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EFFECT OF POLYPROPYLENE FIBERS ON THE MECHANICAL PROPERTIES OF NORMAL CONCRETE

Mohamed R. A. S.
Associate Profosser, Civil Engineering Department, Faculty of Engineering, El-Minia University, El-Minia, Egypt.

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The present work investigates the effect of addition of pure polypropylene fibers to concrete in order to diminish some poor performances particularly in case of ductility and tensile strength. The effect of the addition of polypropylene fibers on the mechanical properties of normal strength concrete is studied. The polypropylene fibers were added at concentration of 0.25, 0.5, 1.0 and 1.5% by volume. Compression, pull-out and bending tests were carried out to determine the mechanical properties such as maximum compressive strength, modulus of elasticity, splitting strength, ductility, bond strength, modulus of rupture and the percentage of absorption.

On the basis of the experimental results, it can be concluded that, ductility of concrete significantly increased and maximum compressive strength slightly increased with increasing the content of polyproplylene fibers materials. Further increase of polypropylene fibers (higher values than 0.5 vol. %) did not increase the ultimate bond strength, but it provided much more ductile bond behaviour. Besides, the addition of polypropylene fibers caused a significant increase in the percentage of water absorption for the tested concrete specimens.

KEYWORDS: *Concrete, compressive strength, bond strength, polypropylene fiber.*

1 INTRODUCTION

The use of fiber reinforced concrete has increased in building structures to improve the toughness, flexural strength, tensile strength, impact strength as well as the failure mode of concrete. It has also been known that addition of fibers in concrete has little or no effect on the compressive strength and modulus of elasticity [1]. Concrete is a tension-weak building material, which is often crack ridden connected to plastic and hardened states, drying shrinkage, and the like. The cracks generally develop with time and stress to penetrate the concrete, thereby impairing the waterproofing properties and exposing the interior of the concrete to the destructive substances containing moisture, bromine, acid sulphate, etc. The exposure acts to deteriorate the concrete, with the reinforcing steel corroding. To counteract the crack, a fighting strategy has come into use, which mixes the concrete with the addition of discrete fibers [2, 3]. The concrete-reinforcing fibers include metal, polymer, and various others. Among the polymer fibers, the polypropylene fibers enjoy popularity in the domain of concrete [4, 5] and the nylon fibers show a rising acceptance[6, 7]. The polypropylene fibers claimed contribution to the concrete performance subjected to crack opening and slippage [8]. Furthermore, the fibers reinforced the performance under not only compression, flexure, and tension [9], but also under impact blows [10] and plastic shrinkage cracking [11].

In the present paper, test specimens were prepared for studying the effect of polypropylene fibers on the mechanical properties of normal strength concrete. The tests conducted included determinating the compressive strength of hardened concrete at different times, bond strength, modulus of rapture, modulus of elasticity, the splitting strength, ductility and maximum strain for standard concrete specimens.

EXPERIMENTAL WORK

The experiments include the measurements of the compressive strength for five sets of concrete cubes 10 × 10 × 10 cm, (45 cubes in total) at different ages, modulus of elasticity of the concrete prisms 10 × 10 × 40 cm, (15 prisms in total), modulus of rapture of the concrete prisms 10 × 10 × 50 cm and prism concrete compressive strength (15 prisms in total), splitting strength of concrete cylinders 10 × 20 cm, (15 cylinders in total), bond strength of concrete cylinders 10 x 20 cm, (15 cylinders in total) and percentag of absorption of concrete cubes 10 × 10 × 10 cm (15 cubes in total) for the same five sets of concrete mixes. In all these test specimens however, the same amount of cement, sand and gravel were used. A water cement ratio of o.45 was used. Test specimens free from polypropylene fibers (control mix) were prepared as a base of comparison. The used white colour pure polypropylene fibers (CMB FIBER) have 0.91 gram/cm3 density, bundle thickness 2mm, fibrils bundle 10, cut length 15mm, 370 N/mm^2 tensile strength and 3750 N/mm^2 modulus of elasticity as shown in **Fig. 1**. Details of all concrete test specimens are given in **Table 1**.

