# Improving Strengths of Porcelanite Aggregate Concrete by Adding Chopped Carbon Fibers

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## Abstract

In this work chopped carbon fibers are used to improve tensile strength of Porcelanite lightweight aggregate concrete. Silica fume was added in order to improve the mixes compressive strength. Silica fume increase water demand and using fibers reduce workability, to improve workability and decrease water demand high rang super plasticizers are used. The results showed that compressive strength, splitting tensile strength, modulus of elasticity of carbon fibers Porcelanite lightweight aggregate concrete increase with increasing of carbon fiber up to 2% compared to reference Porcelanite lightweight aggregate concrete without fibers. The percentages of increasing were 14.40%, 68.00%, and 10.66% for compressive strength, splitting tensile strength, and modulus of elasticity, respectively. Flexural Strength continues in increase with increase of fibers. The dry unite weight of mixes with chopped fiber decrease with increase of fiber percentage. Besides the chopped carbon improved the ductility of Porcelanite lightweight aggregate concrete and that clear from stress-strain relationship.

## Introduction

The main purpose of using lightweight aggregate as coarse aggregate in concrete is to reduce concrete self-weight, which leading to reduce the dimension of foundation. According to ACI committee 213 [1] Structural Lightweight Concrete (SLWC) defined as a concrete with an air-dried density at 28 days in the range of 1120 and 1920 kg/m$^3$ and a compressive strength above 17.2 MPa. The same committee defined high strength lightweight concrete as SLWC with a 28-day compressive strength of 41.4 MPa or greater. In 1986 an investigations were taken place by the State Company of Survey and Mining which led to discovering Porcelanite rocks in Traifawi in the Iraqi Western Desert, near Rutba [2]. Many studies were made to discover its mineral and chemical properties, as well as estimating reserve of these rocks. Depending on these studies, the State Company of Survey and Mining recommended using Porcelanite as a lightweight coarse aggregate in concrete. [2], [3] AL-Rawi [4] investigated the properties of Porcelanite concrete, with Cement content between 272-687 kg/m$^3$, water cement ratios from 0.65 to 1.6, a strength ceiling up to 32 MPa with an air dry density of 1815 kg / m$^3$ were observed. While AL-Dhaher [5] produced lightweight concrete using Porcelanite with density between 1400–1960 kg/m$^3$ and 28 days compressive strength between 13.0–22.4 MPa. Al-Duleimy[6] studied the effect of addition of superplasticizer and SBR on some properties of Porcelanite lightweight aggregate concrete . A density and compressive strength ranging between 1965.05–1818 kg/m$^3$ and 17.08 – 34.8 MPa at 28 days was observed using cement content of 550 kg/m$^3$. Many other investigations were made and this work is part of continuing research on the subject of application of Porcelanite concrete.

## Carbon Fibers

Carbon fiber; is a thin fibers about (0.005-0.010) mm diameter mostly composed of carbon atoms. carbon fibers density is lower than steel fibers density, which it ideal with application requiring low weight. Carbon fibers have good alkaline resistance as well as resistance to salt water and many other chemical environment, more chemically stable than glass fibers in an alkaline environment and low thermal expansion, which making carbon fibers very popular in civil engineering [7]. Carbon fibers have higher strength and stiffness than metallic fibers that made carbon fibers perfect as strengthening and stiffening building materials [8]. Chen and Chung [9] reported that the use of chopped carbon fibers with nominal length from 3.0 to 12.7mm with volume fraction 0.189% together with a dispersant, chemical agents and silica fume in normal strength concrete resulted in: Flexural strength increase of 85%, Compressive strength increase of 22 % and Slump decrease from 152mm to 102mm. Wasan and Akar [10] study the mechanical properties of high performance carbon fibers concrete. They observed that the addition of carbon fibers caused a little increasing in compressive strength and modulus of elasticity, while the splitting tensile and flexural strengths showed a significant increase relative to the reference concrete (without fibers).

