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EFFECT OF VARIOUS STEEL FIBERS ON REINFORCED CONCRETE BEAMS

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ABSTRACT

With increasing urban growth worldwide and the need for maintenance work for various facilities, a huge amount of concrete waste is produced. In addition, the development of the metalworking industry has produced a large amount of metal waste, and in order to preserve the environment and natural resources and save landfill spaces, there is a need to reuse these wastes. Therefore, the replacing of natural aggregate that used in concrete mixes and using recycled concrete aggregate it is reduced the consumption of large amount of natural aggregate. This paper presents the significant of adding mixed steel fiber which is containing of (industrial steel fiber with recycled lathe fiber) and super-plasticizer on the mechanical properties of different concrete mixes such as (compressive strength, tensile strength and flexural strength) and study the shear behavior of reinforced concrete beams. The concrete mixes made of two types of coarse aggregate the first one is natural coarse aggregate (NCA) and second one is recycled concrete aggregate (RCA) with replacement ratio 30%. The concrete mixes designed to obtain 30 MPa target strength after 28 days. The laboratory tests performed on 3 different concrete mixes to determinate the mechanical properties and 3 different reinforced concrete beams using a two-point load test to determine shear behavior. The results show that the effect of adding mixed steel fiber and super-plasticizer to concrete mixes improves the mechanical properties of concrete and the ability of concrete to resist cracks.

KEYWORDS: Mechanical properties, Mechanical testing, Shear behavior, Crack, Ductility.

تأثيرالألياف المعدنية المختلفة علي الكمرات الخرسانية المسلحة

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الملخص

مع زيادة النمو الحضاري في جميع أنحاء العالم والحاجة إلى أعمال الصيانة لمختلف المرافق ، يتم إنتاج كمية هائلة من المخلفات الخرسانية. بالإضافه إلى أن تطور صناعة تشغيل المعادن أنتج كميات كبيرة من المخلفات المعدنية ، ومن أجل الحفاظ على البيئة والموارد الطبيعية وتوفير أماكن لمدافن المخلفات ، أدي إلى الحاجة لإعادة أستخدام هذه المخلفات. لذلك ، استبدال الركام الطبيعي

المستخدم في الخلطات الخرسانة واستخدام ركام خرساني معاد تدويره من خلالة يتم تقليل أستهلاك كميات كبيرة من الركام الطبيعي ، وبالتالي الحفاظ على موارد الركام الطبيعي. تعرض هذه الورقة البحثية أهمية إضافة الألياف الفولاذية المختلطة و التي هي عباره عن (ألياف فولاذية صناعية مع ألياف فولاذية معاد تدويرها) والملدنات الفائقة على الخواص الميكانيكية للخلطات الخرسانية المختلفة مثل (قوة الانضغاط وقوة الشد وقوة الانحناء) و دراسة سلوك القص للكمرات الخرسانية المسلحة.حيث أن الخلطات الخرسانية مصنوعة من نوعين من الركام الخشن النوع الأول هو ركام خشن طبيعي والنوع الثاني هو ركام خرساني معاد تدويره مع نسبة استبدال 30 ٪. تم تصميم الخلطات الخرسانية للحصول علي قوه مستهدفه قدرها 30 ميجا باسكال بعد 28 يوما. تم إجراء الأختبارات المعملية على 3 خلطات خرسانية مختلفة لتحديد الخواص الميكانيكية و 3 كمرات خرسانية مسلحة مختلفة باستخدام أختبار تحميل من نقطتين لتحديد سلوك القص. أظهرت النتائج أن تأثير إضافة الألياف الفولاذية المختلطة والملدنات الفائقة إلى الخلطات الخرسانية يحسن الخواص الميكانيكية للخرسانة وقدرة الخرسانة على مقاومة التشققات.

الكلمات المفتاحية : الخواص الميكانيكية، الأختبارات الميكانيكية، سلوك القص، الشروخ ، الممطولية.

1. INTRODUCTION

The recycled concrete topic is considered as very important in the general effort for prospective growth and environmental conservation in our times [1]. Because of the fast increment in the generation and utilization of concrete, this requires a huge amount of natural aggregates. It was necessary to look for an alternative by recycling concrete wastes and obtaining RCA [2-3].

Because of the weakness of recycled aggregate concrete and the increasing development of the construction industry, this led to need to increase the ability of concrete to resist the loads therefore resorted to the use of additives that improves the mechanical properties of concrete such as steel fibers and super- plasticizer.