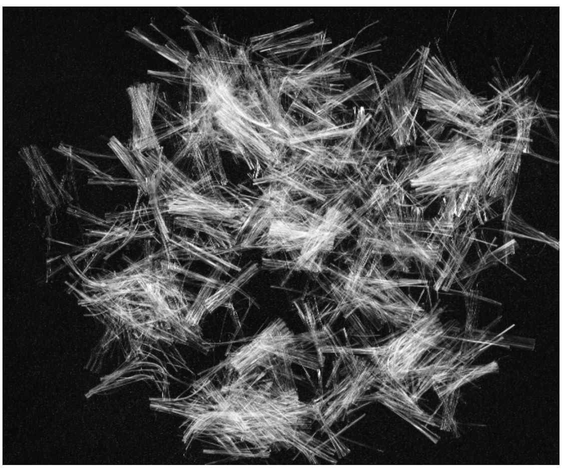

Fig. 1: The used polypropylene fibers.

Table 1: Details of concrete mixes for 1 cubic meter.

Mix No.	Slump mm.	Cement content kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	W|C ratio	% of polypropylene fiber by volume by volume of concrete
1	45	350	620	1240	0.45	0.0
2	15	350	620	1240	0.45	0.25 %
3	3	350	620	1240	0.45	0.5 %
4	0.0	350	620	1240	0.45	1.0 %
5	0.0	350	620	1240	0.45	1.5 %

A natural siliceous sand and gravel from El-Minia quarries were used as a fine and coarse aggregates. The physical and mechanical properties of sand and gravel are given in **Table 2**.

Table 2: Physical properties of sand and gravel.

Property	Test results for sand	Test results for gravel
Max. Nominal Size. (mm)	5 mm	20 mm
Specific weight	2.56	2.61
Volume weight (t|m^3)	1.62	1.59
Absorption (24 hrs)	0.7 % by weight	1.0 % by weight
% of fine materials by weight	1.3 % by weight	0.9 % by weight
Crushing value	-	14%
Voids ratio	36.7 %	39.1 %

The cement used in this investigation is ordinary portland cement. The mechanical properties of used cement are given in **Table 3**. Tap water was used in all concrete mixes. Mixing of concrete components was completed by using a horizontal rotating counter flow mixer pan of 0.09 cubic meter capacity with speed of 13 revolutions per minute. Prior rotating the mixer pan, the pan mixer was wetted and only the half of the amount of sand, gravel and polypropylene fibers were added together into the mixer and mixed for 2 minutes. While rotating the cement was added into the mixer, followed by the remaining amount of sand, gravel and polypropylene fibers and mixed for 2 minutes. The mixing was performed for anther 3 minutes by adding water for the purpose of uniformity. The mixing operation was carried out in accordance to ASTM C (192-81). Before casting directly, the internal surfaces of the moulds were coated with a thin layer of mineral oil to avoid the development of bond between the mould and the concrete. Fresh concrete was taken from the mixer and poured into the molds in three layers by using blunted trowel. The trowel was moved around the top edge of the cube in order to insure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate. Each layer of concrete was compacted using a standard compacting rod, after compacting the third layer was compacted by a mechanical vibrator. After that, the top surfaces of cubes were finished and leveled with a metal trowel, then the specimens were kept in the cubes and covered by plastic sheets for 24 hours to prevent rapid moisture evaporation from the surface and plastic shrinkage.

Table 3. Properties of the used cement.

