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EXPERIMENTAL INVESTIGATION OF CONCRETE WITH RECYCLED TYRE-RUBBER WASTE AS FINE AGGREGATE MATERIAL

EKSPERIMENTALNA RAZISKAVA BETONA Z DODATKOM FINEGA AGREGATNEGA MATERIALA IZ RECIKLIRANIH ODPADNIH AVTOMOBILSKIH GUM

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Waste tyre-rubber disposal is a serious global problem, posing a severe danger to the environment. This present study aims to investigate the performance of concrete utilizing recycled tyre-rubber waste as a partial replacement for natural fine aggregate. Three different sizes of crumb rubber were combined to produce a well-graded sample. Based on various trials, mixed proportions of M30 grade concrete and the crumb rubber replacement percentages were determined. The test specimens were prepared. Experimental investigations have been carried out to study the mechanical, durability and temperature properties of the developed Crumb rubber concrete (CRC). In this study, crumb rubber replaced the fine aggregate in various percentages, such as (0, 5, 7.5, 10 and 15) %. Microstructural analysis was also carried out with EDX and scanning electron microscopy (SEM) to visualize the performance of rubber with CSH gel under different temperature conditions. The study found that (CRC5) a 5 % replacement of crumb rubber is the optimum percentage to replace the natural fine aggregate to develop the crumb rubber concrete. The durability tests concluded that the proposed model of rubberized concrete is suitable for any structural elements exposed to acidic environmental conditions.

Keywords: waste, rubber aggregate, concrete, recycling

Odlaganje odpadnih avtomobilskih gum predstavlja resen ekološki in varnostni problem po vsem svetu. V članku je predstavljena študija lastnosti betona z dodatkom recikliranih avtomobilskih gum, kot nadomestilo za naravni fini agregat. Kombinirane so bile tri različne velikosti drobirja (zdrobljene gume) in s tem pridobljen material. Preizkušanci so bili pripravljeni iz različnih preizkusnih mešanic, z različno količino drobirja, finega in grobega agregata in kot osnovo beton kvalitete M30. Določene so bile mehanske lastnosti iz betona (CRC; angl.: crumb rubber concrete) izdelanih preizkušancev, z vsebnostjo različnih dodatkov drobirja iz recikliranih avtomobilskih gum. Določena je bila tudi trajnost, temperaturna stabilnost in odpornost proti kislemu oz. bazičnemu okolju preizkušancev. V tej študiji je bil fini agregat zamenjan z različno količino drobirja (0, 5, 7,5, 10 in 15) %. Izvedene so bile tudi mikrostrukturne analize s pomočjo rentgenske difrakcije (EDX) in vrstične elektronske mikroskopije (SEM) z namenom določitve lastnosti CRC betona, ki je pri različnih temperaturah vseboval različno količino kalcij-silika-hidratnega gela (CSH). Študija je pokazala, da je optimalni dodatek 5 % (CRC5), kot nadomestilo za dodatek naravnega finega agregata. Testi trajnosti betona CRC5 so pokazali, da je predlagani model izdelave betona, ki vsebuje reciklirano gumo primeren za katerikoli strukturni (gradbeni) element, ki je lahko v naravi izpostavljen kislemu ali bazičnemu okolju.

Ključne besede: odpad, gumijasti agregat, beton, recikliranje

1 INTRODUCTION

One of the common issues faced by most countries is waste handling and management. The production of large numbers of automobiles results in the deposition of a huge quantity of waste tyres all around the world. It was estimated that approximately 4 billion waste tyres were in landfills and stockpiles worldwide and only a few percent of waste tyres have been utilized for civil engineering projects.[1] Hence, numerous studies show that attention was not paid to identifying the civil engineering applications of waste tyres.[2] Waste tyre rubbers are categorized into crumb rubber, ground rubber and scrap tyre. These tyre wastes are used in various engineering applications such as embankment and highway base courses.[3] Amirkhanian et al.[4] have tested highway pavements by laying asphalt rubber concrete on various portions of the road, which attains high tensile strength compared to conventional concrete. Crumb rubber also can reduce the density, brittleness, freeze-thaw damage, ride noise, drying and temperature expansion of concrete.[5] An increase in crumb rubber in concrete decreases the workability and unit weight of the tyre rubber aggregate concrete (TRAC) mixture.[6] The percentage of air voids is large even though air-entraining agents are not used in TRAC.[7] Bisht and Ramana[8] reported that the inclusion of 4 % crumbed rubber in concrete would reduce the compressive and flexural strength of concrete. Assaggaf et al.[9] investigated the performance of concrete incorporated with rubber crumbs treated with NaOH, $KMnO_4$ and cement

