Effect of Plastic Optical Fiber on Some Properties of Translucent Concrete

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ABSTRACT

Translucent concrete is a building material with light-transmitting properties, due to embedded light optical elements in its mixture; and has the advantage of energy saving in addition to providing nice view to a building. The present study investigated the use and properties of translucent concrete mixture as a construction material with light admittance. The work includes two parts: in the first part many trail mixes are designed and tested to produce self-compact mortar (SCM).Then the obtained mixture is used to prepare a new type of translucent composites with plastic optical fibers POF embedded in the SCM mixture. The second part investigates some of the mechanical properties of translucent concrete by using three concentration of (POF) and three different diameters. The tested results indicate that it is possible to use SCM to produce translucent concrete contain plastic optical fiber (POF) with compressive strength between 31.1 to 40.4 MPa and flexural strength between 5.89 to 8.12MPa for different POF volume fraction content and diameter size at 28 days age.

Keywords: Transparent concrete, Tlastic optical fiber, Self-compact mortar, Mechanical properties.

تأثير الالياف الضوئية البلاستيكية على بعض خواص الخرسانة شبه الشفافة

الخلاصة

الخرسانة شبه الشفافة هي مادة للبناء مع خصائص ناقلة للضوء ,بسبب تضمين عناصر مضيئة في خليطها, و تمتلك فوائد في توفير الطاقة بالإضافة الى أعطاء الجمالية للابنية.

قامت الدراسة الحالية بالتحري عن استخدامات وخصائص الخرسانة شبه الشفافة كمادة انشائية مع نقلها للضوء.وهذا العمل يتضمن جزئيين: في الجزء الاول صممت العديد من الخلطات التجريبية وتم أجراء الاختبار عليها لإنتاج المونة الذاتية الرص (SCM).وبعدها الخلطة المنتجة تم استخدامها لتحضير نوع جديد شبة شفافة مركب من الالياف الضوئية البلاستيكية المضمنة في المونة الذاتية الرص. الجزء الثاني يتحرى عن بعض الخصائص

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الميكانيكية للخرسانة شبه الشفافة باستخدام ثلاث انواع من التراكيز للألياف الضوئية البلاستيكية وبثلاث اقطار مختلفة. وقد اظهرت نتائج الفحوصات امكانية استخدام المونة ذاتية الرص لانتاج الخرسانة شبه الشفافة تحتوي على الالياف الضوئية البلاستيكية بمقاومة انضغاط بين 31.1 الى 40.4 MPa ومقاومة انثناء بين 5.89 الى 8.12 MPa لمحتوى حجمي POF وحجم أقطار متغير عند عمر 28 يوم.

INTRODUCTION

With science and technology development energy saving is the important factor that the industry of construction materials looks for besides nice view. So, the natural sunlight is the best source for light which is actually free of cost. With translucent concrete walls in a room, it'd be brightly illuminated with natural sunlight. It's a requirement for green buildings and it can help add a great deal of security and supervision in places like schools, museums and prisons etc, where the presence of the people and their actions are seen but not their entire image, thereby protecting their privacy as well. In addition, translucent concrete has very good architectural properties for giving good aesthetical view to the building [1–4].

Translucent concrete is composed of two main components: the first is concrete and the other component is optical fiber that, and has good light guiding property that can be used to transmit the light.

Translucent concrete content 2-4% of embedded within the concrete [5–7]. The optical fiber is a thin, flexible, transparent fiber that acts as a waveguide, or light pipe, to transmit light. Light is conducted through the concrete from one end to the other [8]. Therefore the fibers have to go through the whole object. These properties can be beneficial in providing natural inner illumination for buildings.

Self-Compacting mortar SCM has a high content of powder materials to achieve the desired relative flow value. The mortar is a combination of powder, fine aggregate, admixture and water. The efficiency of the mortar mix depends on the simultaneously flow behavior of all the ingredients of mortar during the mortar trial mix test [9–11]. The addition of super plasticizer helps maintain concrete flow ability even with reduced water content.SCM have ability to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement and not require vibration for placing and compaction. The hardened concrete is dense, homogeneous and has similar engineering properties and durability as traditional vibrated concrete[12].In this research a self -compact mortar SCM and plastic optical fiber POF will be used to prepare a new type of translucent composites.