Mechanical properties	Test results	E.S.S limits
Specific gravity	3.15	3.15
Fineness %	7 %	Max 10 %
Specific surface cm^2/gr.	2550	Min 2250
Water demand %	26	Min 25, max 30
Initial setting time (minute)	140	Min 45 min.
Final setting time (minute)	400	Max 10 hr.
Soundness (mm)	1.5 mm	Max 10 mm
Compressive strength At 3 days Kg/cm^2 At 7 days Kg/cm^2	 225 318	 Min 180 Kg/cm^2 Min 270 Kg/cm^2

After mixing the concrete, the consistency of all concrete mixes were measured by using slump test in accordance with B.S.S 1881. All the concrete specimens were cast and compacted according to the standard method of Egyptian Standard Specifications (ESS). They were demoulded after 24 hours, and then, cured in a water tank for another 6 days and the others for another 27 days. The compressive strength was carried out on the cubic specimens at the ages of 7, 28 and 59 days from the cast date as well as the prism strength was determined after 28 days from the casting date by carrying out the compressive test on the half of concrete prisms with dimensions 10 x 10 x 50 cm. The other size of concrete prisms (10 x 10 x 40 cm) were tested under compression to find out the modulus of elasticity after 28 days from the cast date as well as to find the maximum strain. Each prism (10 x 10 x 40 cm) has two demec studs on one side of it in the direction of the longitudinal axis of the prism. The distance between the demec studs was kept constant and equal to 20 cm. Each demec stud was fixed at a distance of 10 cm from the top edge of the prism, while the other demec stud was fixed at a distance of 10 cm from the bottom edge of the prism. A demec gauge has standard length of 20 cm was used to measure the contraction of the concrete prism during the test. The main aim of the previous technique is to measure the contraction and the corresponding load during the test procedure and to find out the stress and the corresponding strain of concrete to get out the modulus of elasticity of concrete as will be illustrated in the results figures. The flexural test was performed using four point loading according to BS: 1881: part 4: 1970 on a span of 450 mm to determine the modulus of rupture of the other half number of concrete prisms of $10 \times 10 \times 50$ mm also at the age of 28 days. The Brazilian test was carried out on the cylindrical specimens at the age of 28 days from the casting date to find out the splitting strength of concrete. Deformed bars with 12mm diameter and 400 mm long were used for steel-concrete bond strength determination. The rod was placed concentrically in the concret cylinder of size 10 x 20 cm using all different concrete mixes. The rebars were projected down for a distance of about 20 mm from the bottom face of the cylinder as cast and projected upward from the top up to 220 mm in order to porovide an adequate length to be gripped for application of load. The same procedure as indicated above was followed for casting and curing of the specimens. After the curing period, the steel-concrete bond strength was determined using a universal testing machine of capacity 30 t. The bond strength was calculated from the load at which the slip was 0.25 mm divided by the embedded area of steel rebar. The percentage of water absorption for all concrete specimens were determined by measuring the increase in weight of an oven-dried three cubes from each mix when immersed in water for 24 hours (the surface water being removed). The ratio of the increase in weight to the weight of dry sample, expressed as a percentage, is termed absorption. The tests were carried out in triplicate specimens on all different tests and the average values were obtained.

RESULTS AND DISCUSSION

The observed properties of the hardened concrete in this research programme are the uniaxial compressive strength, splitting strength, flexural sterngth, bond strength, modulus of elasticity and percentage of absorption of concrete.The results of the maximum compressive strength of concrete after 7, 28 and 59 days as a function of the polypropylene fibers content by volume of concrete can be seen in **Table 4** and **Figure 2**. Compressive strength significantly increased up to maximum at o.5 vol. % polypropylene fibers content at different ages then decreased with increasing polypropylene fibers content. The maximum compressive strength recorded relatively lower values with used higher contents of polypropylene fibers (1.0 % and 1.5 %) also at different ages. The improvements of compressive strength with small content of the used fibers (0.25 % and 0.5) came principally from the fibers interacting with the advancing cracks.

It seems that the presence of polypropylene fibers in the concrete matrix resembles significant resistance against the propagation of the fine cracks in the direction of the load. This resistance is responsible for the delay of the formation of the main crack that causes failure. Besides, polypropylene fibers can reduce stress concentration accumulated around the cracks and consequently the strength increased. Increasing the polypropylene fibers to 1.5 vol. % decreased the compressive strength due to the decrease of the cohesion of the concrete.

