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Granüle atık lastik agregası içeren kauçuk betonunun fiziksel özellikleri

Yazar(lar) (Author(s)): Özlem SALLI BİDECI, Rasim Cem SAKA, Alper BİDECI

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Physical Characteristics of Rubberized Concrete Including Granulated Waste Tire Aggregate

Araştırma Makalesi / Research Article

Özlem Sallı BİDECİ^{1*}, Rasim Cem SAKA², Alper BİDECİ¹

¹Düzce University, Art, Design and Architecture Faculty, Department of Architecture, 81600, Düzce/TURKEY

²Düzce University, Faculty of Technology, Department of Civil Engineering, 81600, Düzce/TURKEY

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ABSTRACT

Every year hundreds of millions of tyres come out as waste because they fill their service period and this situation causes global problems in respect of health and environment. Today, as the natural building sand became a limited and costly material, and fine aggregate is more economical and sustainable, this lead to the usage of fine aggregate in concrete technology. In this study, rubber granule aggregate (CRA) obtained from waste tyres with 0% (control), 5%, 10% and 15% ratios by weight was replaced with the amount of fine aggregate which remains at 1-2 mm sieve opening, and mechanical and morphological properties of the samples were investigated. For this purpose, unit weight, water absorption, compressive strength for 3,7 and 28 days, freezing-thawing (100 cycles) and ultrasonic pulse tests of concrete samples were performed. Also, SEM (Scanning Electron Microscope) images and EDS (Energy-Dispersive X-ray Spectroscopy) spectrum analyses of samples were examined. As a result of the study, it was determined that the sample containing CRA with 5% ratio gave more suitable results than the other samples.

Keywords: Aggregates/recycled aggregates, concrete, concrete technology, construction materials, size effect.

Granüle Atık Lastik Agregası İçeren Kauçuk Betonunun Fiziksel Özellikleri

ÖZ

Her yıl yüz milyonlarca araç lastiği servis süresini doldurması nedeniyle atık olarak ortaya çıkmakta, bu durum sağlık ve çevre açısından küresel sorunlara neden olmaktadır. Günümüzde doğal inşaat kumunun az bulunan ve daha maliyetli bir malzeme haline gelmesi, doğal kuma göre daha ekonomik, sürdürülebilir olması beton teknolojisinde ince agrega olarak kullanımının yolunu açmıştır. Bu çalışmada, atık lastiklerden elde edilen kauçuk granül agrega (CRA), beton karışım dizaynında ince agreganın 1-2 mm elek aralığında kalan miktarına ağırlıkça %0 (Kontrol), %5, %10 ve %15 oranlarında ikame edilmiş ve numunelerin mekanik ve morfolojik özellikleri araştırılmıştır. Bu amaçla beton numunelerinin; birim ağırlık, su emme, 3, 7 ve 28 günlük basınç dayanımları, donma-çözünme (100 çevrim) ve ultrases deneyleri yapılmıştır. Ayrıca, numunelerin SEM (ScanningElectronMicroscope) görüntüleri ve EDS spektrum analizleri incelenmiştir. Çalışmanın sonucunda, %5 oranında CRA içeren numunenin diğer numunelere göre daha uygun sonuçlar verdiği belirlenmiştir.

1. INTRODUCTION

Today, waste tyres not only give harm to health and environment, but also cause esthetical problems. As they have an extremely complex structure, recycling of waste tyres is a very difficult process. Also during the burning process, which is the most economical and easiest method for elimination of used waste tyres, the harmful gases released to environment cause significant air pollution. Therefore, such an elimination method is banned in many countries by law. Today, to make savings from consumed natural sources, waste products are being used within the concrete. So, the harm given by the rubber tyres, which is one of the several harmful solid wastes, is reduced to minimum.

Studies were conducted on the effect of utilization of waste rubber in the content of concrete after a series of

processes on mechanical resistance and durability properties. In a study performed on the effect of rubber addition on concrete permeability; although the permeability coefficient of pervious concrete decreased by 28% with 10% rubber addition, the acceptable values for such concretes were not exceeded and despite this decrease, in case of rain shower, as rain waters are drained to soil rapidly, it was concluded that pervious concretes containing rubber could be utilized in construction of structures such as parking areas, walk ways and road shoulders[1]. As rubber addition decreases the manufacturing cost of concrete and increases its damping capacity against impacts, it is stated to be suitable for using in pavement coatings[2]. Investigation was made on the effect of particle size and the content by volume of waste tyre rubber in pervious concretes against its resistance to bending strength, abrasion and freezing-thawing effects; and as a result of the study it was determined that there was a significant increase in abrasion and freezing-thawing resistance of rubber added

