# SOME PROPERTIES OF HIGH PERFORMANCE CARBON FIBRES CEMENT COMPOSITES

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## ABSTRACT

The paper presents properties of high performance concrete reinforced with relatively high percentage of choped carbon fibers vol. fraction ranging from (1 to 5) %. The great advantage of such composites is their relatively high flexural strength. A low water to cement ratio of 0.3 with super plasticizer was used in order to keep the cement mix easily workable. To improve the properties, a locally existing pozzolan based on reactive meta- kaolin was used in the mixture together with silica sand. A high modulus carbon fibers (450 $KN/mm^2$) were also used. In addition to the flexural strength, dynamic modulus of elastisity were found using dynamic methods.

The results showed that the specimen failed in flexureal by a single crack although the ultimate tensile strength and the stiffness of the composite were increased as the fibers content was increased.

**Keywords: carbon fibers, reactive meta- kaolin, silica sand, super plasticizer, flexural strength, dynamic modulus of elastisity**

# بعض خواص الخرسانة عالية الأداء المسلحة بألياف الكاربون

## الخلاصة

يقدم البحث خواص الخرسانة العالية الأداء المسلحة بألياف الكاربون بنسب حجمية عالية نسبياً تتراوح من (1 – 5) % . إن الفائدة الكبيرة لهذا النوع من الخرسانة هي مقاومتها العالية للشد في الانحناء.تم استخدام نسبة واطئة من الماء/السمنت تساوي (0.3) مع استخدام ملدن متفوق للحصول على قابلية تشغيل مقبولة كما تم استخدام بوزلان محلي متكون من دقيق الكاؤولين النشط واستخدام رمل ذو أساس سيليكي وكانت ألياف الكاربون من نوع ذات معامل المرونة العالية (450 كيلونت/ملم$^2$)، بلإضافة إلى الخواص الانحنائية فقد تم بحث الخواص الديناميكية باستخدام طرق ديناميكية، وبينت النتائج بأن نوع فشل النماذج كانت بشق منفرد (single crack) وأن كلاً من مقاومة الانثناء القصوى ومعامل المرونة تزداد بزيادة نسبة الألياف.

## INTRODUCTION

During the last few decades, fiber reinforced cement composites have attracted much interest, because of their high strength enhanced ductility and toughness (Hannant 1977,R.N.Swamy1989). This paper is concerned with a new type of fiber cement composite with comparatively a high volume fraction of high modulus carbon fibers (Raouf 1976) ranging from 1 to 5 % by volume. In order to reduce porosity a low w/c ratio (0.3) has been used together with a super plasticizer to provide a suitable workability.

In order to improve the strength and durability fine and sintered Kaolin at 750 $^{o}$C has been used as an active pozolan having an activity index of 115 (Mohammad 2005) using 20 % Kaolin/cement ratio.

Very few is published on properties of carbon fiber cement composite, it was therefore decided to carry out further work for obtaining further information.The great advantages of carbon fibers are their high tensile strength and high stiffness, it was therefore thought necessary to find out how these properties affect that of composite.

The main features of this work as compared with others can be summarized as follows :

a – A relatively high carbon fiber volume fractions have been used ranging from 1 to 5 %.

b – A fine sintered local pozolan have been used as partial replacement of cement in order to obtain a high performance cement matrix (Edward 2001).

c – Electro dynamic and ultrasonic tests in addition to flexural test have been used to find dynamic and flexural properties

## MATERIALS AND METHODS

### - The cement

The cement used in casting all specimens was ordinary portland cement supplied by Kubaisa factory the chemical analysis and physical properties are shows in table (1) and table (2) which conforms to IQS-5.

### Pozalan

The pozalan used consisted of meta kaolin sintered at 750$^{o}$c and crushed into fine powder in a ball mill into a very fine powder (7213 cm$^{2}$/gm) all passing seive 325 as shown in tables 3 and 4.

## carbon fibers

These fibers have much higher specific strength and stiffness than steel fibers, and for this reason their use for stregthening and stiffening building materials such as wood, plastics, and concrete, is attractive.

Carbon fibers are manufactured by heat treatment of certain types of acrylic fibers which are stretched whilst at high temperatures(Walter 1972). This operation increases the tensile strength and stiffness of the graphite, and provides a certain desired molecular orientation.