The splitting strength of the concrete reinforced by polypropylene fibers content up to 1.0 vol. % represented higher values than that observed for concrete free of fibers (**Table 5** and **Fig. 3**). This behaviour can be explained on the ability of polypropylene fibers to diminish the fine cracks in the concrete matrix. The maximum splitting strength was observed at 0.5 vol. % polypropylene fibers. Once the splitting occurred and continued, the fiber bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibers and thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the fiber reinforced concrete and therefore, increased the splitting tensile strength of the reinforced concrete over the unreinforced control counterpart.

Table 4: Relation between fiber content and compressive strength at different ages.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
Fc_7 days Kg/cm^2	210	250	255	235	190
Fc_{28} days Kg/cm^2	245	285	290	270	225
Fc_{59} days Kg/cm^2	270	310	302	2900	235

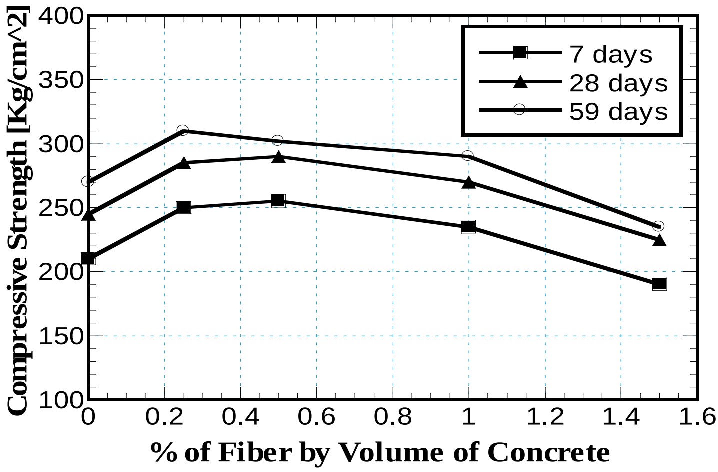

Fig. 2: Relation between compressive strength and % of fiber at different ages.

Table 5: Relation between fiber content and splitting strength at 28 days.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
Fc_{sp} after 28 days Kg/cm^2	21.7	22.5	24	22	19.1

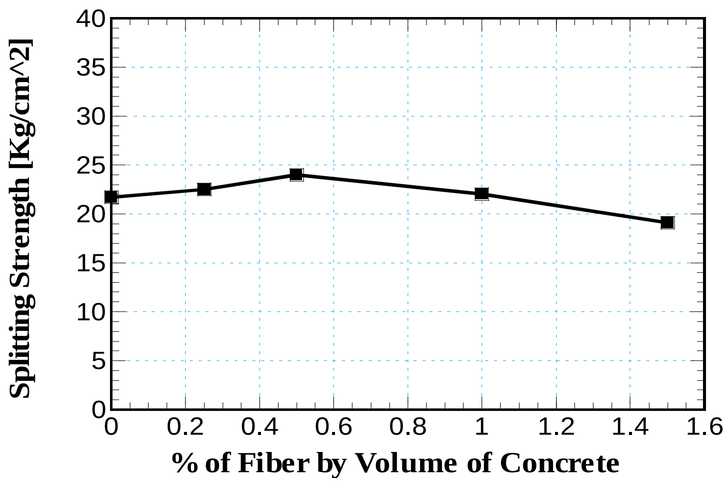

Fig. 3: Relation between splitting strength and % of fiber.

The results of the flexural strength of concrete as a function of the polypropylene fiber content is given in **Fig. 4** and **Table 6**.