## Research Significance

Sufficient literature is not available on the stress-strain behavior and mechanical properties of chopped fiber Porcelanite lightweight concrete. Hence considering the gap in existing literature an attempt has been made to work the mechanical properties and stress – strain behavior of chopped carbon fiber lightweight Porcelanite concrete.

## Experimental work

**1- Materials:** Ordinary Portland Cement (Type I) from Kubaisa cement factory is used. The cement complies with Iraqi specification No.5/ 1984 [11]. The fine aggregate used was natural sand from west region in Al-Anbar Governorate, it complied to the requirements of the Iraqi specification NO. 45/1984 [12]. While the coarse aggregate used was crushed Porcelanite with maximum size 9.5mm, it met the requirements of ASTM C330-05 [13]. Silica fume, which is used in this research as hardened, is a grey colored pozzolanic material, it's is complying with the strength activity index with Portland cement requirements of ASTM C1240 – 05[14] and ASTM C311 – 05[15]. The superplasticizer used in this study is Sikament – 163 (high range water– reducing agent and superplasticizer); which complies with ASTM C494–05[16] type F, as listed in Table (1). High performance chopped carbon fiber brought from Fosam Company Limit, as filaments were used in this investigation, it's mechanical properties are listed in Table (2).

**Table (1):** Properties of superplasticizer*

| Properties | Description |
|---|---|
| Main action | Highly effective water–reducing agent and superplasticizier for the production of high quality concrete in hot climates |
| Dosage | 0.6% – 2.5% by weight of cement |
| Type | Polymer type dispersion |
| Appearance | Liquid |
| Color | Brown |
| Specific gravity | 1.2 kg/l |
| PH value | 10 ± 1.0. |

* Supply by manufacture

**2. Mixing Procedures**: First, all required materials for each of concrete mix were weighed according to the mix proportions [17] as shown in Table (3). Mechanical mixer of (0.1) $m^3$ capacity was using for mixing procedure. initialy, about half of the quantity of Porcelanite was placed in the mixer with half of the quantity of the sand. Then, the full quantity of cementous material (cement + silica fume) was poured over them. The remaining portion of Porcelanite and the sand were adding in sequence, and premixed about 1 minute as dry mix. The (SP) is added to the mixing water in the beginning and the solution is thoroughly stirred before using, then the required quantity of the solution (water+SP)

**Table (2):** Properties of Chopped Carbon Fibers*

| Properties | Results |
|---|---|
| Filament Diameter, μmm | 7 |
| Filament Length, mm | 6 |
| Density, g/L | 1800 |
| Elongation, % | 1.5 |
| Tensile Strength, MPa | 165 |
| Flexural Strength, MPa | 259 |
| Electrical Resistivity, Ω.cm | $3 \times 10^{-3}$ |

* Supply by manufacture

## Tests

1. **Compressive Strength;** according to ASTM C39-01[18], an average of three (300*150 mm) cylinder for each mix, were used for investigating compressive strength at 28-days age .
2. **Splitting Tensile Strength;** the splitting tensile test was obtained according to the ASTM C496-05[19] using (150x300mm) concrete cylinders at 28-day age for average three cylinder for each mix.
3. **Flexural Tensile Strength;** flexural tensile strength was determined according to the ASTM C293–05 [20], using (100x100x500mm) prisms at 28-day age for average three prisms for each mix.
4. **Static Modulus of Elasticity;** modulus of elasticity were calculating from stress-strain relationships depending on to ASTM C469–02 [21] at 40% of ultimate load at 28 -days age. added and the whole constituents and were mixed for other 3 minutes.. After the aggregate, cement and water were fully mixed, the carbon fibers were slowly added to the mixing by hand spraying. the Mixing was continued for additional 3 minutes to have a uniform distribution of fibers throughout the mix.
5. **Dry Unit Weight;** An average weight of three (300x150mm) cylinders were recorded with their dimensions prior to test in order to determine dry unit weight at 28–day age [22].