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Table 1: Various mix proportions of concrete used in this study

Mix	Grade of concrete	Cement (kg/m^3)	Replacement % of CR as FA	Fine aggregate (kg/m^3)		Coarse aggregate (kg/m^3)	Water (kg/m^3)
				Sand	Rubber		
Control	M30	425.73	0	689.06	0	1132.42	191.58
CRC5	M30	425.73	5	654.61	34.45	1132.42	191.58
CRC7.5	M30	425.73	7.5	637.38	51.67	1132.42	191.58
CRC10	M30	425.73	10	620.16	68.9	1132.42	191.58
CRC15	M30	425.73	15	585.65	103.3	1132.42	191.58

and concluded that a 40 % replacement of sand aggregates by cement-treated rubber crumbs perform better under acidic attack. Asutkar et al.[10] reported that the percentage of rubber crumbs in concrete is directly proportional to the toughness of concrete but inversely proportional to the compressive strength of concrete. It is also mentioned that the strength reduction is negligible with up to 15 % replacement of fine aggregate by rubber crumbs. Lashari et al.[11] used rubber crumbs as a partial replacement for sand and concluded that adding crumb rubber greatly improves skid resistance. Researchers[12] investigated concrete with rubber aggregates at elevated temperatures up to 800 °C. As the temperature exceeds 400 °C, concrete strength rapidly decreases due to the disintegration of calcium silica hydrates (CSH) and at around 800 °C the structure of CSH disperses.[13] The quantity of rubber aggregate in the concrete should be limited to avoid significant loss in mechanical and durable qualities. Hence, it is necessary to develop a crumb rubber concrete by utilizing the tyre rubber waste as a fine aggregate. The current study aims to investigate the performance of concrete utilizing recycled tyre-rubber waste (crumb rubber) as a partial replacement for natural fine aggregate. The research had the following objectives:

- To design the mix proportion of concrete incorporating the crumb rubber waste using the IS code.
- To investigate the mechanical strength parameters of the concrete utilizing crumb rubber waste.
- To examine the durability of concrete incorporating the recycled crumb rubber waste.
- To study the performance of concrete when it is subjected to elevated temperature and to find the optimal percentage of crumb rubber aggregate replacement to develop the crumb rubber concrete.

2 EXPERIMENTAL PART

2.1 Materials

Crumb rubber concrete was developed using the following materials such as Portland cement, water, fine aggregate, coarse aggregate and crumb rubber aggregate. Following the IS provisions, the physical properties of the materials were tested to ensure their suitability for use in concrete. Cement in concrete functions as a binder that hardens once water is added. Ordinary Portland cement (OPC) of 53 grade with a specific gravity of 3.12 and a consistency of 32 % complying with IS:12269–2013 standard[14] was used in this investigation. The sand used in the mix confirms ZONE II as per IS 383–1970 standard[15] which indicates that the aggregate is fit for concreting purposes. The fineness modulus of fine aggregate is 3.11. This experiment makes use of crushed angular material as coarse aggregate with sizes of 10 mm and 20 mm.

In this study, tyre-rubber waste is used as a partial replacement for natural fine aggregate. The tyre-rubber granules that are used as a replacement for natural fine aggregate are obtained by the reduction of scrap tyres to aggregate sizes using factory-made mechanical grinding into the required dimensions. These are also called crumb rubber (CR). The blending of crumb rubber in trials was carried out and found the best proportion of rubber crumbs suitable for the mix. The size of the rubber crumbs varies from 1–4 mm of which 25 % of the rubber crumbs belong to 2–4 mm, 35 % belong to 1–2 mm and 40% are less than 1 mm. This proportion is made for all types of rubberized concrete mixes without affecting the zone and fineness modulus of the combined aggregate. Sand and crumb rubber aggregate were graded by IS 383–1970. The gradation curve of the combined aggregate and the combined aggregate with rubber is shown in

