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Properties of tire rubber ash mortar

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Abstract

The present study explores the effect of tire rubber ash (TRA) filler on different properties of Portland cement mortar. The properties investigated include air content, setting time, compressive and flexural strength, freezing and thawing damage, and chloride-ion penetration. The TRA was obtained by incinerating bulk quantities of tire rubber chips in an oven at a controlled temperature of 850 °C for 72 h. The TRA filler was utilized as partial replacement of sand in mortar mixtures at four levels: 2.5%, 5%, 7.5%, and 10% by weight. The water to cementitious materials ratio used in the mortar mixtures was 0.65. The test results showed that TRA could be used as a partial replacement of sand in mortar mixtures to produce workable mortar. The air content of the fresh mortar decreased with increasing TRA content. The initial and final setting time of fresh paste increased with increasing TRA content. The mortar containing different TRA replacement levels showed higher compressive strength at various curing periods up to the age of 90 days compared with control mortar. Also, the flexural strength of the TRA mortar was higher than that of control mortar. The mortar containing 5% and 10% TRA showed higher resistance to freezing and thawing damage and chloride-ion penetration than that of control mortar.

Keywords: Tire rubber ash; Mortar; Compressive strength; Setting time; Freezing and thawing damage; Chloride-ion penetration

1. Introduction

Solid waste management is a major environmental issue in many countries around the world. Previous studies have indicated that waste tires constitute a significant portion of non-hazardous solid waste materials [1,2]. Many waste tires are currently stockpiled in many countries around the globe. These stockpiles are dangerous because they pose a potential environmental concern, fire hazards, and provide breeding grounds for mosquitoes [3]. The practice of disposing waste tires in landfills is becoming unacceptable because of the rapid depletion of available landfill sites. Additionally, tires may break through landfill covers, floating upward through a sea of settling and consolidating trash [4].

Innovative solutions to deal with waste tire disposal are being developed. Among the most promising solutions are: reuse of ground tire rubber in a variety of rubber products, thermal incineration of waste tires for the production of heat and electricity, and use of tire rubber in asphalt pavement and Portland cement concrete mixtures [5,6]. Unfortunately, the generation of waste tires far exceeds its current recycling applications.

Previous studies on the utilization of waste tires in asphalt pavement mixtures were very encouraging. They reported that rubberized asphalt had better skid resistance, reduced fatigue cracking, and achieved longer asphalt pavement life than conventional asphalt pavement [7–9]. However, the initial cost of rubberized asphalt is higher than that of conventional asphalt and the long-term durability of rubberized asphalt is questionable [10]. The use of waste tires in Portland cement concrete mixtures has not been investigated as much as their use in asphalt pavements. Most of the studies have dealt with waste tires as individual particles replacing coarse aggregates. Recent results have indicated that rubberized concrete mixtures possess lower density, increased toughness and ductility, higher impact resistance, lower compressive and splitting tensile strengths, lower durability to freezing and thawing damage, and more efficient heat and sound insulation [11–13]. However, no research studies have been reported in the literature concerning the use of tire rubber ash (TRA) in

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concrete mixtures. This study investigates the influence of TRA waste filler on different properties of Portland cement mortar.

2. Experimental program

2.1. Materials

2.1.1. Cement

Type I ordinary Portland cement was used in the study. The physical properties and chemical analysis of the cement are presented in Tables 1 and 2, respectively.

2.1.2. Fine aggregate

The fine aggregate was graded natural silica sand. The bulk specific gravity and fineness modulus of the sand were 2.63 and 1.8, respectively.

2.1.3. Tire rubber ash

Tire rubber ash was obtained by incinerating bulk quantities of tire rubber chips in an oven at a controlled temperature of 850 °C for 72 h. In practice the TRA may be obtained from incineration of tires to generate power. The TRA was collected from the oven and fine ground to pass a no. 100 sieve (150 μm). Tire rubber waste contain about 13% TRA. The physical properties and chemical composition of the TRA are presented in Tables 1 and 2, respectively. The TRA has a dark color and a specific surface area of 410 m^2/kg using the Blaine Method. The SiO_2 and CaO content of TRA are 26.5% and 12.9%, respectively. The TRA has a small water absorption capacity value of 0.2%. The water absorption of TRA will influence some properties of TRA mortar such as strength. The scanning electron micrograph examination of TRA particles (Fig. 1) shows that most particles of TRA are porous and irregular in shape (some particles are sticky).

