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Effect of cement content and steel fiber additions on reactive powder concrete properties

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الملخص
فى هذا البحث تم دراسة بعض خواص الخرسانة المحتوية على مواد فائقة النعومة وتم تنفيذ البرنامج العملى بإستخدام نسب ثابتة من الرمل الناعم وغبار السليكا وملدن وبنسب مختلفة من محتوى الأسمنت والألياف الفولازية وقد تمت معالجة العينات فى درجة حرارة الغرفة وعند 90 درجة مئوية بإستخدام جهاز الاوتوكلاف. وقد أظهرت النتائج أن الخصائص الميكانيكية قد تحسنت بدرجة ملحوظة حيث بلغت مقاومة الضغط ومقاومة الشد ومقاومة الإنحناء من 70.5 ، 4.1 ، 7.9 ميجا بسكال إلى 110 ، 5.19 ، 12.5 ميجا بسكال على الترتيب وذلك بزيادة محتوى الأسمنت من 600 كجم / م^3 إلى 900 كجم / م^3 .
وكذلك أظهرت النتائج أنة بإضافة الألياف الفولازية تحسنت الخصائص الميكانيكية حيث بلغت مقاومة الضغط 110ميجا بسكال بزيادة نسبه الألياف الفولازية الى 1.5%. بينما مقاومة الشد بلغت 5.19 ميجا بسكال وأيضا مقاومة الأنحناء بلغت 12.5 ميجا بسكال وذلك بزيادة نسبة الألياف الفولازية إلى 1.5% وذلك بعد معالجتها مدة 28 يوما فى درجة حرارة الغرفة.

ABSTRACT
The mechanical properties (compressive strength, flexural strength, and tensile strength) of reactive powder concrete (RPC) produced with different contents of Portland cement and steel fiber were investigated under different curing conditions (standard, autoclave).. The experimental program were carried out using fixed percentages of fine sand, silica fume, super plasticizer. The samples were treated at room temperature and at 90 ° C using an autoclave. The results show that the mechanical properties have improved significantly. The compressive strength, tensile strength and flexural strength increased from 70.5, 4.1 and 7.9 MPa to 110, 5.19 and 12.5 Mpa respectively, by increasing the cement content from 600 kg / m^3 to 900 kg / m^3.
The results also showed that with the addition of fiber, the mechanical properties improved significantly were as the compressive strength reached 110 Mpa with increasing the percentage of steel fiber to 1.5%. While tensile strength was 5.19 MPa and flexural strength was 12.5 Mpa with increasing the percentage of steel fiber to 1.5% after treatment for 28 days at room temperature.

KEYWORDS: Concrete, Reactive powder concrete, Mechanical properties

1. INTRODUCTION
Reinforced concrete is the most commonly used composite material in structural practices due to ease in applications and lower cost of construction. Besides, reinforced concrete structures offer good service under certain environmental conditions [1-6]. Reactive powder concrete (RPC) is relatively new cement based material developed through micro-structural engineering. Conventional RPC is composed of cement and ultra-fine powders, such as crushed quartz and silica fume; it also has low water content

(water/cementitious ratio generally lower than 0.20). A highly dense matrix is achieved by optimizing the granular packing of these powders [7]. The basic principles for the development of RPC have been explained by the Richard and Cheyrezy [8].
Nowadays, RPC is regarded as a promising material for special prestressed and precast concrete members, including those within industrial and nuclear waste storage facilities [8].Although production costs of RPC are generally high; some economic advantages also exist in RPC applications. It is possible to reduce or eliminate passive reinforcement using steel fibers. And, due to ultra-high mechanical performance of RPC, the thickness of concrete elements can be reduced, which results in materials and cost savings [9].

The expression (RPC) has been used to characterize a silica fume, fiber reinforced, super plasticizer cement mixture with very low water-cement ratio (w/c) describe by the presence of very fine sand (600 μm) instead of coarse aggregate in the cement mixture. The cement agent of the RPC is as high as 900-1000 kg/m^3. This exceptional cement agent could increase creep strain and during shrinkage of the RPC with respect to ordinary concrete which its cement factor in the range 300-500 kg/m^3 [10].
The physical and mechanical properties of RPC are acquired by improvement density of concrete mixture with scare of all mix particles and by using high percentage silica fume to improve the micro structure of hydrated cement out of pozzolanic reaction [23]. To make a very high compressive strength of RPC, implementation of pressure before during setting and heat treatment after setting are normally required compressive strength of 200 to 800 MPa and flexural 6 to 13 Mpa [11, 22].
The purpose of this research is to study the effect of cement content and steel fibers addition on the mechanical properties of (RPC) using local material and curing at room temperature and 90°C using autoclave.

2. EXPERIMENTAL WORK

2.1. MATERIALS

2.1.1. Cement

Ordinary Portland Cement Type I was used. The grade used was CEM I 52.5 N. produced locally in accordance with Egyptian standard code ESS (4756-1 /2009). The physical, chemical and mechanical properties of this cement are given in Table 1.