It is well known the ability of concrete to resist compressive strength is good enough other than that concrete's ability to resist tensile strength [4-6]. In order to overcome this defect and improves the mechanical properties of concrete it is resorted to use fiber in concrete mix [7]. Fiber reinforced concrete could be defined as a concrete contains fibrous materials that increases its structural safety and contains short discrete fibers that are uniformly distributed and randomly oriented [8]. So the benefits of adding steel fiber are increase load bearing capacity, develop durability and very good crack control [9]. With the increasing of adding steel fiber to concrete mixes led to reduce the mixture workability and to increase it the addition of super-plasticizer is used which reduce the amount of water added to concrete mix [10].

This study presents the effect of using different type of fiber such as mixed fiber which is the combination between two types of fiber with the same percentage (industrial steel fiber and recycled lathe fiber), on the mechanical properties of concrete mixes and behavior of reinforced beams.

In this section, present previous studies about mechanical and physical characteristics of recycled concrete aggregate and the effect of using different types of steel fibers.

RCA have the high rate of absorption of water because cement mortar relates to the accumulation of aggregates and because of its negative influence on the characteristics of the substance itself and on the mechanical properties of fresh and hardened concrete [2]. To get a similar slump of normal concrete the free water content of the RCA shall be increased by 5% [11].

With the increasing percentage of adding recycled concrete aggregate the compressive strength decreased the result show the compressive strength has dropped about 5.14% at 20% RCA even up to 10.79% at 60% RCA [12].

The adding of metallic waste as fibers such as empty beverage tins, soft drink bottle caps and mild steel lathe to improve the properties of concrete. Where the percentage of adding waste fibers to concrete mix are 0.6%, 0.8%, 1.0% and 1.2% respectively. The result show waste steel fibers helps in better bonding of concrete and helps to increases the compressive strength of concrete [13]. In this study 0.5% 1.0% and 2% addition of scrap steel fiber like Binding wire and steel nails is used in the concrete with target strength M25, and they have casted a total number of 162 specimens for compression strength, flexural strength, tensile strength and tested after 3,7,28 days. The results show the tensile strength and flexural strength is maximum at 1.5% additions of scrap steel fiber and compression strength is found to be maximum at 1% addition of steel scrap [14].

Various experimental tests have been conducted to study the behavior of reinforced concrete elements made with RCA [15-19]. The shear behavior have been studied of reinforced concrete beams that produced from recycled concrete aggregate with adding steel fibers. 27 RC beams had a cross-section of 15*20 cm and 150 cm long. Recycle aggregate were obtained from building demolition and were used in the concrete mixes at 0%, 50% and 100% .The percentages of adding steel fiber to RC beams were (0.0%, 1.0% and 2.0%). The results show that steel fiber improves the deformation characteristics, strength of concrete and the ductility of RC beams [19]. The shear behavior have been studied of RC beams that made with natural aggregate (NA) and 100% recycled concrete aggregates (RCA). Beams had a cross-section of 200*250 mm and 1900 mm long without stirrups were casted with target strength 35 and 45 MPa and with shear span-to-depth ratio (a/d) equal to 1.5 and 3.0. They found that shear failure mechanisms in recycled aggregate concretes are the same compared to the natural aggregates while the shear strength of RC beams made from recycled aggregate concrete (RCA) is lower than the one made from natural concrete aggregate (NCA) [20].

2. EXPERIMENTAL PROGRAM

2.1 Materials and concrete mix

Fine aggregate: fine aggregate (sand) that was used in the concrete mix is natural siliceous sand specific weight and volumetric weight were equal to be 2.59 t/m^3 and 1.56 t/m^3. Coarse aggregate in this study include two types natural coarse aggregate (NCA) and recycled concrete aggregate (RCA). Natural coarse aggregate that used in concrete mix is natural crushed stone with a specific weight equal to 2.64 t/m^3. Recycled concrete aggregate that used in the concrete mix were obtained from crushed cubes and specimens cast in the laboratory. This crushing stage was done in two phases, the first stage involved crushing the concrete elements such as cubes and cylinders into smaller parts, followed by a further break-down to get the required particles sizes in the second stage. Specific weight, volumetric weight, and water absorption were equal to 2.48 t/m^3, 1.32 t/m^3, and 8.52 %. Sieve analysis of NA and RCA are shown in **Table 1** and **Fig. 1**.

Table 1. Sieve Analysis for both types of aggregate natural aggregate and recycled concrete aggregate.