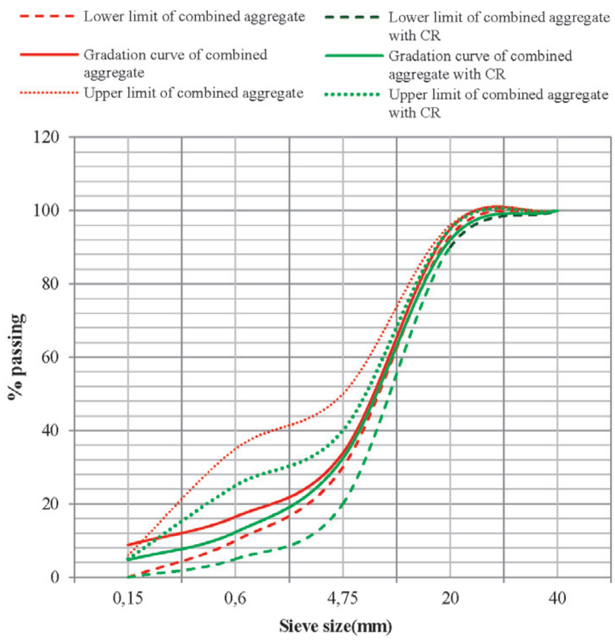

Figure 1: Gradation curve

Figure 1. The gradation of combined aggregates and combined aggregates with rubber crumbs were similar, which clearly shows that the particles are well graded. Hence, it was considered to replace the crushed sand (natural fine aggregates) with the crumb rubber that was procured at 7.5 % of total crushed sand weights.

2.2 Mix design and methodology

The M30 grade of concrete considered for this present study and it is designed based on IS 10262: 2019 standard[16] and IS 456:2000 standard.[17] Based on the trials, the final mix proportion of M30 concrete is achieved and provided in **Table 1**.

To develop a crumb rubber concrete investigations were undertaken on five different mixes of concrete in which (0, 5, 7.5, 10 and 15) % of fine aggregates are replaced by rubber crumbs. Primary tests were conducted on fresh concrete to determine the workability (**Figure 2**) and thereafter hardened concrete tests were conducted to determine the compressive strength, flexural strength and split tensile strength of the concrete with various mixes.

2.3 Preparation of specimens

Using a conventional blade-type mixer, samples were cast by mixing the materials as per the mix proportions proposed in this study. The procedure of mixing is similar for all the types of concrete mix. In the case of rubberized concrete, the crumb rubbers are added only after loading the cement, fine aggregate and coarse aggregate into the mixer. We made sure that the rubber crumbs are mixed thoroughly with cement and aggregates. The weight fraction of crumb rubber aggregates over fine aggregate varied from (0, 5, 7.5, 10 and 15) % of natural fine aggregates. Though rubber crumbs are less in the percentage they occupied more volume due to the less specific gravity and density. Water is progressively added to the mixture for 2 min, followed by 5 min of mixing to make a homogenous mix. A standard 150 mm × 150 mm size cube is prepared for the compressive strength test, acid test, chloride test and temperature test. To conduct the flexural and split tensile strength test, prism (100 × 100 × 700) mm and cylinder 150 mm × 300 mm specimens were prepared, respectively. The size of the specimen used for the shrinkage test is (76 × 76 × 286) mm and is selected based on ASTM C 157 standard.[18] The fresh concrete is filled in mould in three layers and vibrators are used to expel the confined air from the mixture. To make sure full compaction, the visual appearance of the fresh concrete is recorded and the vibration time is adjusted accordingly. The specimens were demoulded after 24 h and put into the curing tank for up to 28 d.

Figure 2: Workability of the concrete-slump test

3 RESULTS AND DISCUSSIONS

The concrete specimens were tested in this research to find the mechanical and durability performance of the developed CR concrete.

