Properties of Recycled Concrete utilizing Waste Rubber

Moataz Badawi

Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Saudi Arabia
mabadawi@uqu.edu.sa

Ayman G. Ahmed

Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Saudi Arabia
agahmed@uqu.edu.sa

Tarek A. Eldamaty

Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Saudi Arabia
tadamaty@uqu.edu.sa

Medhat M. Helal

Civil Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Saudi Arabia | Department of Engineering Mathematics and Physics, Zagazig University, Egypt
mmhelal@uqu.edu.sa (corresponding author)

ABSTRACT

Globally, billions of tires are being disposed of, representing a natural danger. Until now, a little part of that waste is reused, and most tires are simply accumulated. The present paper studies the durability phenomena of recycled concrete with partial substitution of fine aggregate by waste rubber tires. Silica fume, fly ash, and Cement Kiln Dust (CKD) were utilized as substitutions for the binding material. The overall substitution material reached about 30% of the cement content. The long-term behavior was surveyed by methods for water retention, chloride ions penetrability at 28 and 90 days, and protection from aggressive media (sulfate) at 1, 7, 14, and 28 days. Likewise, the compressive strength of concrete samples at 7, 14, 28, and 90 days was measured. The presence of cementitious framework, CKD, silica fume, and fly ash limit the utilization of waste rubber. Substitution percentages of up to 10% rubber fraction and 30% paste framework accomplish a satisfying strength level (35 MPa). These blends also exhibit higher protection from sulfuric corrosive assault than the reference blend.

Keywords-paste framework; rubber waste; recycled concrete; Cement Kiln Dust (CKD); durability

I. INTRODUCTION

Creating asphalt materials by utilizing rubber aggregates is a powerful way to deal with the enormous amount of waste related to tires. Globally, billions of tires are being disposed in landfills addressing a genuine environmental danger [1-3]. More than half of the waste tires are disposed of with no treatment. Removal of crumb rubber is a significant objective in urban communities. The most effortless and least expensive technique for tire removal is burning, but the inevitable contamination makes this practice inadmissible and is prohibited by law in many countries. Tire tuber aggregates acquired from waste tires may be acquired either by mechanical crushing at surrounding temperature or by cryogenic pounding at a temperature underneath the glass progress temperature. The primary strategy creates chipped rubber to supplant coarse aggregates. The second technique normally creates crumb rubber able to replace fine aggregates [4, 5]. The strength at failure is more significant when crumb rubber aggregates are utilized due to the low attachment at the Interfacial Transition Zone (ITZ) of the matrix, yet a few studies suggested various actions to improve the elastic bonds

[6–8]. In addition, it was found that concrete containing elastic material, such as crumb rubber has high fracture toughness [9-11].

The persistent age of waste results with pressure driven and pozzolanic properties tackle ecological issues and layout the requirement for more of their use in various market areas. It was referenced that the development area unmistakably retains most of the composite, by joining it with binder as beneficial binder [12]. For many reasons, the concrete development industry isn't economical. It devours colossal amounts of raw materials. The foremost paste in concrete is Ordinary Portland Cement (OPC), the creation of which is a significant producer of greenhouse gas emissions. Also, many concrete constructions experience the ill effects of concrete durability, which adversely affects the profitability of the industry. A trial program clarified that high-volume fly ash concrete framework tends all three mentioned maintainability issues, and its appropriation will empower the concrete industry to be more sustainable [13]. Recent studies have shown that ternary blended cement, as opposed to OPC, can greatly improve the appearance of concrete. Due to the low heat of hydration of concrete, three different types of mineral admixtures containing OPC, granulated slag, and Fly Ash (PC-SL-FA framework) were developed in [14]. Its structure can be compared to fly ash and slag cement fused together. FA can improve the workability and lessen bleeding in slag cement concrete. It was also found that the strength development of this framework is slightly slower at an early age. The ternary OPC-SL-SF (OPC, blast-furnace slag, and Silica Fume), and OPC-FA-SF (OPC, FA, and SF) mixed cements were developed and are commercially produced in Canada [15-17]. They contain consolidated silica rage.

Reprocessing concrete parts to produce new concrete aggregates is recognised as a viable alternative and is beneficial for the long-term sustainability of concrete [18]. Using Recycled Aggregates (RA) is a crucial step toward creating a more sustainable society. The use of RA in structural concrete has been positively impacted by later studies on concrete built using Coarse Recycled Concrete Aggregates (CRCA) and Fine Recycled Concrete Aggregates (FRCA) [19-22].

