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Behavior of fiber reinforced concrete pavement slab by using crumb rubber

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ABSTRACT : *Concrete pavement construction has seen an increase in interest. Today, there is a trend towards building pavement sections that are lighter, more sustainable, and of higher quality, thus relieving stress on the foundation soil. The study aims to enhance the surface properties of pavement concrete slabs through compressive strength and flexural strength. In this research, fourteen mixtures were designed to study the effect of adding crumb rubber (CR) at 0%, 10%, and 20% on the properties of concrete fibers. Steel fiber (SF) and polypropylene fiber (PF) were used with contents of 0%, 1.5%, 1.8%, and 2%, respectively. It includes fly ash (FA) with a content of 10% by weight of cement. Tests were performed for compressive strength, density, flexural strength, and ultrasonic (UPV) testing. The results showed that compressive strength, density, and flexural strength decreased with increasing (CR) ratios. The results of the wave velocity of the ultrasound test recorded the highest results at 10% of the crumb content with steel and polypropylene fibers, while the wave velocity decreased at 20% of the crumb rubber content.*

KEYWORDS *Steel fiber (SF), Polypropylene fiber (PF), Crumb rubber (CR), Flexural strength, Compressive strength, and Pavement slabs.*

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I. INTRODUCTION

Determining engineering parameters, such as materials and structural performance, against upfront costs and life cycle costs when selecting the type of pavement is one of the most important considerations. Since performance and cost may vary. The life span of a long-life pavement system may be 30 years or more. Throughout the useful life of a pavement, changes in vehicular traffic characteristics can have significant impacts on performance and life-cycle costs [1].

Tens of millions of tires are discarded around the world each year. Disposing of tire waste is a challenging task because tires have a long life and are not biodegradable. Invalid tires are stored by burying them illegally. Therefore, the solution was to take advantage of recycling rubber tires to benefit from them in concrete as a percentage of the weight of fine aggregate [2].

Resilient pavements are better at withstanding minor deformations, but they do not last as long as concrete, which is inherently stiffer. Although rubberized concrete is manufactured with hardness values equivalent to those of asphalt pavement, it may be an alternative substrate for pavements with flexibility. However, it is widely recognized that adding an excessive amount of rubber to Portland concrete can also lead to property damage. Furthermore, virgin rubber aggregates are much more expensive than natural aggregates [3, 4].

With an increased crumb rubber CR percentage, rubberized concrete loses workability; however, it can be improved by including additives such as superplasticizer and pozzolanic materials. Due to its lower specific gravity and capacity to trap air, rubber concrete loses density significantly when its CR content increases. This reduces the weight of the rubberized concrete [5].

The best strategy for reducing crumb rubber CR damage is to add fibers to the mixtures, despite the fact that doing so significantly affects mechanical strength, toughness, and strength, as well as their key environmental benefits [6].

Rubberized concrete pavement has been used in actual conditions in various applications such as road pavements, sidewalks, parking lots, and airport runways to provide better pressure distribution in the pavement to bear traffic loads [7].

Pavement structures use layers of concrete in the frame through which vehicles move. It has two benefits: it gives vehicles a smooth, long-lasting surface and reduces pressure on the soil below. The scope of building and lifting loads in pavement structures is to improve the behavior of rigid fiber-reinforced concrete pavement slabs. Adding fibers to pavement concrete improves mechanical properties, including ductility, breakdown toughness, flexural strength, shrinkage, and cracking properties [8].

All compressive strengths of the mixtures decreased with increasing percentages of rubber aggregate replacement in steel fiber SF concrete. Compressive strength values when rubber crumb CR is added to concrete mixtures decrease by 20%, as does the flexural strength upon initial crushing and final collapse of concrete beams [9- 10]. The study found that by replacing more crumb rubber as a proportion of natural aggregate, the use of polypropylene fibers also results in a slight reduction in the specific gravity of recycled concrete [11].

Worldwide, concrete is the most widely used material. Fibers are added to concrete due to its natural properties. However, it has certain disadvantages, such as severe brittleness, poor tensile strength, and poor fracture strength [11]**.** To enhance its hardness, such as mineral fibers [12] and synthetic fibers [13-14].

The purpose of the experiment is to compare the performance of steel fiber (SF) and polypropylene fiber (PF), two distinct types of fiber-reinforced concrete, when added in various amounts by volume with different percentages of crumb rubber (CR) added by weight of sand. In order to test the materials, the study divided them into three groups: a group of control mixtures of two mixtures without crumb rubber CR or fibers; a group of polypropylene fibers PF with crumb rubber CR; and finally, a group of steel fibers SF with crumb rubber CR.

The objectives of this research are to determine the extent of the effect of different fibers, steel fibers SF and polypropylene fibers PF, on the mechanical and physical properties of fiber-reinforced concrete when adding crumb rubber CR, and to evaluate the types of fibers that achieve the best results when CR crumb rubber is added to them to reduce pressure on the foundation soil and prevent any subsidence grounding that may occur on concrete slabs.

II EXPERIMENTAL PROGRAM

A-MATERIALS

1. WATER

Tap water free of impurities was used to prepare the concrete mix and improve the workability of the concrete mixtures. In this research, the w/c ratio is 0.45, taken out.