2.1.2. Fine aggregate

Natural available clean fine sand having fineness modulus 2.297, specific weight 2.631gm/cm^3,max nominal size (.6 mm) and unit weight 1.4 gm/cm^{3}was used as fine sand passes from sieve (600μm) (No.30) according to ASTM C 109/C 109M-02[12].the sieve analysis for sand as shown in Table 2 , Figs. 1 and 2 .

Table 1: Properties of cement type O.P.C

Chemical	Composition %	Physical properties	Compressive strength (N/mm^2)
SiO_2	21.06	Fineness (cm^2/g) 3545	3 day 22.4
Al_2O_3	5.41	Specific gravity 3.15	7 day 35.6
Cao	62.78	Soundness (mm) 1.55	28 day 57.3
Fe_2O_3	3.75	Initial setting time (minutes) 54	
Mgo	.92		
SO_3	2.92		
LOI	.038		

Table 2: Sieve analyses of fine sand.

Sieve		Weight Reserved(gm)	Total Weight Reserved (gm)	% Weight Reserved(gm)	% Passing
NO	Size				
30	600 µm	0	0	0	100
50	300 µm	192	192	38.4	61.6
100	150 µm	277	469	93.8	6.2
200	75 µm	19	488	97.6	2.4
Pan		12	500	100	0

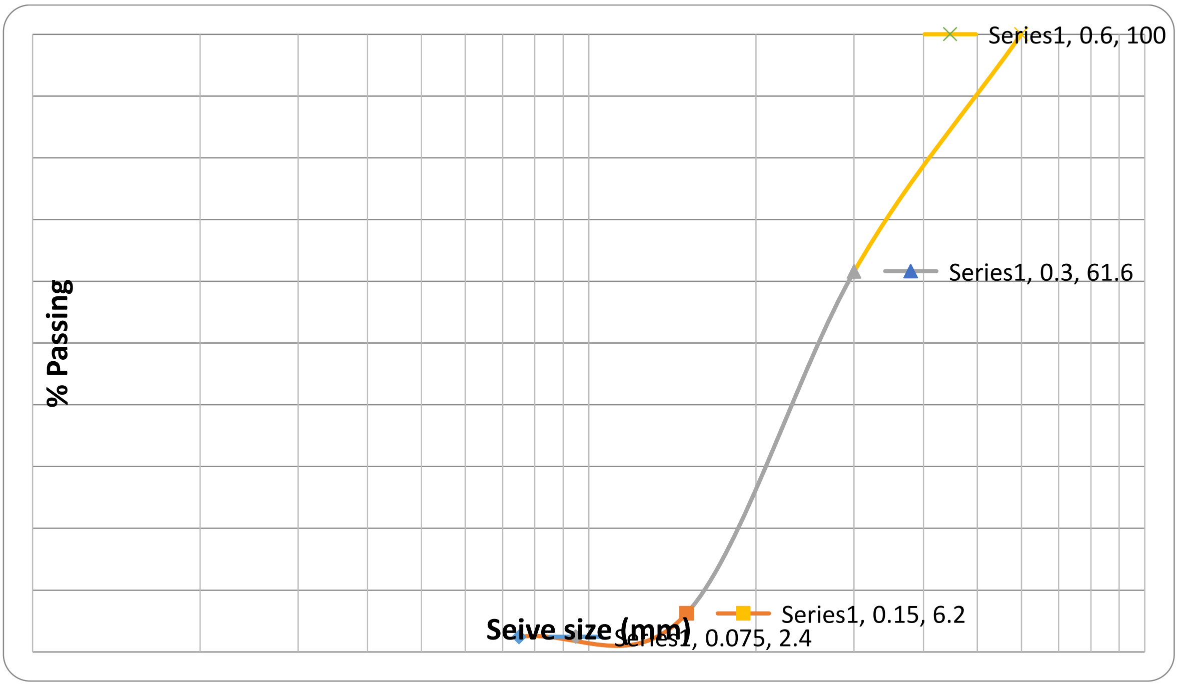

Fig.1. Sieve analysis of fine sand

Fig.2.Fine sand passes from sieve (600µm)

2.1.3. Mixing water

The water used is fresh, clean, and free from impurities, ordinary drinking (tap**)** water and was taken from portable water supplies.

2.1.4. Silica fume

The silica Fume was obtained from SIKA Egypt Company. Its properties are given in Table 3.

Table 3: Properties of silica fume

Property	Description
Composition	A latently hydraulic blend of active ingredients
Color	Grey powder
Bulk Density (Kg/m^3)	330
Specific Gravity	2.2
Specific Surface	15000 To 30000 (m^2/kg)
Particle Size (µm)	$< 1\ micron$

2.1.5. Chemical admixture

High range water reducing concrete admixture and high performance super plasticizer, produced by SIKA Egypt Company according to (ASTM C494, 2004) specification was used in mixing [13]. It can be used with all types of Portland cement to achieve highest concrete durability and performance the main properties are shown in Table 4 and shown in Fig 4.