Experimental Work Materials

The materials include a description of the cement, fine aggregate, mineral and chemical admixtures, and plastic optical fibers (POF) used in this research.

- **Cement**

The cement used was Ordinary Portland Cement manufactured in Iraq. The cement was tested and checked according to IOS 5:1984 [13].Table (1) and (2) show the chemical properties and the physical properties of cement.

- **Aggregate**

Al-Ekhaider natural sand was used throughout this research as the fine aggregate. All particles greater than 600µm and smaller than 150µm were removed by sieving. The sand grading and the sulfate content were within the requirements of the IOS No.45/1984[14] and the results of chemical and physical properties of the sand used show that the specific gravity, absorption %, dry loose-unit weight kg/m^3, and sulfate content as SO_3 are 2.60, 2.00%,1595kg/m^3,%0.24 respectively.

- **Water**

Tap water was used for both mixing and curing of composite products.

- **Mineral Admixture**

Densified silica fume was used as a partial replacement of cement (10% by wt.) in this study Table (4) shows some properties of the product where was produced by a well established Materials Company**.**

Table (1): Chemical composition and main compounds of cement.

Oxides composition	**Content %**	**Limits of Iraqi specification No.5/1984[**13]
CaO	61.12	---
SiO_2	20.18	---
Al_2O_3	5.00	---
Fe_2O_3	3.30	---
MgO	3.80	<5.00
SO_3	2.34	<2.80
L.O.I.	3.16	<4.00
Insoluble residue	0.14	<1.5
Lime Saturation Factor, L.S.F.	0.96	0.66-1.02
Main compounds (Bogue's equations)		
C_3S	50.47	---
C_2S	19.78	---
C_3A	7.67	---
C_4AF	10.04	---

Chemical analysis has been conducted by Central Organization for Standardization and Quality Control.

Table (2): Physical properties of cement.

Physical Properties	Test results	Limits of Iraqi specification No.5/1984[13]
Specific surface area (Blaine Method), m^2/kg	330	≥230
Setting time (Vicat Apparatus), Initial setting, hr:min Final setting, hr:min	 3:00 5:30	 ≥00:45 ≤10:00
Compressive strength, MPa 3 days 7 days	 19.6 28.9	 ≥15.00 ≥23.00
Soundness (Autoclave Method), %	0.09	≤0.8

Physical analysis has been conducted by Central Organization for Standardization and Quality Control.

Table (3): Grading of sand compared with requirements of Limits of IOS No.45/1984[14].

Sieve size (mm)	Cumulative passing %	Limits of IOS No.45/1984 (Overall grading)
10.00	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	47.3	15-50
0.15	0	0-15

- **Water**

Tap water was used for both mixing and curing of composite products.

- **Mineral Admixture**

Densified silica fume was used as a partial replacement of cement (10% by wt.) in this study Table (4) shows some properties of the product where was produced by a well established Materials Company.

- **Chemical Admixture**

(High range water reducing) One of the generations of Polycarboxylic ether based superplasticizer, designed for the production of SCM was used (Glenium 51). Table (5) shows the main characterization of this product.

- **Plastic optical fiber**

The Plastic Optical Fibers is PMMA (Poly Methyl Methacrylate) fibers manufactured by a specialized company, there different diameters of (POF) were used (1.5, 2 and 3mm). Tables (6) and (7) show the details of the POF.

Table (4): Chemical analysis of the densified silica fum. *

Oxide composition	Oxide content %
SiO_2	94.10
Al_2O_3	0.38
Fe_2O_3	0.01
Na_2O	0.00
K_2O	0.07
CaO	1.20
MgO	0.15
SO_3	0.22
L.O.I.	3.87

Test has been carried out at the National Center of Geological Survey and Mining.

Table (5): Typical properties of (Glenium 51).

Main action	Concrete super plasticizer
Color	Light brown
pH. Value	6.6
Form	Viscous liquid
Subsidiary effect	Hardening
Relative density	1.082 - 1.142 kg/liter
Viscosity	128 ± 30 cps at 20°C
Transport	Not classified as dangerous
Labeling	No hazard table required

Given by the manufacture.