2. SUPERPLASTICIZER

An aqueous solution of modified polycarboxylates in the form of a clear liquid and having a density of approximately 1.08 kg/liter at room temperature, with a trade name of Sika Visco Crete-3425," supplied by Sika Company Egypt Superplasticizer (SP) types G and F were used to improve the workability of all fiber concrete mixes.

3. CEMENT

CEM II/AP 42.5N was obtained from El-Almeria Company and satisfied the requirements of EN 197-1/2011 and Egyptian Standard Specification E.S.S. 4756-1/2022. The cement content per cubic meter is 400 kg. The water-to-binder ratio was 0.45 in all mixtures. The specifications of the cement according to ASTM C150/2022 [15] are shown in **Tables 1 and 2**.

Table 1: physical properties of cement

Test	Specification limits
Specific gravity	3.15
Compressive strength after 28 days	42.5 (MPa)
Initial setting time (min)	≤ 60 min
Final setting time (min)	≥ 600 min

Table 2: The chemical characteristics of cement

Components	Test results	Specification limits
SiO2%	20.6	-
Al2O3%	4.4	6 max

Fe2O3%	3.3	6 max
MgO%	2.2	6 max
CaO%	62.9	-
C3S%	59	-
C2S%	10	-
C3A%	5	8 max
C4AF%	20	-

4. COARSE AGGREGATE

Dolomite was used as a coarse aggregate [16], having a specific gravity of 2.6 and a maximum nominal size of 19 mm. **Table 3** presents the physical properties of the tests carried out on the aggregates. Before use in FRC, sieve analysis testing was also used; the results are shown in **Table 4** according to ASTM C33[17].

Table 3: The physical characteristics of coarse aggregate

Properties	Test results	Specification limits
Specific gravity	2.6	2.6-2.7
Water absorption (%)	2.7 %	≤ 3%
Abrasion (%)	22.9 %	≤ 30%

Table 4: Sieve analysis of coarse aggregate

Sieve opening, (mm)	38	19	9.5	4.76
Passing %	100	99.71	36.79	0.92

5. FINE AGGREGATE

The fine aggregate used in concrete mixes was high-quality siliceous sand, natural, and free from impurities. The fine aggregate used in this study was evaluated to make sure that it meets the Egyptian Standard Specifications (ES 1109-2021). **Table 5** presents the physical properties of the sand used, while **Table 6** shows the sand sieve analysis.

Table 5: Physical characteristics of fine aggregate

Properties	Test results	Specification limits
Specific gravity	2.5	2.5-2.6
Fineness modulus	2.33	2- 3.5
Abrasion (%)	1.6 %	≤ 2%

Table 6: Sieve analysis of fine aggregate

Sieve opening, (mm)	5	2.36	1.18	0.6	0.3	0.15
Passing (%)	100	99.9	88.6	55.7	17.9	4.5

6. FLY ASH

In this experimental study, fly ash (FA) was used as the main source of aluminosilicate material for the production of fiber concrete. The fly ash (FA) from Sika Company used for construction was class F (low calcium) and had a specific gravity of 2.45. The physical and chemical characteristics of fly ash according to ASTM C 618 [18] specifications are listed in **Tables 7** and **8**.

Table 7: The physical characteristics of fly ash

Properties	Specifications
Composition	Alumina silicate pozzolana
Appearance/ Color	Grey-fine powder
Specific Gravity	2.45

Table 8: The chemical characteristics of fly ash

Components	Results	ASTM C618 limits
Silicon Oxide (SiO_2)	61	-
Aluminum Oxide (Al_2O_3)	18	-
Iron Oxide (Fe_2O_3(T))	5.2	-
Sulfur Trioxide (SO_3)	2.3	5max
Calcium Oxide (CaO)	6	-
Magnesium Oxide (MgO)	0.7	-
Sodium Oxide (Na_2O)	1.2	-
Moisture Content	0.5	3max

7. POLYPROPYLENE FIBER

According to the manufacturer's data sheet and the polypropylene fiber (PF) in Fig. **1** used for the present study, Modern Building Chemicals (CMB) Company created it. The characteristics of the polypropylene fiber are shown in **Table 9**. Three different proportions of fiber, i.e., 0%, 1.5%, 1.8%, and 2%, have been used.

Fig.1 Polypropylene fibers

Table 9: Properties of the polypropylene fiber

Properties	Specifications
Color	Natural/ white
Specific Gravity	0.91
Length	18 mm
Diameter	0.02 mm
Aspect Ratio L/d	> 150
Tensile Strength	600 MPa

H. STEEL FIBER

The Egyptian European Steel Fiber Company EESF® [19] Xorex Corrugated Segment 0.7/50 according to specification ASTM A820 [20]. The properties of the used steel fibers are shown in **Table 10** and **Fig.2** shows the fiber that was used. Three different proportions of fiber, i.e., 0%, 1.5%, 1.8%, and 2%, have been used.

