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Properties of high strength concrete containing surface-modified crumb rubber

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Research Paper

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Properties of high strength concrete containing surface-modified crumb rubber

This study presents a new approach on surface modification of crumb rubber using organoclay composites in order to improve the poor adhesion between cement paste and crumb rubber. The change in functional groups on the surface of modified crumb rubber was observed by FTIR spectra. Mineral admixtures such as silica fume and metakaolin were used as property enhancers. Tests on workability, compressive strength and flexural strength, static modulus of elasticity, impact resistance, sulphate attack, and acid attack, were conducted. The results show that the properties of concrete were enhanced by surface modification.

Key words:

crumb rubber, surface modification, high strength concrete, silica fume, metakaolin

Prethodno priopćenje

Chellakavitha Nagarajan, Prabavathy Shanumugasundaram, Sree Rameswari Anmeeganathan

Svojstva betona visoke čvrstoće s površinski tretiranom drobljenom gumom

U radu se primjenjuje novi pristup površinske modifikacije drobljene gume pomoću organoglinskih kompozita kako bi se poboljšala slaba prionljivost između cementne paste i drobljene gume. Primjenom FTIR spektara promatrana je promjena funkcionalnih skupina na površini tretirane drobljene gume. Za poboljšanje svojstava korišteni su mineralni dodaci poput silikatne prašine i metakaolina. Provedena su ispitivanja obradljivosti, tlačne čvrstoće, čvrstoće na savijanje, modula elastičnosti, otpornosti na udar te otpornosti na djelovanje sulfata i kiselina. Postignuti rezultati pokazuju da površinska obrada gume dovodi do poboljšanja svojstava betona.

Ključne riječi:

drobljena guma, površinska obrada, beton visoke čvrstoće, silikatna prašina, metakaolin

Vorherige Mitteilung

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Eigenschaften von hochfestem Beton mit oberflächenbehandeltem zerkleinertem Gummi

In der Arbeit wird ein neuer Ansatz zur oberflächlichen Modifizierung von Gummibruch durch organische Verbundstoffe verwendet, um die schlechte Haftung zwischen Zementpaste und Gummibruch zu verbessern. Unter Verwendung der FTIR-Spektren wurde eine Änderung der funktionellen Gruppen auf der Oberfläche des behandelten zerkleinerten Gummis beobachtet. Zur Verbesserung der Eigenschaften wurden mineralische Zusätze wie Silikatstaub und Metakaolin eingesetzt. Es wurden Tests zur Verarbeitbarkeit, Druckfestigkeit, Biegefestigkeit, Elastizitätsmodul, Stoßfestigkeit und Beständigkeit gegen Sulfat und Säuren durchgeführt. Die erzielten Ergebnisse zeigen, dass die Oberflächenbehandlung des Gummis zur Verbesserung der Betoneigenschaften führt.

Schlüsselwörter:

Gummibruch, Oberflächenbehandlung, hochfester Beton, Silikatstaub, Metakaolin

1. Introduction

End of life tires rank among those non-biodegradable materials that have a serious impact on the environment. Recycling of these materials could be a partial solution to mitigate the negative environmental impact. Incorporation of end of life tires in the form of crumb rubber or rubber chips into cement concrete is one of the ways to recycle the waste material [1-6]. Crumb rubber in concrete mixtures can adversely affect the compressive strength, flexural strength and workability of concrete but it has better toughness, impact strength, ductility, energy absorption capacity, and durability when compared to conventional concrete [7]. The decrease in mechanical properties of concrete is due to poor adhesion between cement paste and crumb rubber. Cement paste is intrinsically hydrophilic whereas crumb rubber surface is hydrophobic [8]. Many efforts have been made in recent years to improve adhesion between the cement paste and crumb rubber through surface modification. Mohammadi et al. [9] treated the rubber particles with NaOH and evaluated mechanical properties of concrete. The mechanical properties were improved but there is only notable improvement in the adhesion between cement paste and rubber particles. Obinna Onuaguluchi et al. [10] proposed a pre-coating technique in which the crumb rubber is coated with limestone powder. These authors evaluated both mechanical and durability properties of concrete. The strength improvement was quite low but the adhesion between cement paste and crumb rubber was improved. Qiao Dong et al. [11] employed a surface treatment method in which the crumb rubber is coated with a chemically active agent and further treated with silane coupling agent. The compressive strength and energy absorption capacity were determined and the results showed that the compressive strength of concrete containing coated crumb rubber improved by 10-20 % compared to the control mix. Fernando Pelisser et al. [12] treated the recycled tire rubber with NaOH and further added silica fume to concrete mixture to enhance mechanical properties of concrete. Gengying Li et al. [13] modified the rubberized concrete with the combination of silane coupling agent and carboxylated SBR. The compressive strength and flexural strength of concrete containing treated rubber were improved by 4 % and 13 %, respectively, as compared with the control mix. Blessen Skariah Thomas et al. [1] studied performance of the high strength concrete in which the crumb rubber was partially replaced with fine aggregate. Crumb rubber was partially replaced from 0 % to 20 % in 2.5 % increments. Silica fume was added by 6 % by weight of cement. The results showed that there is a creeping decrease in compressive strength when compared to the control specimen. Baoshan Huang et al. [14] employed a two staged surface treatment in which rubber particles were treated with a silane coupling agent and further coated with a layer of cement. Here, the compressive strength of modified rubber concrete was greater than that of the control mix. Liang He et al. [8] proposed a surface modification process in which the crumb rubber was oxidized and sulphonated in order to introduce strong polarity groups to the rubber surface. The adhesion strength between cement and crumb rubber was increased. Here the compressive strength of concrete with modified rubber showed better results compared to concrete with ordinary rubber.

The objective of this study is to improve the adhesion of crumb rubber to cement mortar by surface modification using a new approach based on organoclay composites [15, 16]. In this study, the crumb rubber partly replaces fine aggregate from 0 % to 25 % in 5 % increments by weight [6, 17, 18] in high strength concrete. The concrete mix design was made as per ACI guidelines with a water/cement ratio of 0.3 [1]. Supplementary cementitious materials such as silica fume and metakaolin were used as partial replacement for cement by 15 % of the weight of cementitious material [4, 19]. Fourier Transform Infrared spectra (FTIR) were used and a microstructural analysis was carried out to find the change of functional groups on the surface of the modified crumb rubber [8]. The compressive strength test and flexural strength test were performed to measure mechanical properties of rubberized concrete [20-25]. The static modulus of elasticity in flexure was evaluated for each specimen. Also, durability tests, such as resistance to sulphate attack test [1], resistance to acid attack test [26, 27], and impact resistance test [28], were performed on concrete specimens as these tests are important for ensuring durability of concrete in aggressive environment [26].