Preparation of the plastic optical fiber in mold:

The fabrication process of standard translucent concrete requires a very high skillness during the preparation of the molds and the arrangement and alignment of the plastic optical fibers according to its content. Some holes with orthogonal arrays are drilled in the plastic sheet the details of arrangement and number of fibers are shown in Table (6) and (7) and Figures (1) and (2).(POFs) are through the holes the two plastic sheets which are fixed on the slots of base wood formwork as shown in Figures (3) and (4).

Table (6): No. of (POF) in the cubic sample for each diameter used.

Plastic Optical Fiber 1.5mm		Plastic Optical Fiber 2mm		Plastic Optical Fiber 3mm	
Percentage	**No. of (POF)**	**Percentage**	**No. of (POF)**	**Percentage**	**No. of (POF)**
2%	30	2%	16	2%	8
3%	44	3%	24	3%	11
4%	57	4%	32	4%	15

Table (7): No. of (POF) in the prism sample for each diameter used

Plastic Optical Fiber 1.5mm		Plastic Optical Fiber 2mm		Plastic Optical Fiber 3mm	
Percentage	**No. of (POF)**	**Percentage**	**No. of (POF)**	**Percentage**	**No. of (POF)**
2%	73	2%	40	2%	18
3%	113	3%	61	3%	28
4%	150	4%	82	4%	37

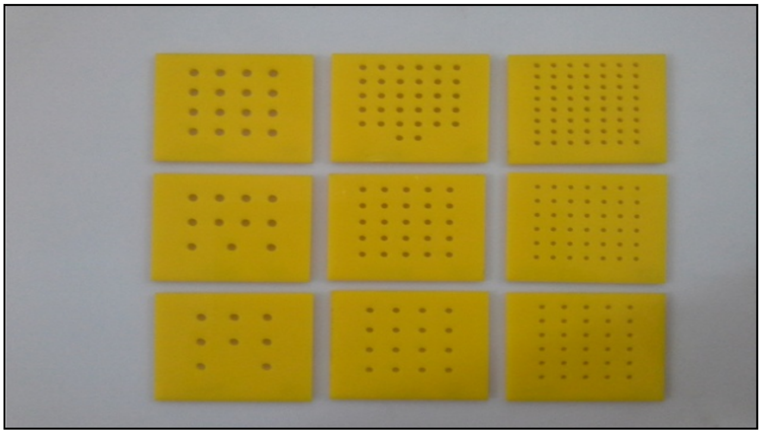

Figure (1): Details of holes in the plastic sheets.

Figure (2): Details of fixing the POFs through the square plastic sheet for cubic samples.

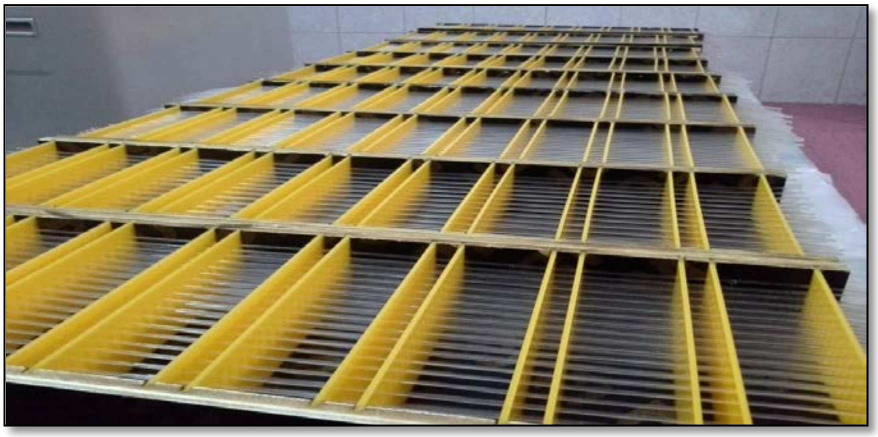

Figure (3): Details of prisms of wood mold after fixing the POFs.