**Table (3): Mixes proportions**

| No. of mix | Cement Content (kg) | Sand ($kg/m^3$) | Porcelanite ($kg/m^3$) | W/C Ratio | Chopped Carbon Fiber ( % Mix Volume) | Silica Fume (%weight of cement) | Superplasticizer (%weight of cement) |
|---|---|---|---|---|---|---|---|
| 1 | 420 | 500 | 510 | 0.4 | 0 | 10 | 2.5 |
| 2 | 420 | 500 | 510 | 0.4 | 0.5 | 10 | 2.5 |
| 3 | 420 | 500 | 510 | 0.4 | 1 | 10 | 2.5 |
| 4 | 420 | 500 | 510 | 0.4 | 1.5 | 10 | 2.5 |
| 5 | 420 | 500 | 510 | 0.4 | 2.0 | 10 | 2.5 |
| 6 | 420 | 500 | 510 | 0.4 | 2.5 | 10 | 2.5 |

## Test Results and Discussion

Table (4) shows the tested properties of concrete specimens as follow:

1. **Compressive Strength:** As it is clear from Table 4 and figure (1), an improvement in compressive strength of the carbon fibers Porcelanite concrete samples are noticed compared to control samples without carbon fibers. The mixes, with carbon fibers, have shown higher compressive strength compared to reference mix without fiber by 4.68%, 6.52%, 11.20%, 14.40% and 5.20% for 0.5, 1.0, 1.5, 2.0 and 2.5%.Compressive strength increased with an increasing of volume fraction up to 2.0%. For 2.5% carbon fibers, compressive strength decreased but still higher than control mix without carbon fibers. The fibers are bridging the cracks inside the microstructure of the concrete at the failure stage but the volume of fibers lead to forming of bulks and segregation in mix. [10]

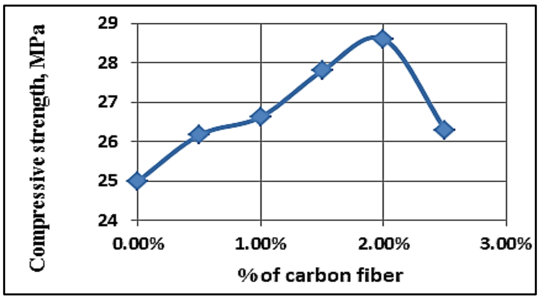


**Figure 1:** Development of Compressive Strength with Different Ratios of Carbon Fiber.

2. **Splitting Tensile Strength:** The results, which listed in Table 4 and shown in figure (2), indicated that the incorporation of carbon fibers in to the lightweight mixes, improved the splitting tensile strength. The mixes, with carbon fibers, have shown higher splitting strength compared to reference mix by 21.67%, 38.67%, 56.00%, 68.00% and 52.00% for 0.5, 1.0, 1.5, 2.0 and 2.5%. Splitting tensile strength of carbon fibers Porcelanite concrete samples increased with increasing of volume fraction of carbon fibers up to 2.0%. For 2.5% fibers, the splitting tensile strength decreased but still higher than control mix without fibers. This increasing in splitting tensile strength is due to arrest cracks progression by chopped carbon fibers.