*Sorumlu Yazar (Corresponding Author)
e-posta : ozlembideci@duzce.edu.tr

pervious concretes whereas there were a decrease in their bending strength based on the increase of rubber content[1,4-6]. Also, in another study, it was stated that concretes manufactured by shredded waste rubber chips are suitable to be used in concrete barriers in highways due to the increase in their energy absorption capacity [7]. However, it was determined that when exposed to high temperatures, strength of such concrete decreases compared to normal concretes [8]. In a study, in a self-consolidating concrete manufacturing, the rubber dust was replaced with fine aggregate in 5-10-15-20% ratios by volume and as a result of the experiment it was observed that the shrinkage increased by the increase of rubber amount and this value was at the maximum with 20% rubber replacement, and also ultrasonic pulse velocity decreased when the replacement amount increased[9]. So, it was revealed by the experiments that rubberized concretes might be beneficial to be used in places where voice isolation is required [10]. Several studies were performed on mechanical, morphological and durability characteristics of concrete by adding rubber aggregate in concrete. In a study performed, it was concluded that concretes having rubber has high resistance in environments where they were exposed to acid attacks and they could be applied in such environments [11]. In another study aiming to reduce the expansion caused by alkali-silica reactions, for samples having 16% rubber, there were determined a decrease in 43% ratio in the alkali-silica reaction expansion [12]. As a result of these studies it was determined that compressive strength, bending strength, tensile splitting strength and elasticity module properties of rubber aggregate added concretes decrease, but energy absorption capacity and ductility property of them increase[1,5-7,9,13-15]. As a result of microstructural examinations performed on the samples prepared with such concretes, it was observed that the decrease in strength was based on the poor adherence between the rubber aggregate and concrete paste [4,14]. Therefore rubber particles had been firstly oxidized in $KMnO_4$ solution and then exposed to sulphonisation process in $NaHSO_3$ solution in order to increase the chemical link between the rubber aggregates and cement paste. As a result of the experiment, it was observed that the adherence between rubber surface and cement paste had increased in 41.1% ratio and mechanical properties of rubberized concretes that were exposed to such modification processes had increased [16].

In this study, rubber granule aggregate (CRA) obtained from waste tyres with 5%, 10% and 15% ratios by weight was replaced with the amount of fine aggregate which remains at 1-2 mm sieve opening, and engineering properties of the samples were investigated. For this purpose, unit weight, water absorption, compressive strength for 3, 7 and 28 days, tensile splitting, freezing-thawing (100 cycles) and ultrasonic pulse tests of concrete samples were performed. Also, SEM (Scanning Electron Microscope) images and EDS (Energy-

Dispersive X-ray Spectroscopy) spectrum analyses of samples were examined.

2. MATERIAL AND METHOD

2.1 Material

Aggregate:It is a known fact that suitable aggregate should be used to obtain a good concrete. Properties of aggregate such as chemical and mineralogical composition, petrographic structure, specific weight, hardness, strength, physical and chemical stability, void structure and color depend on the properties of rock. However, in practice, typically properties of aggregate such as particle shape and size, surface structure and water absorption are considered. All of these aggregate properties have significant effects on the concrete properties[17,18]. During the study, natural aggregate produced as per TS 706 EN 12620[19](Figure 1) and rubber granule within 1-2 mm range obtained from Kahya Kauçuk were used. Properties of the used aggregate are given in Table 1 and its granulometry curve is given in Figure 2.

Table 1. Specific weight and water absorption ratios of aggregates

Aggregate Properties	Specific Weight (g/cm ³)	Water Absorption Capacity (%)
Crushed sand	2.64	1.80
Crushed stone No I	2.66	0.60
Crushed stone NoII	2.70	0.40

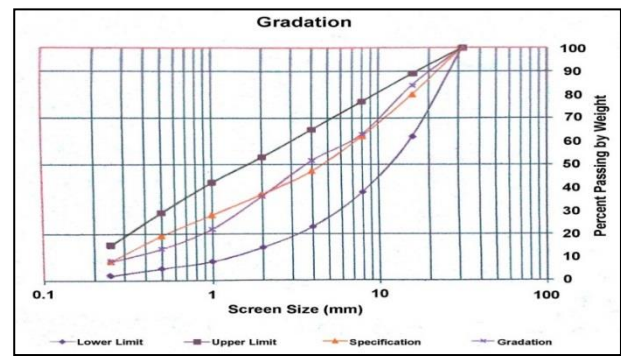


Fig. 2. Aggregate granulometry curve

Cement: CEM I 42.5R cement produced according to TS EN 197-1 [20] standard obtained from Nuh Çimento San. A.Ş. cement factory was used. Physical and chemical analysis of the cement is given in Table 2.

