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INVESTIGATION ON IMPROVING RIGID PAVEMENT PROPERTIES BY ADDING RECYCLED RUBBER

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ABSTRACT

In this study different mechanical, physical and durability tests were manufactured to investigate the effect of recycled rubber as a partial replacement of fine aggregate by volume on the properties of plain concrete pavements (PC). First step of this paper, the slump, flexural and compression tests are carried out for trial batches to choose airfield PC mix. The second step, the slump, flexural and compression tests are carried out to select the optimum percentage of rubber as a partial replacement of fine aggregate by volume. Afterward, the tests of slump, compression, three point bending of single edge notched beam, splitting, flexural, impact, ultrasonic pulse velocity, Schmidt hammer, electric resistivity, water absorption and abrasion resistance were performed. Results of the experimental study indicated that the addition of rubber recorded significant to slight improvement in the mechanical, some physical and some durability properties of PC. Slight reduction in other properties of PC was observed.

1. Introduction

All civil infrastructures have a definite life span and all structures are designed to fail at some point, and this includes the vast network of road pavements [1]. Plain Concrete is widely used in concrete pavement construction. It has excellent strengths, but poor tensile strength and very low elasticity and when strength increases, elasticity decreases. It is desirable for concrete pavement to have both relatively high tensile strength and elasticity [2]. Plain concretes are representative materials for both the construction and maintenance of pavements. They have good mechanical characteristics with a cheap price. However, they also have multiple drawbacks such as shrinkage, bad chemical resistance, and low tensile strength, which shorten the life expectancy of runway and pavements [3]. Low volume of traffic on airfields relative to most road situations increased the tendency of sealing aggregates to “polish” [4]. Discrete cracks exist in most concrete structures such as rigid pavements. Concrete cracks are caused by many factors such as humidity and temperature differences, mechanical loading, and chemical attack. Small or large crack openings can lead to premature concrete deterioration [5]. Intensive effort was devoted to enhance the performance of concrete pavement surface to prolong the service life and give superior durability of pavement [6]. One billion end-of-life tires are generated globally each year, on other hand there is a lack of aggregate resources in some sites and countries [7]. With realization a lot of environmental benefits, researchers suggest that rubberized concrete (RC) is more flexible than standard concrete pavement, serve as sustainable and cost effective solutions for improved rigid pavement [2]. The objective of this study is to evaluate the behavior of rubberized concrete pavement by evaluate the mechanical, physical and durability properties through destructive and nondestructive tests. Therefore, this study is conducted to improve the pavement properties and reduced concrete pavement maintenance cost. This approach is of great importance to the economic and environmental impacts.

2. Experimental work

Experimental work deals with the description of the test program including used materials, test procedures, test specimens, and instrumentations. The following tests procedures are taken to evaluate the behavior of rubberized concrete Pavement.

2.1. Materials and mixing procedure

Type I Portland cement with grade of 42.5 N was used. Local natural sand and crushed gravel from Assuit were used as fine and coarse aggregates respectively. Recycled rubber of (0.85-3.5) mm was produced by Sama United Recycling factory in Ismailia was used as a partial replacement of sand by volume. Drinking water was used for both mixing and curing. High-range water reducing admixture (HRWRA) CMB addicrete BVF was provided by CMB Co. Assiut was used. Physical and chemical properties of the used materials are listed in Table 1. All materials were tested according to the ECP203 [8].

Table 1.
Physical and chemical properties of the used aggregates.

property	sand	Gravel 1	Gravel 2	Rubber
Volume weight in loose state (t/m^3)	1.45	1.2	1.28	0.41
Volume weight in compacted state (t/m^3)	1.63	1.43	1.48	0.6
Specific gravity	2.50	2.77	2.63	1.2
% Absorption	1.0	1.13	1.17	-
% Fine Materials	2.0	0.5	0.63	-
% Crushing Value	-	19	18	-
% Loss of wear	-	-	19	-
Fineness Modulus	2.2	6.0617	7.33	1.2
% Chloride ions	0.041	0.018	0.032	-
% Sulphate ions	0.139	0.125	0.12	-
PH	8.78	8.50	8.50	-
maximum nominal size	-	10	20	-

2.2. Design of PC mix

Trial mixtures are prepared to obtain target strengths, a 28-day flexural strength between 4.14 to 5.17 MPa as recommended for most airfield applications and to comply with the requirements of FAA 150/5320-6F and FAA Item P-501 [9,10]. All mixtures possess w/c=0.4, that may be required for concretes exposed to sulfate soils or waters, freezing and thawing and for protection of reinforcement corrosion [11]. There is a need to use water reducing admixtures to improve the workability [12]. The amounts of materials required to produce 1 m^3 of PC mix are given in Table 2.