The current research proposes a new approach to improve the poor adhesion of recycled crumb rubber from waste tires to cement paste, when used as a partial replacement of fine aggregate in high strength concrete. The use of crumb rubber in high strength concrete is an effective way to reduce negative environmental impacts and consumption of energy for extracting material such as river sand.

2. Experimental investigation

2.1. Materials

Ordinary Portland cement (OPC) of grade 53 conforming to IS 12269-2013, with the specific gravity of 3.15, was used. The initial and final setting times were found to be 30 minutes and 453 minutes, respectively. The locally available natural sand conforming to zone II as per IS 383-1970, of specific gravity 2.6, fineness modulus 2.68, and bulk density 1415 Kg/m^3, was used as fine aggregate. Coarse aggregate obtained from crushed stone, conforming to IS 383-2016, 20mm in size, with the specific gravity of 2.66 and bulk density of 1383 Kg/m^3, was used. Crumb rubber with the specific gravity of 1.08, and with the particle size ranging from 0.075mm to no more than 2.36mm, was used as partial replacement for fine aggregate. A sulphonated naphthalene polymer based superplasticizer conforming to IS 9103-1999, with the specific gravity of 1.24, was used to enhance workability of rubberized concrete. Silica fume and metakaolin of specific gravity 2.2 and 2.6, respectively, were used as supplementary cementing materials in high strength concrete. Bentonite clay with a chemical composition of 56.47 % O, 1.64 % Mg, 8.24 % Al, 20.92 % Si, 0.94 % K, 5.06 % Ca, and 6.73 % Fe by weight, and cetyl trimethyl ammonium bromide (CTAB), were employed in the preparation of organoclay used for surface modification of crumb rubber. Bentonite is absorbent, aluminium phyllosilicate clay mostly consisting of montmorillonite. The cetyl trimethyl ammonium bromide (chemical formula $(C_{16}H_{33})N(CH_3)_3Br$) is a commercially available cationic surfactant with the molecular mass of 364.46 g/mol. The chemical structure of CTAB is shown in Figure 1.

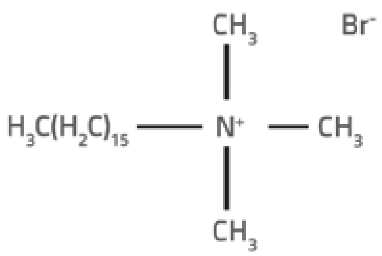

Figure 1. Chemical structure of CTAB

2.2. Surface modification of crumb rubber

The preparation of Organo clay composites, and surface modification of crumb rubber, are schematically presented in Figure 2 and Figure 3, respectively.

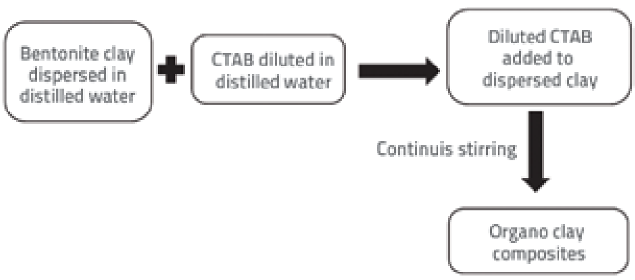

Figure 2. Schematic representation of preparation of Organo clay composites

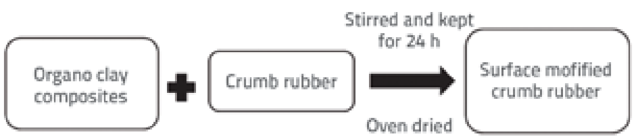

Figure 3. Schematic representation of surface modification of crumb rubber

Crumb rubber was modified with the combination of bentonite clay and cetyl trimethyl ammonium bromide. A coating developed around the surface of crumb rubber [15, 16]. The following procedure was used for the surface modification of crumb rubber:

- A desired amount (1 g) of CTAB was diluted in 10ml of distilled water using a magnetic stirrer.
- Simultaneously, a considerable amount of bentonite clay (1 g) was dispersed in 80ml of distilled water under continuous stirring.
- The diluted CTAB solution was added to bentonite clay and continuously stirred at room temperature.
- The resultant product was the Organo clay composite.
- Crumb rubber (1 kg) was added into the 800ml of solution and continuously stirred. The solution was kept for 24 hours at room temperature.
- Then the crumb rubber was dried in hot air oven until removal of moisture. The obtained product was the surface modified crumb rubber.

In this process, the pores in rubber were filled with organoclay composites by adsorption, thereby improving adhesion between the cement paste and rubber particles.

2.3. Concrete mix design

The concrete mix was designed as per ACI method with the water-cement ratio of 0.3 [1]. Crumb rubber was used as partial replacement for fine aggregates, i.e. from 0 to 25 % of crumb rubber was added in 5 % increments. Supplementary cementitious materials such as silica fume and metakaolin were used at 15 % each, as partial replacement for cement from the total cementitious content. A sulphonated naphthalene polymer based super plasticizer was used at constant dosage of 2 % by weight of cementitious materials to study the effect of varying slump [29]. The mix proportions are given in Table 1.

2.4. FTIR Characterization of modified crumb rubber

FTIR was used to identify functional groups on the surface of crumb rubber and modified crumb rubber [8]. The test was performed using the Bruker Alpha model spectrometer, which uses infrared rays in the frequency range from 4000 to 400 cm^{-1}.

2.5. Slump test

Slump test is the method that is most commonly used for measuring consistency of concrete. The slump test was carried out for all specimens at various rubber replacement levels.

2.6. Compressive strength test

The compressive strength test was performed on cubes in accordance with IS 516-1959 (Reaffirmed 2004). Concrete cubes measuring 150mm x 150mm x 150mm were cast, cured under water for 7 days and 28 days, and then subjected to compressive strength test using the compression testing machine with the capacity of 3000 kN.

Table 1. Mix proportions

Specimen	Untreated rubber content [%]	Surface modified rubber content [%]	Mix proportions [kg/m³]							
			Cement	Silica fume	Metakaolin	Water	Fine aggregate	Rubber	Coarse aggregate	S.P.
M1	0	-	369	79	79	144	595	0	1180	11
M2	5	-	369	79	79	144	565	30	1180	11
M3	10	-	369	79	79	144	535	60	1180	11
M4	15	-	369	79	79	144	505	90	1180	11
M5	20	-	369	79	79	144	475	120	1180	11
M6	25	-	369	79	79	144	445	150	1180	11
M7	-	5	369	79	79	144	565	30	1180	11
M8	-	10	369	79	79	144	535	60	1180	11
M9	-	15	369	79	79	144	505	90	1180	11
M10	-	20	369	79	79	144	475	120	1180	11
M11	-	25	369	79	79	144	445	150	1180	11

S.P. - Super plasticizer dosage

2.7. Flexural strength test

Concrete prisms measuring 500 mm x 100 mm x100 mm were prepared as per IS 516-1959 (Reaffirmed 2004) to measure the modulus of rupture. The specimens were cured for 28 days and then tested under the four-point loading configuration using the universal testing machine 1000kN in capacity, at the loading rate of 180kg/min.