Although recycling demolished concrete can help the environment, there are concerns regarding the resulting structure's stability and safety. Tests of RA concrete containing crumb rubber waste related to durability are abundant, but studies on supporting additional tests are scarce. Moreover, tests using rubber waste and ordinary strength concrete indicate a research gap regarding the use of a low water/fastener concrete.

II. EXPERIMENTAL PROGRAM

A. Concrete Constituents

- Cement: Type I privately delivered OPC of 60 MPa at 28 days compressive strength was utilized for all the mixes.

- Admixtures: SF, FA, and CKD as mineral admixtures used for the test were included. The SF used had a 93% SiO_2 content and was a dry, uncompacted powder. A 1.6% of the total was retained on a 45-lm sieve. FA obtained from power stations is classified as Class C according to ASTM C 618. A cement factory in Saudi Arabia donated the CKD. The highly alkaline by-product waste material known as CKD is characterized by granules with diameters ranging from a few to 50 mm that are separated from cement kiln drain gas by air pollution control. When the furnace temperature ranges between 800 and $1000^{o}C$ during the manufacturing cycle, CKD structures are present in cement plants. The convergence of its constituents is differing dependent on the underlying crude materials. In any case, it generally contains a high level of alkali bases, e.g. K_2O and Na_2O. It was tentatively discovered that, in KSA cement plants, the variety of these syntheses isn't huge due to the similarity of the crude materials (quarries). All properties of the mineral admixture are shown in Figure 1.

- Waste rubber: The rubber aggregates utilized in the current investigation were acquired by destroying worn out tires. The crumbs had a normal diameter measurement of 1-3.5 mm sieve size, a specific gravity of 1.1, and a dissolving point of $170^{o}C$. The elastic was utilized at concentrations of 5%, 10% and 15% replacement of fine aggregates.

- Sand: The utilized clean sand had a specific gravity of 2.62, a fineness modulus of 2.85 (medium sand), and a water absorption of 0.65% and was validated with the ASTM requirements (ASTM C-33).

- Crushed stones with specific gravity of 2665 kg/m^3 and water absorption of 0.87% were used. The coarse aggregate size ranged from 5 to 14 mm.

- Recycled Concrete Aggregates (RCA) sourced from a reusing office in Saudi Arabia were utilized. The reused aggregates contained less than 1.0% by weight impurities, as reported by the quality control requirements office. Hence, it is possible to classify the RCA used in this study as CRCA. The grading was changed to meet the requirements of ASTM C-33 and the N.M.S. of the normal and RCA were 14 mm. Mercury interruption porosimeter was used to determine the aggregate's penetrability. The RCA's specific gravity and water absorption were 2550 kg/m^3 and 4.9%, respectively, and they featured continuous grading in sizes from 5 to 14 mm. The sum of the coarse aggregate's mechanical and physical characteristics is given in Figure 2.

- Super plasticizer: A second era super plasticizer, in light of poly-carboxylic either polymer, utilized at proper rates to hold the slump of the fresh concrete somewhere in the range of 120 and 180 mm.