Aggregate	Percentage pass of aggregate % according to sieve size (mm)					
	37.5	25	19	12.5	9.5	4.75
NA	100%	100%	98%	39.3%	3.3%	0.8%
RCA	100%	100%	96.4%	66.9%	42%	10%

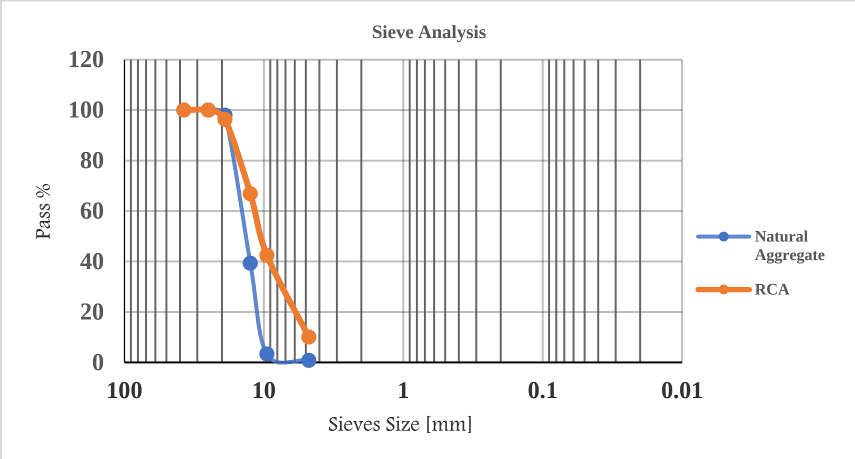

Fig. 1. Sieve analysis of NA and RCA.

Water used in the mixing and curing process is tap water. Cement ordinary Portland cement type CEM I 42.5 N with specific gravity equal to 3.15. Super-plasticizer supplied for construction by SIKA EGYPT chemical company, under the brand name ViscoCrete 3425 that used to improve the workability of the concrete mix. Super- plasticizer was chosen to be used in this study. Conforming to (BS EN 934 part 2: 2001) and (ASTM C494) Type G and F and its specific gravity was 1.08 t/m^3. Steel bars two types of steel reinforcing type I: mild steel bar 24/35 with a diameter of 6 mm used for stirrups and type II: deformed high-grade steel with two diameters of 12 mm and 10 mm. Industrial steel fiber (I.S.F) that used in this study have herringbone surfaces with semi-circular cross-sections as shown in **Fig. 2** and the geometric demission of the steel fibers are shown in **Table 2**. Recycled lathe fiber (R.L.F) that used in this study are the type of fiber that was produced from the manufacturing metal work process by using lathe machines as shown in **Fig. 3**. The geometric demissions of recycled steel fibers used are shown in **Table 3**. In this research there are three different types of concrete mixes were designed as shown in **Table 4**. The first mix made from natural aggregate (NA), the second mix made from natural aggregate (NA) with adding 1.5% mixed steel fiber (0.75% industrial steel fiber + 0.75% recycled lathe fiber) and the third mix made from recycled concrete aggregate (RCA) with partially replacement ratio about 30%.

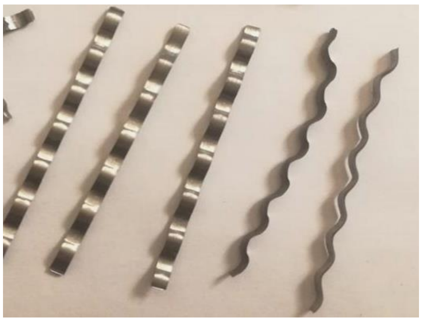

Fig. 2. Corrugated segment industrial steel fiber shape.

Fig. 3. Recycled lathe fiber shape.

Table 2. Properties of steel fiber.

Length	Thickness	Aspect ratio	Width	Wave depth	Wave length
50 mm	1.0 mm	53	2 mm	2 mm	6-7mm

Table 3. Properties of recycled lathe fiber.

Average length	Average Thickness	Aspect ratio	Average width	Density kg/m3
40-70mm	0.5-0.9 mm	55-100	1.5-2.5 mm	7850

Table 4. Properties of concrete mixes.

Mix	Water [kg]	Cement [kg]	Sand [kg]	C.A [kg]		Fibers [kg]		S.P [kg]
				NA	RCA	SF	RLF	
M1	157.5	350	760	1184	0	--	----	0
M2	157.5	350	760	1179	0	65	65	2.8
M3	157.5	350	760	825	321	--	----	2.8

2.2 Specimen Details

The experimental program of this study contains the concrete elements that casted to prepare it for laboratory tests such as cubs, cylinders, prisms and RC beams. Nine cubes were casted with standard dimensions 150*150*150 mm, nine cylinders were casted with dimensions 100*200 mm, three prisms were casted with dimensions 100*100*500 mm. The laboratory test compressive strength test and indirect tension test are shown in **Fig. 4** and **Fig.5**. Three R.C. beams where casted with cross section 100 mm×250mm and 2000 mm total length. All RC beams have the same reinforcement by 3Ø12 mm diameter as the main reinforcement at the bottom, and 2Ø10 mm as a top reinforcement. All beams were provided with two branches Φ 6 mm stirrups @ 300 mm spacing as shown in **Fig. 6**.