Fig.2 Steel fibers

Table 10: The physical characteristics of steel fiber

Properties	Specifications
Density	7.87 kg/m3
Melting point	1.480 C°
Tensile strength	1200 N/mm
Fiber length	50 mm
Width	o.7mm
Aspect Ratio (L/d)	53

8. CRUMB RUBBER

Crumb rubber (CR) aggregate in **Fig. 3** (with no steel wires) having a maximum size of 2 mm and 3 mm was used as a percentage of sand weight. The properties of crumb rubber are shown in **Table 11**. Three different proportions of fiber, i.e., 0%, 10%, and 20%, have been used.

Fig.3 Crumb rubber

Table 11: The physical Properties of crumb rubber [21].

Properties	Specifications
Specific gravity	0.92-0.95
Apparent density (gm./cm3)	0.45
Tensile resistance (MPa)	4.2-21
Speed of Combustion	Very slow
Impact effect	Nil
Water absorption	Negligible

B. MIX DESIGN PROCEDURE

Fourteen mixtures were used, including two control mixtures (MC1 and MC2) without any additions of fiber or rubber, six mixtures with different ratios of steel fiber (SF), and the remaining six mixtures with varying proportions of polypropylene fiber (PF). All mixtures, except for the two control cells, contained different amounts of crumb rubber (CR), which was added as a percentage of sand weight. The absolute volume method was used to determine the weight of each component needed to produce one cubic meter of concrete. **Table 12** shows the components of the proportion of the concrete mix. 100% of the coarse aggregate in all concrete mixes is dolomite. The ratio of sand to coarse aggregate was 1:2. The ratio of fly ash (FA) to cement was 10%, and the ratio of water to cement was 0.45. According to ASTM C494 [22], types G and F were added as a percentage of the weight of cement to improve the workability of the fiber concrete.

Table (12): The components of the proportion of the concrete mix

M-ID	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Dolomite (kg/m^3)	% FA	% SF	% PF	% CR	% SP
MC-1	185	400	635	1270	-	-	-	-	-
MC-2	185	400	635	1270	10	-	-	-	0.7
M-PF1	185	400	572	1144	10	1.5	1.5	10	0.7
M-PF2	185	400	508	1016	10	1.5	1.5	20	0.7
M-PF3	185	400	572	1144	10	1.8	1.8	10	0.7
M-PF4	185	400	508	1016	10	1.8	1.8	20	0.7
M-PF5	185	400	572	1144	10	2.0	2.0	10	0.7
M-PF6	185	400	508	1016	10	2.0	2.0	20	0.7
M-SF1	185	400	572	1144	10	1.5	1.5	10	0.7
M-SF2	185	400	508	1016	10	1.5	1.5	20	0.7
M-SF3	185	400	572	1144	10	1.8	1.8	10	0.7
M-SF4	185	400	508	1016	10	1.8	1.8	20	0.7
M-SF5	185	400	572	1144	10	2.0	2.0	10	0.7
M-SF6	185	400	508	1016	10	2.0	2.0	20	0.7

C- MECHANICAL PROPERTIES FOR FRESH CONCRETE

1. SLUMB TEST

In accordance with ASTM C143 [23], slump testing was performed to confirm the workability of FRC mixtures, as shown in **Fig. 4**. The inner surface of the conical mold has been thoroughly cleaned to remove any remaining moisture. The mold is placed on a solid, horizontal, non-absorbent, smooth, hard surface. Three layers, each about a third of the mold's height, were used to fill the mold. Using a standard applicator, each layer was pressed with 25 strokes. Excess concrete was then removed, and a trowel was used to level the surface. The mold was immediately removed from the FRC by slowly and carefully increasing it in the air. This allows the concrete to slump naturally, and the slump is immediately assessed by comparing the mold and the height of the sample's highest point.

Fig.4. Slump test

D- MECHANICAL PROPERTIES FOR FRESH CONCRETE

1. COMPRESSIVE STRENGTH TEST

The compressive strength tests were carried out for 7 and 28 days of curing on the fiber-reinforced concrete cubes using a hydraulic testing machine with a capacity of 3000 KN, as shown in **Fig. 5.** Before testing, all samples were taken from the treatment basin and dried in the laboratory for approximately 2 hours. According to ASTM C109 [24], three cubes 150 x 150 x 150 mm from each mixture were tested, and the average was taken.

Fig. 5: Compressive strength testing machine.

2. DRY DENSITY TEST

After 28 days from the casting date, the density of the concrete was determined using samples of 150 x 150 x 150 mm cubes. The density was calculated according to BS EN 12390-7. The density was the average of three samples.

3. FLEXURAL STRENGTH TEST

Using the three-point bending test according to ASTM C78 [25], the flexural strength of fiber-reinforced concrete was tested using the hydraulic testing machine with a capacity of 3000 KN in **Fig. 6**. Fourteen rectangular samples measuring 100 x 100 x 500 mm from each mixture were tested for 7 and 28 days, and the results were averaged.

Fig. 6: Flexural strength testing machine.

4. ULTRASONIC PULSE VELOCITY (UPV) TEST

According to ASTM C 597-02 [26] and EN 12504-4:2004, the ultrasonic pulse velocity test can be performed. The device in **Fig. 7** is used in quality control to evaluate the elastic stiffness and mechanical strength of fiber concrete. Two transducers are placed on opposite sides to track the pulse velocities (direct transmission method), and 14 test beams are used to determine the pulse velocity within the fiber-reinforced concrete. The transceiver was carefully placed 10 cm apart from the samples and lubricated.