B. Proportions of the Mix Design

In the concrete blend designed by ACI strategy 211, compressive strength of 60 MPa was utilized. A mix of 450 kg/m^3 was designed. The MNS was 14 mm and the W/B ratio was 0.35. The concrete samples were cured at 21 ± 2°C in tap water. All mixes were termed with regard to their composition. A concrete mix of 5%, 10%, and 15% of crumb rubber, 10% SF, 10% FA and 10% CKD reached 60 MPa compressive strength at 28 days. All concrete mixes are reported in Table I.
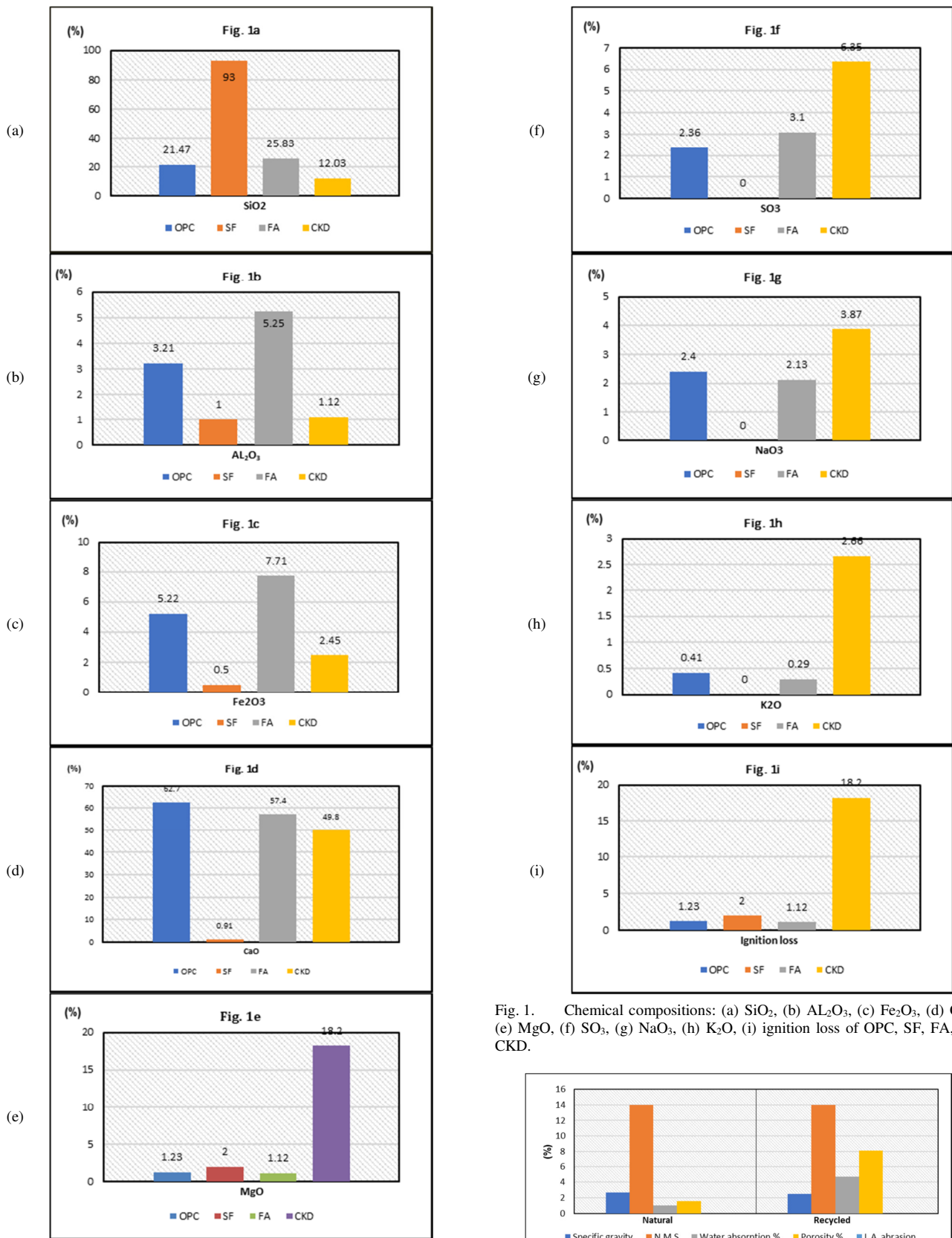
Fig. 1.   Chemical compositions: (a) SiO₂, (b) AL₂O₃, (c) Fe₂O₃, (d) CaO, (e) MgO, (f) SO₃, (g) NaO₃, (h) K₂O, (i) ignition loss of OPC, SF, FA, and CKD.

Fig. 2.   Properties of natural and recycled aggregates.

C. Preparation of Specimens

The concrete blends were made with a drum mixer of 0.1 m^3. The inside of the drum was first washed with water to forestall water ingestion. To prevent variations in the underlying slump, the coarse and fine aggregate divisions were blended first, followed by the amount of water consumed by the aggregates, and left to rest for 30 min. Next, sand was added, followed by the cementitious materials (C, SF, FA, and CKD), and water containing about 75% of the super plasticizer. The remaining one-fourth of the super plasticizer was held back until the final 3 min of blending. The concrete mixtures were crushed by a vibrating table as they flowed in cylinders. The vibration speed increased when each mold was properly filled to ensure optimum compaction.