Table 1
Physical properties of TRA and Type I cement used in the study

Property	Unit	TRA	Type I cement
Specific gravity	–	2.21	3.15
Passing 45 μm	%	90	78
Median grain size	μm	13	18
Blaine specific surface	m^2/kg	410	300
Initial setting time	min	–	145
Final setting time	min	–	270

Table 2
Chemical analysis of TRA and Type I cement used in the study

Component (%)	TRA	Type I cement
SiO_2	26.5	21.2
Al_2O_3	8.7	5.5
Fe_2O_3	9.3	3.1
CaO	12.9	63.7
MgO	6.4	1.5
SO_3	1.6	2.63
Na_2O	1.4	0.18
K_2O	1.1	0.71
TiO_2	1.0	–
Cl^-	0.1	–
Zn	20.2	–
Loss on ignition	10.6	0.96

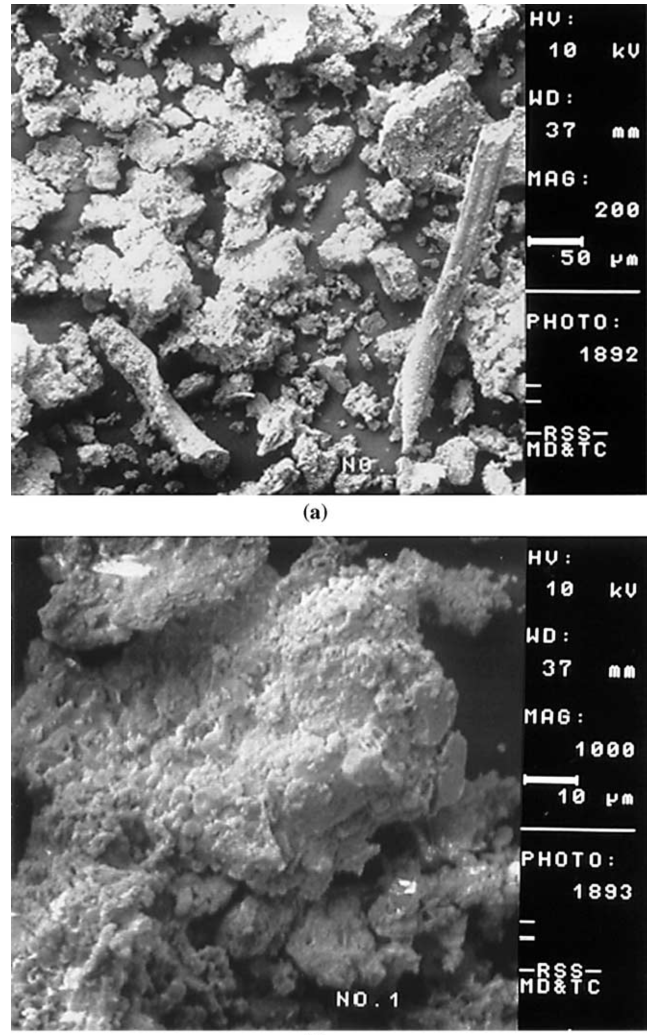

Fig. 1. Scanning electron micrographs of TRA particles. (a) 200× magnification and (b) 1000× magnification.