It can be seen that flexural strength increased significantly up to maximum at 0.5 vol. % polypropylene fiber. Further increase of polypropylene caused content then slight decrease of the flexural strength of concrete. The increase may be resulted primarily from the fibers intersecting the crack in the tension half of the reinforced beam. These fibers accommodated at the crack face separation by stretching themselves, thus providing an additional energy absorbing mechanism and also stress relaxing the microcracked region neighboring the crack-tip.

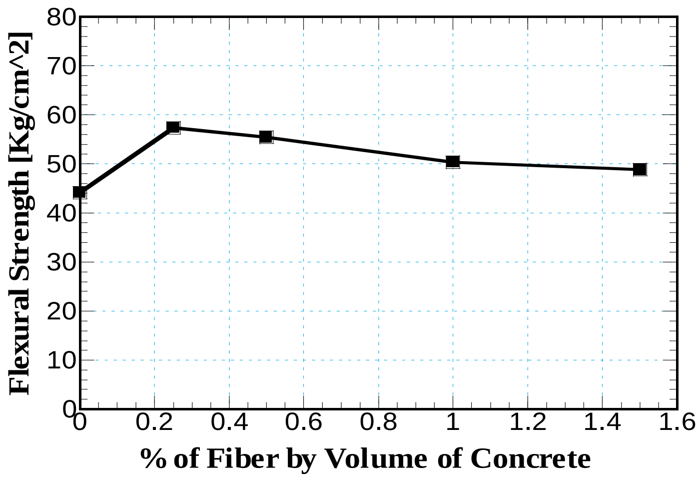

Fig. 4: Relation between flexural strength and % of fiber.

Table 6: Relation between fiber content and flexural strength after 28 days.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
F_r after 28 days Kg/cm^2	44.125	57.38	55.4	50.3	48.9

The results of the maximum bond strength of concrete after 28 days as a function of the polypropylene fibers content are shown in **Fig. 5** and **Table 7**. The bond strength increased significantly with increasing polypropylene fibers content up to o.5 vol. %. Further increase of polypropylene fibers content caused slight decrease in the bond strength. The improvement of the bond strength at small content of the tested fibers (0.5 vol. %) came principally from the fibers interacting the advancing cracks.

Figure 6 and **Table 8** show the relationship between the initial modulus of elasticity and the polypropylene fiber content. The initial modulus of elasticity significantly decreased with increasing polypropylene fiber content. Under loading, concrete deforms in a non-linear, inelastic manner, while polypropylene fibers have linear and elastic deformation. However, an estimate of modulus of elasticity is useful for determining the behaviour of the concrete reinforced by polypropylene fibres. The decrease of the value of the initial modulus of elasticity can reflect the fact that the ductility of the concrete can be increased by adding polypropylene fiber into concrete.

The percentage of absorption for concrete cubes after 28 days as a function of the polypropylene fibers is illustrated in **Fig. 7** and **Table 9**. The percentage of absorption decreased down to minimum at 0.5 vol. % polypropylene fibers then increased with increasing the polypropylene fibers. It seems that concrete containing 0.5 vol. % polypropylene fibers has relatively lower number of fine cracks inside the matrix. As the fiber content increased the cracks increased and consequently percentage of absorption increased.

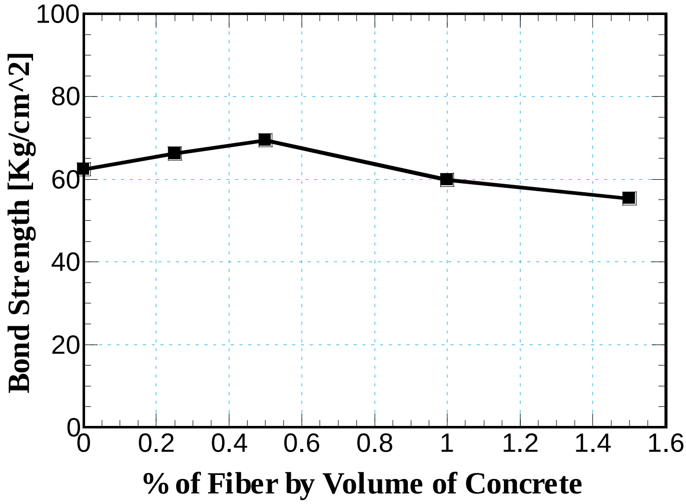

Fig. 5: Relation between bond strength and % of fiber.