Fig. 7: Ultrasonic device

III EXPERIMENTAL RESULTS AND DISCUSSION

1. SLUMP TEST RESULTS

The addition of polypropylene fibers in concrete had greater effects on workability than steel fibers, which don't indicate workability [8]**.**

Fig. 8 shows the slump value for concrete mixtures of polypropylene fibers (PF) and crumb rubber (CR). It was observed that the control mixtures had 30 mm less slump than the other five groups, where the slump was 35 mm. The M-PF6 mixture had the same amount of slump as the control mixtures at a fiber content of 2% and a crumb rubber (CR) content of 20%.

Fig. 9 shows the slump value for steel fiber (SF) and crumb rubber (CR) concrete mixtures. It was observed that the control mixtures had 30 mm less slump than the other five groups, which had a 20 mm higher slump. The M-SF1 and M-SF6 mixtures had a slump of 20 mm, fiber content of 1.5% and 2%, and crumb rubber (CR) content of 10% and 20%, respectively. The results show that as the content of fiber and crumb rubber increases, the amount of slump increases.

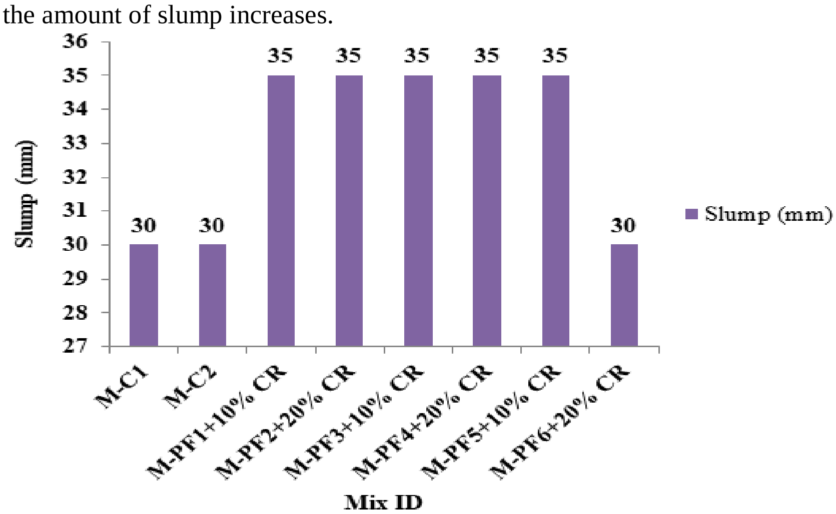

Fig. 8: Relationship between slump (mm) and %PF using %CR.

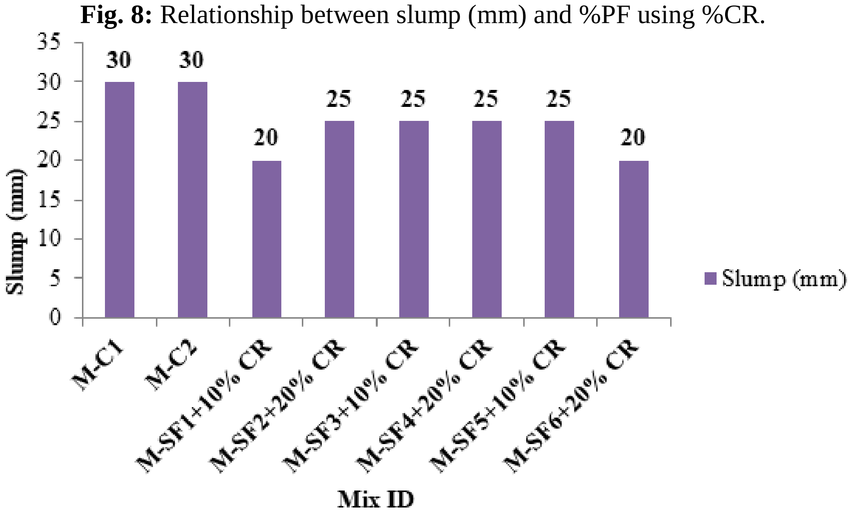

Fig. 9: Relationship between slump (mm) and %SF using %CR.

2. COMPRESSIVE STRENGTH TEST RESULTS

Table 13 shows the compressive strength test results for (PF) by using (CR) after 7 and 28 days, the compressive strengths of the M-C1 and M-C2 control mixes were 27.4 and 26.7 MPa after 7 days, respectively, and increased to 37.4 and 30.3 MPa after 28 days. The maximum value of compressive strength of a (PF) mixture with a (CR) of 20.7 MPa after 7 days decreased to 24.45% for MPF-3 at a content of 1.8% PF and 10% CR compared to the control mixture M-C1. The minimum value of the mixture M-PF6 was 11.5 MPa, decreasing at a rate of 58.03% at a content of 2% PF and 20% CR.