Table 2.
Amount of constitute materials for 1m^3 of the used plain concrete

Cement (kg/m^3)	Water ($Liter/m^3$)	W/C	Sand (kg/m^3)	Gravel 1 (kg/m^3)	Gravel 2 (kg/m^3)	S/G	G1/G2	HRWRA (kg/m^3)
400	160	0.4	675	784	422	0.56	65/35	8

2.3. Rubberized concrete (RC) mix

Trial mixtures with rubber were prepared to select the rubberized mix, based on the next reasons and trial mixtures as shown in Fig. 1. In this investigation the percentage of rubber used was 10% replacement of fine aggregate by volume. Concrete with 30% or more rubber results in difficulty with finishing of rigid pavement surface and should be avoided. Rubber content should be from 8 to 12%, which leads to increase in the energy absorption. So, big content of rubber may have a negative effect on the ductility of the concrete. These remarks are compatible with ref. [13, 14].

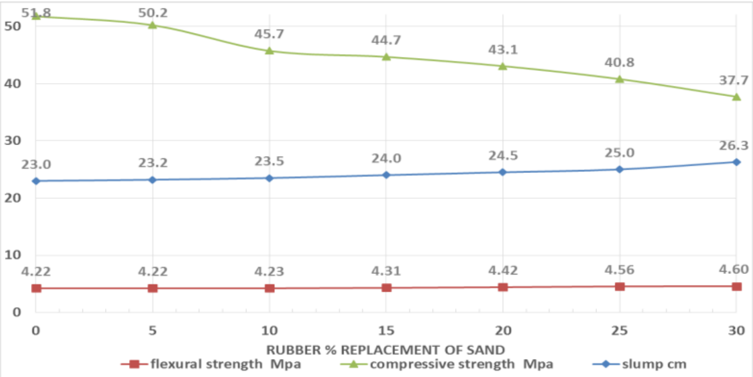


Fig. 1 Trial mixtures as a function of rubber replacement results.

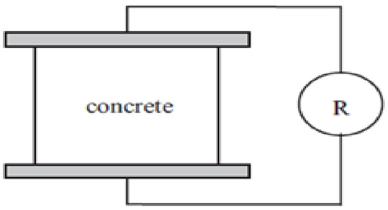
2.4. Tests for rubberized and plain concretes

Instrumentation was connected to a computerized data acquisition system (TDS-150) to record the readings at every second of loading during the tests. The load was measured using the load cell with a capacity of 2000 kN. The load cell was located under the loading piston of the machine. The vertical deflection of the concrete beam at mid-span was measured by using LVDT of 100 mm stroke and accuracy 0.00001 mm. Different instrumentation including external devices was used to obtain data during the tests in the experimental program, as shown in Table 3.

Table 3.
All tests details

Test	Details of samples	According to	Fig.	notes
slump		ECP203		
compression	3 Cubes 15 cm each side	ECP203		
Three-point bending	3 prisms 10x10x40 cm with a loaded span of 35 cm [15]	[16]		Single edge notched prisms, (a/d=0.1), notch width is 5mm [17]
Objective of this test: To understanding the progressive failure of concrete pavements and specifically the crack propagation in the concrete materials and to determine the crack mouth opening displacement CMOD maximum load.				
Splitting tensile	3 cylinders (10x20 cm),	ECP203		
Flexural	3 Prisms 10 x 10 x 40 cm with a loaded span of 30 cm [17]	ASTM. (2010a) [18], and ECP203.		
Objective of this test: To determine the flexural load–deflection curve, net deflection at any applied load (First-crack net deflection), first-crack load at different mix combinations and flexural strength.				

Table 3. (Continue)

Impact resistance using modified drop-weight impact	5 specimens 10X10 cm and 6 cm thick	[19]		Rubber sheet with a thickness of 3 mm between the specimen and the base plate to prevent stress concentrations at the bottom only specimens cracking through the line of impact are accepted [20].
Objective of this test: To determine the energy absorption can be obtained by using the following formula: $E= N x (w x h)$ *joules*, where E= energy in joules, w= weight in Newton, h= drop height in meter, N= blows in numbers. In the above equation, the weight dropping 48.5429 N (a hammer weighing as 4.45 kg and Impact piston weighing 0.5kg), the height of fall 0.457 m were maintained constant throughout the experiment.				
Ultrasonic pulse velocity	3 cubes 10 cm each side	ASTM C597 [21]	 Pundit Lab	
Objective of this test: To determine UPV by direct transmission. The following formula ultrasonic pulse transmission time was determined at m/s: $V=L/T$, where L is transmission distance (m), T is transmission time in the concrete (s) and V is pulse transmission velocity in concrete (m/s).				
Rebound Hammer	3 cubes 10 cm each side	ASTM C 805 – 97 [22]		
Abrasion resistance	4 concrete cubes 7 cm each side	ECP269 [23].		
Water absorption	3 cubes 10 cm each side	ASTM C642 [24].		
Electric resistivity	3 cubes 10 cm each side	Resistivity testing by two-electrode method using external copper plates [25]		to ensure electrical connection a wet cloths were inserted in between copper plate and concrete specimen [25]
Objective of this test: To determine electrical resistivity of the concrete as follows: $\rho = A*R/L$, where ρ is the resistivity (k Ω cm), A the area (cm2) of the specimen in contact with plates, R the resistance (k Ω) and L is the length of specimen in the direction of the current (cm).				