Table 4: The Properties of HRWR

Type	A&F (ASTM C494)
Name	SIKA MENT 163
Color	Brown liquid
Density at $20°c$	1.200 (ASTM C494)
Specific gravity	1.05±0.02

Fig.4. Super plasticizer produced by SIKA Egypt Company

2.1.6. Steel fiber

The steel fibers used in this study Fig.3 are clean of rust. The steel wires are cut into the length of 12 To 15 mm and diameter 0.25 mm with length/diameter ≈ 54 . The tensile strength of steel fiber ≈275Mpa and density of 7.8 g/cm^3.

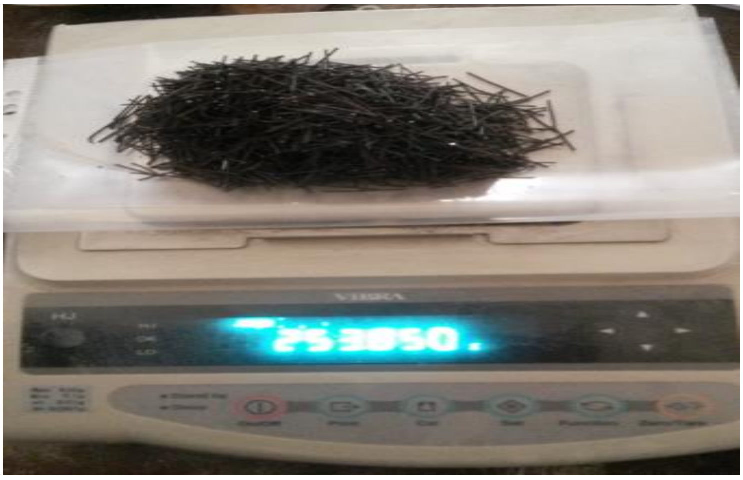

Fig.3. Steel fibers

2.2. MIXING AND CASTING

All mixes of RPC were mixed in a rotary mixer of 0.1 m. The silica fume and cement were mixed in dray state for about two minutes, then the sand and steel fiber was added and the mixture was mixed for three minutes, the super plasticizer is dissolved in water and was added in the mixture, the mix proportions are shown in Table 5 and Table 6.The samples was casting under laboratory conditions 63 cubes with dimensions of (100×100×100 mm), 21 cylinders with dimensions of (150×300 mm) and 21 beams with dimensions of (100×100×500 mm),were prepared and compacted by compacting rod . After casting all sample stored in the laboratory for 24 hours. The sample then demolded, and cured in water for 28 days.

Table 5: The mix proportions with different cement content

Material	Mix600		Mix700		Mix800		Mix900	
	Kg/m^3	%	Kg/m^3	%	Kg/m^3	%	Kg/m^3	%
Cement	600	1	700	1	800	1	900	1
F.Sand(600µm)	1100	1.83	110	1.57	1100	1.37	1100	1.22
Silica Fume	120	.2	140	.2	160	.2	180	.2
S. Plasticizer	24	.04	28	.04	32	.04	36	.04
Steel Fiber	9	.015	10.5	.015	12	.015	13.5	.015
Water	180	.3	210	.3	240	.3	270	.3

Table 6: The mix proportions with different steel fibers content

Material	Mix0.0%		Mix.5%		Mix1%		Mix1.5%	
	Kg/m^3	%	Kg/m^3	%	Kg/m^3	%	Kg/m^3	%
Cement	900	1	900	1	900	1	900	1
F.Sand(600µm)	1100	1.22	1100	1.22	1100	1.22	1100	1.22
Silica Fume	180	.2	180	.2	180	.2	180	.2
S. Plasticizer	36	.04	36	.04	36	.04	36	.04
Steel Fiber	0	0.0	4.5	.05	9	.01	13.5	.015
Water	270	.3	270	.3	270	.3	270	.3

2.3. CURING

The curing process was classified in to two types. The first was at room temperature while to second type was at 90°C in to autoclave for one day Fig 5.

Fig .5.Steam curing using autoclave

2.4. FRESH PROPERTIES OF CONCRETE MIXES

The workability of the concrete mixes was evaluated using the slump test. The test was executed according to ASTM Cl43 [14].

2.5. MECHANICAL PROPERTIES

The compressive strength tests was performed 7and 28 days for specimens treated in room temperature while the test was performed for sample treated at 1 day in autoclave[21] . The splitting tensile strength test was performed at 28 days. The flexural strength tests on beam at 28 days. All tests were performed on universal testing machines.

3. RESULTS AND DISCUSSIONS

3.1. FRESH CONCRETE

3.1.1. Effect of cement content on slump results

Fig. 5 shows the effect of cement content on slump of RPC. It is obvious that increasing the cement content reduces the slump flow values, this can be reasonable because cement is a very fine materials need to much more quantity of water to break the flocculation forces and improvement workability.

