"Effect of Polypropylene Fibers on Producing Sustainable Accelerated Hardened Cementitious Materials"

تأثير ألياف البولي بروبلين في أنتاج مواد أسمنتية مستدامة سريعة التصلب

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Abstract

The aim of this research is to produce environmental friendly cementitious materials using polypropylene fibers as recyclable reinforcement materials and silica fume (side-product in manufacturing of ferro-silicon alloys and silicon metal) material. The manufacturing process includes using accelerating curing with carbon dioxide for the fresh cementitious mixtures to decrease setting time and improve hardening, particularly in precast concrete plants.

Mix proportions used in this research were cement: silica fume: Sand (1: 0.75: 1.3) and 0.5 w/c ratio. Also, four percentages of polypropylene fibers are used (0, 0.3, 0.9, and 1.5%) by weight of cement. All specimens are exposed to 100% of carbon dioxide gas concentration for 2 hours. Compressive, flexural, and direct tensile strengths have been tested at 7 and 28 days. The results show a significant improvement of flexural strength and direct tension for specimens. The increasing percentages of flexural strength and direct tension with (1.5% polypropylene) compared with control mixture at age 28 days were about (+ 28%) and (+ 117%) respectively.

Keywords: cementitious materials, carbon dioxide curing, silica fume, polypropylene fibers

الخلاصة

ان الهدف الرئيسي في هذا البحث هو انتاج مواد سمنتية صديقة للبيئة باستعمال الياف البولي بروبلين كمواد تسليح قابلة لاعادة الاستعمال وكذلك مادة غبار السيليكا (منتج ثانوي في صناعة سبائك الحديد والسيليكون ومعدن السليكون). ان عملية التصنيع تتضمن الانضاج المعجل باستعمال ثنائي اوكسيد الكربون للخلطات السمنتية الطازجة من اجل تقليل زمن التجمد وتحسين التصلب وخصوصا في معامل الخرسانة مسبقة الصب .

نسب الخلط المستعملة في هذا البحث هي سمنت: سيليكا فيوم :رمل (1 : 0.75 : 1.3) ونسبة الماء الى السمنت هي 0.5 .اضافة الى ذلك، تم استعمال اربع نسب من الياف البولي بروبلين هي (0,0.3,0.9,1.5)% من وزن السمنت .تم تعريض كل النماذج الى غاز ثنائي اوكسيد الكربون وبتركيز 100% ولمدة ساعتين . تم فحص مقاومة الانضغاط , الانثناء ,والشد المباشر بعمر 7 و 28 يوم . بينت النتائج تحسن ملحوظ في مقاومة الانثناء والشد المباشر للنماذج .نسب الزيادة في مقاومة الانثناء والشد المباشر باستخدام نسبة (1.5% بولي بروبلين) مقارنة مع الخلطة المرجعية وبعمر 28 يوم كانت حوالي (+28%)و(+117%) على التوالي .

الكلمات الرئيسية : مواد اسمنتية ، انضاج بثنائي اوكسيد الكربون ،غبار السيليكا ، الياف البولي بروبلين .

1. INTRODUCTION

Carbon dioxide (CO_2) is the essential greenhouse gas emitted from different sources such as industrial processes, human activities, and electricity generation. It has harmful effects on the environment despite its benefits for that there is several methods to decrease its emissions. One of these methods is the consumption of CO_2 in curing process of concrete .The prevalent chemical reaction includes reaction of carbon dioxide with calcium hydroxide $Ca(OH)_2$ result from cement hydration, producing calcium carbonate $CaCO_3$. Carbonation reactions may decrease the time of curing for cementitious materials in CO_2 existence. Another advantage including is utilize CO_2 which also reduces greenhouse gas emitted because of consumption of CO_2.

Valuable results of exposing precast or masonry concrete to CO_2 after product formation have been distinguished such as: improving strength, resistance to chloride permeability, freeze-thaw performance, and reduced absorption [1],[2], [3], [4], and [5].