2.8. Static modulus of elasticity test

Static modulus of elasticity test was performed in accordance with IS 516-1959. Concrete cylinders 150 mm in diameter and 300mm in height were cast and tested to determine the modulus of elasticity of concrete. The specimens were cast for both untreated and surface modified rubber concrete and tested using the universal testing machine 1000kN in capacity equipped with a longitudinal compressometer.

2.9. Impact resistance test

Cylindrical specimens 150 mm in diameter and 65 mm in height as per ACI Committee 544 were cast for each mix to find the energy absorption capacity of concrete. The drop weight test was performed for each specimen [23]. A steel ball weighing 1 kg was placed at the centre and dropped continuously from a constant height of 450 mm. The specimen was placed at the base plate. The number of blows required to cause the initial crack (N_1) was noted and the number of blows required to cause the peak failure (N_2) was also recorded for each specimen. The impact energy at initial crack (E_i) was calculated as follows:

$$E_i = N_1 \cdot m \cdot g \cdot h$$

Similarly, impact energy at peak failure (E_u) was calculated by

$$E_u = N_2 \cdot m \cdot g \cdot h$$

where N_1 and N_2 are the number of blows at initial crack and peak failure, respectively, m is the mass of the steel ball (m= 1 kg), h is the drop height (450 mm), and g is the gravity acceleration (9.81 m/s²).

2.10. Sulphate attack test

The sulphate attack test was performed according to ASTM C1012-89 [1]. Concrete cubes measuring 150 mm x 150 mm x150 mm were taken out of the container after 28 days of water curing, and were then oven dried and weighed. The specimens were soaked in 3 % $MgSO_4$ solution for 3 months and the solution were replaced at regular intervals. Two types of tests were conducted on the sulphate attacked specimens. After 90 days, the cubes were taken out of the container. Then the specimens were air dried and weighed. The percentage of weight reduction with respect to the dry weight before immersion in $MgSO_4$ solution was calculated. The compressive strength of sulphate attacked specimens was determined after 90 days of immersion in $MgSO_4$ solution. It was compared with the results of 28-day compressive strength of the specimens that were not subjected to sulphate attack.

2.11. Acid attack test

The acid attack test was performed as per ASTM C 267-97. A 3 % sulphuric acid was taken as a medium for the acid attack test. Concrete cubes measuring 150 mm x 150 mm x 150 mm were immersed in the diluted sulphuric acid solution for a period of 90 days. Two different tests were carried out on acid attacked specimens. After 90 days, the cubes were taken out of the tank, air dried and weighed. The percentage of weight reduction with respect to the control specimen (the weight before immersion in $H2SO_4$ solution) was calculated. The compressive strength of acid attacked specimens was determined after 90 days of immersion in $H2SO_4$ solution. It was compared with the results of the 28-day compressive strength of the specimens not subjected to acid attack.

3. Results and discussion

The FTIR characterization of modified crumb rubber was conducted. The FTIR spectra of the original rubber and modified crumb rubber are shown in Figure 4 & Figure 5, respectively. In the FTIR spectra of untreated raw crumb rubber, bands appear at 1520 ~ 1650 cm^{-1}, confirming presence of the C = C bond or benzene. Two strong bands appear at 2830 ~ 2910 cm^{-1} and they represent the C-H bond stretching to the benzene ring. But, in the FTIR spectra of the modified crumb rubber, bands appear near 3580 cm^{-1} and 1000 cm^{-1}, which represents the O-H bond, while bands at 1500 cm^{-1} represent the C=O bond. Bands appear at 2845 ~ 2914 cm^{-1}, pointing to the presence of the C-H bond. Thus the surface modification process introduced functional groups on the surface of crumb rubber, which improved the adhesive nature of rubber.

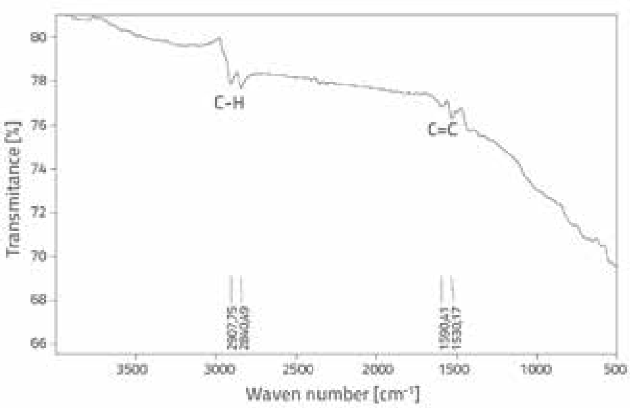

Figure 4. FTIR spectra of original crumb rubber

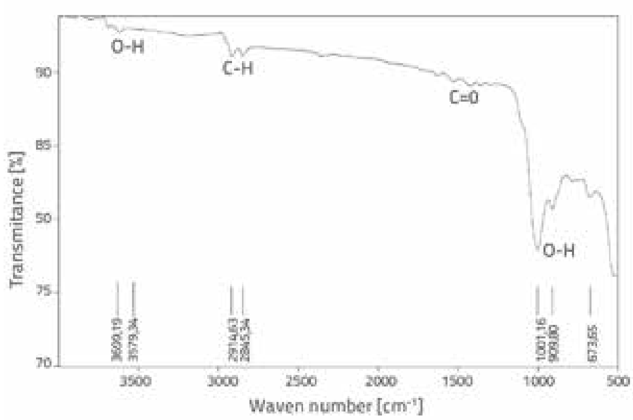

Figure 5. FTIR spectra of surface modified crumb rubber

3.1. Slump Test

For the desired water cement ratio, it was inferred that the slump value increases as the rubber content increases. This indicates that higher rubber content tends to increase the workability of concrete. The slump value of concrete mixes compared to control mix is shown in Figure 6.