3.1 Workability of concrete

To determine the workability of the fresh concrete, slump tests were performed. The workability of the conventional concrete was in the range 50–75 mm. The crumb rubberized concrete performed well while handling, placing and finishing were similar to that of the control mix. Moreover, due to low unit weight, mixtures with a greater rubber aggregate component necessitate more work and effort to smooth the completed surface. The graph in **Figure 3a** shows that the flow value of concrete specimens with rubber crumbs was very close to the behaviour of conventional concrete. It was also observed that the increase in the percentage of rubber crumbs in the concrete gradually decreases the workability of fresh concrete. This reduction in workability is also due to the absorption of water content by the rubber particles present in the mixture. Rubber can absorb large quantities of water compared to sand particles.[19]

3.2 Compressive strength

In this study, the compressive strength of concrete with a partial replacement of fine aggregate by rubber crumbs was carried out as per IS 516:2014 standard.[20] The compressive strength results are presented in **Figure 3b**. It is observed that the increase of rubber content decreases the compressive strength of rubberized concrete. The performance of fine aggregate replacement with crumb rubber in M30 grade concrete is good up to 5 % of replacements, and they nearly achieve the target mean compressive strength. The CRC5 attained 93.13 % strength of the conventional specimen and 7.5 % replacement crumb rubber results attained 83.81 % of 28 d strength of conventional concrete samples. It is found

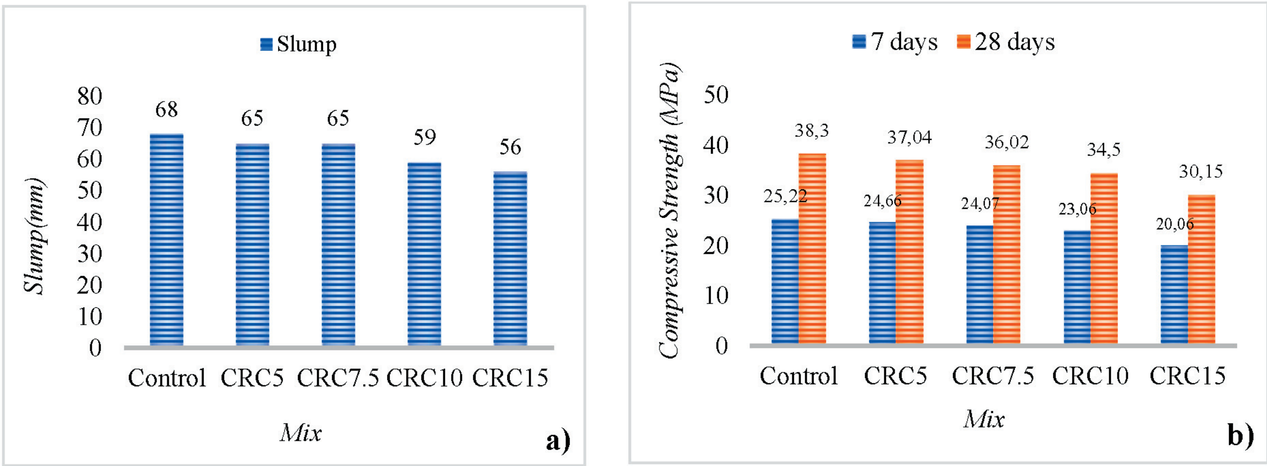

Figure 3: Experimental results of: a) slump cone test, b) compressive strength test

that, except for the 5 % replacement of crumb rubber (CRC5), all other percentage replacements give a lower compressive strength than that of the target mean compressive strength of M30 grade concrete.

3.3 Splitting tensile strength

The split tensile strength of concrete is determined as per IS 5816:1999.[21] **Figure 4a** shows the split tensile strength of concrete. The crumb rubber concrete mixture (CRC5) achieves a maximum tensile strength of 3.54 MPa at 28 d, which is 3.38 % higher in comparison with the control mix. The mixes CRC7.5, CRC10 and CRC15 show a reduction of 13.23 %, 26.99 % and 38.0 % strength, respectively, compared to the control mix at 28 d strength. As the stress induced on a brittle material increases, minute cracks are formed within the material.[22] Hence, the usage of soft materials like rubber within these brittle materials could be able to resist this expansion. Thus, in this research crumb rubber soft material acts as a barrier against the propagation of cracks, leading to an increase in the tensile strength of the CRC5 mixture.