In water, $CaCO_3$ is less solvent than Ca $(OH)_2$, and there's a reduction in porosity and an increment in hardness and impermeableness associated with the development of $CaCO_3$. The variation in its composition and structure improve the durability of cementitious materials. Additionally, CO_2 curing decreases the pH of pore water in cementitious materials [6]

All products of concrete and cementitious material known for being weak in tension unless they have reinforcement, and for absence of toughness that provide increment in early cracks because of impact loads and/or thermal shock. Cementitious materials reinforced with fiber may be utilized to solve these cases. Cellulose (derived from softwood or hardwoods) is one kind of fibers that used in reinforcement of cementitious materials composites show high strength and toughness, fire resistance, life-cycle economy, and adequate longevity [6],[7] and [8] . Wood fibers offer highly cheap means of thin reinforced cement products that have proper bonding capacity, stiffness and strength of cement-based forms to enhance toughness, impact resistance and flexural strength. Wood fibers improve the arresting of cracks spreading in brittle cement-bond forms[9]. Saturated composites have considerably increase toughness and in the same time reduce flexural strength. They show attractive dimension stability and durability [10] and[11]. With time, strength and stiffness will increase, and they will tend for losing ductility. Cellulose–fiber cement composites production can have advantage from accelerated curing in CO_2 prosperous environment and reduce setting and hardening time[12], [13], [14] and [15].

Vegetable fibers have been utilized pulp or short fibers as reinforcement. These composite systems exhibit a tension softening in low tensile strength, producing products that are more applicable for non-structural applications. Various cracking acting below direct tension can't be accomplished up to the current time for non- continuous vegetable cement composites because of the difficultness in spreading fiber portions more than 3– 4% and fiber length more than 25–30 mm [16] and [17]. In pulp fibers–cement based composites, despite the fact that volume portions as high as 8–10% may be utilized, the composites still show a tension softening under direct tension for the short fiber. These composites can be used as formworks, facades, tanks, long span roofing members, pipes, structural building members and strengthen the existing structure [18].

The aim of this research is to ensure the utilizing of composites using as substance of cement which reduce the CO_2 emission in cement producing. Less environment effect of this material is accomplished through a green cementitious matrix and the use of renewable reinforcement. Tests were completed in this research to characterize this newly developed material.

2. EXPERIMENTAL PROGRAM

Materials are prepared and weighed in the laboratory. Mix proportions used in this research are cement: silica fume: Sand (1: 0.75: 1.3) and 0.5 w/c ratio. There are four mixtures; the first one is the control mixture. The other three mixtures are mixed using three percentages of Polypropylene (PP) (0.3, 0.9, and 1.5%) as weight replacements of cement. All mixtures are cured with CO_2. The mixtures are used to study the effect of adding PP fibers using different proportions and cured with CO_2 gas.

2.1 Materials

In this research, Ordinary Portland cement (OPC) (type I) was utilized as apart in mixtures. The chemical composition and physical properties of cement was according to Iraqi specification IQS (No.5:1984) [19]. The specific surface area (Blaine fineness) was 342 m^2/kg. Bogue composition of 38 % C3S, 34 % C2S, 9 % C3A and 10 % C4AF conforms to ASTM C150 [20].

Al-Ukhaider natural sand was utilized with maximum size 4.75 mm and the grading was within the requirements of IQS (No.45:1980) Zone2 [21].

Silica fume is a fine powder with a mean diameter of 0.1μm and surface area 15 to 25 m^2/g. Chemical composition of silica fume utilized as a part in this research showed in **Table 1**, and the physical requirements are listed in **Table 2**. Results demonstrate that the utilized silica fume conforms to ASTM C1240 [22]. In this work, PP fibers were used with three different percentages (0.3%, 0.9% and 1.5% by weight of cement). Physical properties of this fiber are shown in **Table 3**.

Table1. Silica Fume chemical analysis *

Oxides Composition	Oxides content %	**ASTM C1240-15** %
SiO_2	91.5	Min. 85
Al_2O_3	0.73	< 1
Fe_2O_3	0.46	< 2.5
CaO	0.86	< 1
SO_3	0.96	< 1
$K_2O + Na_2O$	1.33	< 3
L.O.I.	4.37	Max. 6
Cl	0.1	< 0.2
CaO (free)	2.34	< 4

* Performed in laboratory of building materials-University of Baghdad

Table 2. Silica Fume physical properties *

Property	Result	**ASTM C1240-15**
Strength activity index	106	≥105 %
Specific gravity	2.3	----
Physical form	Powder	----
Color	Grey	----
Size	0.15	≤ 0.15 micron
Density (dry bulk) kg/liter	0.51	----
Moisture (%)	00	≤ 2
Specific surface, m^2/gm	16.1	≥15