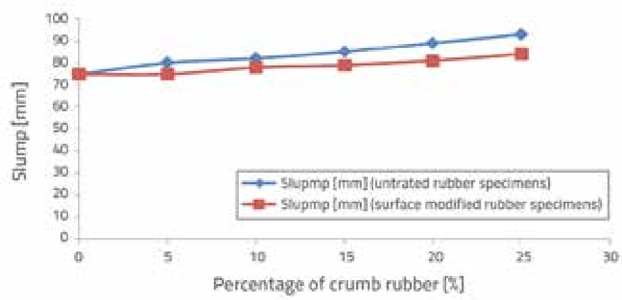

Figure 6. slump value of concrete mixes

In the case of untreated rubberized concrete, the replacement of fine aggregates with 5 %, 10 %, 15 %, 20 % and 25 % of untreated crumb rubber increased the slump value by 7 %, 9 %, 13 %, 19 % and 24 %, respectively, compared to slump value of the control mix. But in the case of surface modified crumb rubber concrete, the replacement of fine aggregates with 5 %, 10 %, 15 %, 20 % and 25 % of (surface modified) crumb rubber increased the slump value by 0 %, 4 %, 5 %, 8 % and 12 %, respectively, compared to slump value of the control mix. The slump increase can be explained by the fact that rubber is intrinsically hydrophobic, i.e. it repels water. Hence, free water in the mix increased, which contributed to the increase in slump [30, 31]. Comparing results of untreated and surface modified rubber concrete, it was established that the slump value decreased by 6 %, 5 %, 7 %, 9 % and 10 %, at rubber content of 5 %, 10 %, 15 %, 20 %, and 25 %, respectively, compared to untreated rubber concrete. The slump decreases for surface modified concrete because surface modification improves the hydrophilic nature of rubber.

3.2. Compressive strength test

The compressive strength of concrete, with the percentage of crumb rubber at 28 days, is shown in Figure 7. It can be noted that an increase in rubber content results in a decrease of compressive strength of concrete. Compared to the control mix, the loss of compressive strength at 7 days registered for specimens M2, M3, M4, M5 and M6 amounted to 22 %, 31 %, 48 %, 59 %, and 72 %, respectively. At 28 days, the loss of strength of specimens M2, M3, M4, M5, and M6 amounted to 17 %, 29 %, 44 %, 53 %, and 68 %, respectively, compared to strength of the control mix. The reduction in strength of concrete containing untreated crumb rubber was due to

- poor adhesion between crumb rubber and cement paste,
- lower stiffness of rubber resulting in reduction of mass stiffness and its compressive strength [2, 20].

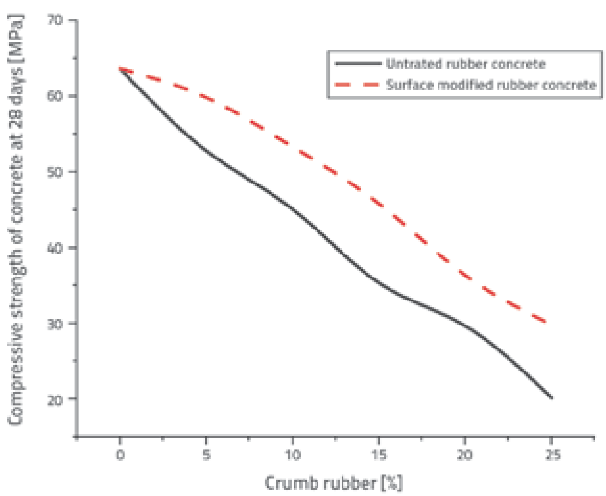

Figure 7. Compressive strength of concrete specimens at 28 days

When an external load is applied on the concrete surface, cracks are formed at the interfacial region between rubber particles and cement paste. Due to the formation of cracks, the load carrying capacity reduces at various replacement levels. But in the case of surface modified crumb rubber concrete, the replacement of fine aggregate with 5 %, 10 %, 15 %, 20 % and 25 % of (surface modified) crumb rubber reduced the strength by 3 %, 11 %, 17 %, 35 %, and 62 % at 7 days and by 6 %, 16 %, 28 %, 43 %, and 53 % at 28 days, respectively. The compressive strength gradually reduced in the concrete containing untreated crumb rubber as well as in the surface modified crumb rubber. But the reduction in strength of the surface modified crumb rubber concrete was smaller compared to the untreated rubberized concrete. The percentage of increase in compressive strength of the surface modified crumb rubber concrete, compared to the untreated crumb rubber concrete, is shown in Figure 8. Compared to specimens M2, M3, M4, M5, and M6, the increase in strength of specimens M7, M8, M9, M10 and M11 amounted to approximately 23 %, 30 %, 59 %, 59 %, and 35 % at 7 days, and to 13 %, 18 %, 29 %, 23 %, and 48 % at 28 days, respectively. Thus the surface modification of crumb rubber enables a higher adhesion between cement paste and crumb rubber. With the 5 % rubber content, the percentage of compressive strength loss at 28 days of the untreated and surface modified crumb rubber concrete, compared to the control mix, amounted to 11 % and 6 %, respectively. The reduction in strength of the surface modified rubberized concrete was very low compared to untreated concrete. Thus, low level replacement of crumb rubber for fine aggregates can be enhanced in concrete which showed closer results to control mix.

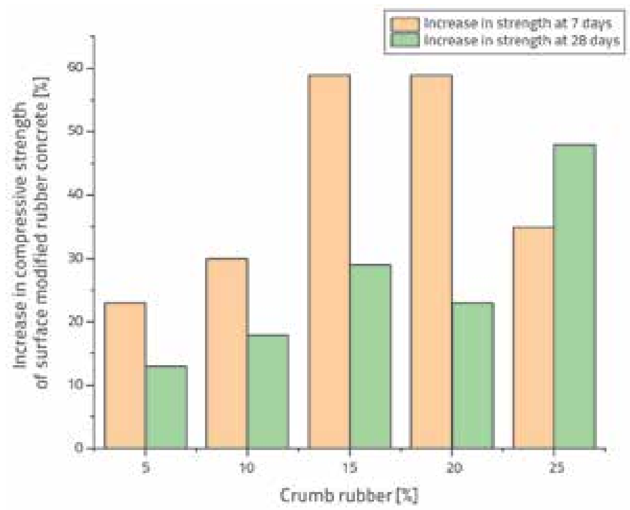

Figure 8. Increase in compressive strength of surface modified rubber concrete specimens

3.3. Flexural strength test

The flexural strength of untreated and surface modified rubber concrete at 28 days is shown in Figure 9. The results show that there were several undulations in flexural strength of concrete at various replacement levels. The flexural strength of specimens M2 and M4 at 28 days was by 51 % and 11 % higher than that of the control mix (M1), whereas specimens M3, M5, and M6 achieved flexural strength that was by 24 %, 19 %, and 9 % lower compared to the control mix M1. Similarly, specimens M7 and M9 achieved flexural strength that was by 61 % and 46 % higher than that of M1 whereas for M8, M10 and M11, the flexural strength was by 16 %, 8 %, and 17 % lower compared to the control mix. Specimens containing 5 % and 15 % of rubber (M2, M4, M7, and M9) showed flexural strength that was greater compared to the control mix. This increase in flexural strength shows that rubber particles provide better link between the cracks due to elastic behaviour of rubber [2]. But specimens with 10 %, 20 % and 25 % of rubber (both untreated and surface modified) exhibited lower flexural strength than the control mix. This is due to the lack of interlocking between rubber particles and cement paste. The reduction in flexural strength in specimens with 10 % of rubber was due to poor compaction of concrete since specimens with 5 % and 15 % achieved greater flexural strength compared to the control mix.