3.4 Flexural strength

Figure 4b depicts the experimental setup of the flexural strength test. The flexural strength of conventional and concrete specimens containing varying percentages of crumb rubber was evaluated by IS 516–2014. As shown in **Figure 4b**, CRC5 performs exceptionally well. CRC5 and CRC7.5 show an increase in the flexural strength compared to the control mix by 2.62 % and 1.04 %, respectively. But CRC10 and CRC15 have lower strength compared to the control mix. As the amount of rubber particles in the concrete increased, flexural strength decreased gradually. This reduction in flexural strength is due to the irregular shape and the smooth texture of the rubber crumbs that fail to interlock the cement matrix as the rate of loading increases.[23]

3.5 Shrinkage test

The drying shrinkage of the concrete specimens was tested based on ASTM C 490.[24] The experimental results of the shrinkage test are presented in **Figure 5** in which the average values for the restrained concrete specimens at (1, 7, 14, 21 and 28) d were plotted. The drying shrinkage of the control mix after 28 d of curing is found to be 26.13 %, whereas the CRC5, CRC7.5, CRC10 and

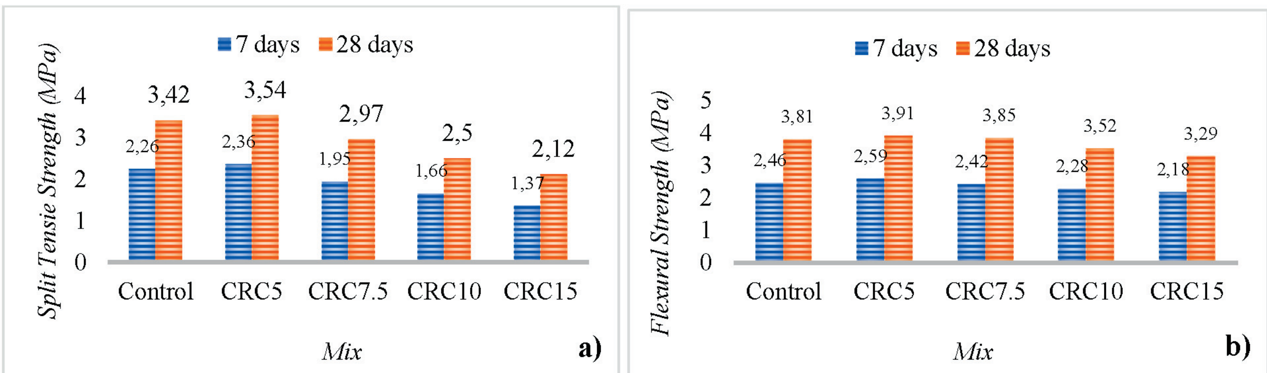

Figure 4: Experimental results of: a) split tensile strength test, b) flexural strength test

CRC15 replacements show a decrease in shrinkage value of (9.21, 10.84, 11.64 and 13.79) %, respectively. The shrinkage value decreases as the crumb rubber aggregates are added to the concrete mixture. CRC5 shows the least shrinkage value, whereas CRC15 shows the maximum shrinkage. Though the drying shrinkage of rubberized concrete is less than the control mix, the addition of rubber crumbs to the mixture is limited to 15 %. Since, the crumb-rubber particles possess very good deformation capacity, the shrinkage strain is partially transferred to the rubber particles and thus the overall shrinkage strain of the concrete specimen was reduced. A high water-cement ratio also influences the increase in shrinkage value. Hence, a further reduction in the w/c ratio of the samples could also reduce the shrinkage value of rubberized concrete.[25]

3.6 Acid and chloride attack test

3.6.1 Acid attack

The acid test was conducted by immersing concrete cubes with various mixes in a solution made with a combination of concentrated HCL acid (5% by volume) and ordinary potable water. The response of the CR concrete to the acidic conditions is indicated through percentage loss and gain in weight after 28 d of immersion. It is evident from **Figure 6** that the crumbed rubber concrete immersed in concentrated HCl solution shows a considerable loss of weight compared to conventional concrete. The weight reduction is less up to 7.5 % replacement (CRC7.5) and then it is gradually increased as the percentage of rubber crumbs in the concrete increases. Conventional concrete attains a maximum weight loss, whereas CRC7.5 shows a minimum weight loss, which is 57.89 % less than the control specimen. The percentage weight losses in CRC10 and CRC15 are also less than the conventional concrete. When concrete material is exposed to concentrated HCl, the concrete matrix is disintegrated due to the formation of calcium chloride, which thereby causes weight loss. This disintegration creates large cavities inside the concrete matrix, enlarging the gap at the interfacial transition zone.[26]