Table 7: Relation between fiber content and bond strength after 28 days.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
F_c bond after 28 days Kg/cm^2	62.4	66.3	69.47	59.8	55.3

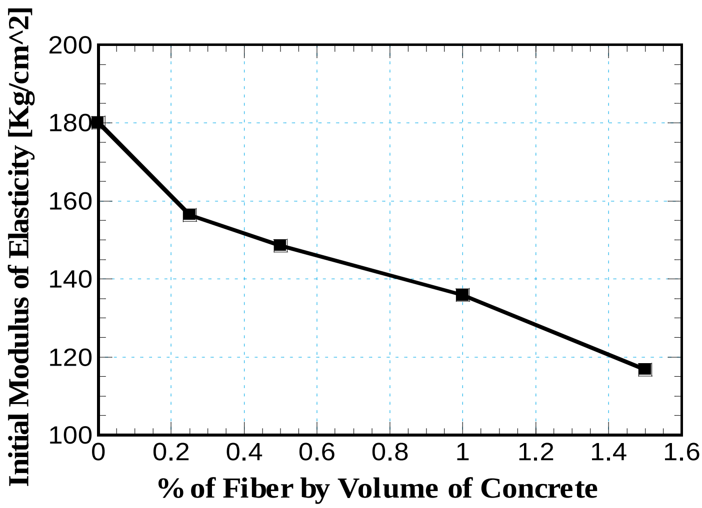

Fig. 6: Relation between Initial modulus of elasticity and % of fiber.

Table 8: Relation between fiber content and Initial modulus of elasticity after 28 days.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
E_c after 28 days t/cm^2	180.05	156.4	148.6	135.9	116.4

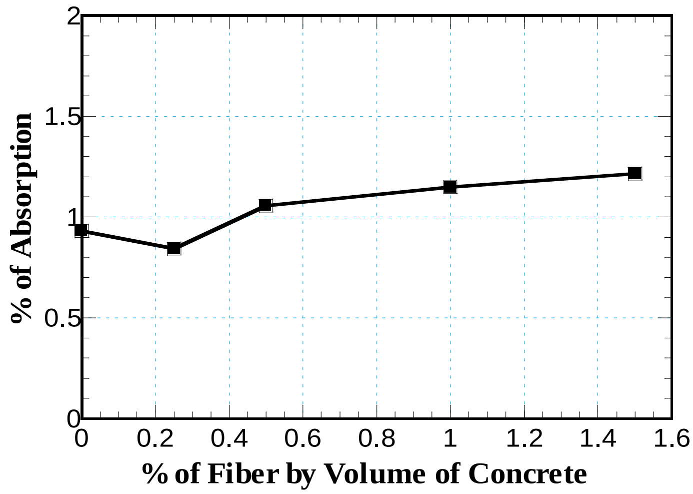

Fig. 7: Relation between % of absorption of concrete and % of fiber.

Table 9: Relation between fiber content and % of absorption for concrete cubes after 28 days.

% of fiber by volume of concrete	0.0	0.25	0.5	1.0	1.5
% of absorption after 28 days for concrete cubes	0.932	0.842	1.0548	1.1502	1.215

CONCLUSIONS

Based on the test results presented in this paper, it can be concluded that,

- Ductility of concrete significantly increased and maximum compressive strength slightly increased with increasing the content of polyproylene fibers up to o.5 vol. % in the tested concrete.
- Further increase of polypropylene fibers (higher values than 0.5 vol. %) did not increase the ultimate bond strength, but it provided much more ductile bond behaviour.
- The addition of polypropylene fibers caused asignificant increase in the percentage of water absorption for the tested concrete specimens.
- Regarding their advantageous properties and beneficial price, the use of polypropylene fibers is often recommended recently to enhance some performances of normal cnocrete strength, particularly its poor ductility behaviour. Besides that, some mechanical properties of normal-strength concrete can also be improved by use of 0.5 % polypropylene fibers by volume of concrete.