3. Results and discussions

Table 4 shows the results of all tests. Discussions of these results are presented in the following sections:

3.1. Slump results

The workability of fresh-state concrete increased by using rubber as a fine aggregate partial replacement by percentage 2.13%. This may be attributed to three reasons. First, since the rubber particles are much softer than the cement past. Second, rubber did not absorb water at all and most of the rubber floated on the surface of the water. Third, due to the lack if adhesion between the particles of rubber and the cement paste, soft rubber particles behave as voids in the concrete matrix, less water is needed for rubberized concrete to achieve good workability. These remarks are compatible with ref. [26, 27]**.**

3.2. Compressive strength and hardness results

The addition of rubber slightly decreased the plain concrete's compressive strength and hardness by percentage 12.89 and 12.53% respectively because the hardness for rubber is less than that of aggregate. Rubber particles are more flexible and weaker than the cement matrix. Therefore the cracks first of all start developing at the contact zone of the rubber and the cement matrix [28]. So, the maximum rubber percentage is suggested to not exceed 12% replacement of fine aggregates.

3.3. Three-Point bending, splitting, flexural strength and impact resistance results

The addition of rubber increased the plain concrete's CMOD maximum load, splitting strength, first-crack load, first-crack deflection, flexural strength, energy absorption at first crack and at ultimate failure by percentages of 8.41, 8.08, 1.75, 41.67, 1.75, 46.15 and 58.33% respectively as shown in Fig. 2-4. RC is more flexible than PC. Rubber improved the strain capacity before the macro-crack formation. Rubber can therefore withstand large deformations, as it acts like a spring inside the composite and delays crack widening. Crack tip bridging of rubber within the fracture zone, resulting in the arrest of crack propagation. This phenomenon is described as "strain hardening" in fiber-reinforced concrete under tension, where the tensile behavior has demonstrated the fiber bridging within propagating cracks. The presence of rubber in concrete increased the resistance of concrete to crack initiation under impact load and absorbs vibration to a large extent. Rubber content contributed to increasing the post cracking resistance. As reported by other researchers [29- 33].

3.4. Ultrasonic pulse velocity (UPV) results

The addition of rubber too slightly decreased the plain concrete's ultrasonic pulse velocity by percentage 2.94%. Because the cavities formed by rubber develops resistance against the transmission of ultrasonic waves and thus passing of waves is attenuated. As referred by [34].

3.5. Electrical resistivity results

The addition of rubber increased the plain concrete's electrical resistivity by percentage 15.35%. because it is an insulating material. In general all concretes had high resistance to chloride penetration based on electrical resistivity, (15-35 kΩcm) according to ASTM C1760, and had low corrosion rate (based on electrical resistivity >20 kΩcm). Which confirmed with ref? [35 and 36].

