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Mechanical Behavior of Self-Compacting Concrete Pavements Incorporating Recycled Tire Rubber Crumb and Reinforced with Polypropylene Fiber

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ABSTRACT: Increasing quantity of scrap tires are potential sources of fire and health hazards. Rubberized pavement is being considered as one of the promising and sustainable solutions to this current environmental and economic crisis in the world. This research focused on finding the best way of producing paving concrete with the use of tire rubber waste as a component material. Therefore, Tire Rubber Crumb (TRC) was used as a partial sand replacement (5%, 10% and 15%) material in the mix design of self-compacting concrete. Self-compacting concrete (SCC) is considered an energy efficient material; because it reduces on-site working and does not need any compacting energy. Fine aggregates with fineness modulus of 2.9,specific gravity of 2.64 (g/cm3) and water absorption of 1.5% and coarse aggregates with maximum size of 12.7 mm, specific gravity of 2.68 (g/cm3) and water absorption of 0.8 were used in this research. According to the results of this study, fresh concrete tests showed that both fiber and TRC have negative effects on rheological properties of fresh concrete. Furthermore, the hardened concrete tests showed that TRC decreases compressive strength, tensile strength, flexural strength, abrasive strength and modulus of elasticity while increasing water absorption of SCC. Therefore, polypropylene fibers were added into SCC specimens containing TRC and resulted in significant increases in compressive, tensile, flexural and abrasion strength but had no considerable effect on the modulus of elasticity of these specimens. Moreover, the presence of fiber in rubberized SCC decreased water absorption based on evaluation of ultrasonic waves velocity

I. INTRODUCTION

Rapid growing amounts of rubber tire wastes is a seriousconsequence of significant increase in the number of vehicles. Thehigh volume storage of scrap tires has deleterious effects on theenvironment. Waste tires would lead to significant health andenvironmental concerns if not recycled or discarded properly. Oneof the recent way of tackling this challenge is to apply this type ofwastes into civil engineering infrastructures. Shredded rubber tireshave been used as aggregates in concrete and gained popularityover the last years. Many studies have been conducted on using TireRubber Crumb (TRC) in different types of concrete in order to studycrumb rubber effects on these concrete mechanical behavior (Meddah et al., 2014; Murugan& Natarajan, 2015; Elchalakani, 2015). Investigating mortars containing TRC resulted in the decreases in the flexural strength and the increase in probability of occurrence of accumulative plastic cracks (Meddah et al., 2014). Although the concrete made up of the large amount of TRC, up to 75%, and had the required workability, it was not suitable to be used as common structural concrete. Recently, many studies have been dedicated the use of TRC in self-compacting concrete (SCC) (Mishra and Panda, 2015; Venkatesh and Subramanian, 2015; Jedidia et al., 2014). Self-compacting concretes (SCCs), highly fluid concretes placed without vibration, were introduced into French construction works towards the end of the 1990s. Formulating SCCs is a compromise between sufficiently high fluidity to ensure good casting and an adequate consistency to avoid phase separation problems, segregation or bleeding. SCC is able to flow through even heavy reinforcement and achieve full compaction under its own weight Sukontasukkul and Chaikaew (2006) studied concrete blocks of pavement containing TRC. Based on the results obtained in their study, blocks containing TRC have a lower compressive strength compared to normal blocks but yet are lighter, more flexible and have more energy absorption and lower abrasive strength.

1. Methodology

Self-compacting concrete (SCC) with minimum amount of en- ergy consumption in the placement and compaction process has been gaining popularity in the recent decade. Since the flowability is a key feature of SCC, by adding TRC and polypropylene, the flowability of fresh SCC should be studied. Therefore, slump flow, T 50 and L-Box tests were done for studying rheological property of fresh concrete. Each of these tests is indicative of one or several properties of SCC. Slump flow test is introduced to determine the concrete's ability to deflect under its own weight when there are norestrains except for friction and flow plain. Average diameter of the resulting circles formed after the slump test indicates the yield stress of fresh concrete and is a criterion to measure filling ability of concrete. Another parameter measured in slump flow test is the time within which the concrete reaches the radius of 50 cm and is used to determine plastic viscosity of fresh concrete. L-Box test indicates filling and passing ability of SCC and is designed to study flowability of fresh concrete and blockage phenomenon. Moreover, TRC and polypropylene have significant impacts on mechanical features of hardened concrete and as such, compressive strength, tensile strength, flexural strength, modulus of elasticity and abra- sion resistance of SCC were needed to be investigated. Besides, the concrete durability is highly dependent on its permeability. The water absorption test measures the capability of fluid transition within the concrete. In addition, ultrasonic pulse velocity was done for achieving information about the uniformity and pore structures of concrete.

