# Strength of Concrete Using Different Types of Additives

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## Abstract:

***In this investigation, conventional concrete mixes (as a reference mixes) and concretemixes produced with (5, 10, and 20)% of cement replacement by silica fume, crushed glass and crushed nucleate additives respectively, these mixes were used in preparing (144) concrete specimens. Laboratory test results in dictated that:***

***a) There was a significant increase (17.6 to 88.5 and 8.8 to 25.8) % in the compressive strength of concretes produced with silica fume and crushed glass additives respectively, while a significant reduction (29.6 to 62.6)% in the compressive strength was recorded using concrete mixes with crushed nucleate.***

***b) there lation ships between the 7-day($f_{c,7}$)and:the28day($f_{c,28}$)compressive strength areas follows***

- ***[$f_{c,28}$ = 1.701 $f_{c,7}$] for (reference mix);***
- ***[$f_{c,28}$ = (1.590 to 1.931) $f_{c,7}$] for silica fume mixes;***
- ***[$f_{c,28}$ = (1.660 to 1.813) $f_{c,7}$] for crushed glass mixes;***
- ***[$f_{c,28}$ = (1.521 to 1.796) $f_{c,7}$] for crushed nucleate mixes.***

***c) percentages of increasing in both flexural and splitting tensile strengths, as compared with conventional concrete, are as follows:***

- ***for silica fume mixes: (26.92 to 48.72 and 44.44 to 72.22)% respectively;***
- ***for crushed glass mixes: (46.15 to 71.79 and 11.11 to 36.11)% respectively.***

***On the other hand, crushed nucleate mixes recorded a drop in both flexural and splitting tensile strengths (5.41 to 34.48 and 28.57 to 71.43)% respectively.***

***d) Finally, the research included also deriving different relationships between compressive, flexural and tensile strengths of concretes produced using silica fume and crushed glass additives.***

***Key words:** Silica fume, Crushed glass, Crushed nucleate, compressive strength, tensile strength, flexural strength.*

# مقاومة الخرسانة المنتجة باستخدام أنواع مختلفة من المواد المضافة


## الخلاصة:

***في هذا البحث، تم انتاج خلطات خرسانية عادية (كخلطات مرجعية) وخلطات خرسانية اخرى باحلال نسب (5 ، 10 ، 20)% بدلا من الاسمنت البورتلاندي بغبار السيليكا، الزجاج المطحون، و نوى التمر المطحون على التوالي، وهذه الخلطات استعملت في تهيئة (144) نموذج خرساني.***

***نتائج الفحوصات المختبرية بينت ما يلي:***

***أ. تسجيل زيادة معتبرة في مقاومة انضغاط الخرسانة (17.6 to 88.5 و 8.8 to 25.8)% المنتجة بغبار السيليكا و الزجاج المطحون على التوالي، بينما الخرسانة المنتجة بنوى التمر المطحون قد سجلت نقصان في مقاومة الانضغاط بمقدار يتراوح بين (29.6 to 62.6)%.***

***ب. العلاقة بين مقاومة الانضغاط بعمر 7 و 28 يوم كانت كما يلي:***

*- الخلطة المرجعية $[f_{c,28} = 1.701\ f_{c,7}]$،*

*- الخلطات الخرسانية بغبار السيليكا $[f_{c,28} = (1.590 \text{ to } 1.931)\ f_{c,7}]$،*

*- الخلطات الخرسانية بالزجاج المطحون $[f_{c,28} = (1.660 \text{ to } 1.813)\ f_{c,7}]$،*

*- الخلطات الخرسانية بنوى التمر المطحون $[f_{c,28} = (1.521 \text{ to } 1.796)\ f_{c,7}]$.*

***ج. نسب الزيادة في كل من مقاومة الشد والتكسير، مقارنة مع الخلطات المرجعية، وكما يلي:***

*- الخلطات الخرسانية بغبار السيليكا (44.44 to 72.22 & 26.92 to 48.72) على التوالي،*

*- الخلطات الخرسانية بالزجاج المطحون (11.11 to 36.11 & 46.15 to 71.79)% على التوالي.*

*- و من ناحية اخرى، تم تسجيل هبوط في مقاومات الشد والتكسير للخلطات الخرسانية بنوى التمر المطحون بمقدار (28.57 to 71.43 & 5.41 to 34.48)% على التوالي.*

**د. واخيرا، تضمن البحث اشتقاق علاقات رياضية بين مقاومة الانضغاط ومقاومة الشد من جهة ومقاومة الانضغاط ومقاومة التكسير من جهة اخرى للخلطات الخرسانية المنتجة بغبار السيليكا والزجاج المكسر.**



***الكلمات المفتاحية:*** *غبار السيليكا ، الزجاج المطحون ، نوى التمر المطحون ، مقاومة الانضغاط ، مقاومة الشد ، مقاومة التكسير.*