* Performed in laboratory of building materials-University of Baghdad

Table 3. Polypropylene Fiber physical properties *

Properties	Details
Specific gravity	0.92 g/cm^3
Air entrainment	Air content of concrete will not be significantly increased
Constituents	Polymerized polypropylene
Fiber diameter	18 micron
Fiber length	12 mm
Surface area	230 m^2/kg min.
Young's modulus	3500-3900 MPa
Tensile strength	Min 350 MPa
Melting point	160° C

* Manufacturer data sheet

2.2 Mixing Procedure

All mixtures were mixed in drum mixer. The mixer should be clean, moist and free from water. For reference mix, specified weights of silica fume and cement were placed into mixer and blended. For other three mixtures PP Fiber was added with three proportions (0.3, 0.9, and 1.5 %) and then the three materials were blended, after that water was added and mixing continued till getting a homogeneous fresh mortar with standard consistency. The time of mixing was not more than four minutes.

2.3 Casting and Compaction

Steel molds were cleaned, and internal faces were thoroughly lubricated. Mortar was casted in two layers and each layer compacted by using vibrating table. The excess mortar on the surface was removed with trowel. The molds were covered for about 24 hours. A total of (60) samples were casted and **Plate 1** shows part of them.

2.4 Curing

The specimens were demolded after 24±1 hrs. from time of adding water to mix and put in oven for 30 minutes under 50ºC. .The samples of the four mixtures were cured using the CO_2 by putting the samples in the carbonation chamber, as shown in **Plate 2**, closing the chamber firmly, and air discharged. After that, the machine starts to pump CO_2 to the chamber with a proportion of 100% CO_2 and for two hour. Then the samples were kept in plastic bags to avoid losing of moisture from samples till testing.

3. EVALUATION METHODS

3.1 Compressive Strength Test

For compressive strength tests, 50 mm cubes were prepared according to ASTM C109[23] and tested at ages of 7 and 28 days.

3.2 Flexural Test

Using specimens with dimensions (40*40*160 mm), flexural Test was tested according to BS 6319-3 [24] at ages of 7 and 28 days.

3.3 Direct tensile test

For direct tensile strength test, specimens prepared according to BS 6319-7 [25]. Mortar direct tensile strength was determined using the value of the ultimate allowable load. Specimens tested in the age of 28 days.

4. RESULTS AND DISCUSSION

The effect of CO_2 curing with different fiber content on properties of cement composites are shown in **Figs. 1, 2** and **3**. Compressive and flexural strength have been tested at 7 and 28 days for all mixtures, and direct tension at age of 28 days.

The results of compressive strength indicated that with increasing the percentage of PP, as partial replacement of cement, will decrease the compressive strength in comparison with the samples made up without using PP. the decreasing percentage of compressive strength between mixtures with (1.5% PP) compared to control mixture (0% PP) at age 28 days was about (22%), as shown in **Fig.4**.

In case of flexural strength, polypropylene fibers played a positive role for the final performance by increasing the flexural strength. The flexural strength increases as PP percentage increase compared with sample made up without using PP which was the lowest.

The samples of percentage (1.5% PP) show a significant increase in flexural strength. These results demonstrated that fibers could reduce crack formation. It is clear that the fibers are located in the width of formed crack and creating the connection bridges and development and thus led to increasing flexural strength. The variation percentage of flexural strength of mixtures with (1.5% PP) compared with control mixture was about (+ 28%) at age 28 days, as shown in **Fig.5**.

PP has a significant effect on direct tension of sustainable cement based composite materials using CO_2 curing. Direct tension value increases as the percentage of PP increased and have more strength than control samples.

The using of (1.5% PP) confirmed the ability to increase the direct tension strength. The variation percentage in direct tension between samples that using (1.5% PP) and control samples at age 28 days was about (+ 117%), as shown in **Fig.7**. Such behavior is probably due the bridging mechanism of fibers for cracks initiation in the cementitious matrix.