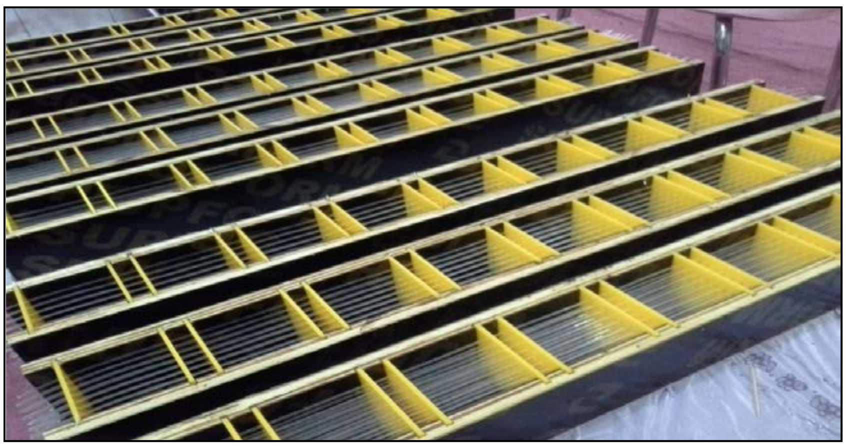

Figure (4): Details of cubes of wood mold after fixing the POFs.

Mix proportions:

After many trail mixes the adopted mix used in this study to produce a SCM estimated in kg/m^3 are listed as below:-

- Portland cement – type I = 495 kg/m^3.
- Natural fine sand (150 – 600 μm) = 1375 kg/m^3.
- Densified silica fume = 55 kg/m^3.
- Water = 247.5 kg/m^3.
- Superplasticizer (Glenium 51)= 20 kg/m^3.

Mixing Procedure

It is necessary in SCM to achieve desirable concrete performance and homogeneity by using enough mixing time to ensure that all particles of material intervened together. In this study Hobart mixer of ($0.001m^3$) capacity was used to produce the tests mixes. This mixer is compliant with the requirements of ASTM C305-99[15].

Curing of Specimens

After 48 hours the hardened specimens were de-molded, and cured in water as shown in Figure (5) with a temperature of 23±2 Cº for 7, 28 and 90 days age. The optical fibers were cut and the plastic sheets were removed. After that, the surface on both sides was polished to produce a highly-smooth surface.

Figure (5): The specimens after de-molded and Curing of samples.

Fresh Mixes Tests

- **Mortar Slump Flow Test**

The slump flow is used to assess the horizontal free flow of self compacting mortar in the absence of obstructions according to EFNARC, 2002 [12]. The diameter of the mortar circle is a measure for the filling ability of the mortar. The apparatus is shown in Figure (6).

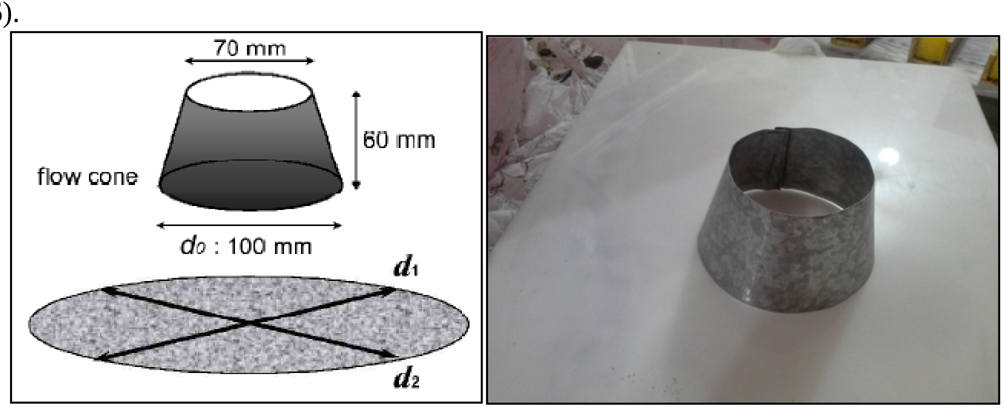

Figure (6): Mortar flow test (mini cone).