The respective flexural strengths of specimens M7, M8, M9, M10, and M11 were by 6 %, 10 %, 32 %, 14 %, and 8 % higher compared to specimens M2, M3, M4, M5, and M6. Thus, the surface modification of rubber particles enhanced the flexural strength of concrete. The results show that replacement with 5 % and 15 % rubber (both untreated and surface modified) increased the flexural strength of concrete. Thus the optimum rubber replacement values of 5 % and 15 % can be applied in concrete to show better results than the control mix.

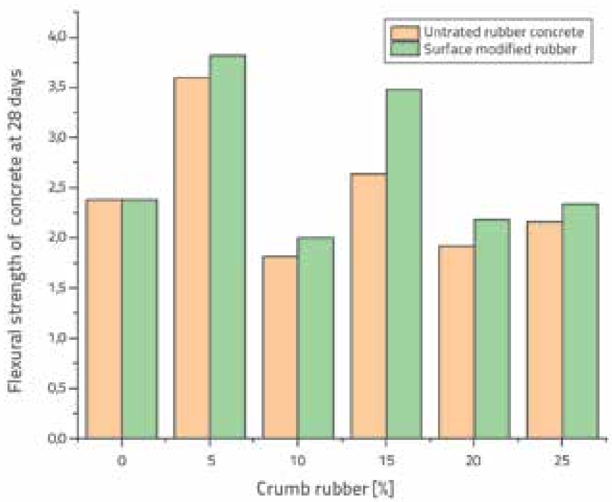

Figure 9. Flexural strength of concrete at 28 days

3.4. Static modulus of elasticity test

Performance of concrete is influenced by the modulus of elasticity. Elastic modulus values for various concrete specimens are shown in Figure 10.

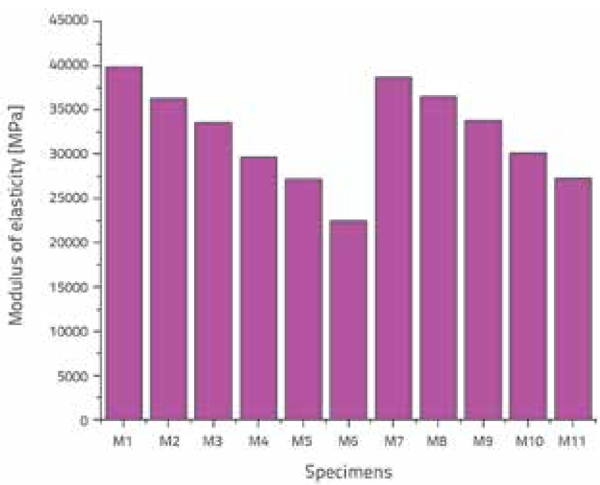

Figure 10. Modulus of elasticity of concrete specimens

It can be seen that the elastic modulus of concrete decreases with an increase in rubber content. This is due to poor interlocking between rubber particles and cement paste, which leads to lower rigidity of concrete, lower stiffness of crumb rubber, and high air content [32, 33]. The variation in elastic modulus of untreated and surface modified concrete specimens is shown in Figure 14. The reduction in elastic modulus of specimens M2, M3, M4, M5, M6, M7, M8, and M9, compared to that of the control mix, amounted to 9 %, 16 %, 25 %, 32 %, 44 %, 3 %, 8 %, 15 %, 24 %, and 32 %, respectively. However, the moduli of surface modified rubber concrete were higher than those of untreated rubber concrete, which points to a strong mechanical bond between rubber particles and cement paste. The elastic moduli of specimens M7, M8, M9, M10, and M11 were by 7 %, 9 %, 14 %, 11 %, and 22 % higher than those of specimens M2, M3, M4, M5, and M6, respectively. The impact strength of untreated and surface modified rubber concrete specimens, at initial crack and at ultimate failure, is shown in Figure 11.

