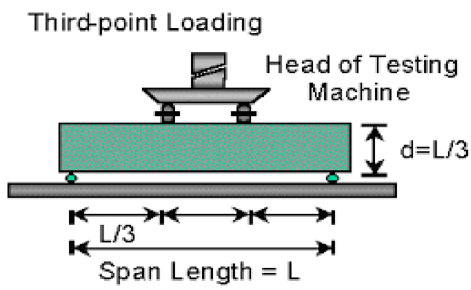


**Figure 1: illustrative figure of third point loading for flexural strength test.**

**Stress-Strain Test and Calculation**

The stress- strain test was done experimental model ( wang and naaman model [9]) for complete stress- strain diagram calculation, this experimental model illustrate in Fig.2, the figure shows the high strength steel tube of 9.3 cm internal diameter with thickness of 3.3 mm and 15 mm high, the concrete specimen for stress-strain test was 7.5 cm x 15 cm, this concrete specimen put inside steel tube and loaded together by putting stiff steel plate above them then subjected to loading, the rate of loading was done according to ASTM –C 469 [10] , of 0.254 MPa / sec.

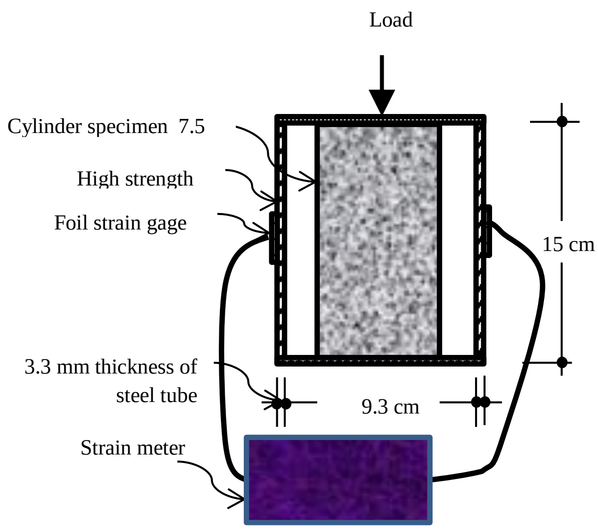


**Figure 2: Experimental Model for Testing Complete Stress- Strain Behavior of Concrete.**

The equations that used for calculation complete stress- strain data shows as follows :

$$F_s = E_s * \varepsilon_s \quad (1)$$

$$P_s = F_s * A_s \quad (2)$$

$$P_c = P_{tot} - P_s \quad (3)$$

Where :

$F_s$ :stress in steel tube.

$E_s$ : modulus of elasticity of steel tube.

$\varepsilon_s$ : strain in steel tube measured by foil strain gauges and equal to strain in concrete specimen.

$P_s$: force in steel tube.

$A_s$ : area of steel tube subjected to load.

$P_c$ : force in concrete.

$P_{tot}$ : total force by machine.

**Results and Discussion**

Table 4 shows the results obtained from experimental program, from this table the test results are compressive, tensile, flexural strength, modulus of elasticity and density. The reference mixes shows the lowest values of these mechanical properties , and by adding SBR (5%) and silica fume the compressive strength increased for 1:5 mixes from 9.4 MPa to 22.8 MPa and that is very high increment , also for 1:4 mixes that the compressive strength increased from 14.1 to 29.7 MPa, tensile strength also increased as shown in table 4, the flexural strength increased from 1.88 to 3.06 MPa for 1:5 mixes and increased from 2.33 to 4.89 MPa for 1:4 mixes .

The modulus of elasticity calculated from stress–strain diagram, the stress-strain diagrams for all mixes shown in Fig.3 and Fig.4, the stress strain diagrams shows complete ascending and descending portions, adding SBR and silica fume give higher

**Table ( 4 ) : Mechanical Properties of Lightweight Concrete (LWC) of Different Mixes in This Study.**

| Mix proportion | Compressive strength ( MPa ) | Tensile strength ( MPa ) | Flexural strength ( MPa) | Modulus of elasticity (MPa) | Density Kg/m$^3$ |
|---|---|---|---|---|---|
| 1:5 ( ref. mix) | 9.4 | 1.12 | 1.88 | 8900 | 1827 |
| 1:5(5% SBR) | 12.2 | 1.58 | 2.29 | 9400 | 1872 |
| 1:5(10% SBR) | 16.3 | 1.95 | 2.72 | 11500 | 1924 |
| 1:( 15% SBR) | 22.8 | 2.24 | 3.06 | 20000 | 1977 |
| 1:4 ( ref. mix) | 14.1 | 1.62 | 2.33 | 14200 | 1888 |
| 1:4 (5% SBR) | 19.3 | 2.26 | 3.16 | 16000 | 1946 |
| 1:4(10% SBR) | 27.8 | 3.03 | 4.23 | 20200 | 1996 |
| 1:4(15% SBR) | 29.7 | 3.87 | 4.89 | 22400 | 2033 |