Table 2. Chemical and Physical analysis of cement

Ingredients [%]	CEMI 42.5R	TS EN 197-1	Physical Properties		TS EN 197-1	
CaO	63.93	C+S≥50%	Setting Time [Min.]	Start	141	min. 60
SiO ₂	19.49			End	202	-
Al ₂ O ₃	4.36		-	Specific weight [g/cm ³]	3.15	-
Fe ₂ O ₃	3.40	-	Blaine fineness [cm ² /g]	3866	-	
MgO	1.67	Lim.≤5%	Total Volume Expansion [mm]	1	max.10	
SO ₃	2.81	Lim.≤4%	32 µm sieve residue %	7.7	-	
Na ₂ O	0.27	-	90 µm sieve residue %	0.1	-	
K ₂ O	0.67	-	Compressive Strength [N/mm ²]	2 Days	28.1	min. 20
Cl-	0.0089	Lim.≤0.10%		7 Days	45.7	-
Loss on Ignition Undissolved Residue	2.91	Lim.≤5%		28 Days	56.8	min. 42.5 max. 62.5
	0.32	Lim.≤5%				

Rubber Granule: Granule rubber, which is within 1-2 mm sieve range, obtained from Kahya Kauçuk (Figure3) was used in the analyses. EDS analysis had shown that the rubber sample contained carbon (C) element in a high ratio. Chemical composition properties of rubber was determined by using EDS and given in Table 3.

Table 3. Chemical composition properties of rubber sample

Composition of element	Symbol	Percentage
Carbon	C	89.80
Oxygen	O	8.04
Sodium	Na	1.32
Sulphur	S	0.84
Total		100.00


Fig. 3. Rubber granule within 1-2 mm sieve range

Plasticiser: During the study polycarboxylate based additive was used as plasticiser. It is mixed to each series of tests in 1% ratio. Physical and chemical properties of the plasticiser obtained from Aydos Construction Chemicals Factory are given in Table4.

Table 4. Physical and chemical properties of plasticiser

Technical properties			
Chemical composition	Polycarboxylate based	Density	1.095 ± 0.02 kg/l (20°C)
		Chlorine % (EN 480-10)	< 0.1
Form	Liquid	Alkali % (EN 480-12)	< 2.5
Colour	Brown	pH	6.5± 1.5

Water: Concrete mixture water used in the study was supplied from Düzce Municipality municipal potable water system.

2.2 Method

Dry unit weight

In the test, for each series of tests three cylinder samples in 100 x 100 mm size were manufactured. Manufactured samples were kept in water curing for 48 hours and then dried in oven at 100-110°C for 24 hours. Dried samples were weighed by analytical balance and their sizes were measured by caliper, and dry unit weights of them were calculated according to the Eq.1.

$$\text{Dry Unit Weight} = W/V \quad (1)$$

[kg/m³]

W: Oven dry weight of sample [kg];

V: Sample volume [m³]

Water absorption

Water absorption test was performed as per TS EN 1097-6[21]“Determination of Particle Density and Water Absorption Ratio of Aggregates” standard. For each series of concretes, water absorption percentage tests were performed on samples of 28 days. For water absorption test, samples for which dry weights had been previously determined were kept in water for 24 hours and then they were taken out and weighed. These values were subtracted from dry weight values and their proportion to dry weight percentage was determined. So, water absorption percentage values were determined for each series according to Eq. 2.

$$A_s = \frac{W_{sh} - W_0}{W_0} \times 100 \text{ [%]} \tag{2}$$

A_s= Water absorption by weight [%];

W_o= Dry weight of sample [g];

W_{sh}= Weight of sample, which is concentrated with water, in air [g].

Compressive strength

If it is known about compressive strength of cement, it is possible to get information about other kinds of strengths. It can be said that knowing compressive strength means providing quantitative information about other properties of concrete [22].