Fig.4. Compressive strength test.

Fig. 5. Indirect tension test.

Fig.6. Reinforcement beams details.

2.3 Test setup

All the beams were tested by the progressive load with 10kN increment under two-point load until failure of the beam by using a hydraulic machine with 1800 mm effective span and 600 mm load distance.

3. TEST RESULTS AND DISCUSSION

3.1 Compressive strength

The control mix M1 was casted from natural aggregate NA without any additives. Concrete compressive strengths of specimen M1 was 30.7 MPa, and for the two other concrete mixes M2 that casted from NA with adding 1.5% mixed steel fiber and M3 that casted from recycled concrete aggregate with a replacement ratio of 30% with adding super-plasticizer. The concrete compressive strengths were 39.8 MPa and 31.1 MPa respectively as shown in **Fig. 7**. **Fig. 7** shows that when adding 1.5% mixed steel fiber and super-plasticizer to the concrete mixes it is improve the compressive strength. So the improvement percentage of compressive strength was 29.6% and 1.3% respectively.

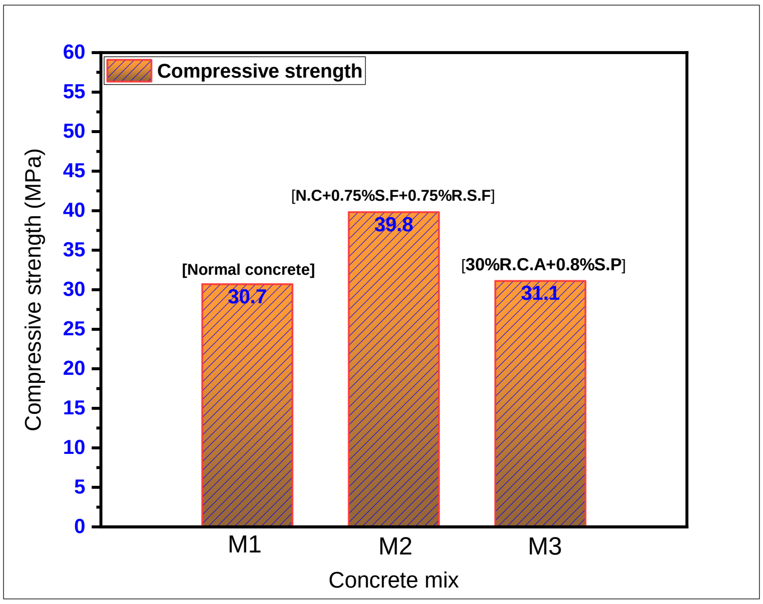

Fig. 7. Compressive strength for three different concrete mixes after 28 days.

3.2 Tensile strength

The concrete tensile strengths of specimen M1 was 4.07 MPa, and for the two other concrete mixes M2 that casted from NA with adding 1.5% mixed steel fiber and M3 that casted from recycled concrete aggregate with a replacement ratio of 30% with adding super-plasticizer. The concrete tensile strengths were 4.88 MPa and 3.46 MPa respectively as shown in **Fig. 8**. **Fig. 8** shows that when adding 1.5% mixed steel fiber to the concrete mixes it is improve the tensile strength. So the improvement percentage of tensile strength was 19.9%. But in the other hand with for the concrete mix M3 the tensile strength decreased.

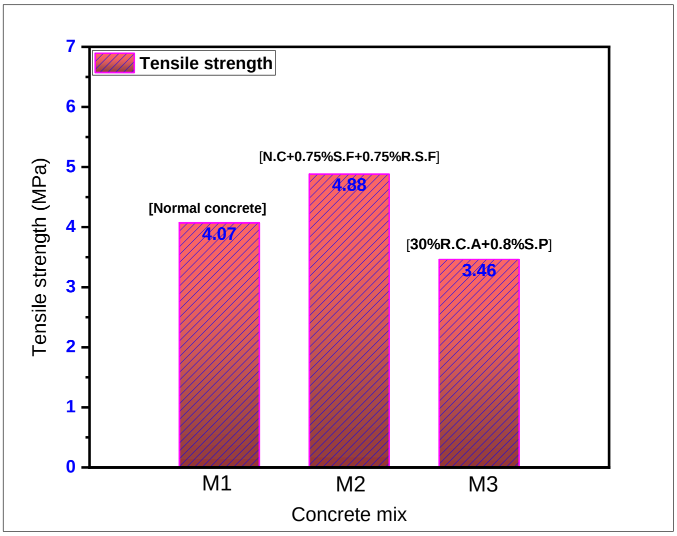

Fig. 8. Tensile strength for three different concrete mixes after 28 days.