1. Experimental design

1.1. Materials used

Table 1

Chemical composition of cement and limestone powder.

Chemical analysis	Cement	Limestone powder
SiO_2 (%)	21.90	0.3
Al_2O_3 (%)	4.86	0.1
Fe_2O_3 (%)	3.30	0.02
CaO (%)	63.32	e
MgO (%)	1.15	0.2
SO_3 (%)	2.1	e
K_2O (%)	0.56	e
Na_2O (%)	0.36	e
Free CaO (%)	1.10	e
$CaCO_3$	e	99.3
SG (g/cm^3)	3.15	2.66
Blaine (cm^2/g)	3050	2730

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Fig. 1. Type of polypropylene employed in this study.

Table 2

Properties of the reinforcing fiber.

Type	Length (mm)	Diameter (mm)	Tensile strength (kg/cm^2)	Aspect ratio l/d	Elastic modulus (GPa)	Density (g/cm^3)
Polypropylene	6	0.1	4500	120	5	0.9

Fig. 2. Type of crumb rubber employed in this study.

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1.1. *Mix designs*

Table 3

TRC specification.

Sievesize	Percentremaining onthesieve
4.75mm	0
2.36mm	13.95
1.18mm	74.10
600mm	10.35
300mm	1.45
150mm	0.10
<150mm	0.05
Specificgravity(g/cm^3)	1.122

Table 4 Concrete mixture proportion.

Series	MixNo.	TRC(%)	FiberVf(%)	Gravel(Kg/m^3)	Sand(Kg/m^3)	Crumbrubber(Kg/m^3)	Limestonepowder(Kg/m^3)	Cement(Kg/m^3)	Water(Kg/m^3)	SP(Kg/m^3)
A	1	0	0.00	722.00	826.00	0.00	288.90	413.10	162.00	7.00
	2		0.10	722.00	826.00	0.00	288.90	413.10	162.00	7.50
	3		0.12	722.00	826.00	0.00	288.90	413.10	162.00	8.00
	4		0.15	722.00	826.00	0.00	288.90	413.10	162.00	8.50
B	1	5	0.00	722.00	784.70	17.55	288.90	413.10	162.00	7.50
	2		0.10	722.00	784.70	17.55	288.90	413.10	162.00	8.00
	3		0.12	722.00	784.70	17.55	288.90	413.10	162.00	8.50
	4		0.15	722.00	784.70	17.55	288.90	413.10	162.00	9.00
C	1	10	0.00	722.00	743.40	35.10	288.90	413.10	162.00	8.00
	2		0.10	722.00	743.40	35.10	288.90	413.10	162.00	8.50
	3		0.12	722.00	743.40	35.10	288.90	413.10	162.00	9.00
	4		0.15	722.00	743.40	35.10	288.90	413.10	162.00	9.50
D	1	15	0.00	722.00	702.10	52.65	288.90	413.10	162.00	8.50
	2		0.10	722.00	702.10	52.65	288.90	413.10	162.00	9.00
	3		0.12	722.00	702.10	52.65	288.90	413.10	162.00	9.50
	4		0.15	722.00	702.10	52.65	288.90	413.10	162.00	10.00

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1. Results and discussion

1.1. Fresh concrete properties

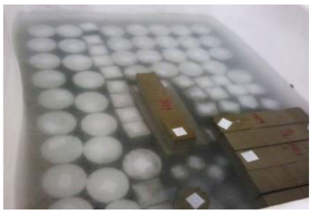

Fig. 3. Curing of specimens.

rheological properties from an allowable range, the properties of hardened SCC containing TRC are not studied when over 0.15% fiber is applied.

4.2. Properties of hardened concrete

4.2.1. Compressive strength tests

Table 5

Result of fresh concrete test.