Table 13: The compressive strength results for PF by using CR after 7 and 28 days

Mix ID	Compressive strength (MPa) after 7 days	Compressive strength (MPa) after 28 days
M-C1	27.4	37.4
M-C2	26.7	30.3
M-PF1	19.2	24.6
M-PF2	13.8	18.5
M-PF3	20.7	24.4
M-PF4	11.8	13.4
M-PF5	16.6	19.6
M-PF6	11.5	16.8

The maximum value of the test results achieved after 28 days for the mixes M-PF1 is 24.6 MPa; it decreased by 10% with a content of 1.5% PF and 10% CR, while the minimum value for the mix M-PF4 was 13.4 MPa, with a decrease rate of 51.09% with a content of 1.8% PF and 20% CR. The relationship between compressive strength MPa and %PF using %CR after 7 and 28 days is shown in **Fig. 10.**

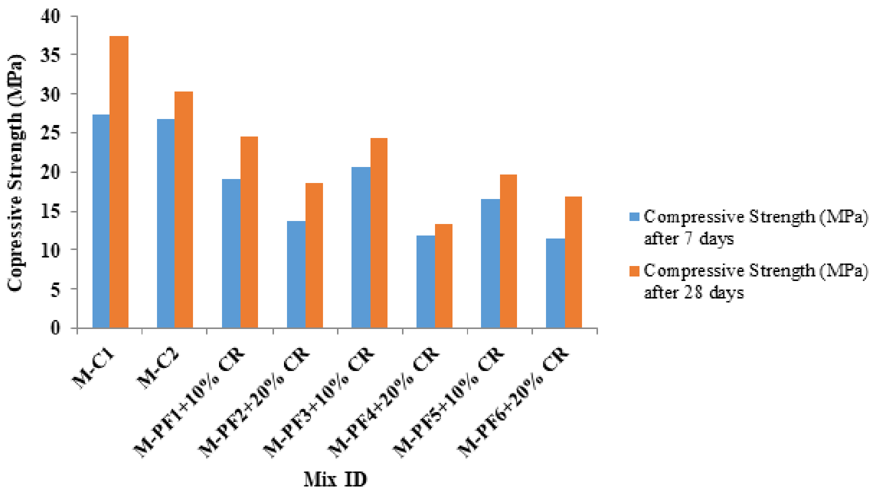

Fig. 10: Relationship between compressive strength (MPa) and %PF using %CR after 7 and 28 days.

Table 14 shows the compressive strength test results for SF by using CR after 7 and 28 days, the compressive strengths of the M-C1 and M-C2 control mixes, where the compressive strengths were 27.3 and 26.7 MPa after 7 days and increased to 37.4 and 30.3 MPa after 28 days, respectively. The maximum value of the compressive strength of the steel fiber (SF) mixture with crumb rubber (CR) after 7 days was 27.6 MPa. It increased by a very small rate of 0.72% for MSF-3 at content of 1.5% SF and 10% CR compared to the control mixture M-C1. The minimum value of the mixes M-SF6 was 17.1 MPa, decreasing at a rate of 50.36% at a content of 2% SF and 20% CR.

Table 14: The compressive strength results for %SF by using %CR after 7 and 28 days.

Mix ID	Compressive strength (MPa) after 7 days	Compressive strength (MPa) after 28 days
M-C1	27.4	37.4

M-C2	26.7	30.3
M-SF1	21.7	27.6
M-SF2	15	18.5
M-SF3	22.6	25.2
M-SF4	18	19.5
M-SF5	19.6	24.5
M-SF6	13.6	17.1

The maximum value of the test results achieved after 28 days for the mixture M-SF1 is 27.6 MPa; it increased with a rate of 0.72% with a content of 1.5% SF and 10% CR, while the minimum value for the mixture M-SF6 was 17.1 MPa and decreased with a rate of 37.54% with a content of 2% SF and 20% CR. The relationship between compressive strength MPa and %SF using %CR after 7 and 28 days is shown in **Fig.11.**

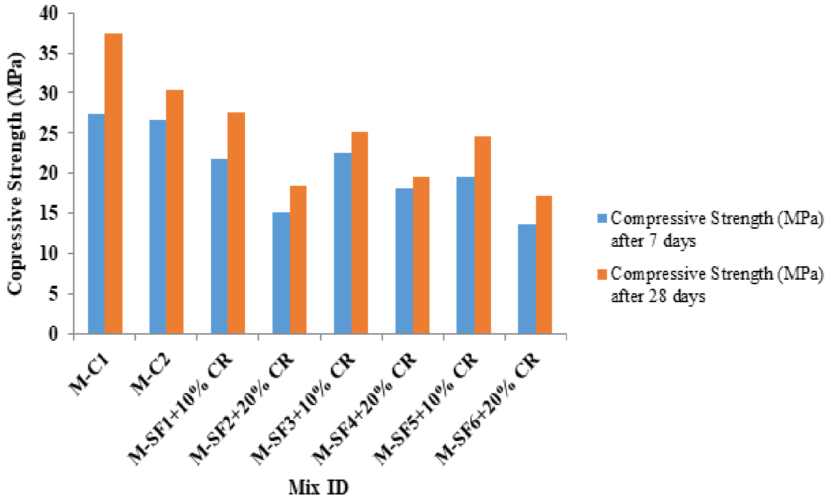

Fig. 11: Relationship between compressive strength (MPa) and %SF using %CR after 7 and 28 days.