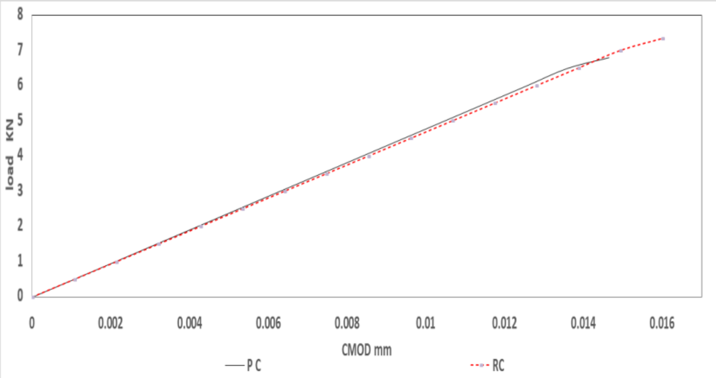


Fig. 2. Load-CMOD behavior for notched specimens

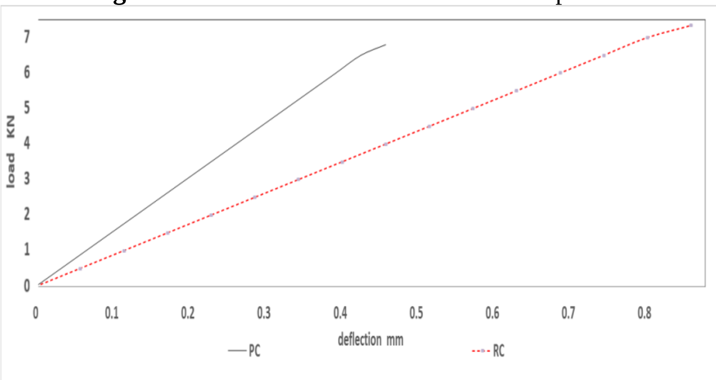


Fig. 3. Load–deflection behavior for notched specimens

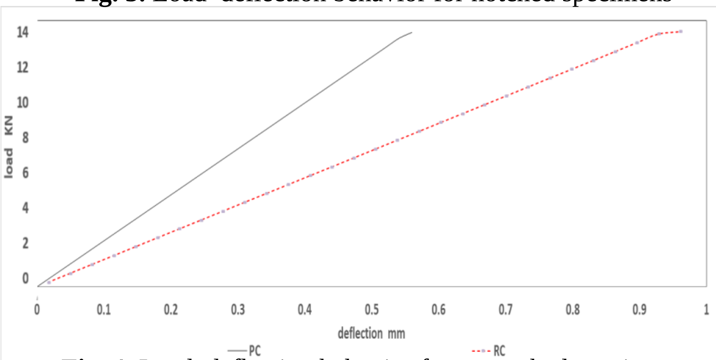


Fig. 4. Load–deflection behavior for unnotched specimens

3.6. Water absorption results

The addition of rubber increased the plain concrete's water absorption by percentage 1.83%. That sand is substituted by rubber which has different shapes and structures, some porosity is formed increasing water absorption. The rubber form effective open pores and capillaries that are easily filled with water. This might have caused the occurrence of micro voids around the surface of the specimen and have enabled more water absorption. These results are compatible with ref. [37].

3.7. Abrasion resistance results

The addition of rubber decreased the plain concrete's loss in mass and in thickness by percentage 7.07 and 6.59% respectively. The rubber is more resistant than the stone aggregate, because of its capacity to retain the elastic property during the longer time period of stress. The friction forces occurring during abrasion, on the contact between the abrasive surfaces are not sufficiently high to tear out the rubber from the concrete composite. As referred by [38].

Table 4.
tests results

Test name	Pc	RC
Slump cm	23	23.5
Water absorbtion %	3.64	3.71
Loss in thickness mm	0.45	0.42
Hardness	46.7	41.5
Ultra sonic V m/s	5882.35	5714.29
Loss in mass g	5	4.67
Compressive strength Mpa	51.8	45.89
Flexural strength MPa at First crack-load	4.12	4.19
Splitting strength MPa	3.06	3.33
First crack-load N	13.73	13.97
Deflection at first crack mm	0.54	0.93
The CMOD at the maximum load mm	0.01	0.02
Energy absorption at first crack joules	155.29	288.39
Energy absorption at ultimate failure joules	**221.84**	**532.42**
Electrical resistivity (kΩcm)	**26.42**	**31.21**

4. Conclusions

On the basis of results obtained from the present research the following conclusions can be drawn out:

1- The addition of rubber increases the plain concrete’s slump.
2- The addition of rubber increases the CMOD at the maximum load for notched specimens, the splitting strength, first-crack load, and the first-crack deflection.
3- With increasing percentage of rubber the flexural strength increased, which contradicts the Empirical results.
4- The energy absorption at first crack, at ultimate failure and electrical resistivity increased with the addition of crumb rubber.
5- The addition of crumb rubber decreased loss in mass and thickness. These results confirm the advantages and necessity of using rubber in pavement construction.
6- The addition of crumb rubber slightly reduces compressive strength, the hardness and ultrasonic pulse velocity but increase water absorption. Therefore we recommended adding some enhancements materials to the rubberized concrete to avoid these defects.

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دراسة في تحسين خواص الرصف الخرساني باضافة المطاط المعاد تدويره

الملخص العربى

في هذه الدراسة تم إجراء اختبارات مختلفة للتحقيق في تأثير المطاط المعاد تدويره ليحل محل الركام الناعم في تحسين خواص الرصف الخرساني. الخطوة الأولى من هذه الدراسة انتاج خلطة خرسانة عادية تستعمل في المطارات. الخطوة الثانية استهدفت اختيارنسبة استبدال المطاط من الركام الناعم. بعد ذلك، كانت الاختبارات: الهبوط والضغط وثلاث نقاط اختبار الانحناء ، الشد الغير مباش، الانحناء، الصدم، سرعة الموجات فوق الصوتية، مطرقة شميدت، المقاومة الكهربائية، امتصاص الماء واختبارات مقاومة البري .أشارت نتائج الدراسة إلى أن إضافة المطاط يحسن بعض الخواص الميكانيكية وبعض الخواص الفيزيائية وبعض خواص المتانة في خصائص الرصف الخرساني باستثناء بعض الخواص الأخرى حدث فيها انخفاض طفيف .