The concrete samples were placed in a lab at 21°C and 55% relative humidity for 24 h and were covered with damp burlaps. The demolded specimens were then placed in water. Each model was named according to the date of pouring, the mix used, and the persistent number. After that, the models were taken out of the curing tank one day before testing.

TABLE I.   PROPORTIONS OF THE MIX DESIGN

Coarse aggregate concrete mix	Mix. No.	Cement (kg)	Mineral Admixture (kg)			Sand (kg)	Rubber (kg)
			SF	FA	CKD		
Natural	00%R, 00%M	450	0	0	0	1233	0
	00%R, 30%M	315	45	45	45	1233	0
	05%R, 30%M	315	45	45	45	1168	65
	10%R, 30%M	315	45	45	45	1103	130
	15%R, 30%M	315	45	45	45	1038	195
RCA	00%R, 00%M	450	0	0	0	1233	0
	00%R, 30%M	315	45	45	45	1233	0
	05%R, 30%M	315	45	45	45	1168	65
	10%R, 30%M	315	45	45	45	1103	130
	15%R, 30%M	315	45	45	45	1038	195

III.   HARDENED PROPERTIES

A. Compressive Strength

The tests were conducted on 15 cm × 30 cm concrete cylinders. The compressive strength of concrete was about 60 MPa. The compressive strength for every blend was reported at 7, 14, 28, and 90 days.

B. Water Absorption

For each concrete blend and testing age, a 100×100×100 mm cube sample was used to resolve water retention. Using (1), where W_1 and W_2 represent, respectively, oven dry and soaked saturated surface dry conditions, the water absorption (WA%) of each concrete was calculated. At 28 and 90 days, 3

samples from each combination were analyzed, and the results were accounted for.

$$WA\% = \left(\frac{W_2 - W_1}{W_1}\right) \times 100 \qquad (1)$$

C. Chloride Ion Permeability

The chloride permeability ion test was conducted according to ASTM C-1202. Three samples, each 10 cm wide and 5 cm thick, were molded according to the standards and exposed to a 60 V potential for 6 h. The concrete samples underwent a full charge, which was used to evaluate the permeability of chloride ions.

D. Sulfate Resistance

ASTM C-267 was followed. The tests involved soaking 15 × 30 cm concrete samples in a 10% sulfuric solution for 28 days. Differences in the weight of the dry samples exposed to corrosive media at 1, 3, 7, 14, and 90 days were examined for acid attack resistance.

IV.   RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strength improvement with age for the normal aggregates and RCA of different crumb rubber substances and ternary cementitious framework as outlined in Figure 3. The standard deviation was low and the coefficient of variance did not surpass 10%. Comparative conduct was noticed for all blends. The expansion of waste rubber prompts genuine compressive strength failure as demonstrated in Table II illustrates how the amount of tire waste in a concrete sample causes compressive strength reduction. After 14 days, the RCA's compressive strength improved, both with and without mineral expansion, to what it was with NA concrete. The only blends that are related to a high compressive strength, over 51 MPa, separately and 40 MPa surpassing most of the compressive strength classes used in the construction industry are the blends produced using NA and with 5% waste rubber squanders and 30% ternary cementitious framework (5%R and 30%M), as well as the blend produced using RA and with 5% waste rubber squanders and 30% ternary cementitious framework (5%R, 30%M). When compared with the compressive strength of the reference blend, the blend of 5%R and 30%M exhibited a 37.5% compressive strength reduction at 28 days. The blends with a higher rubber rate showed an extreme compressive strength reduction due to the low modulus of elasticity of the rubber. Elastic rubber aggregates have huge pores, and don't essentially add to the protection from remotely applied loads. Consequently, a tire–rubber concrete sample loses its strength analogous to its rubber content.

The estimations of the compressive strength of the blends with fractional substitutions of concrete by ternary cementitious framework (SF, FA, and CKD) for different degrees of rubber levels can be seen in Figure 5. The outcome shows that the substitution of cement by 30% ternary cementitious framework (SF, FA, and CKD) diminished the compressive strength by about 15% at 28 days and by 5-7% at 90 days for NA blends and RA blends. Figure 5 shows the compressive strength of blends with rubber waste and

fractional substitution of cement by ternary cementitious framework. Up to 10% rubber and 30% ternary cementitious material produce a sufficient strength class esteem (30 MPa), as needed for a wide scope of basic primary uses. This result can be reached through both NA and RA concrete, by reasonably diminishing water/cement ratio with the guide of a super plasticizing admixture to keep up a similar usefulness. The outcome shows the synergetic impact of ternary cementitious framework and recycled aggregates, that limits the strength related to the utilization of rubber waste.