# *Strength of Concrete Using Different Types of Additives*

## 1. Introduction:

### 1-1 Silica fume concrete (SFC):

is the generic name for a new family of ductile, cementitious composite material, ultra-high performance concrete (UHPC) material, formulated from a special combination of constituent materials, developed by the technical division of Bouygues, in the early 1990s, and gives the trade mark name Ductal®. It is characterized by extremely good physical properties, particularly strength and ductility. In 2001, a clinker silo in Joppa, Illinois became the first building in the world to have a long-span roof constructed with Ductal®. Ductal® is a revolutionary, UHPC material that provides a unique combination of ductility, strength, durability, and aesthetic flexibility–with compressive strength up to 32000 psi (220 MPa) and flexural strength of up to 7200 psi (50 MPa)[1]. An experimental program was conducted to determine the uniaxial compressive behaviors of an UHPC. Cylinders were tested in compression and the results were analyzed to determine the strength, modulus of elasticity, strain capacity, and overall stress-strain behaviors of both untreated and steam-treated UHPC. The results show that this concrete exhibits exceptional compressive strength and enhanced stiffness. The resulting high-early-strength materials are capable of delivering a compressive strength of 21 MPa (3.0 Ksi) within 4 hours after placement and retaining long-term tensile strain capacity. The rate of strength and stiffness gain of UHPC is also an important factor in the design of bridges. Test results show that this UHPC mix design begins to gain its strength around 20 hours after casting. The strength gain is relatively rapid, and by (72) hours after casting non-steam treated UHPC exhibited compressive strengths over 80 MPa[2,3,4]. The U.S. Department of Transportation's Federal Administration has investigated the use of silica fume concrete in highway bridges. The advanced properties of this new concrete allow for a rethinking of the basic mechanisms normally used by concrete girders to carry loads. Structural testing has shown that silica fume concrete girders exhibit high flexural and shear capacities due to the tensile load-carrying capabilities of the material without the aid of mild steel reinforcing bar. In discussing the flexural behavior of this type of concrete, the uniaxial stress-strain behavior differs from conventional concrete in several ways[5,6,7]. Additionally, when compared to the compressive stress-strain response of conventional concrete, this type of concrete exhibits a significantly more linear load-deformation response up through compressive failure. Finally, this concrete exhibits a very high compressive strength when compared to conventional and high performance concrete[8].

## 1-2 Glass concrete:

A major research effort has been underway at Columbia University for a number of years, to develop new applications for waste glass as an aggregate for concrete. Specific products such as paving stones, concrete masonry blocks, terrazzo tiles, and precast concrete panels are close to commercial production. The use of waste glass as aggregate for concrete has been attempted decades ago. Therefore, a high priority was assigned to gaining such an understanding, when a major research effort was initiated at Columbia University some six years ago. It was also expected that the glass aggregate would affect the mechanical properties of the concrete. For example, it is known that the concrete strength is typically controlled by the bond strength between cement matrix and aggregate. If natural aggregate with relatively rough surfaces is replaced by crushed glass particles with relatively smooth surfaces, one would expect a drop in strength and in particular a reduction of an already low ductility.

Finally, it was recognized early on that glass concrete is basically a new material that requires the development of appropriate production technologies, as well as answers to other questions that need to be addressed by basic research[9]. Glass Concrete™, is a trademark of Echo Environmental, Inc., New York City, which has an exclusive licence to the technology to produce concrete products with glass aggregate, products can be categorized as *commodity products* and *value-added products*. The development of an appropriate production technology should recognize the differences between glass and natural aggregates. For example, the basically zero water absorption of glass improves the mix rheology and calls for quite different mix designs, including the choice of admixtures, which also depends on whether a dry or wet technology is used. Since plain Glass Concrete™ is quite brittle, just like conventional concrete, it is advantageous to reinforce glass concrete products with either randomly distributed short fibers or, in the case of thin sheets or panels, with fibermesh or textile reinforcement[10].

### 1-2-1 Concrete masonry block unit:

was the first product to be developed for commercial production. Because modest goal was to replace just 10% of the fine aggregate with finely ground glass.

### 1-2-2 Paving stone:

is the next product, also close to being commercialized, which contains up to 100% glass aggregate. The idea was to create a paver with novel colors and surface texture effects, such as special light reflections, that cannot be obtained with regular natural aggregate. Other advantages are the greatly reduced water absorption and excellent abrasion resistance due to high hardness of glass. As an option, the paver may be reinforced with randomly distributed short fibers to offset the inherent brittleness of concrete in general and glass concrete in particular[11].

### 1-2-3 Architectural and Decorative Applications:

the most exciting applications appear to be in the architectural and decorative fields. It is also can create surface textures and appearances using techniques well known in the field of architectural concrete, while fully utilizing the esthetic potential of colored glass. To name just a few: building façade elements, precast wall panels, partition walls, floor tiles, wall tile and panels, elevator paneling, table top counters, park benches, planters, trash receptacles, and ashtray[12]. The effect of replacement of fine and coarse aggregates with recycled glass on the fresh and hardened properties of Portland cement concrete at ambient and elevated temperatures is studied. Percentages of replacement of (0–100%) of aggregates with fine waste glass, coarse waste glass, and fine and coarse waste glass were considered. Samples were cured under 95% RH at room temperatures (20–22$^{o}$C), heated in the oven to the desired temperatures, allowed to cool to ambient temperatures, and then test for their residual compressive strength[13].

## 2. Objective (program significance):

The objective of this research is to determine the different types of strength (compressive, splitting tensile, and flexural) developed in concrete produced using different types of additives, such that: silica fume, crushed glass, and crushed nucleate).

## 3. Experimental investigation:

### 3-1 Materials used:

An ordinary Portland cement (Turkish, Elazig, CEM I 42.5 N) was used as the main binder, its physical tests were done in accordance with the ASTM Specifications[14,15,16,17], shown in Table (3.1). A grey silica fume was added as pozzolanic mineral admixture, its particle size was extremely fine (0.1 µm). A quartz powder flour with a mean particle size of (10 – 15 µm) was used as micro filler. Superplasticizers (Sikament-163, accelerator) was used to ensure the concrete flowing ability. River sand and gravel, were obtained from Danadan place near Mosul city, Their sieve analysis were done in accordance with BS : 882 : 1992[18], their grading requirements and physical properties were shown in Tables (3.2, 3.3, and 3.4). They were prepared by washing them to remove all particles finer than sieve No. 200[19], drying them in ovens for (24) hours at (100-110)$^{o}$C, separating them in many sizes using the standard sieves used in sieve analysis of fine and coarse aggregates, then mix these individual sizes using the calculated satisfying percentages retained on each sieve to prepare the tested samples used in cast concrete specimens. Fine silica sand was a ready-mixed sand, was commercially obtained (Turkish origin), its grading requirement[20] was shown in Table (3.5).