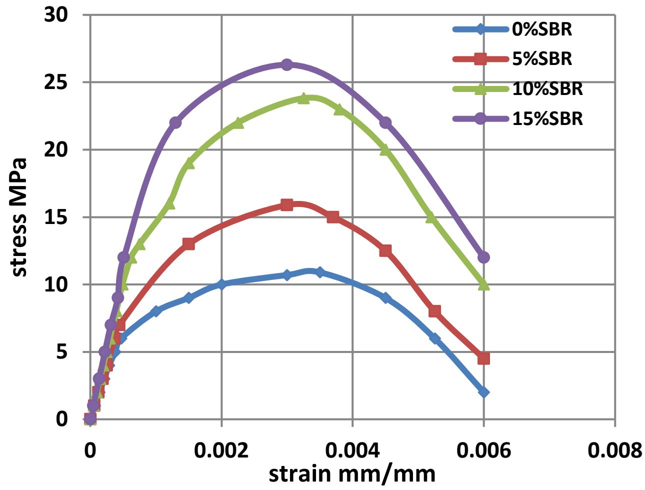


**Figure 3: Stress-strain curves for 1:4 (cement: gravel) mixes, with varies SBR ratios.**

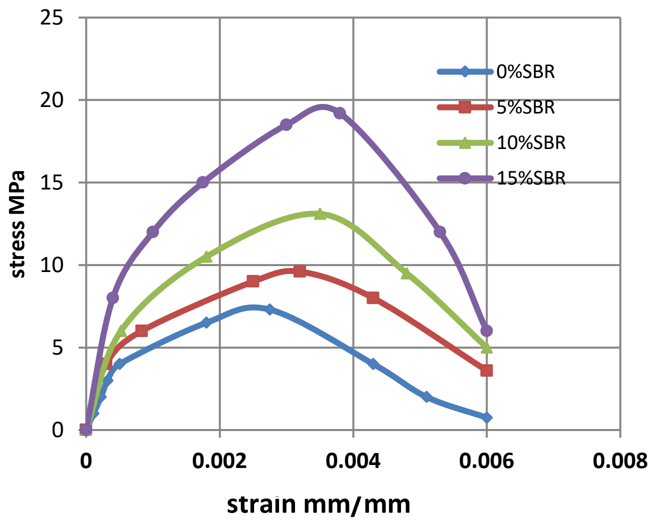


**Figure 4 : Stress-strain curves for 1:5 (cement: gravel) mixes, with varies SBR ratios.**

toughness of concrete, the 15% SBR ratio gives the largest values of toughness( the area under stress-strain curves), and largest values of modulus of elasticity, and that is very important for decreasing the deflection of structural members. The reasons of the improvement in all mechanical properties for this type of lightweight concrete can be illustrated from the following points :

1. Silica fume added bonds with liberated Ca $(OH)_2$ from hydration of cement and gives additional cement gel that filled some pores in concrete, that gives a higher strength [11,12].
2. Adding SBR resin to concrete during mixing, some chemical reactions may take place between the particle surfaces of polymers particles and calcium ions ( $Ca^{+2}$ ), $Ca(OH)_2$ and solid surfaces, or silicate surfaces over the aggregate, that give higher bond between concrete ingredients [13,14], and that lead to higher values of compressive , tensile strength, flexural strengths and higher values of modulus of elasticity.

## Conclusions

Based on the results and observations made in this experimental study, the following conclusions are drawn:

1. The modulus of elasticity increased from 8900 to 20000 MPa for 1:5 mixes(that have 15% SBR), therefore this mix can be used in some structural members because it has compressive strength of 22.8 MPa compared with reference mix that has lower value ( 9.4 MPa). For 1:4 mixes the modulus of elasticity has the values more than 20000MPa for (1:4 10%SBR and 1:4 15% SBR) .
2. The most significance effect done by adding 15% SBR resin for compressive strength tests and gives ( 110 %) increment for 1:4 mixes and ( 142 %)for1:5 mixes.
3. Tensile strength and flexural strength also increased by adding SBR and silica fume, the tensile strength increment was ( 100%) for 1:5 mixes and ( 138%) for 1:4 mixes. The flexural strength increment was( 62%) for 1:5 and( 109.8 %) for 1:4 mixes.
4. Density increased slightly by adding SBR resin for all mixes.

## References


1. ACI-Committee, 2005 " specification of structural concrete" , American concrete institute , p.o.box 9094. pp.301-05
2. www.nrmca.org/aboutconcrete/cips/36p, structural lightweight concrete, concrete in practice, CIP-36.
3. www.argex.eu/download.php?lang=en&id=2 , lightweight concrete density definition.
4. Young, J 2015, " Lightweight concrete produced by using two stage casting process" , open access materials journal-ISSN-1996-1944,pp.1384-1397.
5. T,Abadjieva, "Investigations on Some Properties of no-Fines Concrete ",Department of Civil Engineering, University of Botswana - Private Bag 0061, Gaborone, Botswana.
6. N. Sivalinga Rao, Y.Radha Ratna Kumari, V. Bhaskar Desai, B.L.P. Swami, 2013 "Fibre Reinforced Light Weight Aggregate (Natural Pumice Stone) Concrete", International Journal of Scientific & Engineering Research ISSN 2229-5518,Volume 4, Issue 5.
7. Lakshmi Kumar Minapu1, M K M V Ratnam2, Dr. U Rangaraju3,2014" Experimental Study on Light Weight Aggregate Concrete with Pumice Stone, Silica Fume and Fly Ash as a Partial Replacement of Coarse Aggregate", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 12.
8. Alkhalaf,M ," Concrete technology, ministry of higher education ,technology university Iraq,1984, handbook ,P,558.
9. Wang, P.T., Shah, S.P., and Naaman,1978 " Stress-Strain Curves of Normal and Lightweight Concretes in Compression". Journal of the American Concrete Institute, NO. 75-62, pp :603-611.
10. ASTM Committee, C-469 ,1981" Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression"..
11. Kumar,R ,2012 " Effect of silica fume on mechanical properties of concrete ", Journal of academic industrial research, Vol 1, p.p 176-179
12. Hon. F, 2012 " The effect of silica fume on the properties of concrete", 137th conference in concrete society (Repot)- 29-31 , Singapore.
13. Ohama,Y.,"Polymer-Based Admixtures,1998"Cem. And Conc. Comp., ,20:P.P.,189-212.
14. Radomir,J.andVlastimir,S.1998,"Experimental Research on Polymer Modified Concrete,"ACI Mat. Journal,:P.P.,463-469.