- **Mortar V-funnel Test**

Viscosity and filling ability can be assessed by the V-Funnel flow time according to EFNARC, 2002[12]. The apparatus is shown in Figure (7).

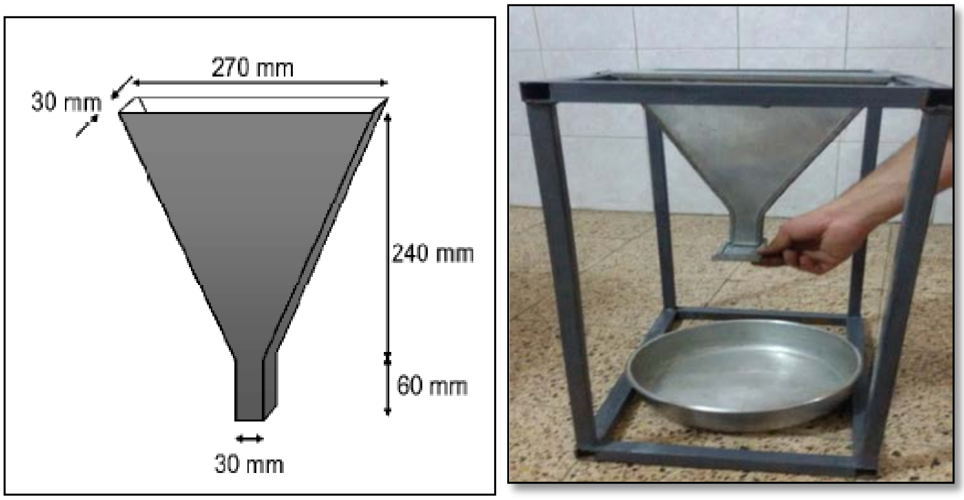

Figure (7): Mini V-funnel test apparatus [12]**.**

Hardened Properties Tests

The hardened properties tests are compressive strength, splitting tensile strength, and flexural strength (modulus of rupture) for the tests samples (cubes and prisms).

- **Compressive Strength**

The compression test was carried out on (50×50×50mm) cubes using a digital compression machine of 2000kN capacity. The load applied at a rate of 1.5 kN/sec, according to ASTM C109/ C109M-05[16]. The average of three cubes was adopted at each testing age (7, 28 and 90 days). The Figure (8) shows the specimens after compressive strength test.

Figure (8): The specimens after compressive strength test.

- **Flexural strength(Modulus of Rupture)**

The modulus of rupture was tested on (40×40×160mm) prism specimens under center line loading according to ASTM C348-02[17] using flexural testing machine of 10 kN capacity. The average of three prisms was taken at each testing age (7, 28 and 90 days) as show in Figure (9).

The modulus of rupture was calculated as follows:

$$F_r = 3PL/2BD^2 \quad \text{….. (1)}$$

Where:

Fr: Modulus of rupture (MPa).

P: Maximum applied load indicated by the testing machine (N).

L: Span length (mm).

B: Width of the specimen (mm).

D: Depth of specimen (mm).

Figure (9): Flexural testing machine and test samples.

Results and Discussion:

The relatively faster strength development for mixes particularly at early ages is believed to be mainly due to the inclusion of fine fillers powder, therefore, the interface zone becomes stronger, more homogeneous and dense, The new generation of carboxylic ether polymer – based super plasticizer leads to an increase in the ultimate compressive strength[18,19].

The silica fume is a very reactive pozzolanic material in concrete. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide (CH). The silica fume reacts with this calcium hydroxide to form additional binder material called siliacate hydrate, Which is very similar to the calcium silicate hydrate (C-S-H) formed from the Portland cement[20].

Compressive strength results

The results of POF 1.5mm diameter for various volume fraction is shown in Figure (10). The obtained results indicated that the compressive strength at 7 days age decreases as fiber content increases, Where the decrease was about (24.5 , 29.5and 33.4%) for (2, 3, 4%) fiber volume fraction content respectively as compared with reference sample without POF. While at 28 and 90 days age the compressive strength improved due to the hydration of cement development of interfacial transition zone between the matrix and the POF. So that the results show the compressive strength decreased by about (23.2 ,16.3 and 14.2%) for (2, 3and 4%) fiber volume fraction content respectively as compared with reference sample without POF and the same trend is observed at 90 days age this mains that the inclusion of POF in the matrix did not affect the compressive strength significantly.