***Table (3.1): Physical properties of the used cement***

| Properties | Used Cement | ASTM limits |
|---|---|---|
| **Blain Fineness, cm$^2$/g** | **3400** | **2250, min.** |
| **Setting time (Vicat method):** | | |
| **Initial time, min.** | **185** | **60, min.** |
| **Final time, hrs.** | **5.0** | **10, max.** |
| **Compressive strength (average):** | | |
| **3-day (MPa), min.** | **27.17** | **14, min.** |
| **7-day (MPa), min.** | **39.55** | **21, min.** |
| **Soundness, Autoclave test, %, max.** | **0.6** | **0.8, max.** |

### *Table (3.2): Sieve analysis of river sand[21]*

| Sieve size | | % Passing | BS : 882 : 1992 (MEDIUM) |
|---|---|---|---|
| ASTM | BS (mm.) | | |
| 3/8 in. | 10 | 100 | 100 |
| No.4 | 4.76 | 90 | 90 – 100 |
| No.8 | 2.36 | 82 | 75 – 100 |
| No.16 | 1.180 | 60 | 55 – 90 |
| No.30 | 0.600 | 40 | 35 – 59 |
| No.50 | 0.300 | 21 | 8 – 30 |
| No.100 | 0.150 | 4 | 0 – 10 |

### *Table (3.3): Sieve analysis of river gravel[21]*

| Sieve size | | % Passing | BS : 882 : 1992 (FINE) |
|---|---|---|---|
| ASTM | BS (mm.) | | |
| 11/2 in. | 40 | 100 | 100 |
| 3/4 in. | 20 | 100 | 100 |
| 3/8 in. | 10 | 52 | 50 – 85 |
| No. 4 | 4.76 | 1.0 | 0 – 10 |

### *Table (3.4): Main properties of river sand and river gravel used[22,23,24]*

| Property | River gravel* | River sand | | |
|---|---|---|---|---|
| | Test results | Specifications | Test results | Specifications |
| Dry sp. Gravity | 2.63 | 2.4 – 3.0 | 2.59 | 2.4 – 3.0 |
| S.S.D. sp. Gravity | 2.64 | 2.4 – 3.0 | 2.65 | 2.4 – 3.0 |
| App. sp. Gravity | 2.66 | 2.4 – 3.0 | 2.79 | 2.4 – 3.0 |
| Absorption capacity (%) | 0.5 | < 1.0 | 2.9 | ≥ 1.0 |
| Rodded unit weight (kg/m$^3$) | 1716 | 1200 – 1760 | 1765 | 1200 – 1760 |
| Voids content (%) | 33.255 | -- | 33.000 | -- |
| Angularity No. | 0.255 | -- | 0.400 | -- |
| Angularity index | 1.038 | -- | 1.060 | -- |
| Fineness modulus | 6.55 | > 3.1 | 2.78 | 2.6 – 3.1 |

* Maximum aggregate size of coarse aggregates are = 10 mm.

– for the properties of the unknown values, there is no specification.

***Table (3.5): Sieve analysis of fine silica sand***

| Sieve size | | % Retained |
|---|---|---|
| ASTM | BS (mm.) | |
| No. 16 | 1.180 | 0 |
| No. 30 | 0.600 | 14 |
| No. 50 | 0.300 | 71 |
| No. 100 | 0.150 | 15 |

## 3-2 Experimental program:

This part of the research consists of studying the mechanical properties of the produced concrete using different types of additives (silica fume, crushed glass, and crushed nucleate).
The mentioned materials were used in preparing and casting following different concrete specimens such that:

a. 150x150x150 mm. concrete *cubes* for conventional concrete, using a mix proportions of (1 : 1 : 1.5), and w/c = 0.300 (by weight), whose cement content is (1000) kg/m$^3$, in order to perform the compressive strength test[25].
b. 100x100x100 mm. concrete *cubes* for mixes with silica fume, fine crushed glass, and fine crushed nucleate, using different mix proportions resulted from different percentages (5, 10, and 20)% of cement replacement, in order to perform the compressive strength test[26].
c. 100x100x100 mm. concrete *cubes* for mixes with 100% of river gravel replaced by a crushed recycled waste glass as coarse aggregate, in order to perform the compressive strength test[25].
d. 150x300 mm. concrete *cylinders* for all the mixes, in order to perform the indirect splitting tensile test[27].
e. 100x100x400 mm. concrete *prisms* for all the mixes, in order to perform the modulus of rupture test[28].
f. Compressive strength, indirect splitting tensile strength, and modulus of rupture tests were done in accordance with (BS : 882 : 1992) or ASTM C192/192 M-02[25,26], using an (2000 Kn) capacity testing machine.

## 3-3 Samples preparation and tests:

The dry concrete constituents were mixed in mechanical mixer, a proper amount of mixing water (tap water for mixing was used, all aggregates were in dry condition, w/c ratios were adjusted for S.S.D. condition), including that of the superplasticizers solution, was used to attain the workability level corresponding to a fluid consistency, i.e., (130-180)% applying the flow table test, which done according to ASTM C1437[29]. As soon as mixing was completed, cast of all specimens was completed within (30) minutes after the completion of mixing. All specimens were cast on a vibrating table and were allowed to remain on the table for approximately (30) seconds after filling, then specimens were removed from the vibrating table and were screeded, each specimen had its exposed surface covered in plastic to prevent moisture loss. Specimens were then sat undisturbed and allowed to harden in their moulds for 24 ± 2 hours at 23°C & 95% RH., normal water curing (23°C) was applied. Tests on concrete specimens were done as follows:

- for compressive strength test at 7 and 28 days age;
- for indirect splitting tensile test at 28 days age; and
- for modulus of rupture test at 28 days age.