2.2. Specimens preparation

The mortar was mixed in a laboratory mixer for a total time of 3 min. The mortar mixture proportions were 1:3:0.65 by weight for cement, sand, and water, respectively. The TRA filler was added to mortar mixtures as a partial replacement of the sand at four levels: 2.5%, 5%, 7.5%, and 10% by weight. Since the TRA is less dense than the sand, the overall volume of the TRA

Table 3
Mortar mixture proportions used in the study

Mix	Cement (g)	Sand (g)	TRA (g)	Water (ml)	Flow (%)
1	1000	3000	0	650	140
2	1000	2925	75	650	130
3	1000	2850	150	650	122
4	1000	2775	225	650	113
5	1000	2700	300	650	105

filler is increased. Table 3 shows the mortar mixture proportions used in the study. The workability of the mortar (as measured by flow test) decreased with increasing TRA replacement level. It was more difficult to compact the mortar as TRA replacement level increased. This behavior is explained, as the surface area of the TRA is higher than that of the sand. The compressive strength specimens were cubes measuring 50 by 50 by 50 mm. The flexural strength specimens were beams measuring 40 by 40 by 160 mm. Freezing and thawing test specimens were prismatic measuring 75 by 75 by 400 mm. Resistance to chloride-ion penetration specimens were cylinders measuring 100 by 200 mm. Three mortar specimens were prepared and tested to obtain average values for each test condition. Each specimen was cast in two layers and compacted on a vibrating table. After casting, all specimens were covered with a wet burlap and left in the casting room at 23 ± 2 °C for 24 h. The specimens were then demolded and cured in lime-saturated water at 23 ± 2 °C until the time of testing.

2.3. Test procedures

The air content of the fresh mortar was measured using the pressure method according to the ASTM C 231-97. The setting time of the fresh paste was conducted using the Vicat apparatus according to the ASTM C 191-01. The compressive and flexural strength tests for hardened mortar mixtures were conducted according to ASTM C 109-02 and C 348-02, respectively. The compressive and flexural strength specimens were tested using a universal testing machine. The rates of loading of compressive and flexural specimens were 45 and 3 kN/min, respectively. The rate of loading was maintained constant throughout the testing program. Accelerated cycles of freezing and thawing damage were performed following Procedure B (rapid freezing in air and thawing in water) according to ASTM C 666-97. The freezing and thawing damage was assessed through the measurement of the fundamental transverse frequency of simply supported prisms according to ASTM C 215-97. The relative dynamic modulus of elasticity was calculated based on the fundamental frequency measured. Resistance to chloride-ion penetration was measured in terms of the electrical charge passed through mortar specimens in coulombs at the ages of 28 and 90 days using 50 mm diameter disks on the top portion of 100 by 200 mm cylinders according to ASTM C 1202-97.

3. Results and discussion

3.1. Air content

Fig. 2 shows the effect of TRA replacement on the air content of fresh mortar. The air content decreased with increasing the TRA replacement level from 2.6% for control mortar to 1.5% for mortar containing 10% TRA. The percent decrease in the air content of mortar mixtures were 15%, 27%, 35%, and 42% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively. The decrease in the air content with increasing TRA replacement level may be attributed to the effect of TRA filler packing where TRA particles fill some of the air voids present in the mortar mixture. The air content of the TRA mortar was decreased in spite of the decrease in the workability with increasing the TRA replacement level. This behavior may be explained by the following facts. The period of compaction on the vibrating table was increased with increasing the TRA replacement level to achieve satisfactory and adequate compaction of TRA mortar. Moreover, the TRA filler was used as a partial replacement of the sand by weight. Since the TRA is less dense than the sand, the overall volume of the TRA filler in mortar mixture is increased. The extra volume of the TRA filler fills the entrapped air voids resulting from the decrease in the workability.

3.2. Setting time

Fig. 3 shows the effect of TRA replacement on the initial and final setting time for fresh paste containing

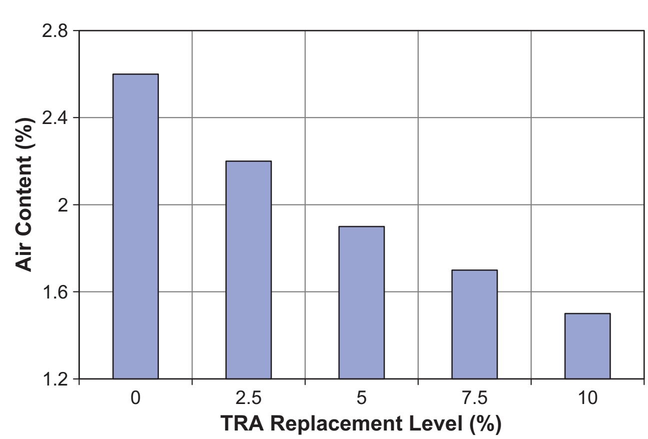

Fig. 2. Effect of TRA replacement on the air content of fresh mortar.