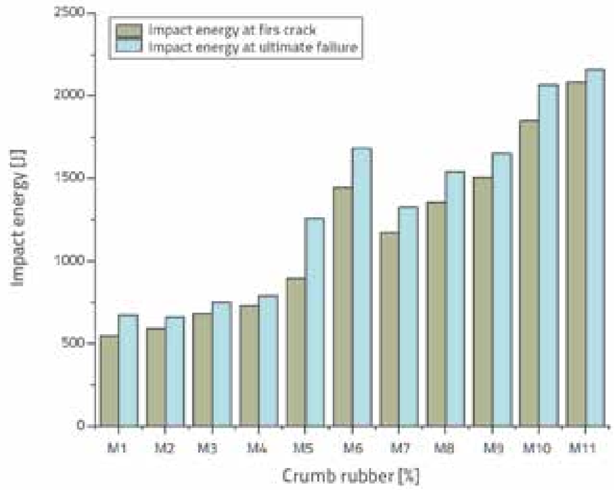

Figure 11. Impact strength of concrete specimens

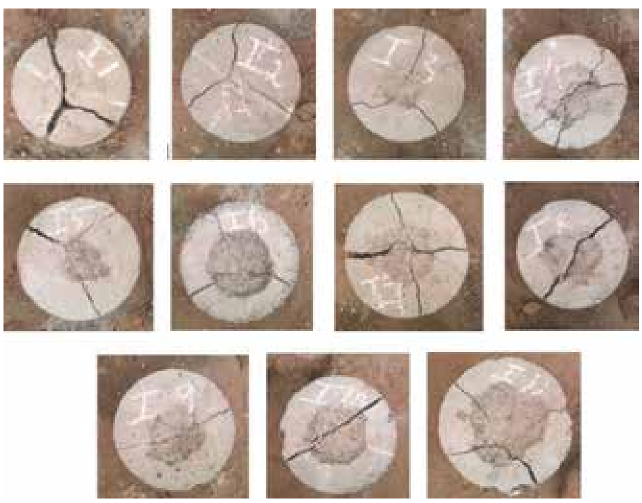

Figure 12. Crack pattern of concrete specimens

It was established that an increase in rubber content increases the impact strength of concrete specimens. The impact strength is the energy that can be absorbed by the specimen. The impact strength was gradually increased at various replacement levels. Specimens M7, M8, M9, M10 and M11 showed greater impact strength than M2, M3, M4, M5, and M6, respectively. The higher energy absorption capacity in surface modified rubber specimens was due to stronger mechanical interfacial bond between rubber particles and cement paste. The crack pattern of concrete specimens is shown in Figure 12. The control specimen (I1) is separated into three parts even at a lower impact energy of 675.42 J whereas the concrete containing rubber (specimens I2 to I11) remained intact even at high impact energy. The concrete with 25 % treated rubber exhibited a higher impact energy of 2163.11 J.

3.5. Sulphate attack test

The variation in weight of sulphate attacked rubber concrete specimens with respect to the percentage of crumb rubber added is shown in Figure 13. It was established that there was a gradual increase in the weight of the specimens. As the amount of crumb rubber increased, the weight of concrete specimens also increased. Compared with the results of non sulphate attacked specimens, the increase in weight of M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, and M11 was 0.47 %, 0.52 %, 0.55 %, 0.59 %, 0.64 %, 0.71 %, 0.51 %, 0.53 %, 0.57 %, 0.61 %, and 0.67 %, respectively. Specimens M7, M8, M9, M10, and M11 showed lesser weight gain than specimens M2, M3, M4, M5, and M6, respectively. Figures 14 and 15 show the compressive strength and increase in compressive strength of sulphate attacked untreated rubber specimens and surface modified rubber specimens with respect to the percentage of crumb rubber added. It was observed that there was a gradual decrease in the compressive strength of rubberized concrete specimens compared to the control mix. Compared with the results of non sulphate attacked specimens, the loss in compressive strength of specimens M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, and M11 amounted to 2.11 %, 3.42 %, 4.52 %, 5.36 %, 6.01 %, 7.39 %, 2.57 %, 3.92 %, 4.06 %, 5.21 %, and 6.38 %, respectively. The compressive strength values of specimens M7, M8, M9, M10, and M11 were by 14.36 %, 19.08 %, 31.26 %, 23.67 %, and 49.59 % higher than those of specimens M2, M3, M4, M5, and M6, respectively. When compared to the control mix, specimens M7, M8, M9, M10, and M11 exhibited a lower loss in compressive strength than specimens M2, M3, M4, M5, and M6, respectively. The results showed that the surface modified rubber concrete specimens were more resistant to sulphate attack compared to untreated rubber concrete specimens.

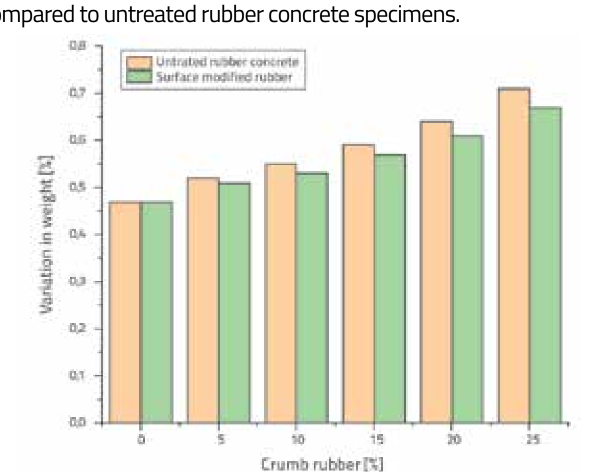

Figure 13. Variation in weight of sulphate attacked concrete specimens

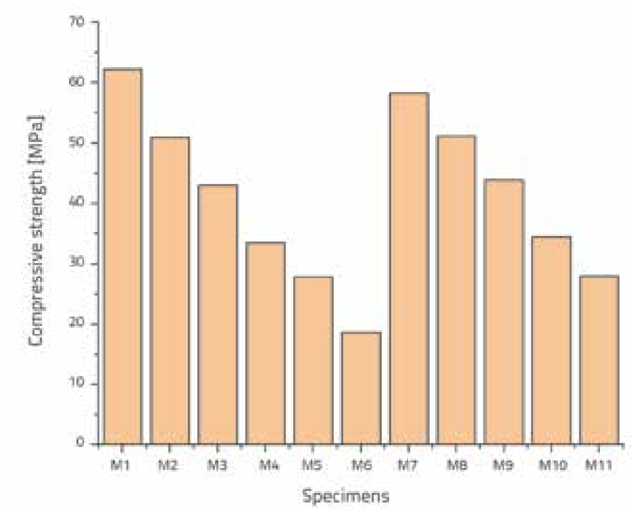

Figure 14. Compressive strength of sulphate attacked concrete specimens

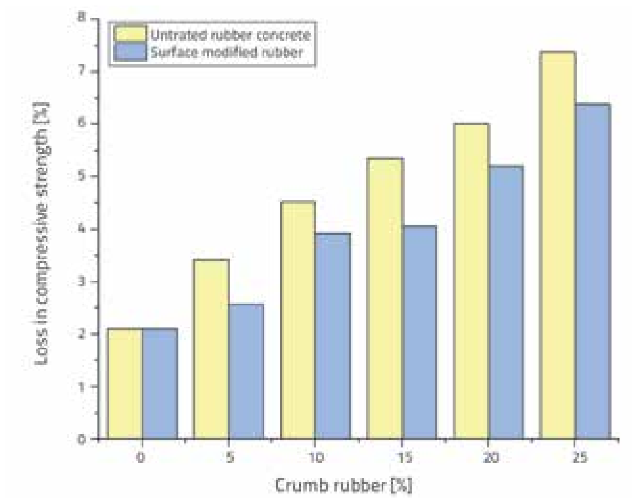

Figure 15. Variation in compressive strength of sulphate attacked concrete specimens