At present the fibers are commercially produced by several firms. Those used in this work were supplied by sika.The fibers were cut from carbon fiber woven cloth into short lengths.The fiber properties are shown in table (5)

**The cement matrix**

An ordinary Portland cement paste with water to cement ratio of 0.3. The low water – cement ratio was selected on the basis of experience, and in order to minimize the tendency of the fibers to segregate during compaction.

**Moulds**

Moulds of formica-lined wood, each holding three specimens. Each specimen measured 250×50×50 mm.

**Testing**

The specimen were first tested nondestructively to find modulus of elasticity according to BS 1881 then they were tested in flexure (4-point loading method)

**Table (1) Chemical analysis and compound composition of cement**

| Oxides | Content % | Iraqi specification limitation IQS 5/1984 |
|---|---|---|
| CaO | 62.2 | |
| $SiO_2$ | 21.8 | |
| $Al_2O_3$ | 5.1 | |
| MgO | 3.4 | 5% max. |
| $Fe_2O_3$ | 3.3 | |
| $SO_3$ | 2.33 | 2.8%max. |
| L.O.I | 0.9 | 4% max |
| I.Res. | 0.7 | 1.5% max. |
| L.S.F. | 0.87 | 0.66-1.02 |
| **Compound Composition (Bogue's equations)** | | |
| $C_3S$ | 41.84 | |
| $C_2S$ | 31.02 | |
| $C_3A$ | 7.92 | |
| $C_4AF$ | 10.03 | |

**Table (2) Physical properties of cement**

| Property | Result | Iraqi specification limitation IQS 5/1984 |
|---|---|---|
| Fineness by air permeability method (Blaine) | 3780 $cm^2$/gm | Not Less than 2300 $cm^2$/gm |
| Initial Setting time | 97 min | Not Less than 45 min |
| Final Setting time | 4 hrs. | Not more than 10 hrs. |
| Soundness (Autoclave method) | 0.4% | Not more than 0.8% |
| Compressive strength<br>3-day<br>7-day | 20.6 Mpa<br>27.8 MPa | Not Less than 15 Mpa<br>Not Less than 23 MPa |

**Table (3) Physical properties of Metakoalin**

| No. | Property | Result |
|---|---|---|
| 1 | Fineness | 7213 $cm^2$/gm(all passing seive 325) |
| 2 | Specific weight | 2.6 $gm/cm^3$ |
| 3 | PH | 6 |
| 4 | Colour | Redish-White |

**Table (4) Chemical properties of koalin clay**

| No. | Oxides | Content % | specification limitation ASTM C-618 |
|---|---|---|---|
| 1 | $SiO_2$ | 47.35 | Not Less than 70% |
| 2 | $Al_2O_3$ | 35.13 | |
| 3 | $Fe_2O_3$ | 1.4 | |
| 4 | CaO | 0.6 | Not more than 1.5% |
| 5 | MgO | 0.4 | |
| 6 | $SO_3$ | 0.2 | |
| 7 | $K_2O$ | 0.2 | |
| 8 | $H_2O$ | 0.34 | Not more than 3% |
| 9 | L.O.I | 8 | Not more than 10% |

**Table (5) Properties of Carbon Fiber(Hannant 1977)**

| Properties | Value |
|---|---|
| Diameter(um) | 9 um |
| Density ($kg/m^3$ $10^3$) | 1.9 ($kg/m^3$) $10^3$ |
| Young modulus ($GN/m^2$) | 400 $GN/m^2$ |
| Tensile strength($MN/m^2$) | 2600 $MN/m^2$ |