Compressive strength test was performed accordance with TS EN 12390-3 [23] "Determination of compressive strength in hardened concrete samples" standard. From each test series, totally 12 cubic samples of 150x150x150 mm were produced for test in order to break them after 3,7 and 28 days of treatment periods. Concrete compression test instrument (Figure 4) with 3000 kN loading capacity, digital control unit and one

axis whose loading rate can be adjusted was used and compressive strength of concrete samples were calculated according to Eq. 3.

$$f_c = \frac{P_{max}}{A_c} \text{ [MPa]} \tag{3}$$

f_c: Compressive strength [MPa];

P: Maximum load achieved at time of breaking [N]

A_c: Cross sectional area of sample [mm²]

Freezing-Thawing

Concretes are subject to many environmental effects. The most efficient of those are freezing and thawing. Because, the water filled in spaces of the material causes expansions in volume and internal tensions by freezing in weather conditions at [-] temperatures. Consequently, physical deteriorations happen in the concrete and compressive strength decreases [24].

The aim of the test was to demonstrate the behavior of the concrete samples obtained by CRA addition against freezing and thawing. Therefore, 12 cylindrical samples of 100x100 mm size were produced and 28 days of water curing was applied to the samples. According to ASTM-C 310 [25], the samples completed their cycle within the set range which was between +4 °C and – 18 °C in freezing-thawing cabinet. The performed freezing-thawing process is called as 1 repetition (cycle). The test was applied by 100 repetitions as such. Concrete compression test instrument having 3000 kN loading capacity and digital control unit with one axis and adjustable loading rate was used and compressive strength of concrete samples were calculated according to Eq. 4.

$$f_c = \frac{P_{max}}{A_c} \text{ [MPa]} \tag{4}$$

f_c: Compressive strength [MPa]; P: Maximum load achieved at time of breaking [N]

A_c: Cross sectional area of sample [mm²]



Fig. 4. Application of compressive strength test

Ultrasonic pulse velocity

Ultrasonic pulse velocity test method carried out as per ASTM C 597 [26] standard is based on the principle of calculating the velocity of the ultrasonic pulse passing through a material and is calculated by Eq. 5.

$$V = \frac{L}{U} \text{ [km/sec]} \tag{5}$$

V: Ultrasonic pulse velocity, km/sec; L: Length of passing, mm

U: Time of passing, μ s

It is difficult to find the compressive strength of a concrete by ultrasonic pulse velocity method (Figure 5) in a satisfactory sensitivity. However, the velocity of ultrasonic wave passing inside a concrete is closely related with the void quantity (density) of that concrete contains, and therefore it is possible to set up a general relationship between obtained ultrasonic velocity and the quality of the concrete. As a result of the experimental studies carried out by White Hurst on concretes having about 2400 kg/m³ of density, results showing how the concrete quality might be when the ultrasonic pulse velocity is known are shown in Table 5.

Table 5. Ultrasound – Concrete Quality Relationship

Wavelength [km/sec]	>4.5	4.5-3.5	3.5-3.0	3.0-2.0	<2.0
Concrete Quality	Excellent	Good	Uncertain	Poor	Very Poor

In general it is known that high velocity (> 4.5 km/sec) indicates high quality concrete, whereas very low velocity (< 3.0 km/sec) indicates poor quality concretes[23]

the hydration. The parts were taken into glass bottles while including particles and sent for analysis. The microstructures of samples were examined in Düzce University, Scientific and Technological Investigations Application and Investigation Centre and their SEM images were taken by FEI trademark, QuantaFeg 250 model variable pressure instrument. EDS analyses were made by using EDAX trademark Apollo X model instrument.

Concrete mixture

In the study, according to rubber granule aggregate (CRA) percentage replaced in the concrete 0% CRA coding was made to control samples and 5% CRA, 10% CRA and 15% CRA coding was made to 5%, 10% and 15% replaced series, respectively.

For mixing of concrete, vertical axis laboratory type pan mixer with 50 dm³ volume was used. Fine and large aggregates were placed in the mixer and it was dry-mixed for 1 minute. Then cement was added and it was mixed for 2 minutes more. 2/3 of mixture liquid was mixed for 2 minutes after the plasticizer was added, and then all the

remaining liquid was added onto the mixture and mixing was continued for 3 minutes more. Fresh concrete was placed into sampling containers carefully in order to avoid the segregation and loss of homogeneity of the



Fig. 5 Application of ultrasonic pulse velocity test

Scanning Electron Microscope (SEM)– Energy-Dispersive X-ray Spectroscopy (EDS) Analyses

In order to form a basis to the experiment, about 100 grams of samples were taken from concrete samples, which were taken from 28 days of curing. These samples were kept in pure acetone for 12 hours in order to stop

concrete. To complete the setting of the samples, they were kept for one day by covering them with a wet cloth and then they were kept in a curing pool having water temperature of 20±2 °C for 3, 7 and 28 days. Concrete mixture design is given in Table 6.