The porosity of the RCA-utilizing mixed is higher than the one of the mixes with typical aggregates. The most plausible explanation is the presence of more vulnerable aggregates. The utilization of recycled aggregates has an impact on the compressive strength as the cement lattice, which is the strength controlling connection of the composite framework, is more grounded. This impact isn't obvious on account of SF expansion, and it isn't even observable in FA mixes due to the pozzolanic action. The adequacy of SF expansion at early curing times is especially clear, due to its densifying impact notwithstanding the pozzolanic action.
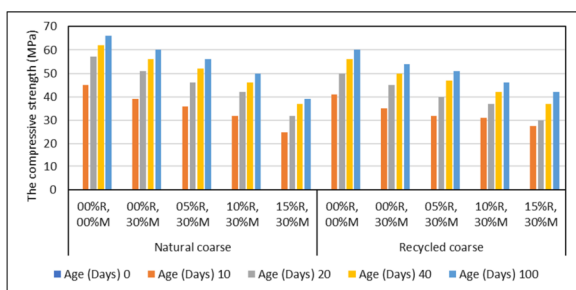

Fig. 3.   Compressive strength vs time for the natural and RCA cements of various proportions.

In addition, this outcome ascribed to that FA and CKD in ternary cementitious framework exhibit moderate hydration subsequently giving little commitment to early age strength, whereas SF has a high reactivity with calcium hydroxide being able to quicken concrete hydration. The decrease in strength could likewise be credited to the critical expansion in free lime content in CKD that build the measure of $Ca(OH)_2$ because of its reaction with water. Calcium hydroxide has a volume bigger than water, thus, this volume increment creates internal stress that debilitates the hardened framework.

TABLE II.   COMPRESSIVE STRENGTH VS TIME FOR NATURAL COARSE AND RCA CONCRETE MIXES

| Mix		Rubber and mineral admixture content	Age (days)					
			0	20	40	60	80	100
Compressive strength (MPa)	Natural coarse aggregates	00%R, 00%M	00.0	57.0	62.0	64.0	65.0	66.0
		00%R, 30%M	00.0	51.0	56.0	58.0	59.0	60.0
		05%R, 30%M	00.0	46.0	52.0	54.0	55.0	56.0
		10%R, 30%M	00.0	42.0	46.0	48.0	49	50.0
		15%R, 30%M	00.0	32.0	37.0	39.0	39.8	39.0
	RCA	00%R, 00%M	0	50	56.0	58.0	59.0	60
		00%R, 30%M	0	45	50.0	52.0	53.0	54.0
		05%R, 30%M	0	40	47.0	49.0	50.0	51.0
		10%R, 30%M	0	37	42.0	44.0	45.0	46.0
		15%R, 30%M	0	30	37.0	39.0	40.0	42.0
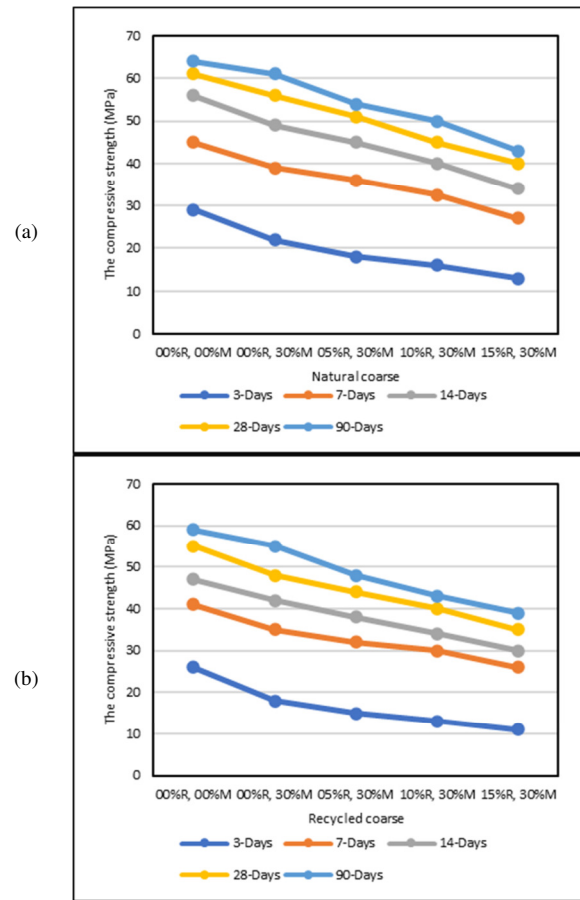
Fig. 4.   Compressive strength of blends with elastic squanders and fractional substitution of concrete by ternary cementitious framework.