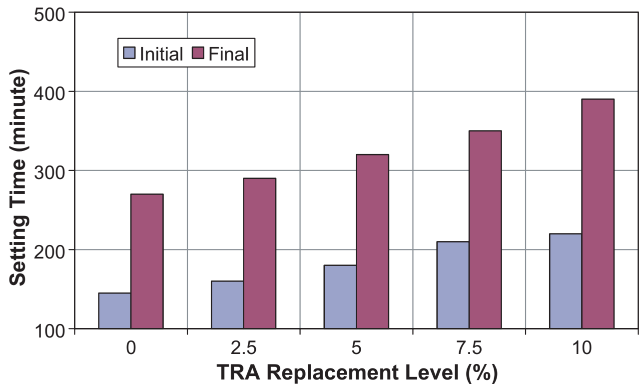

Fig. 3. Effect of TRA replacement on initial and final setting time of fresh paste.

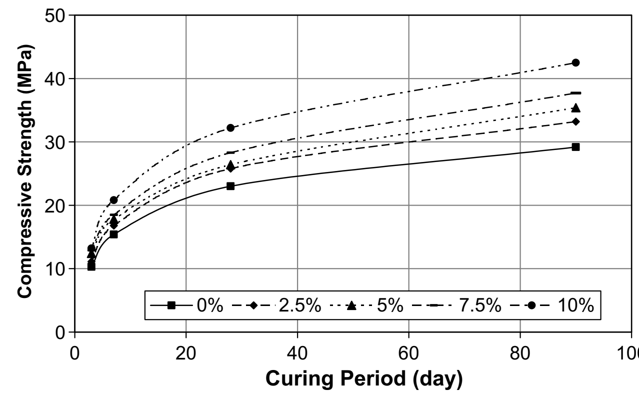

Fig. 4. Development of compressive strength with curing period for TRA mortar.

0%, 2.5%, 5%, 7.5%, and 10% TRA replacement levels. Both the initial and final setting time increased with increasing the TRA content. The initial setting time increased from 145 min for control paste mixture to 220 min for the paste containing 10% TRA. The final setting time increased from 270 min for the control paste mixture to 390 min for the paste containing 10% TRA. The percent increase in the initial setting time of the paste were 10%, 24%, 45%, and 51% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively. The percent increase in the final setting time of paste were 7%, 19%, 30%, and 44% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively. The increase in the initial and final setting time with increasing TRA replacement may be attributed to the presence of substantial amounts of zinc (20.2%) in the chemical composition of TRA (refer to Table 2). The zinc has a retarding effect on the setting time of cement paste (Neville, 1995). The presence of zinc is expected to delay the early strength development (before 3 days) of mortar specimens. However, the later strength development (after 3 days) is usually not affected [14]. The presence of zinc is expected also to increase the plastic shrinkage cracking of mortar and concrete because the duration of the plastic stage is extended.

3.3. Compressive and flexural strength

Fig. 4 shows the development of compressive strength with curing period (3, 7, 28, and 90 days) for hardened mortar containing 0%, 2.5%, 5%, 7.5%, and 10% TRA replacement levels. The rate of compressive strength development is relatively high between 3 and 7 days, followed by slower rate between 7 and 28 days. Between 28 and 90 days, the rate of compressive strength development is relatively slow. The rapid development of compressive strength of mortar containing different TRA replacement levels during the early ages of 3 and 7 days indicates rapid hydration during this period. The development of strength continues even at later ages.