Table 6. Mixture design for 1m³ Concrete

Material [kg]	0%CRA (Control)	5%CRA	10%CRA	15%CRA
Aggregate	Crushed Sand	953.9	906.2	858.5
	Crushed Stone No I	404.5	404.5	404.5
	Crashed StoneNoII	568.1	568.1	568.1
Cement	290.0	290.0	290.0	290.0
Crumb Rubber(CR)	-	47.7	95.4	143.1
Super plasticizer	3.19	3.19	3.19	3.19
Water [kg/l]	166.1	165.2	164.3	163.4

3. RESULTS AND DISCUSSION

3.1 Dry Unit Weight and Water Absorption

Dry unit weight and water absorption ratios of obtained samples are given in Table 7

water absorption ratio was decreased. The graph showing the dry unit weight and water absorption ratio is given in Figure 6.

Table 7. Dry unit weight and water absorption ratios of samples

Mixture	Dry Unit Weight [kg/m ³]	Water Absorption Ratio [%]
0%CRA (Control)	2345.88	4.37
5%CRA	2261.91	4.25
10%CRA	2146.23	3.93
15%CRA	2075.38	3.92

When samples are examined it is observed that highest unit weight and water absorption ratio was for 0% CRA(Control) samples, whereas the lowest values were obtained by 15% CRA samples. Also, in water absorption ratios, it was determined that with replacement of granule rubber aggregate amount, unit weight was decreased and

3.2 Compressive Strength

Compressive strength test results for manufactured concrete samples according to TS EN 12390-3 are given in Table 8 and graphical demonstration of test results are given in Figure 7.

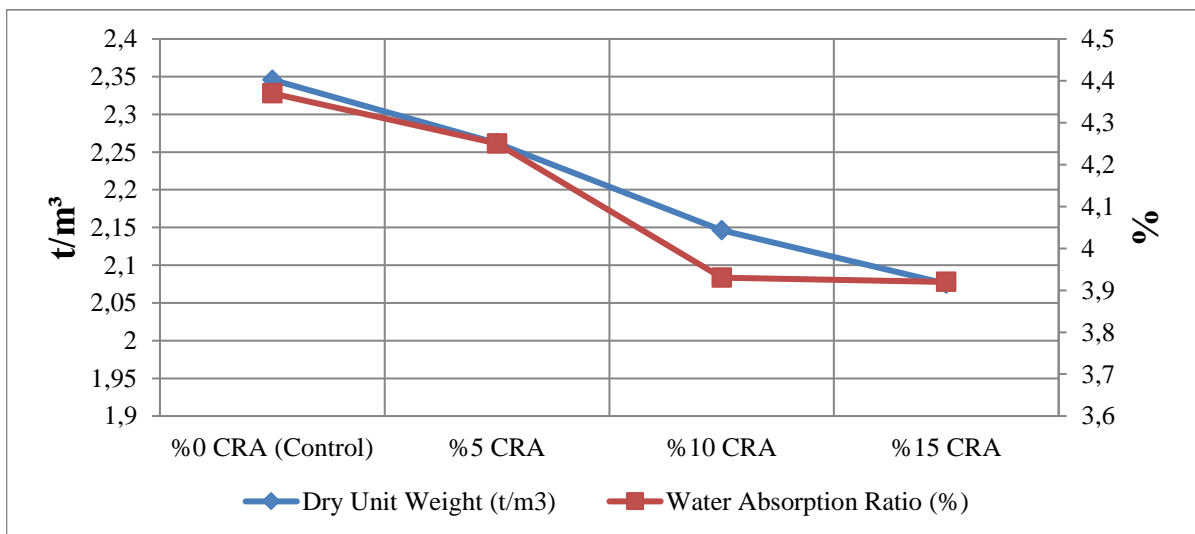


Fig. 6 The graph showing the dry unit weight and water absorption ratio percentage

Table 8. Compressive Strength of Concrete Samples, [MPa]