3.6. Acid attack test

Figure 16 shows the weight of acid attacked untreated rubber specimens and surface modified rubber specimens with respect to the percentage of crumb rubber added. A gradual decrease in the weight of the specimens was observed. As the amount of crumb rubber increased, the weight of concrete specimens decreased. Compared to the results of non-acid attacked specimens, the decrease in weight of specimens M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, and M11 amounted to 8.6 %, 8.2 %, 7.84 %, 7.69 %, 7.46 %, 7.24 %, 8.1 %, 7.93 %, 7.72 %, 7.54 %, and 7.41 % respectively. Specimens M7, M8, M9, M10 and M11 exhibited a smaller weight loss compared to specimens M2, M3, M4, M5, and M6, respectively. Figure 17 shows the compressive strength of acid attacked untreated rubber specimens and surface modified rubber specimens with respect to the percentage of crumb rubber added. When compared to the control mix, a gradual decrease in the compressive strength of the rubberized concrete specimens was observed. Compared with the results of non-acid attacked specimens, the loss in compressive strength of specimens M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, and M11 amounted to 21.6 %, 23.5 %, 26.1 %, 30.3 %, 38.7 %, 42.7 %, 16.5 %, 19.86 %, 15.3 %, 18.6 %, and 30.54 %, respectively. Compressive strength values of specimens M7, M8, M9, M10, and M11 were by 23.67 %, 28.32 %, 57.32 %, 62.76 %, and 79.39 % higher than the corresponding values for specimens M2, M3, M4, M5, and M6, respectively. Specimens M7, M8, M9, M10, and M11 exhibited a lower compressive strength loss than specimens M2, M3, M4, M5 and M6, respectively, when compared to the control mix. The results showed that the surface modified rubber concrete specimens were more resistant to acid attack compared to untreated rubber concrete specimens.

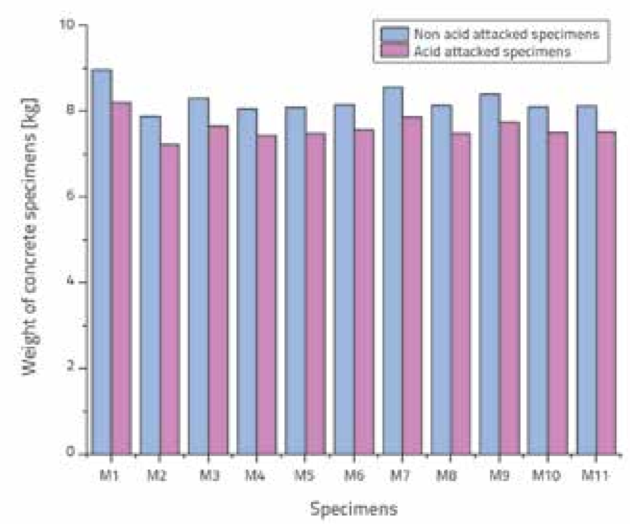

Figure 16. Weight of concrete specimens after acid attack test

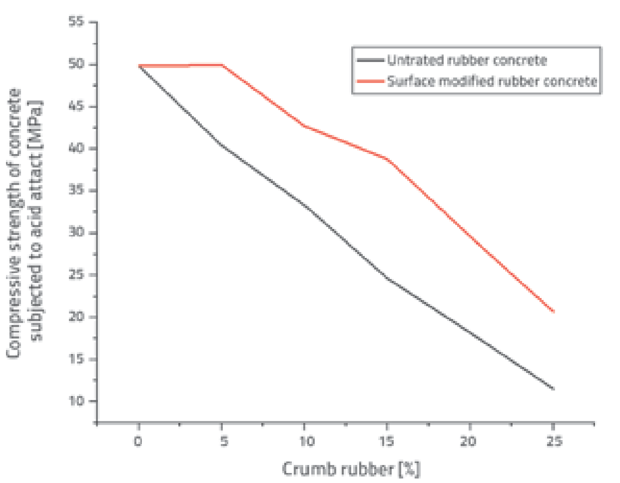

Figure 17. Compressive strength of concrete subjected to acid attack

4. Conclusion

The experimental work was carried out to study the effects of surface modification of crumb rubber using organoclay on the mechanical and durability properties of rubberized concrete. The crumb rubber surface was treated using bentonite clay and cetyl trimethyl ammonium bromide (CTAB), and the effectiveness of this treatment was analysed with the Fourier transform infrared spectrum (FTIR). The results point to the existence of hydrophilic groups on the crumb rubber surface, due to which the bond between crumb rubber particles and cement matrix materials improved.

When rubber content is increased from 0 to 25 % in high strength concrete, the workability also increases due to water repellent nature of rubber. However, the workability decreases in the case of the surface treated rubberized concrete.

The addition of rubber to concrete decreases its compressive strength due to lack of bond between crumb rubber and cement paste. The surface modified rubber concrete showed higher compressive strength compared to the untreated rubber concrete. The percentage of increase in flexural strength of untreated and surface modified crumb rubber concrete at 28 days was by 11 % and 46 % higher compared to the control concrete, for the 5 % rubber content. Thus the optimum rubber replacement values of 5 % and 15 % can be adopted for concrete, as the results are better than those for the control mix.

The decrease in the modulus of elasticity shows that rubber concrete possesses higher flexibility, which in turn improved the impact resistance of crumb rubber concrete.

Concrete specimens were also subjected to durability tests such as the acid attack and sulphate attack tests. The results show that the crumb rubber concrete is highly durable in aggressive environment.

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NOTATION

M1 - Control specimen
M2 - Concrete containing 5% of untreated crumb rubber
M3 - Concrete containing 10% of untreated crumb rubber
M4 - Concrete containing 15% of untreated crumb rubber
M5 - Concrete containing 20% of untreated crumb rubber
M6 - Concrete containing 25% of untreated crumb rubber
M7 - Concrete containing 5% of surface modified crumb rubber
M8 - Concrete containing 10% of surface modified crumb rubber
M9 - Concrete containing 15% of surface modified crumb rubber
M10 - Concrete containing 20% of surface modified crumb rubber
M11 - Concrete containing 25% of surface modified crumb rubber
E_i - Impact energy at initial crack
E_u - Impact energy at peak failure
N_1 - Number of blows at initial crack
N_2 - Number of blows at peak failure
m - Mass of steel ball
g - Acceleration due to gravity
h - Drop height
S.P. - Super plasticizer dosage

REFERENCES

[1] Blessen Skariah, T., Ramesh Chandra, G., Vinu, J.P.: Experimental and modelling studies on high strength concrete containing waste tire rubber.Journal on Sustainable Cities and Society, 19 (2015), pp. 68-73.

[2] Bharathi Murugan, R., Ram Sai, E., Natarajan, C., Shen, E.C.: Flexural fatigue performance and mechanical properties of rubberized concrete, GRAĐEVINAR, 69 (2017) 11, pp. 983-990, https://doi.org/10.14256/JCE.1427.2015

[3] Jing, L., Tianhua, Z., Q, D., Wu, H.: Effects of rubber particles on mechanical properties of lightweight aggregate concrete, Construction and Building Materials, 91 (2015), pp. 145-149.