Series	Mix No.	Slump flow D_{ave} (mm)	Flow time T_{50} (sec)	L-Box (h_2/h_1)
A	1	74.50	2.21	0.88
	2	72.00	2.75	0.83
	3	70.00	3.51	0.82
	4	67.00	4.43	0.76
B	1	74.00	2.52	0.84
	2	70.30	3.13	0.81
	3	68.30	3.84	0.76
	4	65.00	4.85	0.69
C	1	72.50	2.89	0.81
	2	68.70	3.64	0.77
	3	64.50	4.56	0.73
	4	62.50	5.65	0.68
D	1	70.00	3.51	0.76
	2	66.50	4.12	0.72
	3	64.70	5.03	0.68
	4	60.30	6.07	0.65

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Table 6

Result of hardened concrete test.

Series	Mix No.	Compressive strength (MPa)	Tensile strength (MPa)	Modulus of elasticity (GPa)	Flexural strength (MPa)
A	1	78.05	4.90	42.53	8.45
	2	79.65	5.85	44.65	10.66
	3	74.53	6.27	46.39	11.24
	4	-	-	-	-
B	1	68.12	4.82	40.21	8.03
	2	73.21	5.70	43.74	9.94
	3	70.07	6.08	44.09	10.74
	4	-	-	-	-
C	1	59.94	4.63	38.56	7.48
	2	68.55	5.54	41.26	9.49
	3	66.10	5.90	42.76	10.02
	4	-	-	-	-
D	1	55.15	4.20	35.03	6.98
	2	67.21	5.09	36.45	8.45
	3	54.01	5.33	37.59	9.14
	4	-	-	-	-

4.2.2. Splitting tensile strength

4.2.3. Modulus of elasticity

4.2.4. Flexural strength

Fig. 4. Flexural strength test using "Universal Machine".

4.2.5. Water absorption

4.2.6. Ultrasonic pulse velocity

4.2.7. Abrasion resistance

5. Conclusion

Rubberized pavement is being taken into account as a sustain- able approach to deal with the environmental and economic crisis

of large amount of waste tire in the world. In addition, since self- compacting concrete (SCC) reduces the amount of energy needed for filed working, it is considered as an energy efficient material which is sustainably suitable for pavement construction. In the present study, physical properties of SCC containing TRC as partial sand replacement and also the effect of addition of polypropylene fiber to this type of concrete have been investigated and the following results have been obtained.

1. The results of tests carried out on fresh concrete signifies the negative effects of increasing fiber content and TRC in concrete on rheological properties of fresh SCC.

2. addition of fiber up to the optimum content of 0.1% increases the compressive strength.

3. The results of the tensile strength test indicated that the tensile strength decreases by increasing the sand replacement with rubber. For instance, 15% sand replacement with rubber resulted in a 14.29% decrease in the compressive strength. This is due to the fact that the tensile fracture mode in concrete containing fiber is different from tensile fracture mode of normal concrete.

4. Replacing the aggregate with TRC decreases the modulus of elasticity. Moreover, the results showed that presence of fiber does not have considerable effect on modulus of the elasticity of concrete and only an imperceptible increase is detected.

5. Increasing the share of rubber as a sand replacement leads to a reduction in the flexural strength. For instance, 15% sand replacement with TRC, when no finer is used, leads to a 17% decrease in flexural strength. However, addition of fiber can improve the flexural strength after the formation of cracks.

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6. Increasing the rubber content from 0 to 15%, when no fiber is used, increases the water absorption by 26.47% while addition of fiber decreases water absorption.

7. By increasing the rubber content in SCC, the velocity of ultra- sonic wave is reduced. This is due to the shape of TRC which contributes to the pore structure. Also, the increase of poly- propylene fiber causes a reduction in the velocity of the ultra- sonic waves.

8. Abrasion resistance index of has a declining trend by the growth of rubber content or the reduction in the content of fiber. Finally, considering the results obtained, it can be stated that increase of TRC in SCC up to 15% has no considerable negative effect on some of the properties studies in this research. However, this effect can be compensated through adding a certain percentage of fiber to the mix. Since enormous volume of concrete is used in different industries every year, considerable quantities of waste rubber can be used in concrete and thus a huge step is taken toward the elimination of such durable pollutants in the environment.

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