Material		0%CRA (Control)	5%CRA	10%CRA	15%CRA
Compressive Strength [MPa]	3 Days	33.04	24.77	13.32	10.03
	7 Days	43.12	32.66	20.87	13.91
	28 Days	51.63	36.54	24.27	15.36

When 28 days of compressive strength of manufactured samples are analyzed, it is observed that maximum value was obtained in 28 days from the sample containing 0% CRA (51.63MPa) and the minimum value was obtained from the sample containing 15% CRA (15.36MPa). Compared with control samples, compressive strength of samples containing 5% CRA, 10% CRA and 15% CRA were determined to be decreased by 25-70% for samples of 3 days, by 24-68% for samples of 7 days, by 29-70% for samples of 28 days. As a result, optimum result in compressive strength test was obtained from samples with 5% CRA replacement.

Because, the water filled in spaces of the material causes expansions in volume and internal tensions by freezing in weather conditions at (-) temperatures. Consequently, physical deteriorations happen in the concrete and compressive strength decreases.

The aim of the test was to demonstrate the behaviour of the concrete samples obtained by CRA addition against freezing and thawing. Therefore, 12 cylindrical samples of 100x100 mm size were produced. Compressive strength graph for each sample after 100 cycles are given in Figure 8.

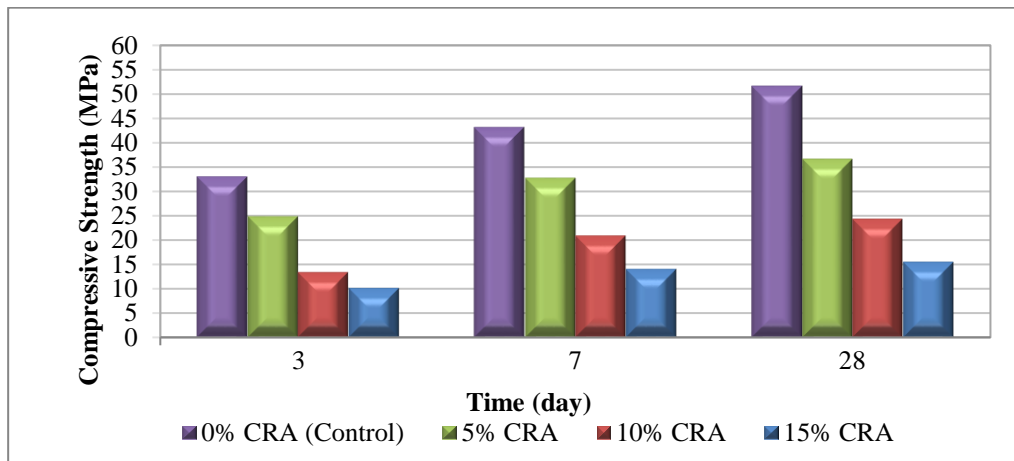


Fig. 7. Compressive strength graph of concrete samples

3.3 Freezing-thawing

Concretes are subject to many environmental effects. The most efficient of those are freezing and thawing.

When Figure 9 is examined, at the end of 100 cycles it is observed that the compressive strength was maximum for samples with 0%CRA (control) (16.81 MPa) and minimum for samples with 15% CRA (6.35 MPa). When