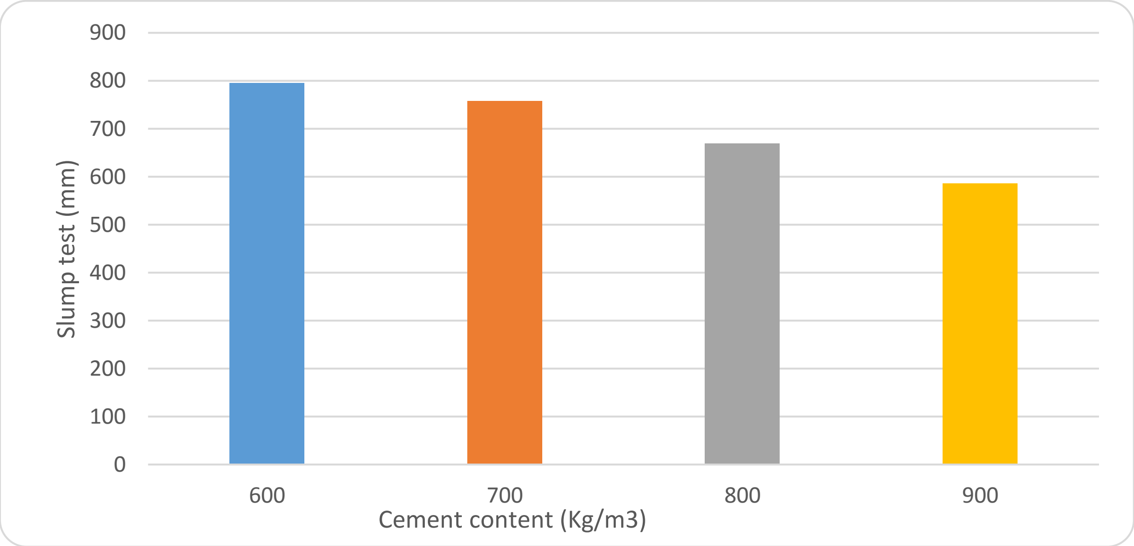

Fig.5. Effect of cement content on slump test results

3.1.2. Effect of steel fibers content on slump

Fig. 6 shows the effect of steel fibers additives on slump of RPC. It can be seen that increasing steel fiber decreases the slump value. This may be due to adding steel fibers increases the resistance to flow and reduces the flowability due to increasing the interlocking and friction between fibers and aggregate [20].