3.6.2 Chloride attack

A chloride test was conducted with a solution prepared by a combination of NaCl and ordinary potable water. The response of the concrete specimen immersed in the NaCl solution with 15 % of rubber crumbs (CRC15) attains a maximum weight gain of 1.71 %, as shown in **Figure 6**. The concrete mixture with 7.5 % replacement (CRC7.5) attains a minimum weight gain of 0.86 % and thereafter as the percentage of rubber crumbs in concrete increases, the weight gain also increases. This weight gain is caused by the reaction between NaCl and $Ca(OH)_2$ in cement forming $CaCl_2$ and NaOH. The CR concrete is eroded by the chloride ions forming fibrous crystals which become distributed within the concrete by filling the cracks between both the cement paste and the rubber aggregates.[27]

3.7 Temperature test

The temperature test was carried out with the concrete specimens containing 5 % crumb rubber (**Figure 8f**). The specimen was subjected to a condition above room temperature for (2, 4, 6 and 8) h. After the application of elevated temperature to the concrete samples. The samples were tested using microstructural analysis to find out whether the crumb rubber starts melting or not when it is subjected to elevated temperature. The results are discussed below.

3.7.1 Results of microstructural analysis

The EDAX microstructural analysis of the CRC5 specimens exposed to elevated temperature show the peak positions of the elements present within the concrete sample. **Table 2** infers that the percentage of oxygen (O) in the samples is found to be more significant

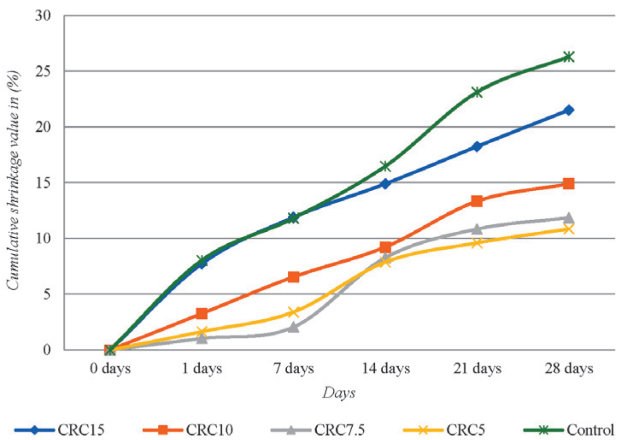

Figure 5: Experimental results of shrinkage test

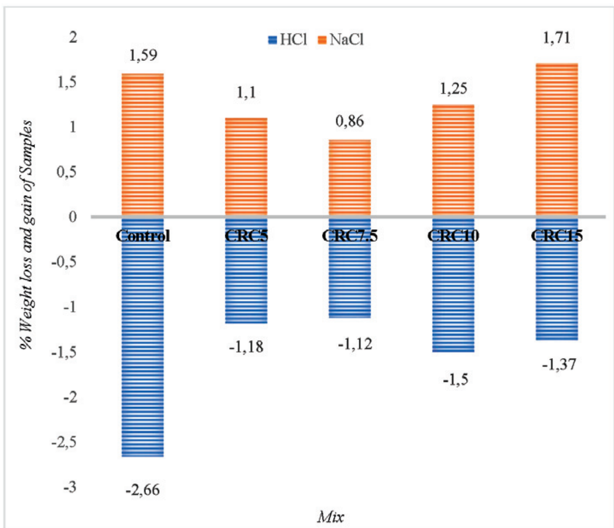

Figure 6: Experimental results of acid and chloride attack test

than any other element. Calcium (Ca) which is responsible for the formation of CaO, one of the primary components of concrete also increases when the percentage of CR concrete. This indication of carbon (C) and sulphur (S) is due to the presence of tyre aggregates, which contain a high quantity of C and S. Overall, the EDAX analysis revealed that the composition of various elements in the concrete mixture varies with the inclusion of rubber crumbs in concrete (**Table 2**). During the hydration period, various degrees of oxidation reaction take place within the concrete mixture due to the rubber components. Hence, the strength of the crumb rubberized concrete is affected by the poor chemical reaction caused by high C and S contents, which act as impurities.