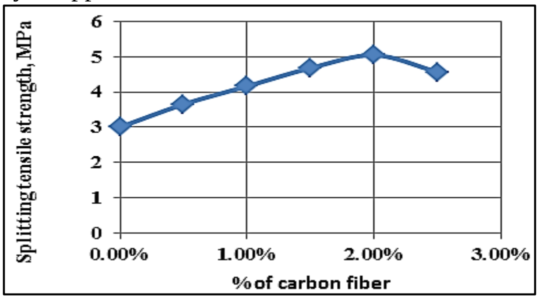


**Figure 2:** Development of Splitting Tensile Strength with Different Ratios of Carbon Fiber.

3. **Flexural Tensile Strength:** Figure (3) shows the development of flexural tensile strength with carbon fibers percentages. The results indicated that the incorporation of carbon fibers in to the lightweight mixes, increased the flexural tensile strength. The mixes, with carbon by 26.78%, 46.94%, 60.46%, 77.55% fibers (have shown higher flexural strength compared to reference mix and 78.57% for 0.5, 1.0, 1.5, 2.0 and 2.5%. The increases in flexural strength is particularly sensitive to the fiber volume and its continued to increase with increasing of fiber volume. This may attributed to the role of the effect of fibers in concrete matrix, which arresting both the initiation of randomly oriented micro-cracks and its propagation [23].

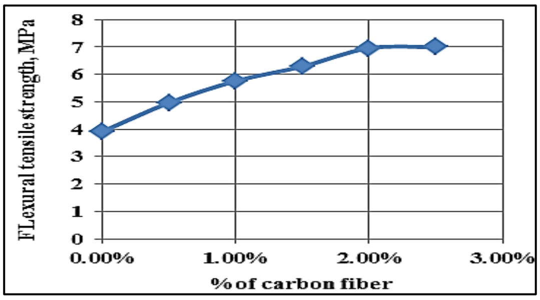


**Figure 3:** Development of Modulus of Rupture with Different Ratios of Carbon Fiber

4. **Modulus of Elasticity:** the modulus of elasticity was measured at 40% of ultimate load. [21] Figure (4) shows the improvement of modulus of elasticity with carbon fibers percentages. The mixes, with carbon fibers have

shown higher modulus of elasticity compared to reference mix by by 4.10%, 8.46%, 9.74%, 10.66% and 2.27% for 0.5, 1.0, 1.5, 2.0 and 2.5%.The carbon fibers show a little effect on modulus of elasticity of the Porcilinete lightweight concrete, but one can notice from stress-strain relationship that the increase of percentage of fibers increases the area under curve, see Figure (5), which mean that fibers improve ductility of concrete. This may be due to a considerable improvement in the fiber-matrix bond. [23]

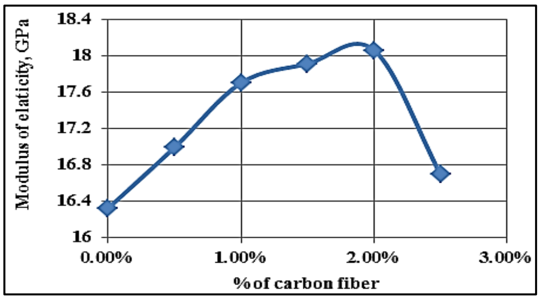


**Figure 4:** Development of Modulus of Elaticity with Different Ratios of Carbon Fiber

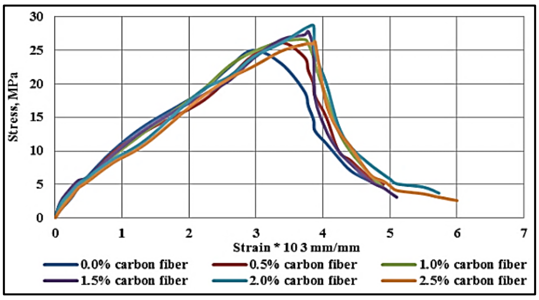


**Figure 5:** Stress-Strain relationship for Different Ratios of Carbon Fiber

5. **Unit Weight (Density):** Based on the experimental results one can see that the dry density of lightweight Porcelanite concrete contains carbon fibers were lower than reference control mix. From Figure (6), it can be concluded that the density decrease with the increase of carbon fibers percentage because the low density of chopped carbon.