B. Failure Behavior

Visual analysis of the concrete samples was used for the identification of failure. Although the concrete proves to be more flexible with the rubber replacement of NA, it is interesting that the tire-rubber concrete failure behavior is more progressive. Figure 5 exhibits how the failure boundaries develop consistently from the base to the highest point of NA and RCA samples. Additionally, after a loading progression, the tire-rubber concrete samples exhibit significant lateral deformation. Concretes made of tire rubber have what is known as post-fracture strength, or the ability to bear loads after the peak load. When the fragments or cuts in the concrete samples are divided, fracture states in the samples are revealed. Because rubber particles cross the cracks in concrete, there was no difference between the failure state and the fracture state. The 5%R and 30%M samples of tire-concrete samples showed significant strength loss but did not show any separation. Furthermore, as can be seen in Figure 5, the fracture that took place on the RA concrete, resulted in two equally symmetric countenances. At the interfacial transition zone, this did not happen frequently. In fact, the old cement matrix of RCA had lower strength for low water/cement than the cement paste matrix of the concrete RCA mixture. For instance, the new matrix's nature was superior to the old matrix. As a result, RCA take care of the composite framework's weakest link and

connection that controls strength. Tire-rubber concrete samples exhibit larger distortions. The adaptive behavior of tire particles during the dumping encounter reduces the internal friction between the concrete components and recovers additional tension. Concrete samples made of tire and rubber regularly and slowly developed fracture qualities, such as discontinuities and cracks. Conversely, the failure progress manifestation was sudden and concentrated for plain concrete. The lateral deformations of tire-rubber concrete samples were greater than those of plain concrete samples, but because tire particles have replaced some of the plain concrete's, the Poisson's ratio for tire-rubber concrete is a little higher. Noting that rubber-treated concrete's conduct isn't entirely elastic, Poisson's ratio isn't constant for the progression of loading. As the conduct of rubber-treated concrete approaches plasticity, Poisson's ratio increases and gets close to 0.5.
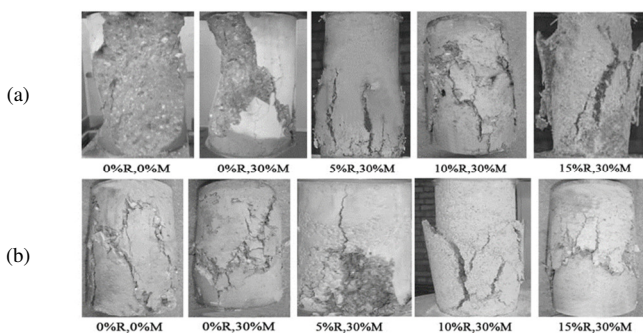

Fig. 5.   Type of failure of (a) NCA, (b) RCA mixtures.

C. Water Absorption

The blends were tested in accordance with ASTM C 642 for water absorption and the results can be seen in Figure 6. It was observed that depending on the waste rubber and ternary cementitious structure, for NA blends, the water intake of the samples varied from 2.8% to 3.8% and from 2.6% to 3.6%, after 28 and 90 days, respectively. Depending on the component rubber and ternary cementitious framework, for RA blends, the water absorption changed from 3.08% to 4.18% and from 2.86% to 3.96% after 28 and 90 days. As expected, the combination with 15% rubber had the highest water absorption. Linking ternary cementitious framework reduces water absorption. For instance, the mix with 0% rubber and 0% ternary cementitious framework had a water absorption estimate of 2.5% at 90 days, but the blend with 0% rubber and 30% ternary cementitious framework had a water absorption estimate of 2.9% at 90 days, indicating a drop of roughly 16%. Due to the filling effect of the ternary cementitious framework during the early ages and its pozzolanic reaction during the later ages, the beneficial influence of ternary cementitious framework in reducing the water absorption was observable. The filling effect is immediate in the presence of ternary cementitious framework, and the pozzolanic response is surprisingly high within 90 days. Using waste rubber increased the concrete's capacity for retention. This conclusion corresponds to the augmentation in porosity with the filling percentage in the combinations and most likely is caused by the specific deviations of rubber particles from sand grain size