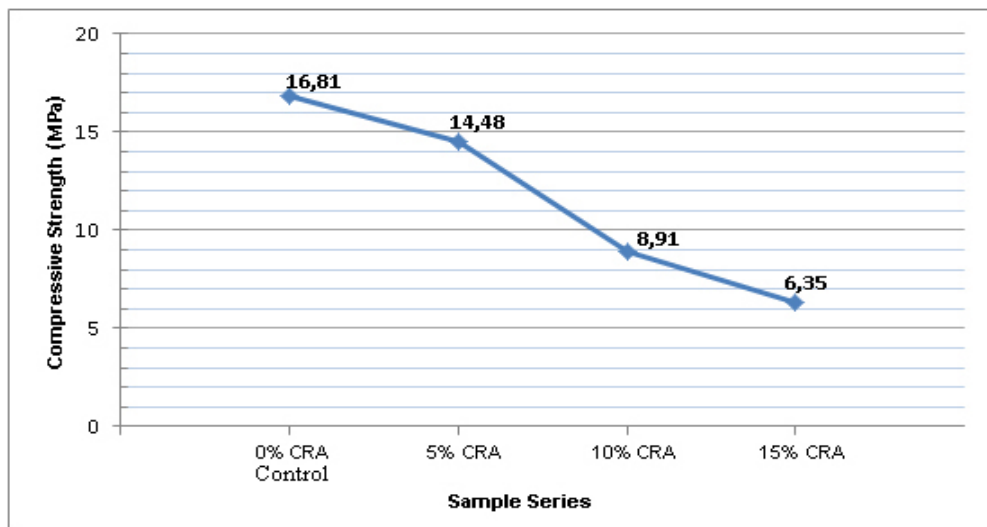


Fig. 8. Compressive strength graph after freezing-thawing test

compressive strength of samples after freezing-thawing was compared with normal compressive strength of them; the maximum decrease is observed in samples with 0% CRA (67%), whereas the minimum is observed in samples with 15% CRA (59%). This shows that CRA replacement positively affected the frost resistance.

3.4 Ultrasonic pulse velocity

Results for ultrasonic pulse velocity test carried out as per ASTM C 597[26] standard are given in Table 9

concretes with 0% CRA, 5% CRA and 10% CRA have “good” (3.5-4.0 km/sec), and concretes with 15% CRA have “not certain” (3.0-3.5 km/sec) concrete quality.

3.5 SEM and EDS analyses

The substances that make cement have a high strength are C-S-H. As a result of the examinations performed by X-ray and electronic microscope [27], it has been possible to examine the structure of C-S-H. According to the studies C-S-H elements have not been properly

Table 9. Ultrasonic Pulse Velocities

Concrete Specimen	0%CRA (Control)	5%CRA	10%CRA	15%CRA
Ultrasonic Pulse Velocity [km/sec]	4.01	3.82	3.56	3.33

When obtained results were compared with ultrasonic pulse-concrete quality literature, it was determined that

crystallized; even they practically have characteristics, which is practically close to amorphous structure. These