3. DRY DENSITY TEST RESULTS

The dry density of the control mix MC-1 was 2500 kg/m3, while the mixtures of polypropylene with crumb rubber decreased to 2200 kg/m3 by 1.5%, 1.8%, and 2% fiber content at 20% crumb rubber, respectively.

The mixtures of steel fiber (SF) and crumb rubber (CR) decreased to 2300 kg/m3 by 1.5%, 1.8%, and 2% fiber content at 20% crumb rubber, respectively. The relationship between dry unit weight (kg/m3) and %fibers using %CR after 28 days is shown in **Fig. 12**.

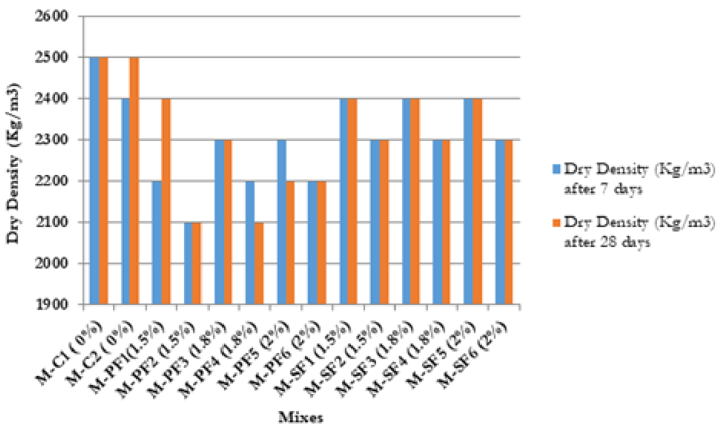

Fig. 12: The relationship between dry density (kg/m^3) with (%PF) and (%PF) by using %CR after 7 and 28 days.

4. FLEXURAL STRENGTH TEST RESULTS

Table 15 shows the flexural strength test results of the M-C1 and M-C2 control mixes, which showed a flexural strength of 3.5 and 3.9 MPa after 7 days, and it increased to 4.6 and 4 MPa after 28 days, while the flexural strength decreased in the mixture of polypropylene fibers (PF) with crumbs. Rubber added (CR) by 3.5 MPa after 7 days was 10.25% for M-PF2, with a content of 1.5% PF and 20% CR compared to control M-C2. Still, it was equal in value to the M-C1 control mixture. The minimum value of the mixture M-PF6 was 2.3 MPa, decreasing by an average of 15.38% at a content of 2% PF and 20% CR.

Table 15: The flexural strength results for PF by using CR after 7 and 28 day

Mix ID	Flexural strength (MPa) after 7 days	Flexural strength (MPa) after 28 days
M-C1	3.5	4.6
M-C2	3.9	4
M-PF1	3.2	4.1
M-PF2	3.5	3.7
M-PF3	2.8	3.5
M-PF4	2.4	3
M-PF5	2.6	3.8
M-PF6	2.3	2.7

The maximum value achieved after 28 days for the mixture M-PF5 was 3.8 MPa; it decreased by a rate of 2.5% with a content of 2% PF and 10% CR, while the minimum value for the mixture M-PF4 was 3 MPa, and the decrease was with a rate of 23.1% with a content of 1.8% PF and 20% CR. The relation between flexural strength (MPa) and PF using CR after 7 and 28 days is shown in **Fig. 13**.

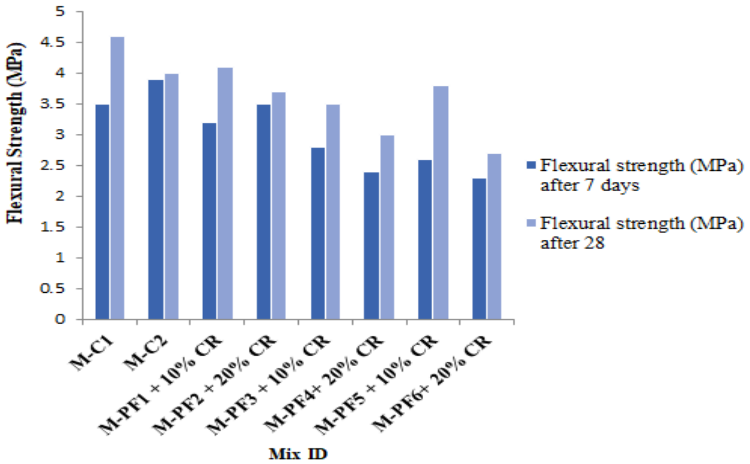

Fig.13 Relation between flexural strength (MPa) and PF using CR after 7 and 28 days.

Table 16 shows the flexural strength test results for SF by using CR after 7 and 28 days. The flexural strength was 3.5 and 3.9 MPa after 7 days and increased to 4.6 and 4 MPa after 28 days, respectively. The maximum value of flexural strength of a steel fiber SF mixture with crumb rubber CR after 7 days was 3.9 MPa, but it was equal in value to the control mixture MC-1 for M-PF6 at a content of 2% SF and 20% CR in the mixture MC-2. The minimum value of the mixtures M-SF2 and M-SF3 was 2.5 MPa; the decrease was at a rate of 35.89% at a content of 1.5%, 1.8% SF, and 20%, 10% CR, respectively.