The compressive strength of mortar specimens increased with the increase of TRA content for all curing periods tested (3, 7, 28, and 90 days). The percentage increase in compressive strength for each TRA level was higher at later ages than that at early ages. Such increase in compressive strength of mortar specimens at 7 days was 9%, 16%, 20%, and 35% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively. The percent increase in compressive strength of mortar specimens at 28 days were 12%, 14%, 23%, and 40% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively. The percent increase in compressive strength of mortar specimens at 90 days were 14%, 21%, 29%, and 45% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively.

Fig. 5 shows the effect of TRA replacement on the flexural strength of mortar at 7 and 28 days. The flexural strength increased with increasing TRA content from 2.26 MPa for control mortar to 2.91 MPa for mortar containing 10% TRA at 7 days and from 3.48 MPa for control mortar to 5 MPa for mortar containing 10% TRA at 28 days. The percent increase in flexural strength at 7 days were 10%, 15%, 25%, and 28% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively,

Fig. 5. Effect of TRA replacement level on flexural strength of mortar at 7 and 28 days.

compared to control mortar. The corresponding increases at 28 days were 12%, 27%, 32%, and 43% at TRA content of 2.5%, 5%, 7.5%, and 10%, respectively, compared to control mortar.

The increase in mortar strength (compressive and flexural) with TRA content may be attributed to the physical effect where TRA behaves as a filler in mortar mixtures. This is particularly significant in the interfacial zone regions where TRA produces more efficient packing structure. Therefore, producing a denser, more homogeneous, and a narrower transition zone. Thus, increasing the strength of TRA mortar.

3.4. Freezing and thawing damage

Durability aspects of mortar to accelerated cycles of freezing and thawing damage were studied using mortar containing 5% and 10% TRA replacement. Freezing and thawing damage was assessed using the relative dynamic modulus of elasticity and durability factor. To accelerate the freezing and thawing damage, mortar specimens were subjected to freezing and thawing cycling after 7 days of moist curing. Fig. 6 shows the effect of TRA replacement on the variation of relative dynamic modulus of elasticity with number of freezing and thawing cycles. Fig. 7 shows the effect of TRA replacement on the durability factor of mortar. The control mortar showed little durability to freezing and thawing damage. The relative dynamic modulus of elasticity reached 55% at only 50 cycles of freezing and thawing and the durability factor was 9%. However, mortar specimens containing 5% and 10% TRA showed higher durability to freezing and thawing damage. Mortar specimens containing 5% TRA reached 55% relative dynamic modulus of elasticity at 150 cycles of freezing and thawing and the durability factor was 28%. Mortar specimens containing 10% TRA reached 60% relative dynamic modulus of elasticity at 225 cycles of freezing and thawing and the durability factor was 45%. This result may be attributed to the effect of TRA filler packing of mortar. Thus, producing more durable mortar to freezing and thawing damage.

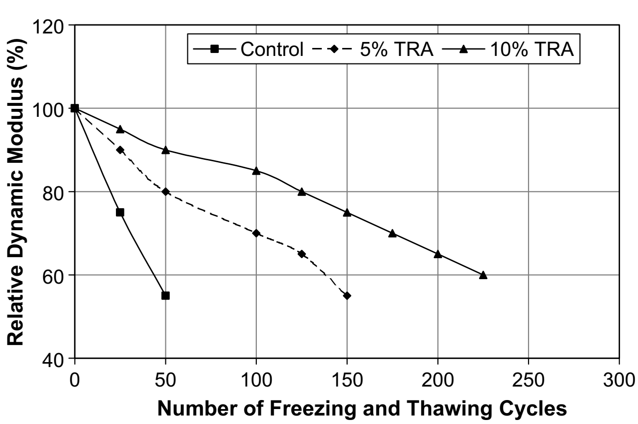

Fig. 6. Effect of TRA replacement on variation of relative dynamic modulus with number of freezing and thawing cycles.