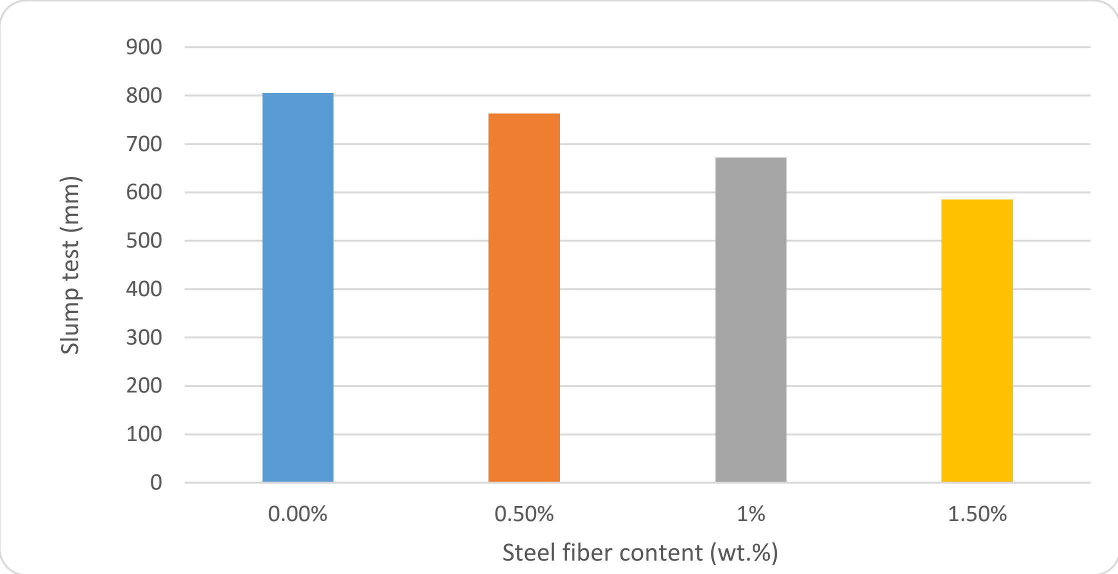

Fig.6. Effect of steel fibers additions on slump test results

3.2. HARDENED CONCRETE PROPERTIES.

3.2.1. Effect of cement content on mechanical properties of RPC

Figs. 7 and 8 show the effect of cement content on RPC compressive strength. The results indicate that all specimens exhibited a continuous increase in compressive strength with progress in age. This increase in compressive strength with age is due to the continuity of hydration process which forms a new hydration product within the concrete mass[19]. Also, Figs. 7 and 8 indicate that increasing cement content in RPC, the compressive strength increases. This behavior is attributed to increasing bond strength of cement. Furthermore, the results indicate that curing mixes at 24 hours have compressive strength equal to which have been obtained at 7 days. Due to increase the hydration rate, accelerate rapid formation of hydration products, resulting in high early strength at high temperature. The compressive strength results were confirmed with the results of Richard and Cheyrezy [8] and Shihada and Arafa [18]. Furthermore, the results indicate that curing mixes at 1day in autoclave had the compressive strengths equal to the compressive strengths of specimens which cured at 7 days in water; this can be attributed to increase the hydration rate and accelerate rapid formation of hydration products resulting in higher early strength at high temperature.

Fig. 9 shows the effect of cement content on splitting tensile strength of RPC. The results indicate that increasing cement content in RPC, the splitting strength increases. This behavior is attributed to increasing pozzolanic effect of cement [26].
The increases in the indirect tensile strengths were related to the increase in the compressive strength. The results show that the ductility of the reactive powder concrete increase with increasing the cement content resulting in enhancing the tensile strength of the reactive powder concrete.

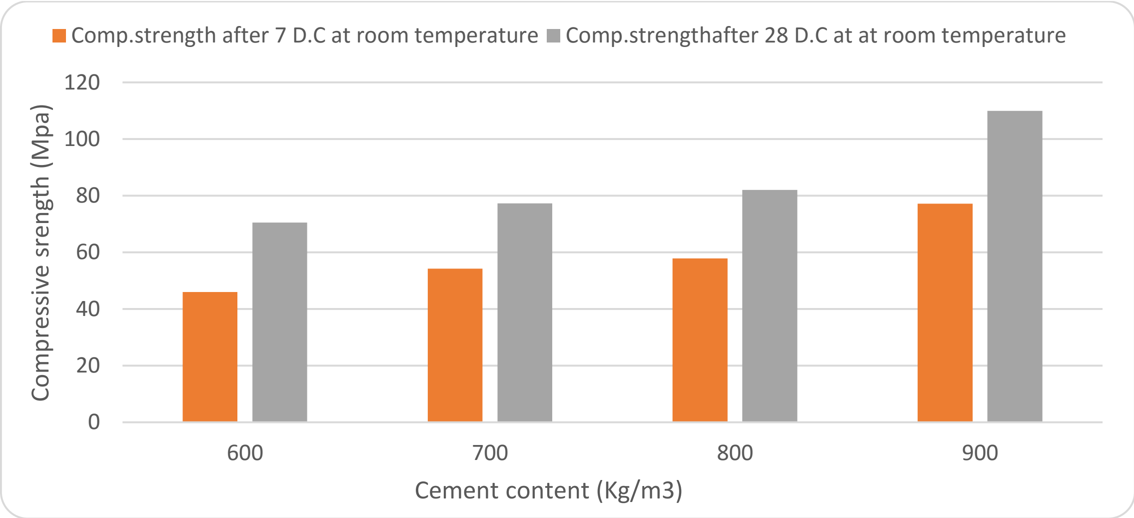

Fig.7. Effect of cement content on the compressive strength at different ages

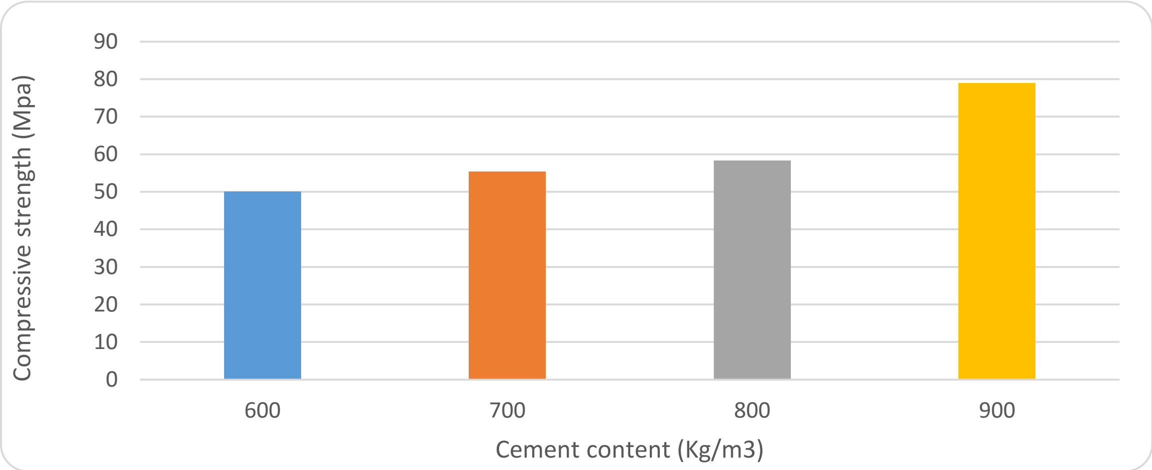

Fig.8. Effect of cement content on the compressive strength after steam curing using autoclave at 90°C