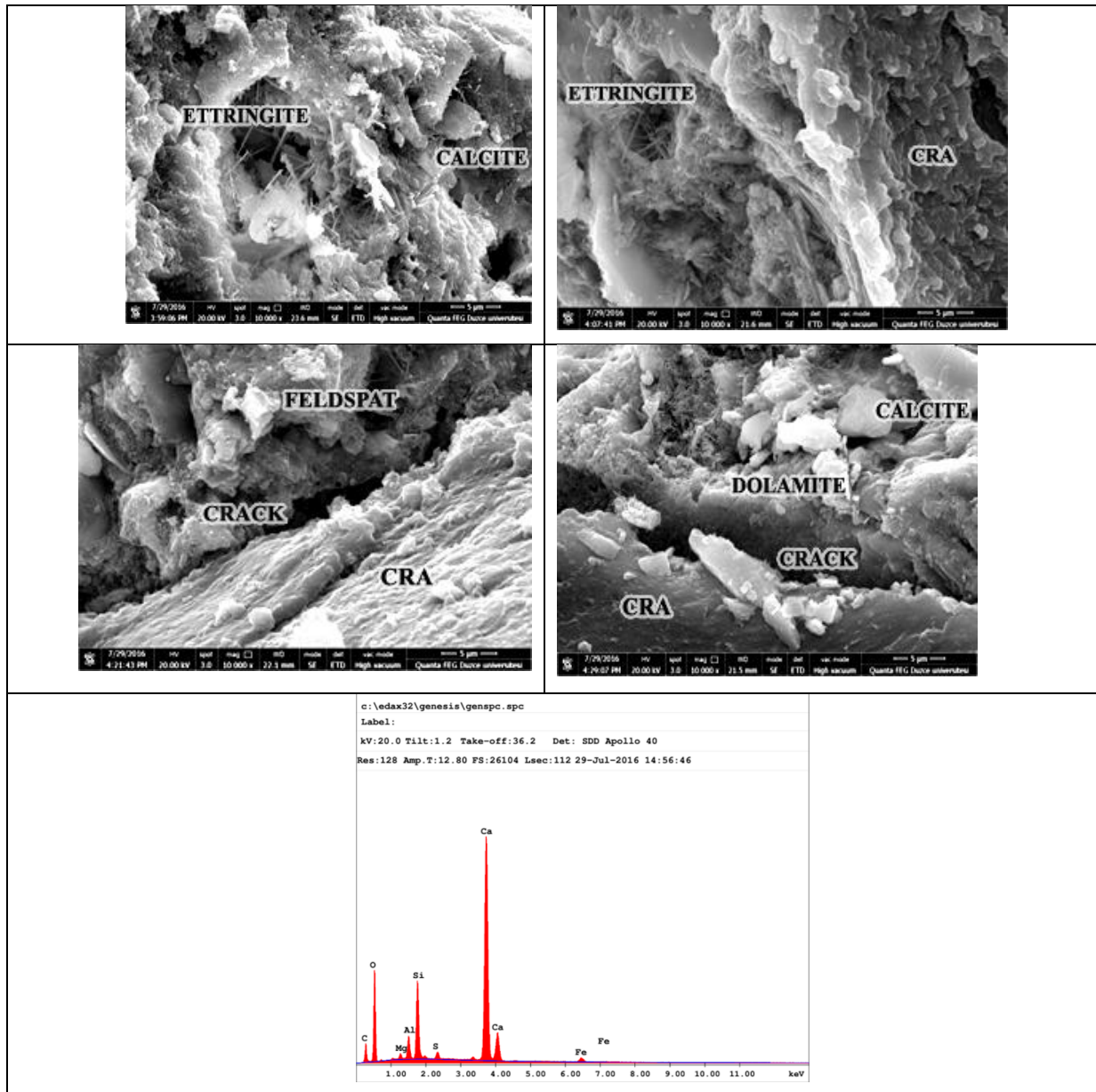


Fig. 9. SEM Images and EDS Analyses of Concrete Matrix after 28 days

elements generally have two different types, in forms of fibres and thin plates or leaves. When hydrated units of calcium silicates are generated, $\text{Ca}(\text{OH})_2$ is formed as hexagonal crystalline and builds up bridges between hydrated units. As a result of increase in C-S-H units in time, the fibres and plates get larger, enter each other and combine together and they provide increase in strength of cement in time [28,29]. SEM images and EDS analysis obtained from the samples in the study are given in Figure 9, respectively.

When SEM images were examined, it was determined that there were aggregates, which had vitreous structure and contained minerals, there were minerals as feldspar, dolomite, calcite and hydrated phases as C-S-H, portlandite and ettringite (trisulphoaluminate hydrate) and non-hydrated cement particles. It was observed that the bond between rubber aggregates and cement sludge is poor and as a result of this poorness cracking had occurred on the interface between cement paste and rubber aggregate, and thus it negatively affected the strength of the concrete.

When EDS results were examined, it was observed that Ca, O, Mg, Al, Si, S, K, CaO, FeO elements and compounds in concrete samples were in parallel when compared with the ones having CRA addition. It was observed that in samples produced with 5% CRA, Ca amount [%] was greater compared to the rest.

4. CONCLUSIONS

In this study, Rubber Granule Aggregate (CRA) obtained from waste tyres in different ratios by weight (Control (0%), 5%, 10% and 15%) was used instead of fine aggregate within 1-2 mm range and obtained results are given below.

- It was observed that unit weights of produced concretes changed between 2346 kg/m³ and 2075 kg/m³. Dry unit weights of (Control) samples with 0% CRA were higher than that of concrete samples with CRA and decreased directly proportional to the CRA amount.
- It was determined that CRA addition to concrete decreased the water absorption ratio (by 2.7%-10%).
- It was observed that regarding compressive strength, maximum value was obtained in 28 days from the sample containing 0% CRA (Control) (51.63MPa) and the minimum value was obtained from the sample containing 15% CRA (15.36MPa). It was determined that as CRA amount increases, the compressive strength decreases.
- As a result of 100 cycles, it was observed that the compressive strength was maximum for sample with 0% CRA (control) (16.81 MPa) and minimum for samples with 15% CRA (6.35 MPa). Also it was determined that directly proportional to the increase of CRA amount, compressive strength decreases.
- As a result of ultrasound pulse velocity test, it was determined that samples with 0% CRA (Control), 5%

CRA and 10% CRA have “good” (3.5-4.5 km/sec), and 15% CRA have “not certain” (3.0-3.5 km/sec) concrete quality.

- When SEM images of samples are examined; it was observed that the bond between rubber aggregates and cement sludge is poor and as a result of this poorness cracking had occurred on the interface between cement paste and rubber aggregate, and thus it negatively affected the strength of the concrete.

As a conclusion; it is determined that in cements manufactured by using CRA, replacing fine aggregate with 5% CRA by weight (optimum) makes positive contribution to the mechanical and durability characteristics of the concrete.

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