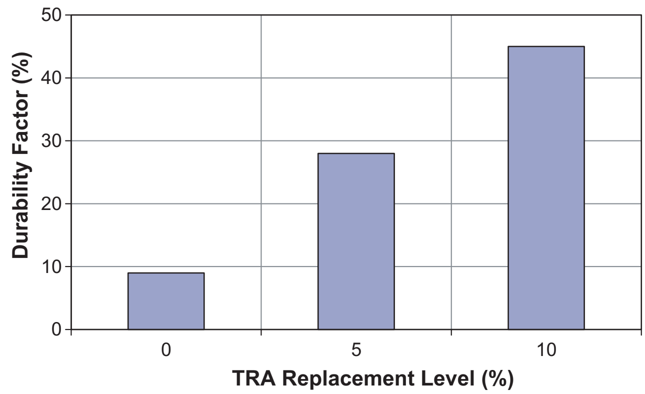

Fig. 7. Effect of TRA replacement on durability factor.

3.5. Chloride-ion penetration

Durability of mortar to chloride-ion penetration was studied using mortar containing 5% and 10% TRA replacement. Fig. 8 shows the effect of TRA replacement on mortar resistance to chloride-ion penetration at 28 and 90 days. The resistance to chloride-ion penetration was measured in terms of the electrical charge passed through mortar specimens in coulombs according to ASTM C 1202-97. The control mortar showed the highest value of electrical charge of 3200 coulombs at 28 days (indicating low resistance to chloride-ion penetration). The electrical charge passed through the mortar containing 5% and 10% TRA were 870 and 420 coulombs, respectively (indicating higher resistance to chloride-ion penetration than control mortar). After 90 days of moist curing, the electrical charge passed through all three types of mortar was reduced. The

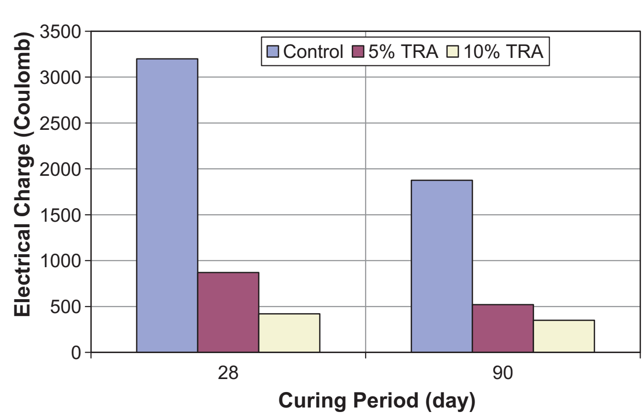

Fig. 8. Effect of TRA replacement on mortar resistance to chloride-ion penetration at 28 and 90 days.

electrical charge passed through the control mortar was reduced to 1875 coulombs, which was significantly higher than that of the mortar containing 5% TRA (520 coulombs) and mortar containing 10% TRA (350 coulombs). According to ASTM C 1202-97, when the electrical charge passed through mortar is below 1000 coulombs, the mortar has high resistance to chloride-ion penetration. This result may be attributed to the effect of TRA filler packing, which reduces the air content of mortar and consequently increases the resistance of mortar to chloride-ion penetration.

4. Conclusions

This study presents the results of partially replacing sand in mortar mixtures with tire rubber ash. Based on the results of the study the following conclusions may be drawn:

1. TRA could be used as partial replacement of sand in mortar mixtures.
2. The air content of TRA mortar decreased with increasing TRA content. The air content decreased from 2.6% for control mortar to 1.5% for mortar containing 10% TRA.
3. The initial and final setting times of TRA paste increased with increasing TRA content. The initial setting time increased from 145 min for control paste to 220 min for the paste containing 10% TRA. The final setting time increased from 270 min for control paste to 390 min for the paste containing 10% TRA.
4. The compressive strength of mortar specimens increased with the increase of TRA replacement level for all curing periods tested (3, 7, 28, and 90 days). The increase in compressive strength for each TRA level was higher at early ages than at late ages.
5. The flexural strength of TRA mortar increased with increasing TRA replacement level.
6. The mortar containing 5% and 10% TRA showed higher resistance to freezing and thawing damage and chloride-ion penetration than that of control mortar.

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