The compressive strength of POF 2.0 mm diameter in Figure(11) shows a decrease when fiber content increased for all ages, and the decrease in compressive strength at 7 days age is (15.4, 25.5and 29.5%) for

(2,3and4%) fiber volume fraction content respectively as compared with reference sample without POF. and (2.8, 9.8 and 26.0%)) at 90 days for (2, 3and 4%) fiber volume fraction content respectively as compared with reference sample without POF. In the same context, the results show that the POF 2.0 mm diameter samples have the highest compressive strength at different fiber concentration and diameters.

From the compressive strength results of POF 3.0 mm as shown in Figure(12) the difference between the compressive strength at 7 days age and the compressive strength at the 90 days age decreased from (30.6, 31.7and 35.3%) to (21.9, 24.3and 28.0%) for 2, 3and 4% fiber volume fraction content respectively as compared with reference sample without POF.

And it can be seen that the POF 3.0 mm diameter also decreases with POF content, but in the case of 4% POF content we can see an increase in compressive strength due to the uneven distribution of POF in concrete and indicates that the irregular distribution weakened the structure of the concrete. The details of distribution of POF appear in Figure (1).

Flexure strength results

The flexure strength of POF 1.5, 2.0 and 3.0 mm diameter for various volume fractions is shown in Figure (13) for 7 days age and is compared with reference samples without POF. It's noticed that flexure strength is slightly decreased with fiber volume fraction content for all the POF diameters, and that the 1.5 mm diameter of POF has the highest value at 7days age. It’s noticed that the failure occurred in interfacial transition zone between the POF and cement paste and occurred partly through the cement past and through the interfacial transition zone. This behavior is due to the smoothness of the optical fiber surface which leads to this type of surface of fraction. We can also see the percentage of the flexural strength reduction between (15.00 to 47.30%) for various diameters and fiber volume fractions content. But, the test results improved with age of samples at 28 and 90 days as seen in Figure (14) and Figure (15).This indicates that the 2.0mm POF diameter have the highest value reached about (8.11,7.7 and7.11MPa) for (2, 3 and 4%) fiber volume fraction content respectively for 90days age.

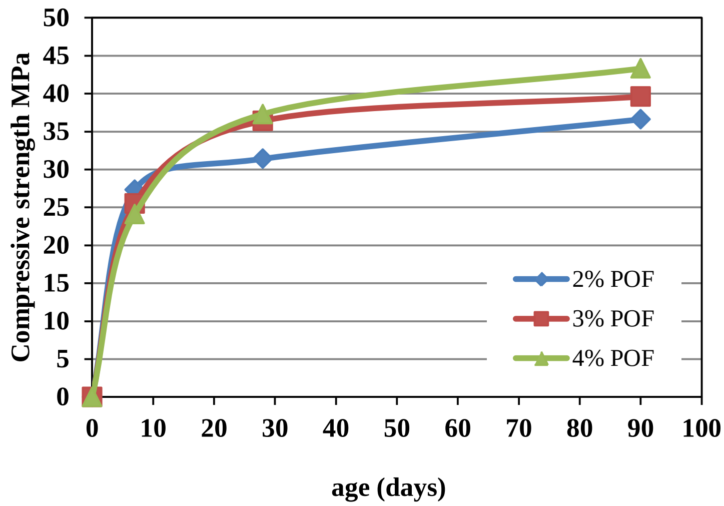

Figure (10): The compressive strength results of 1.5mm diameter of POF in different volum fraction.