The maximum value achieved after 28 days for the mixture M-SF1 was 4.8 MPa; it increased by a rate of 2.5% with a content of 2% PF and 10% CR, while the minimum value for the mixture M-PF4 was 3 MPa, and the decrease was at a rate of 18.75% with a content of 1.5% SF and 10% CR. The relation between flexural strength (MPa) and SF using CR after 7 and 28 days is shown in **Fig. 14**.

Table 16: The flexural strength results for SF by using CR after 7 and 28 day.

Mix ID	Flexural strength (MPa) after 7 days	Flexural strength (MPa) after 28 days
M-C1	3.5	4.6
M-C2	3.9	4
M-SF1	2.9	4.8
M-SF2	2.5	3.3
M-SF3	2.5	4.3
M-SF4	3.2	3.6
M-SF5	3.4	4.3
M-SF6	3.9	4.1

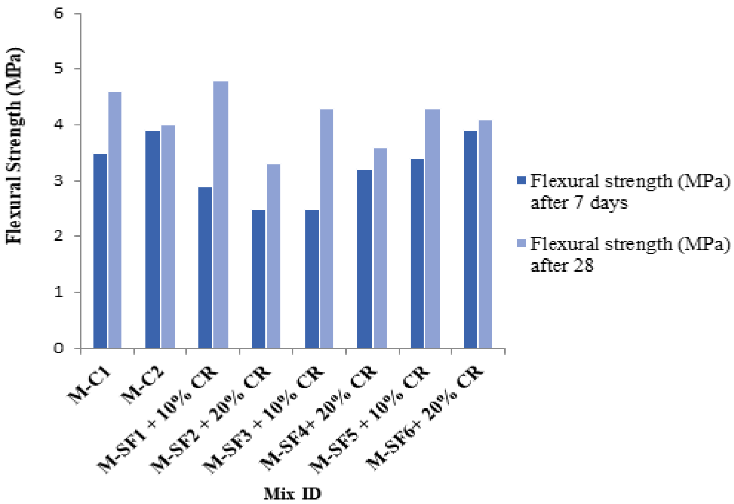

Fig.14 Relation between flexural strength (MPa) and SF using CR after 7 and 28 days.

5. ULTRASONIC PULSE VELOCITY (UPV) TEST RESULTS

The results of wave velocity rates for polypropylene fiber (PF) using mixtures with various ratios of crumb rubber (CR) are shown in **Table 17**. The results showed that the maximum values of the M-PF5 mixture were at 2% of the fiber content with a maximum value of 4.081 Km/sec, which led to a positive evaluation when 10% of CR was used. Compared to the control mixtures, the wave velocity decreased by 20% CR and 1.8%PF in the mixture M-PF4, with a value of 3.623 Km/sec. The relation between ultrasonic pulse velocity (UPV) and PF using CR is shown in **Fig.15**. The results of the ultrasound test when using polypropylene fibers (PF) with crumb rubber (CR) were close to the results of the study [27].

Table17: Results of ultrasonic pulse velocity (UPV) for PF using CR.

Mix ID	%PF	%CR	UPV (Km/sec)	Concrete quality
M-C1	-	-	5.347	Excellent
M-C2	-	-	4.484	Good
M-PF1	1.5	10	4.050	Good
M-PF2	1.5	20	3.676	Good
M-PF3	1.8	10	4.032	Good
M-PF4	1.8	20	3.623	Good
M-PF5	2.0	10	4.081	Good
M-PF6	2.0	20	3.663	Good

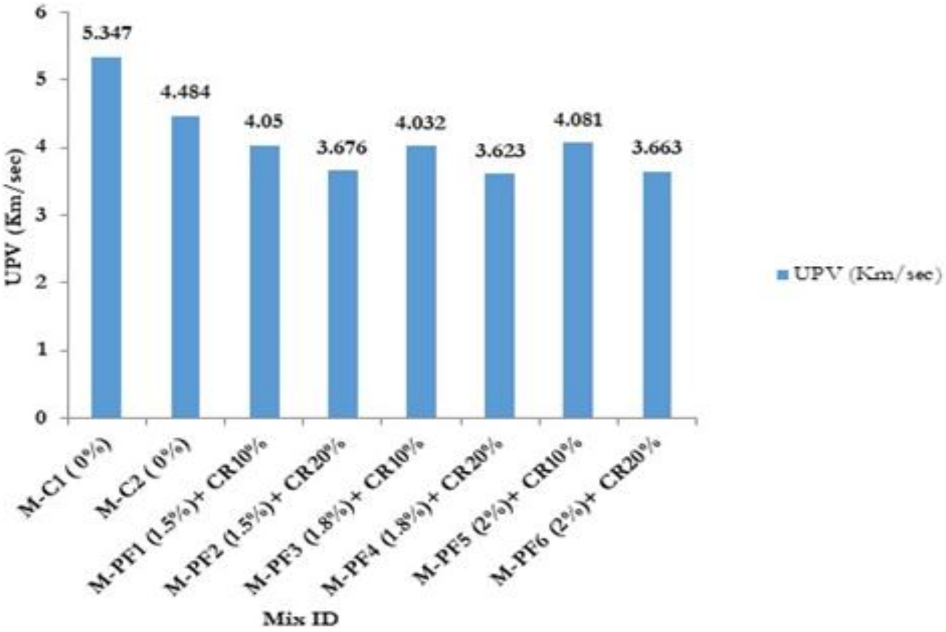

Fig.15. Relationship between UPV using PF using CR.