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تأثير ألياف البولى بروبلين على الخواص الميكانيكية للخرسانة العادية المقاومة

- تعتبر الخرسانة مادة أساسية في صناعة المنشآت في مصر نظرا للجدوى الاقتصادية لها وتحمل الخرسانة مع الزمن من أهم العوامل التي يحرص عليها المهندس المصمم نظرا لإرتباطها بتكاليف الصيانة وقدرة الخرسانة على الإستخدام الأمثل. فى الفترة الأخيرة إتجهت الأبحاث العلمية إلى إستخدام بعض الإضافات لتحسين خاصية معينة للخرسانة تتوقف على نوعية المنشأ المنفذ. ولذا يهدف هذا البحث إلى دراسة تأثير إضافة ألياف البولى بروبلين على الخواص الميكانيكية للخرسانة العادية المقاومة مثل مقاومة الضغط ومقاومة الإنفلاق ومقاومة التماسك ومقاومة الإنحناء ومعاير المرونة وخاصية إمتصاص المياه بالنسبة للخرسانة.
- وقد تناول البحث دراسة تأثير إضافة ألياف البولى البروبلين بنسب مختلفة من حجم الخرسانة وهذه النسب هى 0.0 % ، 0.25 % ، 0.5 % ، 1.0 % ، 1.5 % مع استخدام خمسة خلطات من الخرسانة لها نفس المكونات والنسب بين المكونات المختلفة فيما عدا

نسبة الألياف فقط هى العامل الوحيد المختلف للوصول إلى خلطة لها أفضل الخواص الميكانيكية المختبرة. ومن هذا المنطلق تم تجهيز 12 مكعب قياسي مقاس 10 x 10 x 10 سم من كل خلطة على حدة من الخمس خلطات المختلفة فى نسبة الألياف والمتحدة فى جميع المكونات الأخرى وذلك لقياس مقاومة الضغط عليها عند الأزمنة المختلفة وهى 7 ، 28 ، 59 يوم (ثلاثة مكعبات عند كل زمن على حده) والثلاثة مكعبات الأخرى من كل خلطة تم تحديد نسبة الإمتصاص للخرسانة منها بعد مرور 28 يوم من تاريخ الصب. كما تم تجهيز 3 منشورات بأبعاد 10 x 10 x 50 سم من كل خلطة وذلك لقياس مقاومة الإنحناء كما تم تجهيز 3 منشورات بأبعاد 10 x 10 x 40 سم من كل خلطة وذلك لقياس معاير المرونة كما تم تجهيز 3 إسطوانات بأبعاد 10 x 20 سم من كل خلطة وذلك لقياس مقاومة الإنفلاق للخرسانة كما تم تجهيز 3 إسطوانات بأبعاد 10 x 20 سم من كل خلطة ومدفون بداخلها سيخ حديد بقطر 12 مم وموازى للمحور الطولى للإسطوانة وذلك لقياس مقاومة التماسك بين الحديد والخرسانة مع العلم بأن جميع هذه العينات تم معالجتها في حوض به ماء فى درجة حرارة الغرفة العادية حتى وقت الإختبار.

- وخلص البحث إلى أن استخدام ألياف البولى بروبلين بنسبة لا تزيد عن 0.5 % من حجم الخرسانة المستخدمة تعمل على تحسين جميع خواص الخرسانة فيما عدا نسبة الإمتصاص للمياه وذلك بالمقارنة بالخرسانة التى لا تحتوى على أية نسبة من هذا النوع من الألياف مع ثبوت جميع العوامل الأخرى.