## 3-4 Mixture proportioning:

The mix design of the produced concretes included using very large amounts of Portland cement content; extremely low water/cement and water/cementing materials ratios (w/c and w/cm); high dosages of superplasticisers; the presence of a high reactivity pozzolan (typically silica fume); and fine silica sand. 12 mixes were prepared and cast in this investigation. Their proposed mix proportions are tabulated in Tables (3.6, 3.7, and 3.8). Total No. of specimens tested are = No. of batches x No. of specimens = 12x4 x 3 = 144.

***Table (3.6): Mix proportions for silica fume mixes***

| **Mix No.** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| | **Conventional** | **Silica Fume Replacement** | | |
| **Mix Constituents (kg/m$^3$)** | **Concrete (1 : 1 : 1.5)** | **5 % Silica Fume** | **10 % Silica Fume** | **20 % Silica Fume** |
| **Ordinary cement** | **800** | **760** | **720** | **640** |
| **River sand** | **800** | ----- | ----- | ----- |
| **River gravel** | **1200** | ----- | ----- | ----- |
| **Fine silica sand** | ----- | **1000** | **1000** | **1000** |
| **Quartz flour** | ----- | **250** | **250** | **250** |
| **Superplasticizers** | **60** | **60** | **60** | **60** |
| **Water** | **240** | **240** | **240** | **240** |
| **Silica fume** | ----- | **40** | **80** | **160** |
| **Fine crushed glass** | ----- | ----- | ----- | ----- |
| **Coarse crushed glass** | ----- | ----- | ----- | ----- |
| **Fine crushed nucleate** | ----- | ----- | ----- | ----- |
| **w/c ratio** | **0.300** | **0.315** | **0.333** | **0.375** |

*Table (3.7): Mix proportions for crushed glass mixes*

| Mix No. | 1 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|
| | Conventional Concrete (1 : 1 : 1.5) | Crushed Glass Replacement | | | |
| Mix Constituents (kg/m$^3$) | | 5 % Fine Crushed Glass | 10 % Fine Crushed Glass | 20 % Fine Crushed Glass | 100 % Crushed Glass as Coarse Aggregate |
| Ordinary cement | 800 | 760 | 720 | 640 | 800 |
| River sand | 800 | ----- | ----- | ----- | 800 |
| River gravel | 1200 | ----- | ----- | ----- | ----- |
| Fine silica sand | ----- | 1000 | 1000 | 1000 | ----- |
| Quartz flour | ----- | 250 | 250 | 250 | ----- |
| Superplasticizers | 60 | 60 | 60 | 60 | 60 |
| Water | 240 | 240 | 240 | 240 | 240 |
| Silica fume | ----- | ----- | ----- | ----- | ----- |
| Fine crushed glass | ----- | 40 | 80 | 160 | ----- |
| Coarse crushed glass | ----- | ----- | ----- | ----- | 1200 |
| Fine crushed nucleate | ----- | ----- | ----- | ----- | ----- |
| w/c ratio | 0.300 | 0.315 | 0.333 | 0.375 | 0.300 |

*Table (3.8): Mix proportions for crushed nucleate mixes*

| Mix No. | 1 | 10 | 11 | 12 |
|---|---|---|---|---|
| | Conventional Concrete (1 : 1 : 1.5) | Crushed Nucleate Replacement | | |
| Mix Constituents (kg/m$^3$) | | 5 % Fine Crushed Nucleate | 10 % Fine Crushed Nucleate | 20 % Fine Crushed Nucleate |
| Ordinary cement | 800 | 760 | 720 | 640 |
| River sand | 800 | ----- | ----- | ----- |
| River gravel | 1200 | ----- | ----- | ----- |
| Fine silica sand | ----- | 1000 | 1000 | 1000 |
| Quartz flour | ----- | 250 | 250 | 250 |
| Superplasticizers | 60 | 60 | 60 | 60 |
| Water | 240 | 240 | 240 | 240 |
| Silica fume | ----- | ----- | ----- | ----- |
| Fine crushed glass | ----- | ----- | ----- | ----- |
| Coarse crushed glass | ----- | ----- | ----- | ----- |
| Fine crushed nucleate | ----- | 40 | 80 | 160 |
| w/c ratio | 0.300 | 0.315 | 0.333 | 0.375 |

## 4. Results and Discussion:

Tables (4.1, 4.2, and 4.3) and Figures (4.1, 4.2, and 4.3) show the results of fresh and hardened properties of concrete using the proposed mix proportions shown in Tables (3.6, 3.7, and 3.8), they were tabulated in three groups, according to the type of additives.