Table 2: Chemical composition of control specimens and crumb rubber concrete specimens

S.No	Element	Conventional concrete		5 % crumb rubber aggregate concrete	
		Weight (%)	Atom (%)	Weight (%)	Atom (%)
1	C	2.91	3.42	3.35	4.85
2	O	47.49	66.85	47.57	67.15
3	Na	0.77	0.76	0.08	0.08
4	Mg	0.30	0.28	0.25	0.23
5	Al	2.88	2.40	2.19	1.84
6	Si	11.07	8.88	10.64	8.55
7	S	0.43	0.30	0.39	0.28
8	Ca	35.25	19.81	38.71	21.81
9	Fe	1.80	0.73	0.16	0.06

3.7.2 EDX analysis

The abundance of Ca, Si, and O in typical concrete are observed in **Figure 7a**. The major mineral components present in the concrete samples are exhibited through the spectrum. Ca attains a peak intensity at 3.8 keV, whereas silicon and iron along with oxygen attain the second-highest intensity at 1.8 keV and 0.4 keV. Other elements such as Mg and Al are found to have low intensity. At 2.2 keV and 0.2 keV, S and C had the lowest intensities of all the samples. In the case of 5 % rubber concrete (**Figure 7b**), the intensity of each element was similar to that of conventional concrete. From **Figure 7b**, Ca, Si and O exhibit high intensity at (3.8, 1.8 and 0.4) keV, whereas the intensity of other elements such as Mg and Al was low at 1.5 keV and 1.7 keV. Similar to conventional concrete, C attains the lowest intensity at 0.2 keV and S at 2.2 keV, which is slightly higher than C. At 6.3 keV, a minute sign of Fe was observed on both the conventional and CR concrete samples.

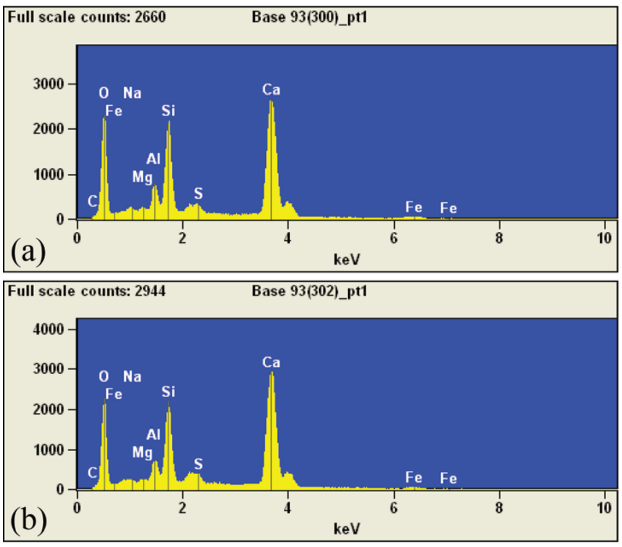

Figure 7: EDX of: a) conventional concrete, b) 5% crumb rubber aggregate concrete

3.7.3 SEM analysis

The microstructure of the CRC5 specimens exposed to various temperature conditions is shown in **Figure 8**. **Figure 8a** shows the microstructure of the concrete not exposed to any temperature condition. The red circle marked in the figure indicates the rubber crumb in the concrete mix, the yellow circle indicates CSH gel and the blue arrow indicates the interfacial transition zone (ITZ) between the rubber cement matrix.