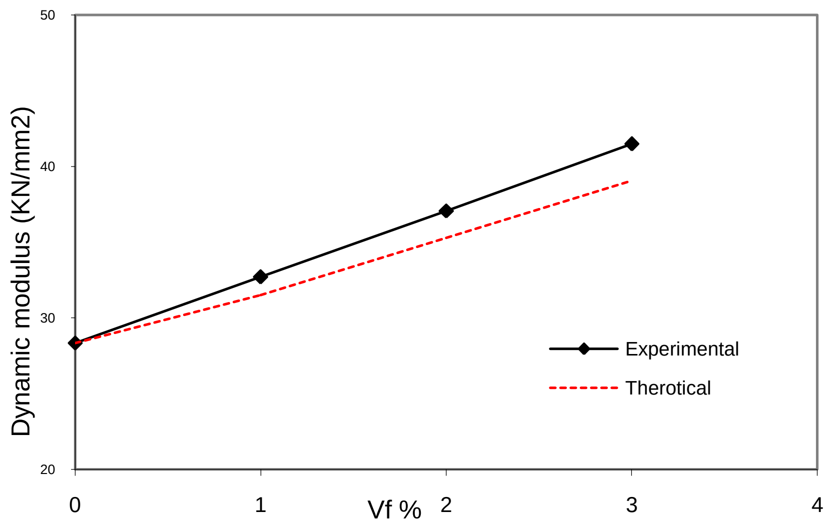


Fig (1) The relationship between dynamic modulus and Vf

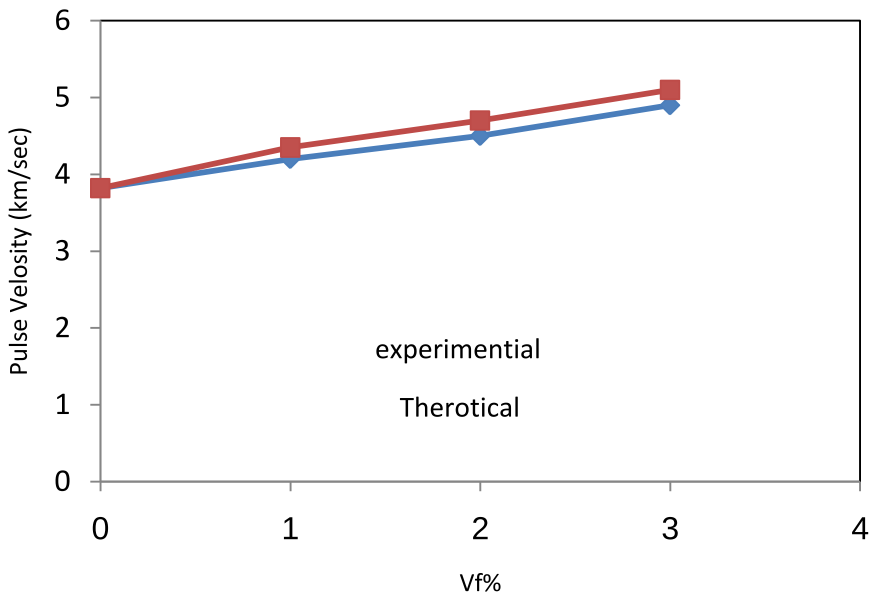


Fig (2) The relationship between Pulse velosity and Vf%

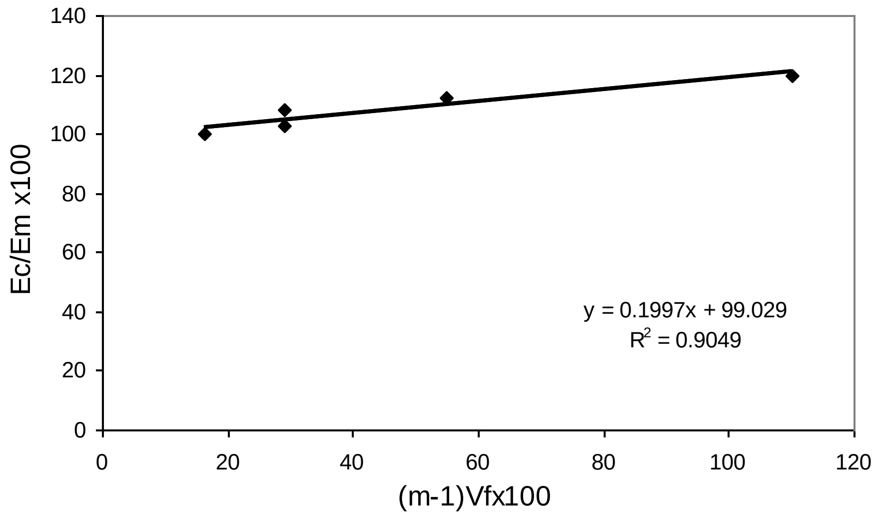


Fig (3) Variation of Ec/Em with (m-1)Vf for randomly distributed fiber, cement composite