### *Table (4.1): Results of silica fume mixes**

| **Mix No.** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| | **Conventional Concrete (1 : 1 : 1.5)** | **Silica Fume Mixes** | | |
| **Mix Constituents ($kg/m^3$)** | | **5 % Silica Fume** | **10 % Silica Fume** | **20 % Silica Fume** |
| **Consistency** | **Fluid** | **Fluid** | **Fluid** | **Fluid** |
| **7-day Compressive strength (MPa)** | **19.4** | **24.4** | **29.2** | **32.2** |
| **28-day Compressive strength (MPa)** | **33.0** | **38.8** | **49.9** | **51.2** |
| **Splitting tensile strength** (MPa)** | **3.6** | **4.95** | **5.3** | **5.8** |
| **Modulus of rupture** (MPa)** | **3.9** | **5.2** | **5.6** | **6.2** |

### *Table (4.2): Results of crushed glass mixes**

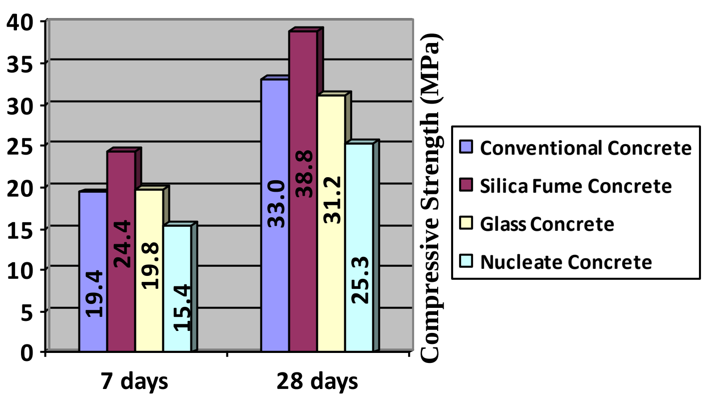
| **Mix No.** | **1** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|
| | **Conventional Concrete (1 : 1 : 1.5)** | **Crushed Glass Mixes** | | | |
| **Mix Constituents ($kg/m^3$)** | | **5 % Fine Crushed Glass** | **10 % Fine Crushed Glass** | **20 % Fine Crushed Glass** | **100 % Crushed Glass as Coarse Aggregate** |
| **Consistency** | **Fluid** | **Fluid** | **Fluid** | **Fluid** | **Fluid** |
| **7-day Compressive strength (MPa)** | **19.4** | **19.8** | **20.4** | **25.0** | **19.0** |
| **28-day Compressive strength (MPa)** | **33.0** | **31.2** | **34.3** | **41.5** | **36.6** |
| **Splitting tensile strength** (MPa)** | **3.6** | **4.0** | **4.5** | **4.9** | **4.1** |
| **Modulus of rupture** (MPa)** | **3.9** | **5.7** | **6.1** | **6.7** | **4.6** |

### *Table (4.3): Results of crushed nucleate mixes**

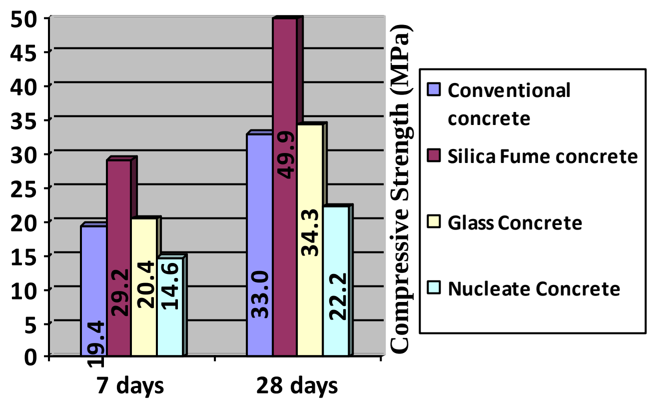
| Mix No. | 1 | 9 | 10 | 11 |
|---|---|---|---|---|
| Mix Constituents ($kg/m^3$) | Conventional Concrete (1 : 1 : 1.5) | Crushed Nucleate Mixes: 5 % Crushed Nucleate | Crushed Nucleate Mixes: 10 % Crushed Nucleate | Crushed Nucleate Mixes: 20 % Crushed Nucleate |
| Consistency | Fluid | Fluid | Fluid | Fluid |
| 7-day Compressive strength (MPa) | 19.4 | 15.4 | 14.6 | 11.3 |
| 28-day Compressive strength (MPa) | 33.0 | 25.3 | 22.2 | 17.9 |
| Splitting tensile strength** (MPa) | 3.6 | 2.8 | 2.5 | 2.1 |
| Modulus of rupture** (MPa) | 3.9 | 3.7 | 3.1 | 2.9 |

*** Results are average of three specimens.**

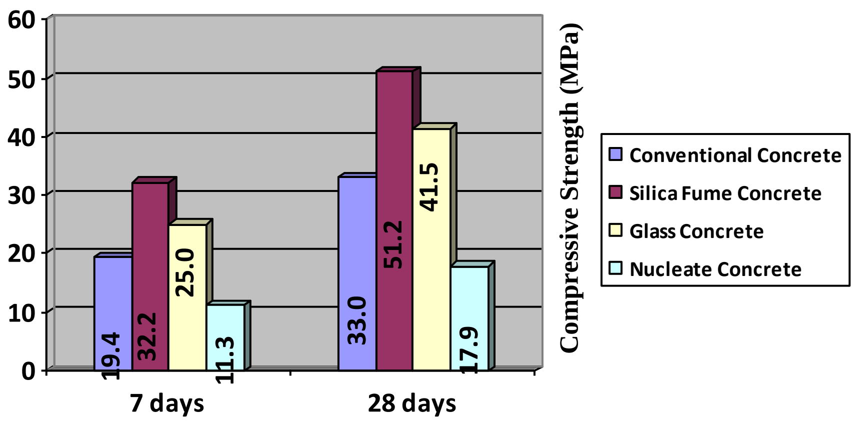
**** Splitting tensile and Modulus of rupture tests were done at 28 days age.**