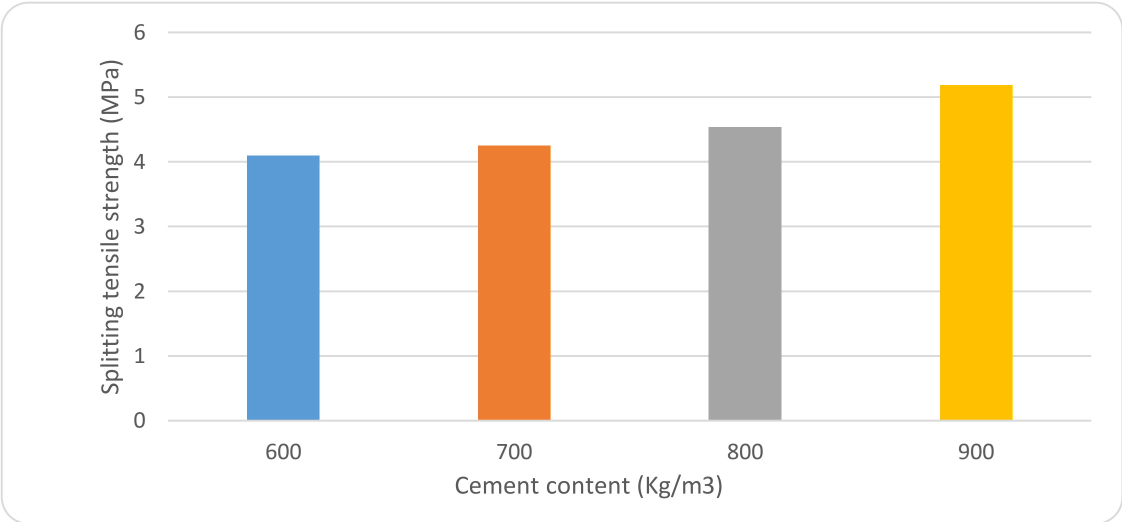

Fig.9. Effect of cement content on the splitting tensile strength at 28 days

Fig. 10 depicts the effect of cement content on flexural strength of RPC after 28 days. The results show that increasing cement content in RPC, the flexural strength increases. This behavior is due to increasing bond strength of cement [24].

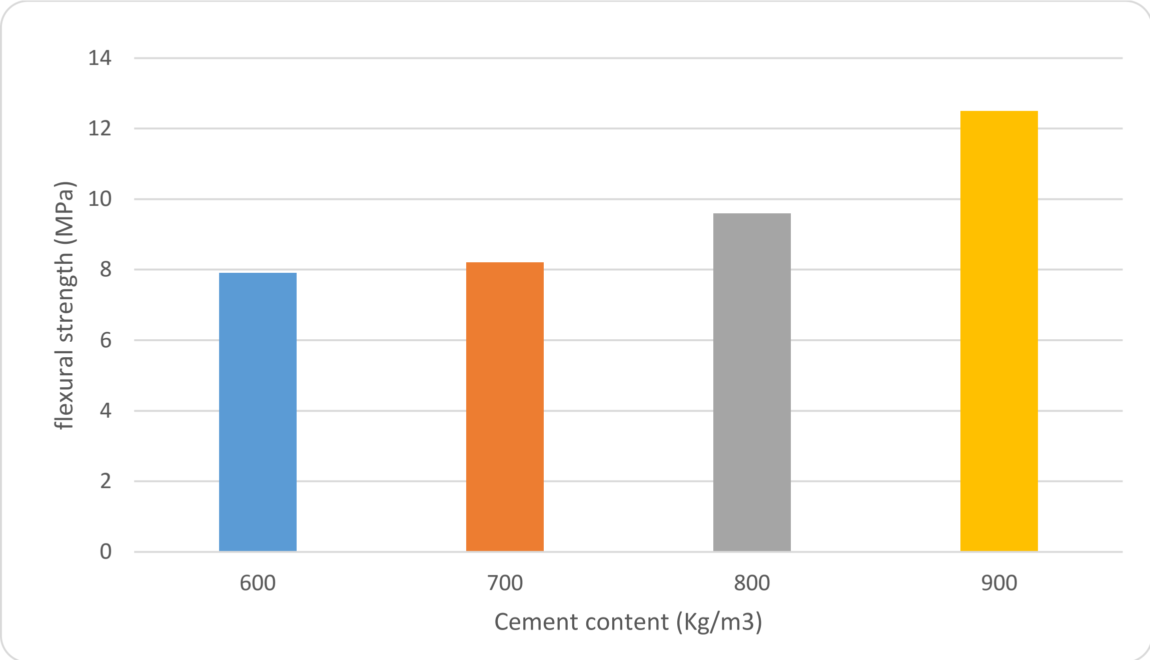

Fig.10. Effect of cement content on the flexural strength at 28 days

3.2.2. Effect of steel fibers content on mechanical properties of RPC

Figs. 11 and 12 shows the effect of steel fiber content on compressive strength of RPC at 7 and 28 days as well as at 24 hours cured in autoclave.