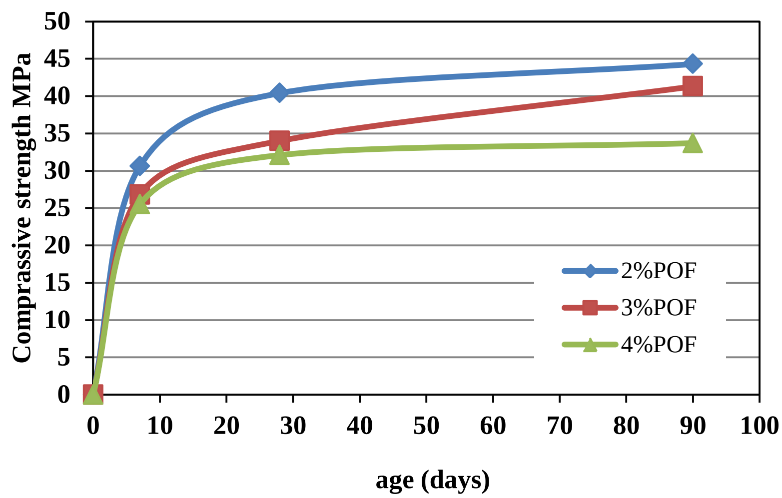

Figure (11): The compressive strength results of 2.0mm diameter of POF in different volum fraction.

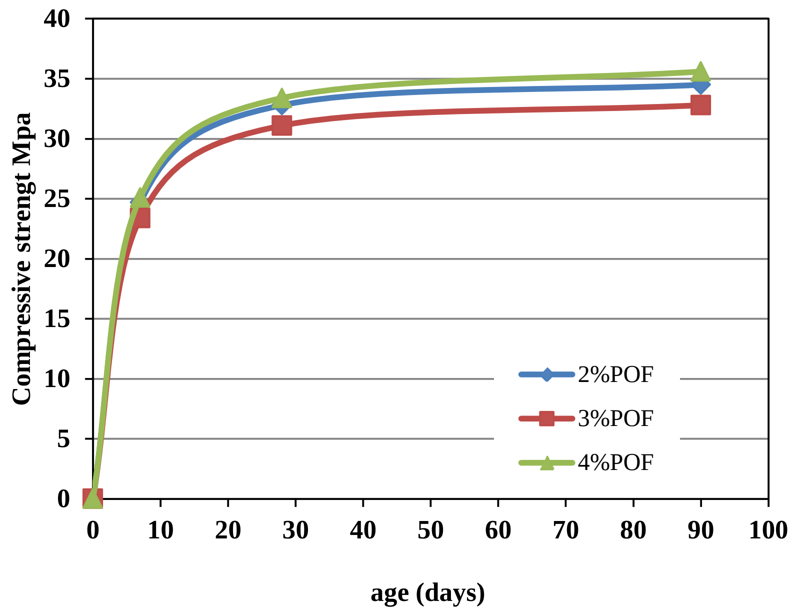

Figure (12): The compressive strength results of 3.0mm diameter of POF in different volum fraction.

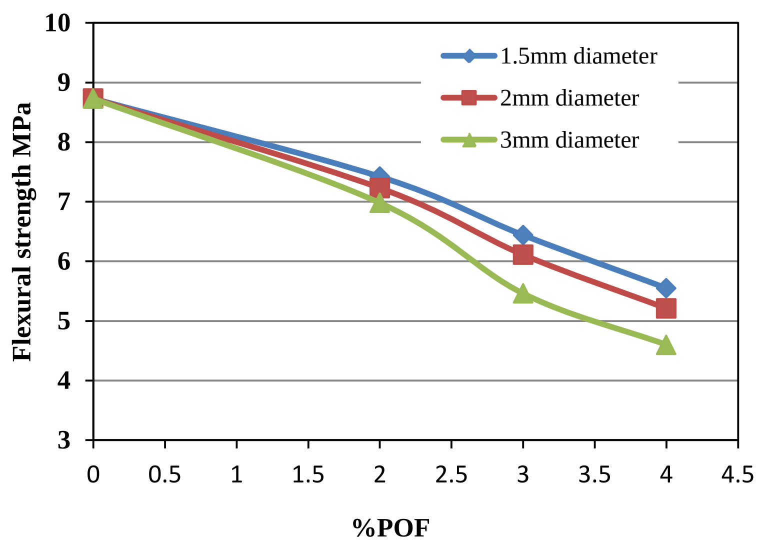

Figure (13): 7 days age flexural strength results for vairous fiber diameter and different volum fraction.