*(a) 5% Fine Additives*

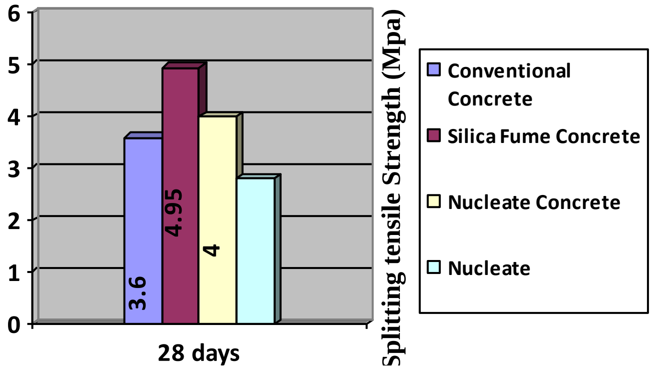



(b) 10% Fine Additives

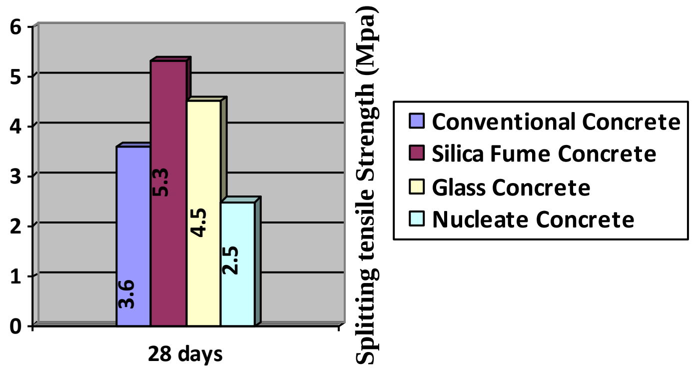



*(c) 20% Fine Additives*

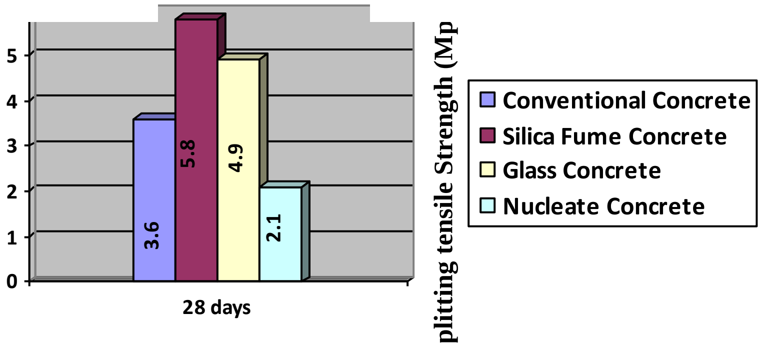
**Fig.(4.1): Effect of Types of Additives on the Compressive Strength of concrete**




(a) 5% Fine Additives

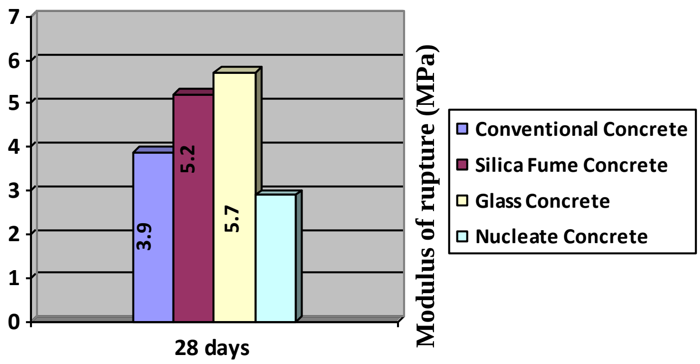



(b) 10% Fine Additives

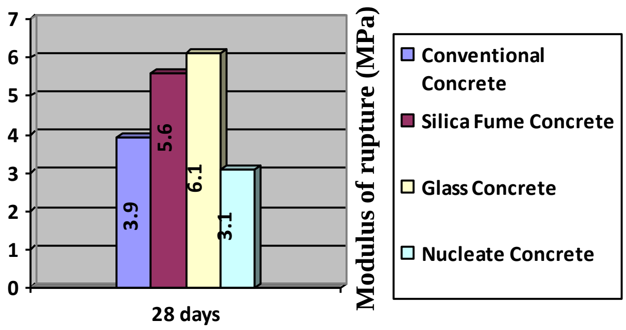



(c) 20% Fine Additives

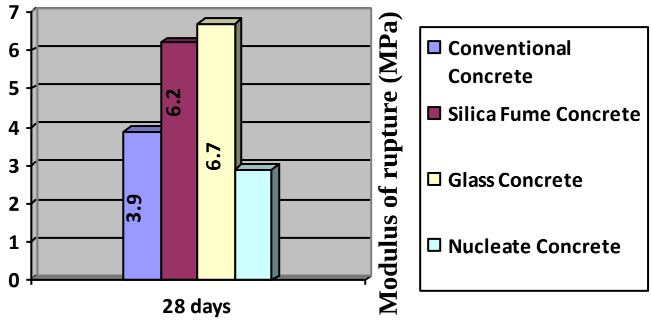
*Fig.(4.2): Effect of Types of Additives on the Splitting Tensile Strength of concrete*




(a) 5% Fine Additives




(b) 10% Fine Additives




(c) 20% Fine Additives

***Fig.(4.3): Effect of Types of Additives on the Flexural Strength of***

## 4-1 Effect of type of additives on the compressive strength of concrete:

A significant portion of this research focused on studying the compressive strength of the produced concretes using different types of additives (silica fume, crushed glass, and crushed nucleate).