transportation and the marginally greater air amount collected through the blending methodology.
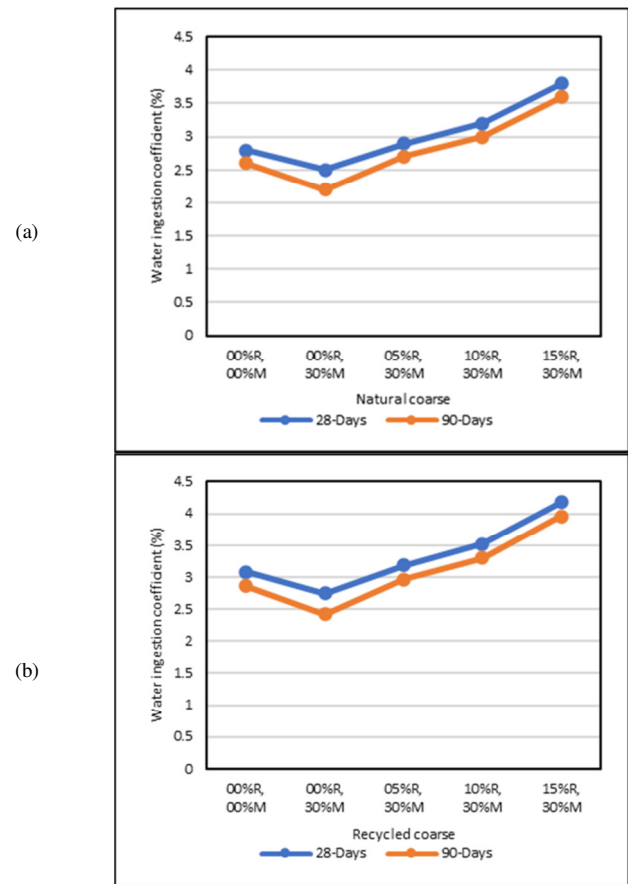

Fig. 6.   Water absorption coefficient of blends with fractional concrete substitution using silica smolder, FA, and CKD, and elastic squanders. (a) NA, (b) RA.

D. Chloride Penetration

Figure 8 shows the results of the chloride ion penetration test of rubber and ternary cementitious framework versus age. The data shown in Figure 8 demonstrate that, for typical total blends, the chloride particle porousness ranged between 2161 and 2792 C and 1888 to 1220 C at 28 and 90 days, respectively. For reused blends, the chloride particle penetrability ranged from 2376 C to 3069 C and 2097 C to 1345 C at 28 and 90 days, respectively. At 28 and 90 days, the chloride particle penetrability ranged from 2376 C to 3069 C and 2097 C to 1345 C, for each blend of RA. Using ternary cementitious framework only reduces the intrusion of chloride particles, particularly at 90 days. As the rubber substance increases from 0% to 15% as a replacement for fine aggregates, the chloride ion penetration increased from 1619 to 2792 C and from 655 to 1220 C at 28 and 90 days, respectively, for NA blends.

As depicted in Figure 7, at 28 and 90 days, respectively, the control concrete's chloride ion penetrability decreased from 2161 C to 1619 C and from 1888 C to 655 C when the blends had incorporated ternary cementitious framework at 30%