5. CONCLUSIONS

A review was directed to evaluate the impacts of CO_2 curing on some mechanical characteristics of polypropylene fiber reinforced cement composites. The mechanical properties investigated include: compressive strength, flexural strength, and direct tensile strength. According to results showed in this paper it can be presumed that:

- This research shows the combined benefit of using CO_2 curing with polypropylene fiber on flexural strength and direct tension of sustainable cement based composite materials. The increasing percentages of flexural strength and direct tension with (1.5% PP) compared with control mixture at age 28 days were about (+ 28%) and (+ 117%) respectively.
- In contrast, its effects of polypropylene fiber on compressive strength appear to be reversible. This behavior introduces these products to be utilized in the fabrications of boards and thin sections in construction sector.

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Plate 1. Some of tested samples

Plate 2. The CO_2 curing chamber

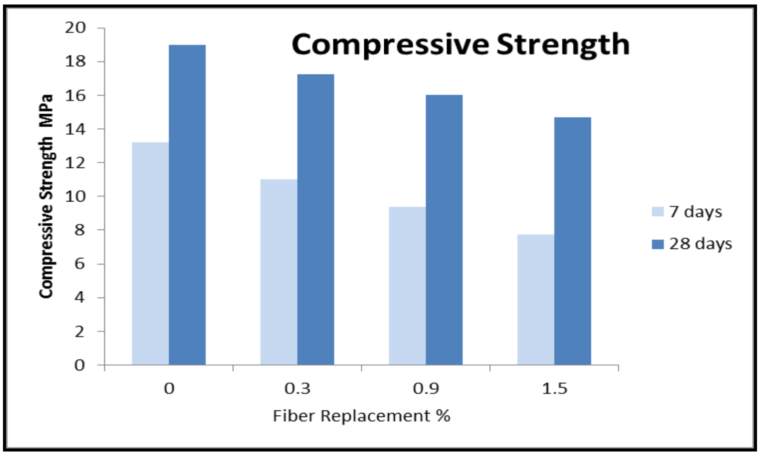

Figure 1. Effect of PP Fiber content on Compressive Strength using CO_2 curing

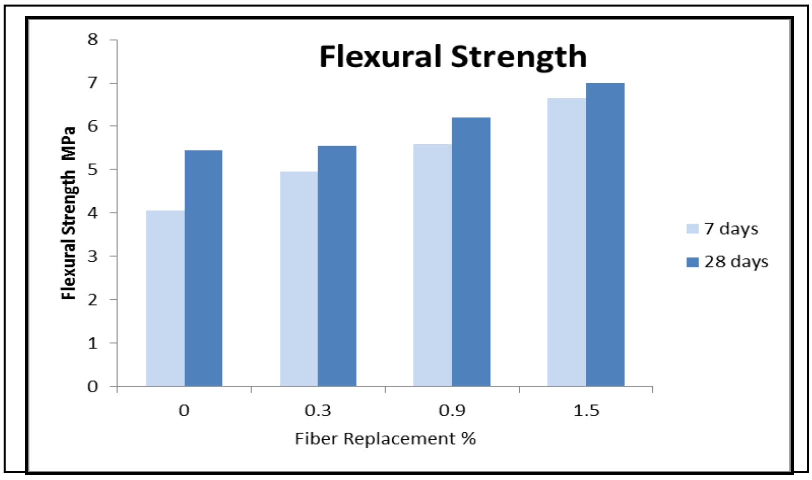

Figure 2. Effect of PP Fiber content on Flexural Strength using CO_2 curing

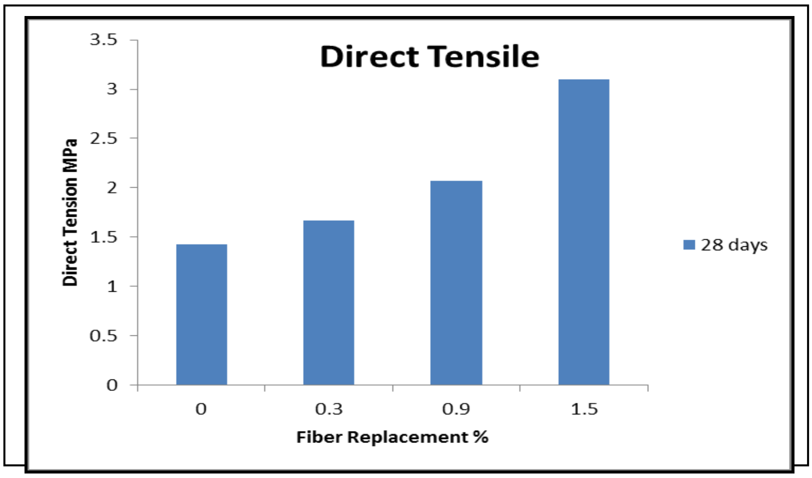

Figure 3. Effect of PP Fiber content on Direct Tension Strength using CO_2 curing