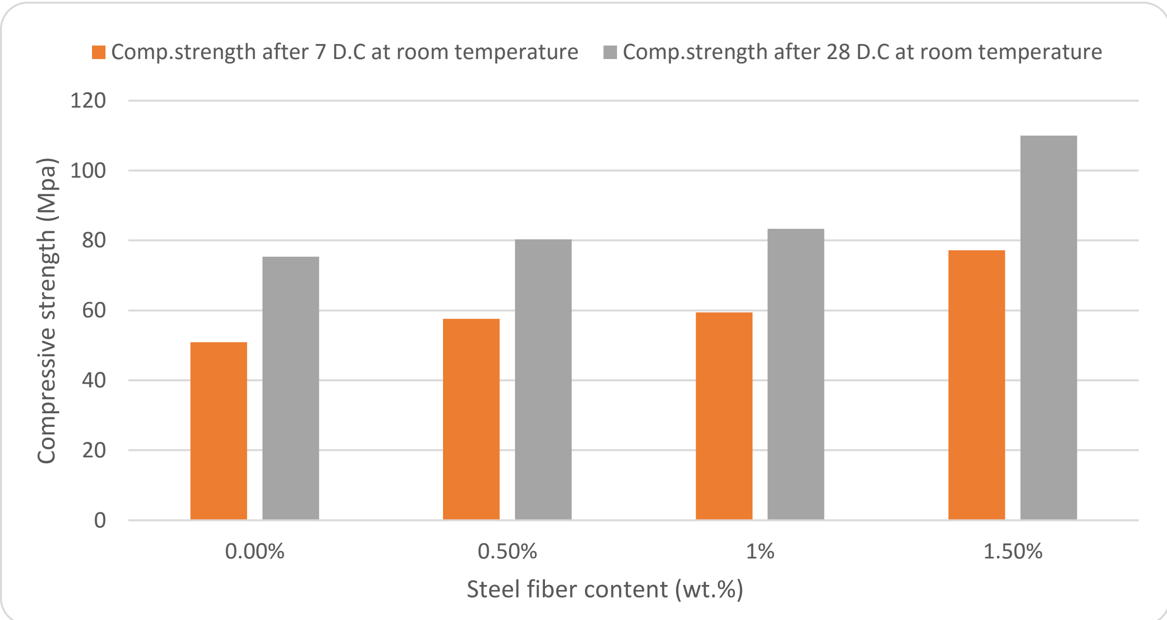

Fig.11. Effect of steel fibers additions on the compressive strength at different ages

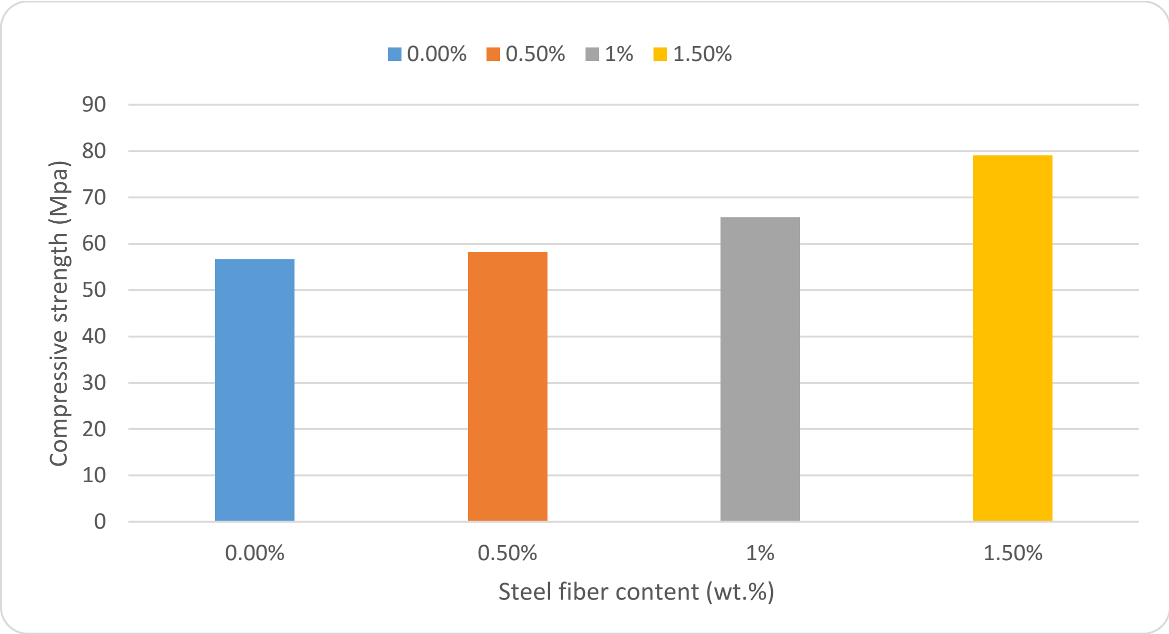

Fig.12. Effect of steel fibers additions on the compressive strength after steam curing using autoclave at 90°C