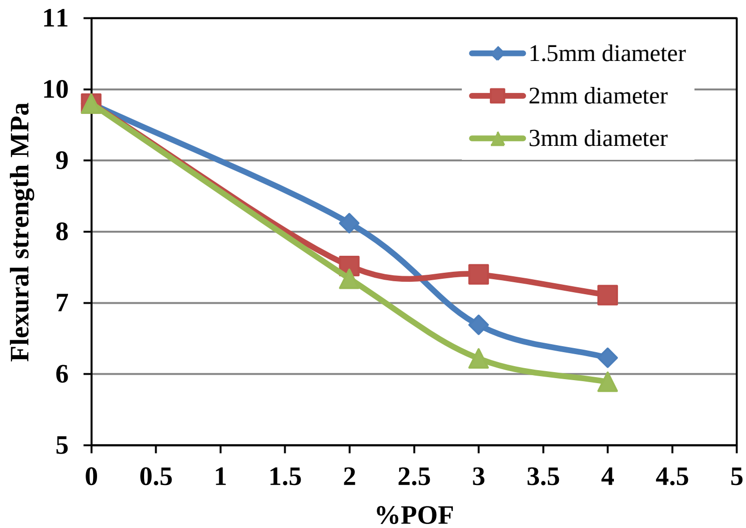

Figure (14): 28 days flexural strength results for vairous fiber diameter and different volum fraction.

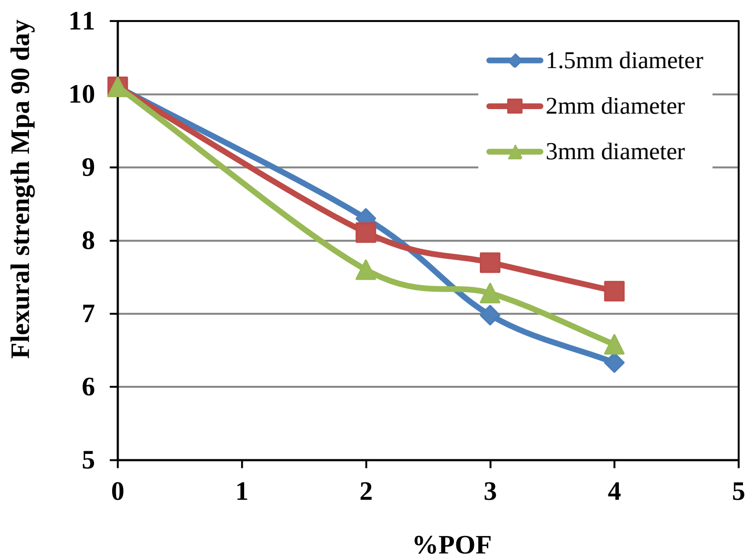

Figure (14): 28 days flexural strength results for vairous fiber diameter and different volum fraction.

CONCLUSIONS

From the discussion of the tests results the following conclusion could be drawn:-

1. The Self Compact Mortar (SCM) is very suitable mixture to produce the translucent concrete due to homogeneity properties, flowability in complex molds with high fiber content. It was easy in casting and finishing.
2. It is possible to produce a self compact mortar with a slump flow of (255 mm) and V-funnel (7.3 sec) by using a mix proposed of [cement, sand, water, 10%silica fume (replacement by weight of cement), and superplasticizer (Glenium 51)].
3. The compressive strength of translucent concrete is about (28.50- 7.12%) less than the reference concrete at age of 28 days for (1.5, 2.0 and 3.0mm) POF diameter and for different volume fraction content. This very intelligent conclusion to use this product as structural elements as well as architectural.
4. The inclusion of POF reduces the modulus of rupture by about (17.14%), as minimum reduction for 2% POF volume fraction and 1.5mm POF diameter, the maximum reduction (39.89%), for 4% POF volume fraction and 3.0mm POF diameter compared with reference concrete (without POF) at age of 28 days.
5. Using 2.0 mm diameter produces elements with higher compressive and flexural strength at 28 and 90 days as compared with 1.5 mm and 3 mm diameter for all volume fraction used.

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