It is clear from Tables (4.1 and 4.2) and Figure (4.1) that there was a significant increase in the compressive strength of concretes produced with silica fume and crushed glass additives, when comparing with the results obtained by the conventional concrete. Depending on replacement ratios, percentages of increasing in the 28-day compressive strength comparing with the results obtained by the conventional concrete were as follows:

***Age of concrete with percent (20%)***

| Replacement ratios | Percentages of increasing | |
|---|---|---|
| | Silica fume concrete | Crushed glass concrete |
| 5% | 17.6% | 8.8% |
| 10% | 51.2% | 16.4% |
| 20% | 88.5% | 25.8% |

While, 10.9% increase was recorded for using (100%) crushed glass as coarse aggregate instead of the river gravel. It was clear that the increasing in the compressive strength is proportional directly with the increase of the percentages of additives (silica fume and crushed glass). This is due to the using of silica fume in different percentages in these concretes provides a number of advantages, the concretes will have a ductility properties, and in this case concretes do not exhibit explosive failure during compression tests, as well as using the very low water /cement ratios in these mixes.
On the other hand, discussing Table (4.3) and Figure (4.1) there was a decrease in the 28-day compressive strength of the concrete produced with crushed nucleate additive compared with the results obtained by the conventional concrete, such that:
29.6% decrease for (5%) fine crushed nucleate replacement; 48.6% decrease for (10%) fine crushed nucleate replacement; 62.6% decrease for (20%) fine crushed nucleate replacement. This decrease is because the fine crushed nucleate is an inert material and it will reduce the binding activity when used in concrete especially when it is replaced instead of cement.

## 4-2 Effect of age of concrete on the compressive strength:

Discussing results shown in Tables (4.1, 4.2, and 4.3) and Figure (4.1), it is concluded that compressive strength is related directly with the age of the concrete for any given percentage of additives. This is because the compressive strength of concrete is affected by the presence of silica fume and crushed glass. In order to explain the relationships between the 7-day ($f_{c,7}$) and 28-day ($f_{c,28}$) compressive strength, using statistical analysis, as compared with the conventional concrete ($f_{c,28} = 1.701\ f_{c,7}$), the following relationships depending upon the type of the additives, can be derived:

#### 4-2-1 Silica fume mixes:

$f_{c,28} = 1.590\ f_{c,7}$ , for concrete with (5%) silica fume replacement;
$f_{c,28} = 1.709\ f_{c,7}$ , for concrete with (10%) silica fume replacement;
$f_{c,28} = 1.931\ f_{c,7}$ , for concrete with (20%) silica fume replacement;

#### 4-2-2 Crushed glass mixes:

$f_{c,28} = 1.813\ f_{c,7}$ , for concrete with (5%) fine crushed glass replacement;
$f_{c,28} = 1.882\ f_{c,7}$ , for concrete with (10%) fine crushed glass replacement;
$f_{c,28} = 1.660\ f_{c,7}$ , for concrete with (20%) fine crushed glass replacement;
$f_{c,28} = 1.926\ f_{c,7}$ , for concrete with (100%) crushed glass as coarse aggregates.

#### 4-2-3 Crushed nucleate mixes:

$f_{c,28} = 1.643\ f_{c,7}$ , for concrete with (5%) fine crushed nucleate replacement;
$f_{c,28} = 1.521\ f_{c,7}$ , for concrete with (10%) fine crushed nucleate replacement;
$f_{c,28} = 1.796\ f_{c,7}$ , for concrete with (20%) fine crushed nucleate replacement.

### 4-3 Effect of type of additives on the Tensile behavior of the concrete:

Two types of tension tests were done in this research in order to determine experimentally the tensile properties of the produced concretes using silica fume, crushed glass as fine and coarse additives, as well as fine crushed nucleate. These tests included split tensile strength testing of cylinders (ASTM C496)[27] and flexural strength testing of prismatic sections (ASTM C78)[28]. Discussing Tables (4.1 and 4.2) and Figure (4.3), it was concluded that there is an increase in both flexural and splitting tensile strengths of concretes produced with silica fume and crushed glass. Percentages of increasing as compared with conventional concrete were as follows:

#### 4-3-1 Silica fume mixes:

| Types of concrete | Percentages of Increasing (%) | |
|---|---|---|
| | Modulus of rupture | Splitting tensile strength |
| 5% silica fume replacement | 26.92% | 44.44% |
| 10% silica fume replacement | 35.90% | 55.56% |
| 20% silica fume replacement | 48.72% | 72.22% |

### 4-3-2 Crushed glass mixes:

| Types of concrete | Percentages of Increasing (%) | |
|---|---|---|
| | Modulus of rupture | Splitting tensile strength |
| 5% fine crushed glass replacement | 46.15% | 11.11% |
| 10% fine crushed glass replacement | 56.41% | 25.00% |
| 20% fine crushed glass replacement | 71.79% | 36.11% |
| 100% crushed glass as coarse aggregates | 17.95% | 13.89% |

These percentages of increasing are due to the presence of silica fume, as well as the crushed glass which influence the tensile and flexural strengths as the bond strength between the aggregates and the mortar is increased due to the higher surface area and higher angularity of the crushed glass aggregates. On the other hand, discussing Table (4.3) and Figure (4.3), it was clear that there was a drop in both flexural and splitting tensile strengths of concretes produced with crushed nucleate, since this additive was regarded as an inert material and reduce the bond strength of the concrete. Percentages of decreasing in flexural and splitting tensile strengths as compared with the conventional concrete are as follows:

| Types of concrete | Percentages of decreasing (%) | |
|---|---|---|
| | Modulus of rupture | Splitting tensile strength |
| 5% fine crushed nucleate replacement | 5.41% | 28.57% |
| 10% fine crushed nucleate replacement | 25.81% | 44.00% |
| 20% fine crushed nucleate replacement | 34.48% | 71.43% |