It is obvious that all specimens show continuous increase in compressive strength with progress in age. This increase is due to the continuity of hydration process which forms a new hydration product within the concrete mass. However, it can be seen that steel fibers have improvement on the compressive strength of RPC. These results are agreement with results of Maroliya and Modhera, [17] Also Figs. 11 and 12 indicates that the curing samples have the same behavior at all mixes. Also this improvement in the compressive strengths of the steel fiber reinforced RPC refer to the control of cracking and the mode of failure by means of post cracking ductility.

It is now well established that steel fiber reinforcement offers a solution to the problem of cracking by making concrete tougher and more ductile. It has also been proved by extensive research and field trials carried out over the past three decades, that addition of fibers to conventional plain or reinforced and prestressed concrete members at the time of mixing/production imparts improvements to several properties of concrete, particularly those related to strength, performance and durability. The weak matrix in concrete, when reinforced with fibers, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete [25].

The composite will carry increasing loads after the first cracking of the matrix if the pull-out resistance of the fibers at the first crack is greater than the load at first cracking. At the cracked section, the matrix does not resist any tension and the fibers carry the entire load taken by the composite. With an increasing load on the composite, the fibers will tend to transfer the additional stress to the matrix through bond stresses. This process of multiple cracking will continue until either fibers fail or the accumulated local debonding will lead to fiber pull-out[26].

Fig 13 shows the effect of steel fiber content on splitting tensile strength of RPC after 28 days. It is obvious that steel fibers have improvement on the steel fiber content on splitting tensile of RPC due to the control of cracking and the mode of failure by means of post cracking ductility. Also this behavior is probably due to the stronger bond between the fibers and matrix. The addition of steel fibers significantly increases the splitting tensile strength of RPC and these results were coincident with the results of Maroliya and Modhera [17].

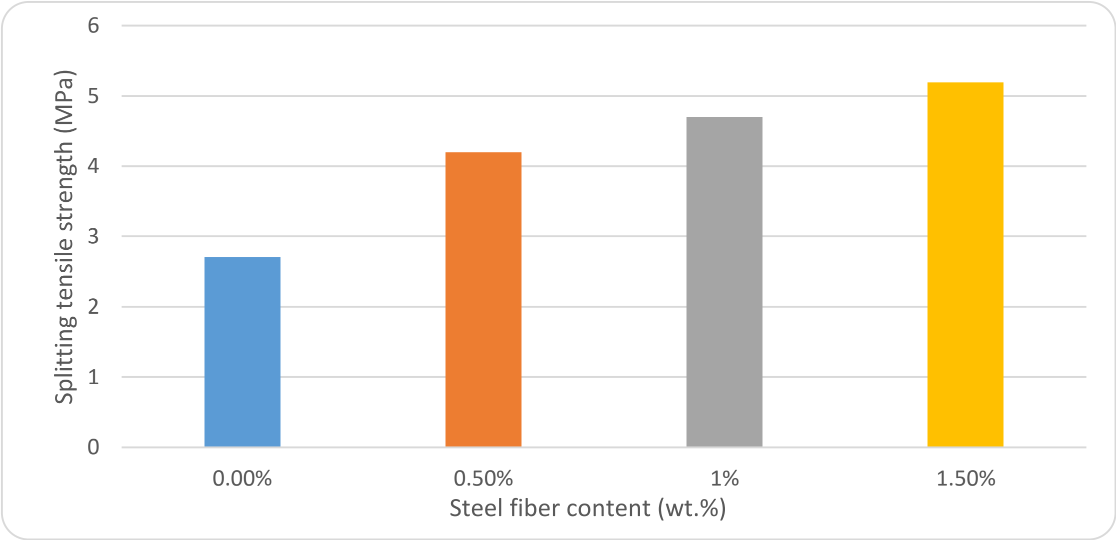

Fig.13. Effect of steel fibers additions on the splitting tensile strength at 28 days

CONCLUSION

The objective of this research was to studded the effect of cement and steel fiber content on RPC properties.

1. Ultra high strength concrete could be produced effectively using cheap available materials in Egypt.
2. Autoclave curing caused increasing in compressive strength in early ages compared to standard curing. However, some reduction in compressive strength comparing to the 28-day standard curing have been obtained.
3. The mechanical properties of RPC have been improved significantly with increasing cement content and steel fiber.

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