Once the concrete is exposed to a temperature of 57 °C for about 2 h, cracks begin to originate where the voids were observed initially. The portion where the cracks begin to originate is marked in the red circle in **Figure 8b**. Again, when the concrete is exposed to a temperature of 57 °C for 4 h, which leads to the development of weak bonds between the rubber and concrete. This formation of weak bonds in concrete is marked in **Figure 8c**. Furthermore, when the period of exposure is exceeded by 6 h, more weak bonding is observed on var-

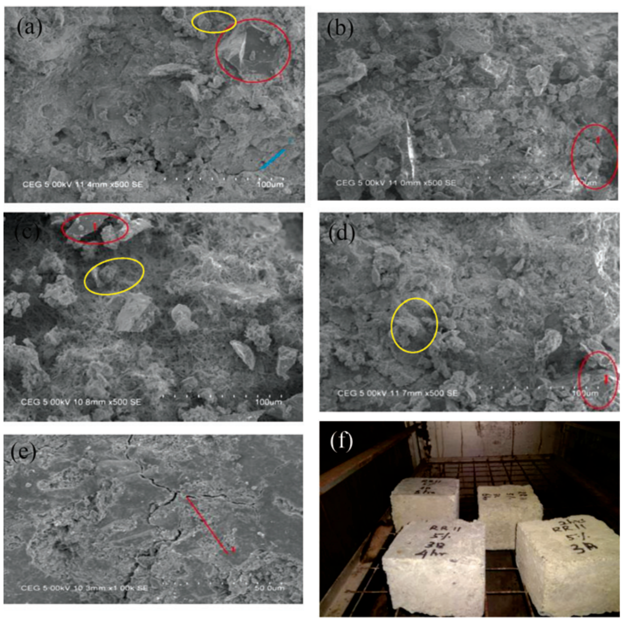

Figure 8: Microstructure analysis of concrete with 5 % rubber: a) at 0 °C, b) at 57 °C 2 h, c) at 57 °C 4 h, d) at 57 °C 6 h, e) at 57 °C 8 h, f) temperature test samples

ious portions of the concrete sample which is displayed in **Figure 8d**. Finally, after 8 hours of exposure, concrete with rubber crumbs is found to have numerous cracks more commonly on the interfacial transition zone between the rubber and the cement matrix, as illustrated in **Figure 8e**. These cracks are probably shrinkage cracks, which occur due to the evaporation of water molecules. The poor bonding of the rubber and the cement matrix causes further widening of the cracks as the period of temperature exposure increases. No crumb-rubber particles were found to melt at a temperature of 57 °C at a rate of (2, 4, 6 and 8) h in the concrete with 5 % rubber aggregate replacement. As the period of exposure increases, only microcracks and weak bond development is observed between the cement paste and the rubber crumb. A similar microstructure was also obtained in research that was conducted by Moghadam et al.[28]

4 CONCLUSIONS

The primary goal of this research was to assess the fresh concrete, mechanical, durability, and temperature effects of concrete with a partial replacement of fine aggregate by crumbed-rubber aggregates. The following conclusions can be drawn.

The compressive strength of concrete decreases as the percentage of replacement rubber aggregate increases. But concrete with 5 % CR aggregate was found to be encouraging, almost attaining the target mean strength of M30 grade concrete.

Concrete containing 5 % rubber crumbs has a 3.38 % greater split tensile strength than the control mix and 2.6 % higher than the control mix in flexural strength, and attains the least shrinkage value, which is 16.92 % lower than the control mix.

Crumb-rubberized concrete immersed in concentrated HCl undergoes a reduction in weight. Whereas concrete immersed in NaCl shows an increase in weight due to the reaction between NaCl and $Ca(OH)_2$. Concrete with 7.5 % of rubber crumb in the concentrated HCL test attains a minimum weight loss of 1.12 %, whereas concrete with 15 % rubber crumb attains a maximum weight gain of 1.71 % under NaCl immersion. Positive outcomes from the durability tests suggest that rubberized concrete can be utilised in marine or offshore structures that are highly susceptible to NaCl exposure.

The high carbon content observed in the rubberized concrete is due to the presence of rubber crumbs containing a high content of C. Overall, calcium is the peak element present in both the samples based on an EDX analysis. A slight bulge of carbon was observed on the rubberized concrete sample and the presence of carbon also affects the strength variation of the specimens.

Weak adhesion between the rubber and cement matrix was found through SEM analysis. The spaces between the rubber and cement paste expand as the temperature of the exposure rises.

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