Table 18 shows the results of wave velocity rates for steel fiber concrete (SF) using mixtures with various ratios of crumb rubber (CR). The results showed that the maximum values of the M-SF3 mixture were at 1.8% of the fiber content with a maximum value of 4.273 Km/sec, which led to a positive evaluation when 10% of CR was used. Compared to the control mixtures, the wave velocity decreased by 20% CR and 1.8% SF in the mixture M-SF5, with a value of 4.132 Km/sec. The relation between ultrasonic pulse velocity (UPV) and PF using CR is shown in **Fig. 16**.

Table18: Results of ultrasonic pulse velocity (UPV) for SF using CR.

Mix ID	%PF	%CR	UPV (Km/sec)	Concrete quality
M-C1	-	-	5.347	Excellent
M-C2	-	-	4.484	Good
M-SF1	1.5	10	4.166	Good
M-SF2	1.5	20	3.322	Acceptable
M-SF3	1.8	10	4.273	Good
M-SF4	1.8	20	3.436	Acceptable
M-SF5	2.0	10	4.149	Good
M-SF6	2.0	20	4.132	Good

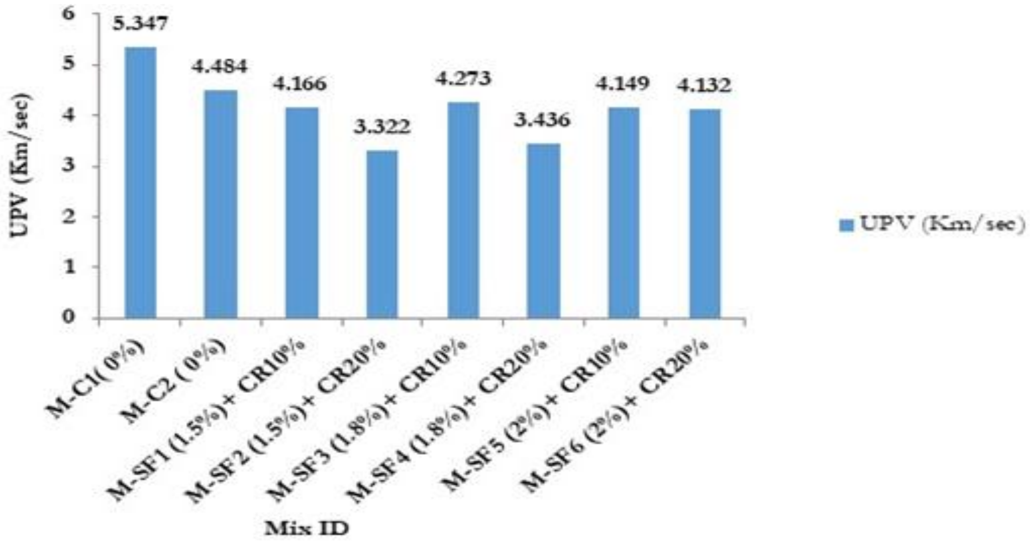

Fig.16. Relationship between (UPV) using PF using CR.

IV CONCLUSION

This study dealt with how the addition of crumb rubber affects the mechanical properties of reinforced steel and polypropylene fibers and evaluated the best results for the use of paving slab concrete. The following conclusions are reached on the basis of experimental results:

- Rubber has a lower specific gravity than natural aggregates, and crumb rubber (CR) significantly reduces the density of fiber-reinforced concrete.
- As for the workability of concrete, it was found through the slump test that with an increase in the percentage of crumb rubber (CR) in the fiber-reinforced concrete, its mechanical and fresh properties decreased.
- The dry density values of steel fiber-reinforced concrete and crumb rubber are higher than the dry density values of polypropylene fiber-reinforced concrete at the same ratios.
- The results showed that after 28 days, steel fiber concrete had the maximum value of compressive strength at 1.5% steel fiber and 10% crumb rubber content, while reinforced concrete with polypropylene fibers had a higher compressive strength value than steel fibers at the same content as crumb rubber and fibers.
- The results showed that after 28 days, the concrete made of (SF) had the highest value of flexural strength at 1.5% steel fibers and 10% (CR), while the best fibers in terms of flexural strength were for concrete reinforced with (PF), where the maximum value of flexural strength was at the content of 2% and the (CR) of 10%; that is, the higher the content of polypropylene fibers, the greater the flexural strength, which is the best in road concrete in terms of flexural strength.
- The results of the wave velocity of the ultrasound test recorded the highest results at 10% of the crumb content with steel and polypropylene fibers, while the wave velocity decreased at 20% of the crumb rubber content.

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