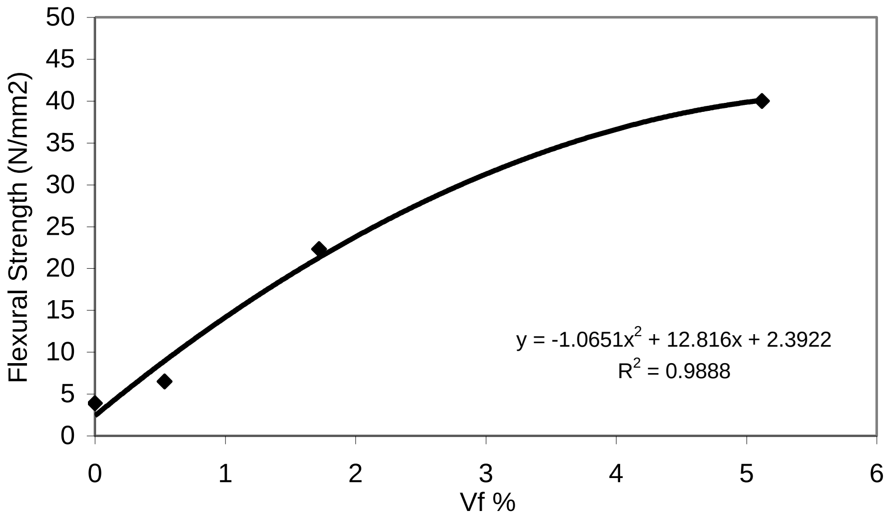


Fig (4) The relationship between flexural strength and Vf

**DISCUSION OF THE RESULTS**

Only 28 days test results are analysed. Each result is an average of 3 tests, all specimens were dried cured inside plastic bags to avoid the adverse effects of unclean water curing on the fibers.

1-Fig (1) shows that the dynamic modulus ($E_d$) of unidirectionaly aligned carbon fibers cement composite increases linearly with volume fraction ($V_f$). The full line (1) indicates the least square fit given by

$E_c = 28.34 + 436\ V_f$ ..................(1)

Correlation coefficient = 0.98

Where :

$E_c$ is the composite dynamic modulus ($KN/mm^2$).

$V_f$ is the volume fraction.

The broken line shows the predicted line given by the theory of two phases on the assumption that $E_f$ of carbon fibers equals 455 $KN/mm^2$.

It can be seen that the therotical values of $E_c$ under estimate those obtained experimentally, this may be for several reasons not included in the theoritical equation for example refect in shrinkage namely the precense of the fibers offers restraint to the shrinkage.

2-Fig (2) shows the relationship of pulse velocity with $V_f$. It can be seen that the varation is similar to that of $E_d$ because of the close relationship between pulse velocity and $E_d$.

3-Fig (3) shows the variation of dynamic (E) in case of randamly oriented carbon fibers. It can be seen that it varies linearly. In order to find a therotical equation the ratio of $E_c$ and $E_m$ where plotted aganist $(m-1)V_f$ as in equation (2)

$E_c/E_m = 0.2(m-1)V_f + 1$ ...........(2)

Where m denotes modular ratio between carbon fiber and the cement matrix.

4-Reference to fig (4) shows relationship between flexural strength and $V_f$.

It can be seen that increase in flexural strength is high and exponantial $V_{f.}$ The failure mode of all specimen was by single cracking.

**CONCLUSIONS**

- The following conclusions can be drawn from the experimental results of this work. The main findings may be summarised as follows:

- The effect of carbon fibers on dynamic modulus of unidirectionally aligned carbon fiber varies linearly with $V_f$ it was shown that the rule of mixture under estimate the dynamic modulus because of the reduction in matrix shrinkage also the pulse velocity vary in smpathy of E- modulus.

- In case of randamly distributed carbon fibers the relationship between Ec and Em vary according to the equation (2) .

- The relationship of the flexural strength and $V_f$ was found to be exponatial with a good correlation factor as shown in fig (4)

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