replacement level. Although adding the ternary cementitious framework to the NA and RA rubber concrete blends significantly improved their resistance to chloride ion penetration, it was reduced by roughly 65% in NA and RA concrete without waste rubber when the time period was extended to 90 days. No matter the rubber type, all blends containing 5-15% elastic demonstrated an increase in the penetrability of chloride particles of roughly 80% for the 15% R, 30% M blend compared to the 0% R, 30% M blend, by using a ternary cementitious framework, the rating of the concrete was changed at 90 days from moderate to low or exceptionally low. Research proved that using a ternary cementitious framework at 90 days significantly minimized the deleterious effects of rubber on chloride ion penetrability. This result is attributed to the prolonged response of the ternary cementitious framework, which improves the cement's pore structure to lessen chloride ion entry. The reduced penetrability of chloride particles was caused by the improved pore structure. Figure 7 shows the relationship between the concrete's ability to absorb water for 28 and 90 days and the penetrability of chloride ions. It was observed that the amount of water absorbed had a significant impact on the cement's ability to penetrate chloride ions.
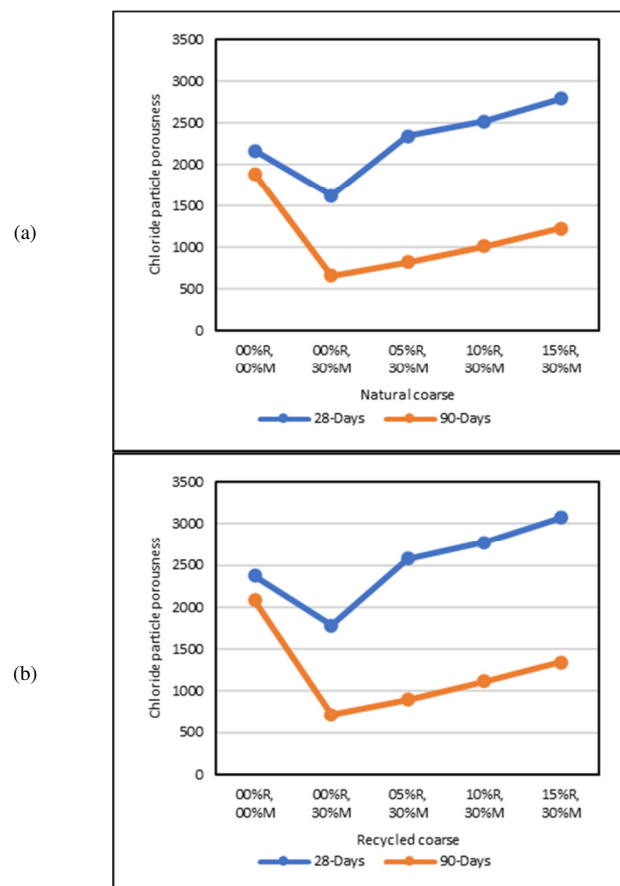
(a)

(b)

Fig. 7.   Penetrability of chloride particles in combinations with concrete that has been partially replaced by silica seethe, FA, and CKD, as well as with elastic squanders for both NA and RA.

V.   CONCLUSION

This experimental work covers the durability phenomena of recycled concrete with half-way substitution of FA by waste rubber tires. SF, FA, and CKD were utilized as substitutions of the binding material. The overall substitution material reached about 30% of cement content. The following conclusions can be derived from the data presented in this study:

- The extreme compressive strength of NA and RA concrete was drastically reduced by more than 40% when fine aggregate substitution with waste rubber tires was used.

- Rubber waste can be used up to 15% and yet maintain low water retention for NA and RA cements. Yet, the combined effect of 30% farmwork cementitious frames reduces the strength loss associated with the use of rubber waste by around 50%.

- On pressure testing, rubber-treated concrete samples exhibited more ductile behavior than the untreated samples. Unlike ordinary concrete, rubber-treated concrete doesn't fracture quickly and doesn't cause any component separation in the sample.

- Porosity is insufficiently influenced by the crumb rubber's presence in the concrete. As a result, estimates of the rubber-treated concrete's water retention increased. Moreover, the water intake increased as the rubber percentage grew. At both 28- and 90-day test results, a substantial increase was observed in the chloride ion penetration of all blends along with the increase in rubber material without ternary cementitious framework. The chloride ion penetration of all concrete samples at 28 days was significantly influenced by the 30% ternary cement framework expansion. However, when the time period was extended to 90 days, the prolonged reaction of 30% ternary cementitious framework refines the cement's pore structure so the chloride particle penetration was significantly reduced.

- The blends with 30% cementitious framework exhibited greater resistance to sulfuric corrosive attack than the reference mix without rubber waste. In comparison to the reference blend, the mixture that included 5% rubber waste and partially replaces concrete with cement (10% SF, 10% FA, and 10% CKD) provides outstanding resistance from sulfuric corrosive attack.

This investigation used local materials to produce the concrete samples and successfully developed concrete mixes with ternary cementitious material to reach the level of normal concrete properties at high level of rubber waste content.

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