## 4-4 Relationships between compressive, tensile, and flexural strengths:

Applying a regression analysis in discussing the results obtained in this research, and presented in Tables (4.1 to 4.3), different relationships between the 28-day compressive strength and flexural strength, as well as between the 28-day compressive strength and splitting tensile strength for all types of concretes produced with different types of additives, were derived, as follows:

### 4-4-1 Conventional concrete:

$fc,28 = 4.2038 \ln (f_f,28) - 11.500$ , $R^2 = 1.00$

$fc,28 = 3.9966 \ln (f_t,28) - 12.600$ , $R^2 = 1.00$

### 4-4-2 Concrete with (5%) silica fume replacement:

$fc,28 = 21.1780 \ln (f_f,28) - 59.386$ , $R^2 = 1.00$

$fc,28 = 22.5830 \ln (f_t,28) - 73.005$ , $R^2 = 1.00$

#### 4-4-3 Concrete with (10%) silica fume replacement:

$f_{c,28} = 21.9930 \ln (f_{f,28}) - 80.213$ , $R^2 = 1.00$
$f_{c,28} = 22.2860 \ln (f_{t,28}) - 79.002$ , $R^2 = 1.00$

#### 4-4-4 Concrete with (20%) silica fume replacement:

$f_{c,28} = 23.8970 \ln (f_{f,28}) - 89.657$ , $R^2 = 1.00$
$f_{c,28} = 24.8340 \ln (f_{t,28}) - 91.976$ , $R^2 = 1.00$

#### 4-4-5 Concrete with (5%) fine crushed glass replacement:

$f_{c,28} = 4.1798 \ln (f_{f,28}) - 12.330$ , $R^2 = 1.00$
$f_{c,28} = 4.3966 \ln (f_{t,28}) - 13.740$ , $R^2 = 1.00$

#### 4-4-6 Concrete with (10%) fine crushed glass replacement:

$f_{c,28} = 4.1862 \ln (f_{f,28}) - 10.995$ , $R^2 = 1.00$
$f_{c,28} = 4.7266 \ln (f_{t,28}) - 11.895$ , $R^2 = 1.00$

#### 4-4-7 Concrete with (20%) fine crushed glass replacement:

$f_{c,28} = 3.9978 \ln (f_{f,28}) - 11.692$ , $R^2 = 1.00$
$f_{c,28} = 4.8964 \ln (f_{t,28}) - 11.805$ , $R^2 = 1.00$

**Where :**

$f_{c,28}$ is the 28-day compressive strength;
$f_{f,28}$ is the 28-day flexural strength;
and $f_{t,28}$ is the 28-day splitting tensile strength.

Relationships for crushed nucleate concretes are not discussed here because of their bad effect on all types of strengths of concrete produced with this additive.

## 5. Conclusions:

The following conclusions, based on the experimental results obtained in this research, may be drawn:

1. There was a significant increase in the compressive strength of concretes produced with silica fume and crushed glass additives, depending on the replacement percentages, percentages of increasing as compared with results obtained by the conventional concrete, were (17.6 to 88.5 and 8.8 to 25.8)% for silica fume mixes and crushed glass mixes respectively, while concrete mixes with crushed nucleate recorded a significant reduction (29.6 to 62.6)% in the compressive strength, depending on the replacement percentages of crushed nucleate.

2. Depending on silica fume and crushed glass replacement, the relationships between the 7-day (fc,7) and the 28-day (fc,28) compressive strength as compared with fc,28 = 1.701 fc,7 for conventional concrete (reference mix), show that:
   fc,28 = (1.590 to 1.931) fc,7 for silica fume mixes;
   fc,28 = (1.660 to 1.813) fc,7 for crushed glass mixes;
   fc,28 = (1.521 to 1.796) fc,7 for crushed nucleate mixes.
3. Depending on silica fume and crushed glass replacement, percentages of increasing in both flexural and splitting tensile strengths, as compared with results obtained by conventional concrete were as follows:
   (a) silica fume mixes: (26.92 to 48.72 and 44.44 to 72.22)% respectively;
   (b) crushed glass mixes: (46.15 to 71.79 and 11.11 to 36.11)% respectively. On the other hand, crushed nucleate recorded a drop in both flexural and splitting tensile strengths of concrete produced with crushed nucleate (5.41 to 34.48 and 28.57 to 71.43)% respectively.
4. Different relationships between compressive, flexural and tensile strengths, of concretes produced using silica fume and crushed glass additives, were obtained as follows:

| Type of concrete | Relationship (fc,28 & ff, 28) | Relationship (fc,28 & ft, 28) |
|---|---|---|
| Conventional Concrete | fc,28 = 4.2038 ln (ff,28) – 11.500 | fc,28 = 3.9966 ln (ft,28) – 12.600 |
| (5%) silica fume replacement | fc,28 = 21.1780 ln (ff,28) – 59.386 | fc,28 = 22.5830 ln (ft,28) – 73.005 |
| (10%) silica fume replacement | fc,28 = 21.9930 ln (ff,28) – 80.213 | fc,28 = 22.2860 ln (ft,28) – 79.002 |
| (20%) silica fume replacement | fc,28 = 23.8970 ln (ff,28) – 89.657 | fc,28 = 24.8340 ln (ft,28) – 91.976 |
| (5%) fine glass replacement | fc,28 = 4.1798 ln (ff,28) – 12.330 | fc,28 = 4.3966 ln (ft,28) – 13.740 |
| (10%) fine glass replacement | fc,28 = 4.1862 ln (ff,28) – 10.995 | fc,28 = 4.7266 ln (ft,28) – 11.895 |
| (20%) fine glass replacement | fc,28 = 3.9978 ln (ff,28) – 11.692 | fc,28 = 4.8964 ln (ft,28) – 11.805 |

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