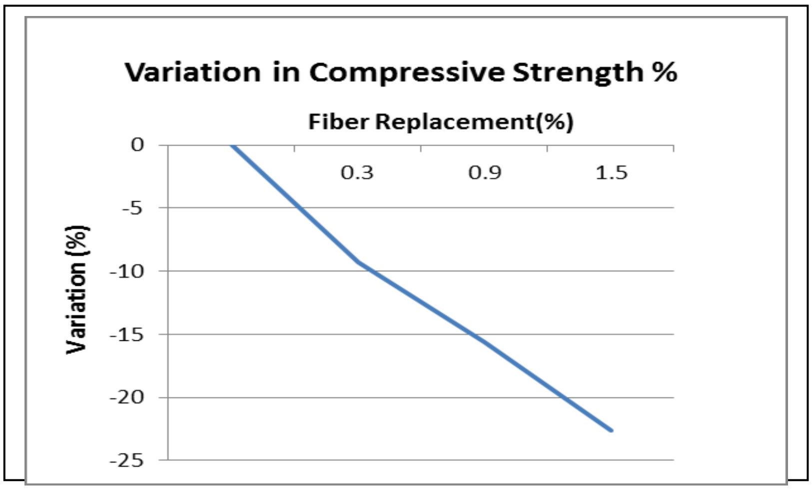

Figure 4. The variation in compressive strength for different mixtures with CO_2 curing

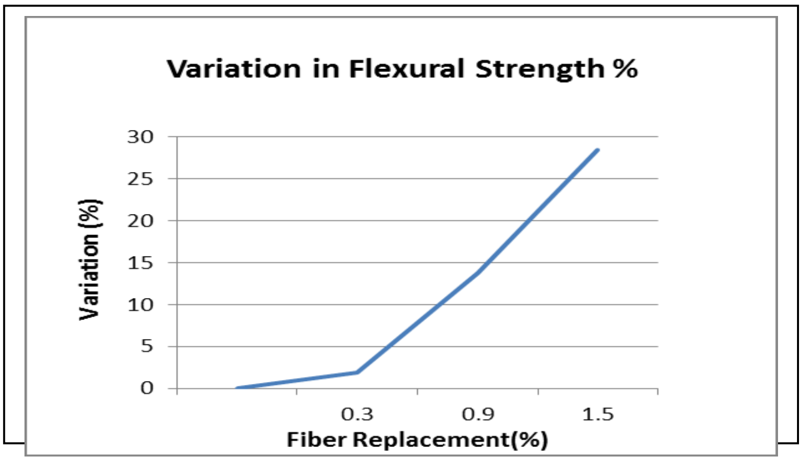

Figure 5. The variation in flexural strength for different mixtures with CO_2 curing

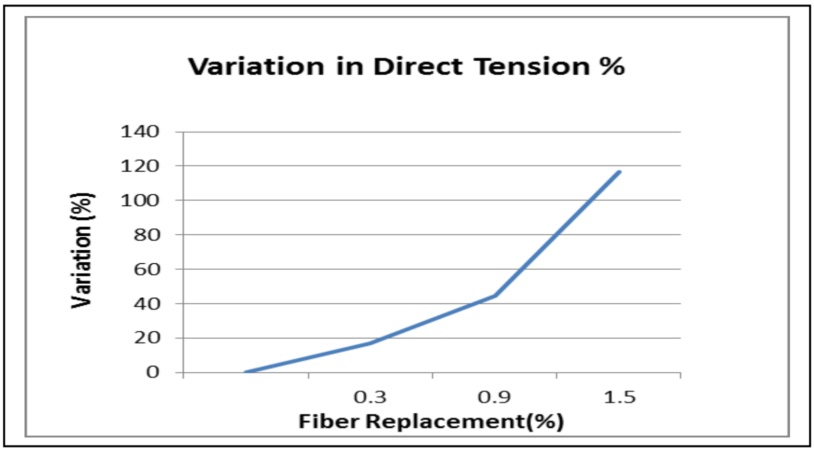

Figure 6. The variation in direct tension for different mixtures with CO_2 curing