[4] Shuaicheng, G., Qingli, D., Ruizhe, S., Xiao, S., Chao, L.: Evaluation of properties and performance of rubber-modified concrete for recycling of waste scrap tire, Journal of Cleaner Production, 148 (2017), pp. 681-689.

[5] Blessen Skariah, T., Ramesh Chandra, G., Vinu, J.P.: Recycling of waste tire rubber as aggregate in concrete: durability-related performance, Journal of Cleaner Production, 112 (2016), pp. 504-513.

[6] Giedrius, G., Nagrockienė, D.: Crushed rubber waste impact of concrete basic properties, Construction and Building Materials, 140 (2017), pp. 36-42.

[7] Aliabdo, A.A., Elmoaty, M.A., Elbaset, M.M.: Utilization of waste rubber in non-structural applications, Construction and Building Materials, 91 (2015), pp. 195-207.

[8] Liang, H., Yu, M., Quantao, L., Yuanhua, M.: Surface modification of crumb rubber and its influence on the mechanical properties of rubber-cement concrete, Construction and Building Materials, 120 (2016), pp. 403-407.

[9] Mohammadi, I., Khabbaz, H., Vessalas, K.: Enhancing mechanical performance of rubberised concrete pavements with sodium hydroxide treatment, Material and Structures, 49 (2016) 3, pp. 813-827.

[10] Onuaguluchi, O., Panesar, D.K.: Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume, Journal of Cleaner Production, 82 (2014), pp. 125-131.

[11] Qiao, D., Baoshan, H., Xiang, S.: Rubber modified concrete improved by chemically active coating and silane coupling agent, Construction and Building Materials, 48 (2013), pp. 116-123.

[12] Pelisser, F., Zavarise, N., Longo, T.A., Bernardin, A.M.: Concrete made with recycled tire rubber: effect of alkaline activation and silica fume addition, Journal of Cleaner Production, 19 (2011), pp. 757-763.

[13] Li, G., Wang, Z., Leung, C.K.Y., Tang, S., Pan, J., Huang, W., Chen, E.: Properties of rubberized concrete modified by using silane coupling agent and carboxylated sbr., Journal of Cleaner Production, 112 (2016), pp. 797-807.

[14] Huang, B., Shu, X., Cao, J.: A two-staged surface treatment to improve properties of rubber modified cement composites. Construction and Building Materials, 40 (2013), pp. 270-274, https://doi.org/10.1016/j.conbuildmat.2012.11.014

[15] Rittirong, K., Uasopon, S., Prachayawasin, P., Euaphantasate, N., Aiempanakit, K., Ummartyotin, S.: CTAB as a soft template for modified clay as filler in active packaging, Data in Brief, pp. 347-50, 2015.

[16] Shirzad-Siboni, M., Khataee, A., Hassani, A., Karaca, S.: Preparation, characterization and application of a CTAB-modified nanoclay for the adsorption of an herbicide from aqueous solutions: Kinetic and equilibrium studies, Comptes Rendus Chimie, 18 (2015), pp. 204-214.

[17] Bisht, K., Ramana, P.V.: Evaluation of mechanical and durability properties of crumb rubber concrete, Construction and Building Materials, 155 (2017), pp. 811 - 817.

[18] Gerges, N.N., Issa, C.A., Fawaz, S.A.: Rubber concrete: Mechanical and dynamical properties, Case Studies in Construction Materials, 9 (2018), pp. e00184.

[19] Azevedo, F., Pacheco-Torgal, F., Jesus, C., Barroso de Aguiar, J.L., Camões, A.F.: Properties and durability of HPC with tyre rubber wastes, Construction and Building Materials, 34 (2012), pp. 186-191.

[20] Blessen Skariah, T., Ramesh Chandra, G.: Properties of high strength concrete containing scrap tire rubber, Journal of Cleaner Production, 113 (2015), pp. 1-7.

[21] Liu, H., Wang, X., Jiao, Y., Sha, T.: Experimental investigation of the mechanical and durability properties of crumb rubber concrete, Materials, 9, 172 (2016), pp. 1-12.

[22] Youssf, O., Mills, J.E., Hassanli, R.: Assessment of the mechanical performance of crumb rubber concrete, Journal on Construction and Building Materials, 125 (2016), pp. 175-183.

[23] Onuaguluchi, O.: Effects of surface pre-coating and silica fume on crumb rubber cement matrix interface and cement mortar properties, Journal of cleaner Production, 104 (2015), pp. 339-345.

[24] Su, H., Yang, J., Ling, T.C., Ghataora, G.S., Dirar, S.: Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes, Journal of Cleaner Production, 91 (2015), pp. 288-296.

[25] Trilok, G., Ravi, K. Sharma, S.C.: Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate, Construction and Building Materials, 73 (2014), pp. 562-574.

[26] Blessen Skariah, T., Ramesh Chandra, G., Mehra, P., Kumar, S.: Performance of high strength rubberized concrete in aggressive environment, Journal on Construction and Building Materials, 83 (2015), pp. 320 -326.

[27] Blessen Skariah, T., Ramesh Chandra, G., Mehra, P., Kumar, S.: Resistance to acid attack of cement concrete containing discarded tire rubber, Ukieri Concrete Congress - Concrete Research Driving Profit and Sustainability.

[28] Trilok, G., Ravi, K. Sharma, S.C.: Impact resistance of concrete containing waste rubber fiber and silica fume, International Journal of Impact Engineering, 83 (2015), 76-87.

[29] Ruizhe, S., Shuaicheng, G., Qingli, D.: Durability performance of rubberized mortar and concrete with NaOH-Solution treated rubber particles, Construction and Building Materials, 153 (2017), pp. 496-505.

[30] Bashar, S.M., Musa, A.: Mechanical performance of roller compacted concrete pavement containing crumb rubber and nano silica, Construction and Building Materials, 159 (2018), pp. 234 - 251.

[31] Musa, A., Bashar, S.M., Mohd Shahir, L.: Mechanical properties and performance of high volume fly ash roller compacted concrete containing crumb rubber and nano silica, Construction and Building Materials, 171 (2018), pp. 521 - 538.

[32] Abdulaziz, A., Lampros, K., Bernal, S.A., Guadagnini, M., Pilakoutas, K.: Mechanical performance of steel fibre reinforced rubberised concrete for flexible concrete pavements, Construction and Building Materials, 172 (2018), pp. 533 - 543.

[33] Guneyisi, E., Gesoglu, M., Ozturan, T.: Properties of rubberized concretes containing silica fume, Cement and Concrete Research, 34 (2004), pp. 2309-2317.