**Table (4):** Tests results

| No. of mix | Carbon fiber % of concrete volume | Compressive strength (MPa) | Splitting strength (MPa) | Flexural Tensile Strength (MPa) | Modulus of elasticity (GPa) | Dry unit weight (kg/m$^3$) |
|---|---|---|---|---|---|---|
| 1 | 0.0% | 25.00 | 3.00 | 3.92 | 16.32 | 1800 |
| 2 | 0.5% | 26.17 | 3.65 | 4.97 | 16.99 | 1786 |
| 3 | 1.0% | 26.63 | 4.16 | 5.76 | 17.70 | 1770 |
| 4 | 1.5% | 27.80 | 4.68 | 6.29 | 17.91 | 1729 |
| 5 | 2.0% | 28.60 | 5.04 | 6.96 | 18.06 | 1707 |
| 6 | 2.5% | 26.30 | 4.56 | 7.00 | 16.69 | 1686 |

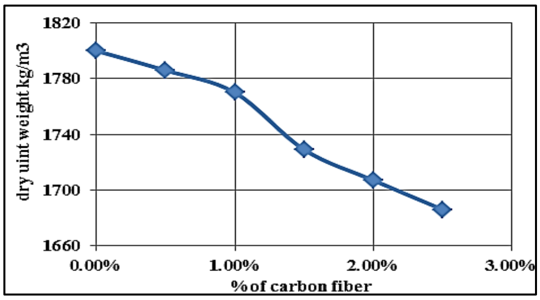


**Figure 6:** Variation of dry unite weight with Different Ratios of Carbon Fiber

## Conclusions

The following conclusions have been made according to the experimental results of this work,:

1. Tests results show that compressive strength is only slightly increased about 4.0% to 14. 0%.
2. Flexural tensile strength has clearly affected by carbon fibers so that its splitting tensile strength. The highest increase has been found in the flexure strength about 78.0%.
3. The carbon fibers have a little effect on the modulus of elasticity of lightweight Porcelanite concrete but improved ductility (area under stress-strain relationship)
4. The density of lightweight concrete decrease with the increase of carbon fibers percentage because the low density of chopped carbon.
5. Depending on the results of this work, recommending of adding 2% chopped carbon fibers, 10% silica fume, and 2.5% superplasticizer to Porcelanite lightweight concrete to get best results for Porcelanite lightweight concrete strengths.

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# تحسين مقاومات خرسانة البورسيلانايت الخفيفة الوزن باستخدام الياف الكاربون

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**الخلاصة**

في هذا العملِ تم استخدام الياف الكاربونِ القصيرة تُستَعملُ لغرض تَحسين مقاومة الشدِّ للخرسانة االبورسيلانايت الخفيفة الوزن . الخرسانةِ خفيفة الوزن بالعادة لها مقاومة انضغاط منخفضة لذا أُضيفَت سليكا فيوم الى الخلطات الخفيفة الوزن لتحسين مقاومة انضغاطها. ان استخدام السليكا فيوم يتطلب زيادة بالمحتوى المائي للخلطة الخرسانية, بالاضافة الى كون استخدام الالياف يخفض قابلية التشغيل, لذا تم استخدام ملدن فائق لتحسين قابلة التشغيل و الحيلولة دون التفريط بزيادة نسبة الماء/الاسمنت. بينت النتائج بان كلا من مقاومة الانضغاط, مقاومة الانفلاق, معامل المرونة للخرسانة زادت بزيادة نسبة الياف الكاربون لحد 2% نسبة كاربون. حيث كانت نسب الزيادة 14.4%, 68% و 10.6% للمقومة الانضغاط, مقاومة الانضغاط و معامل المرونة على التوالي. مقاومة الشد بالانثناء زادت بزيادة نسبة الالياف. بينما لوحظ ان كثافة الخلطة الخرسانية انخفضت بزيادة نسبة الالياف. بالاضافة الى ان الالياف زادت من مطيلية الخرسانة و هذا واضح من علاقة الاجهاد-الانفعال.