3.3 Flexural strength

The concrete flexural strengths of specimen M1 was 9.75 MPa, and for the two other concrete mixes M2 that casted from NA with adding 1.5% mixed steel fiber and M3 that casted from recycled concrete aggregate with a replacement ratio of 30% with adding super-plasticizer. The concrete flexural strengths were 17.25 MPa and 8.25 MPa respectively as shown in **Fig. 9**. **Fig. 9** shows that when adding 1.5% mixed steel fiber to the concrete mixes it is improve the flexural strength. So the improvement percentage of flexural strength was 76.9%. But in the other hand with for the concrete mix M3 the flexural strength decreased. **Tables 5** give a summary of the results for compressive strength, tensile strength, and flexural strength.

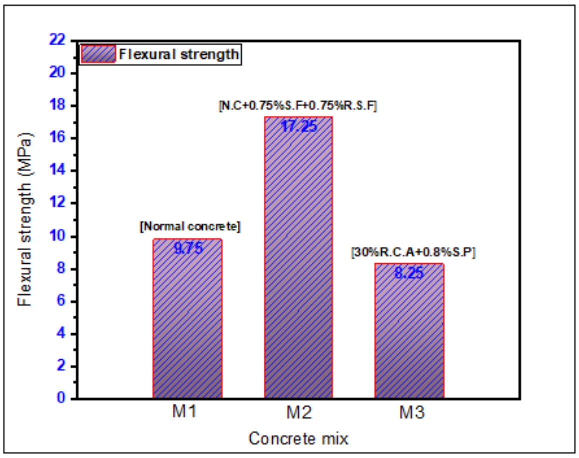

Fig. 9. Flexural strength for three different concrete mixes after 28 days.

Table 5. The summary results for the studied mixes after 28 days.

Mechanical properties	Compressive strength			Tensile strength			Flexural strength		
Mix name	M1	M2	M3	M1	M2	M3	M1	M2	M3
Results MPa	30.7	39.8	31.1	4.07	4.88	3.46	9.75	17.25	8.25

3.4 Beams first crack and ultimate load capacity

The three RC beams were designed to resist bending moment rather than shear force so it has been observed that the collapse mode of all tested beams was a shear failure (SF) as shown in **Fig. 10**. All beams displayed primary flexure cracks at the mid-span of the beam at the beginning of loading on the beam, other cracks followed away from this section. With increasing the load on the beam, one of the bending cracks expanded into an oblique crack near the support and it caused the shear failure. However, the addition of mixed steel fiber and super-plasticizer to the concrete mix increases both the ultimate failure load and the initial crack load. Three different beams B1-I made of normal concrete (natural aggregate) without any additives, B2-I made of normal concrete (natural aggregate) with adding 1.5% mixed fiber (0.75% steel fiber + 0.75% recycled steel fiber) and B3-I made of recycled concrete aggregate concrete mix with replacement ratio 30% where the ultimate failure load of these beams was 73.14, 125.02, and 82.71 respectively.

a) Crack patterns for beam B1-I

b) Crack patterns for beam B2-I

c) Crack patterns for beam B3-I

Fig. 10. Cracks patterns of all beams.

Conclusions

In this research an experimental program was conducted to investigate the mechanical properties of different concrete mixes (M1,M2 and M3) and the structural behavior of RC beams that made of natural aggregate (NA) and recycled concrete aggregate (RCA) with adding mixed steel fiber and super plasticizer. Based on the experimental results the following conclusions were drawn:

-The addition of super-plasticizer on the concrete mix that made of RCA (M3) improves it's workability and the compressive strength improvement percentage is 1.3%.

-Super- plasticizer had no role in improving the tensile strength and flexural strength of the concrete mix M3.

-The addition of mixed steel fiber with percentage of 1.5% on the concrete mix that made of NA (M2) improves the mechanical properties with improvement percentage about 29.6% for compressive strength, 19.9% for tensile strength and 76.9% for flexural strength.

-Using mixed steel fiber and super-plasticizer improve the ability of RC beams to have an ultimate failure load higher than control beams with improvement percentage about 70.9 % for mixed steel fiber and 13% for super-plasticizer.

-Using mixed steel fiber gives the RC beams higher ability to resist cracks and shear force.

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