Mechanical and Physical Performance of Concrete Including Waste Electrical Cable Rubber

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Abstract. Solid wastes are important environmental problem all over the World. Consumption of the plastic solid waste covers big portion within the total solid waste. Although a numerous plastic material is subjected to the recycling process, it is not easy to be destroyed by nature. One of the recommended way to prevent is to utilize as an aggregate in cement-based material. There are many researches on use of recycling rubber in concrete. However, studies on recycling of waste electrical cable rubber (WECR) in concrete is insufficient although there are many research on waste tyre rubbers in concrete. In this study, fine aggregate was replaced with WECR which were 5%, 10%, and 15% of the total aggregate volume in the concrete and researched workability, unit weight, water absorption, compressive strength, flexural strength, ultrasonic pulse velocity, modulus of elasticity, and abrasion resistance of concrete. As a result of experimental studies, increase of WECR amount in concrete increases workability due to lack of adherence between cement paste and WECR, and hydrophobic structure of WECR while it influences negatively mechanical properties of concrete. It is possible to use WECR in concrete taking into account the reduction in mechanical properties.

1. Introduction
Solid wastes are important environmental problem all over the World [1-5]. Consumption of the plastic solid waste covers big portion within the total solid waste [5-7]. World plastic consumption has approximately increased to 300 million tons from 5 million tons per year in the last 65 years [7, 8]. More than half of them can not be recycled and stored [8]. Although a numerous plastic material is subjected to the recycling process, it is not easy to be destroyed by nature.

One of the recommended way to prevent is to utilize as an aggregate, fiber or part of cement binder in cement-based material [2,9]. There are many researches on use of recycling rubber in concrete, and most of them are about concrete with rubber aggregate. However, studies on recycling of waste electrical cable rubber (WECR) in concrete is insufficient although there are many research on waste tyre rubbers in concrete [10-11].

There are different researches which seem to be contradictory about the workability of rubber aggregated concrete but which are actually logical explanations. In some studies, the value of slump decreased, while in others it increased. The researches investigated by Saikia and Brito (2012) have concluded that rubber aggregates have sharp corners in studies with lower slump compared to plain concrete [2,12-15]. On the other hand, in some studies, the increase in rubber aggregates caused an increase in slump value depending on the shape or hydrophobic structure of some plastic aggregates used or to reduce cohesion by reducing adherence in the mortar paste [10, 16-18].
The rubber aggregated concrete is gradually getting lighter due to the lightness of the rubber materials put into it as expected [2, 7, 10, 19]. According to a study by Saikia and Brito (2012) [9], water absorption ratio concrete shows an alteration according to the type of plastic aggregate. In addition, the increase in the amount of plastic aggregate can increase the water absorption of concrete [10].

In the mechanical properties of concrete, significant strength reductions due to the addition of rubber aggregates can be observed. According to result of the research by Eldin and Senouci (1993) [20] in the study Siddique and Naik (2004) [21] can approximately be a 50% reduction depending on replacement of the coarse aggregate by the rubber aggregate; The compressive strength is 85%, the splitting tensile strength is 50% and the fine aggregate is completely replaced by rubber aggregate, the compressive strength is 65% and the splitting tensile strength is 50%. Coarse rubber aggregate in concrete causes more compressive strength reduction than fine rubber aggregate in the researches by Khatib and Bayomy (1999) [22] and Topcu (1995) [23]. Grinys et al. (2015) [10] gives in their study that increase of WECR of 5% and 10% in concrete remarkably reduces compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity. Ultrasonic pulse velocity (UPV) in concrete significantly decreases with increasing rubber aggregates because rubber aggregates cause porous composition [24]. Some studies show that the abrasion resistance in concrete decreases proportionally with the content of the rubber aggregate [25-28].

In this study, fine aggregate was replaced with WECR which were 5%, 10%, and 15% of the total aggregate volume in the concrete and researched workability, unit weight, water absorption, compressive strength, flexural strength, UPV, modulus of elasticity, and abrasion resistance of concrete. As a result of experimental studies, increase of WECR amount in concrete increases workability while it influences negatively mechanical properties of concrete. It is possible to use WECR in concrete without expecting good mechanical performance or increasing ratio % of WECR.

2. Materials and method

**Aggregate.** In this experimental research, we used natural sand in the range of 0 - 3 mm, crushed sand in the range of 0 - 5 mm, crushed stone in the range of 5 - 12 mm, and crushed stone in the range of 12 - 20 mm.

![Figure 1. WECR obtained in granule form](image)

In addition, WECR which is the main element of the study, is granulated and used by replacing rubber cable waste with natural sand (Figure 1). The granulometry of the aggregates used in the concrete is shown in Figure 2.
Figure 2. Granulometry curve of the aggregates and WECR

Table 1. Chemical composition, physical, and mechanical properties of cement and fly ash

| Constituent (%) | Cement | Fly ash | Physical and mechanical properties | Cement | Fly ash |
|-----------------|--------|---------|-----------------------------------|--------|---------|
| SiO₂            | 20.5   | 50.2    | Specific gravity (g/cm³)          | 3.12   | 2.04    |
| Al₂O₃           | 4.65   | 12.7    | Blaine (m²/kg)                    | 360    | 212     |
| Fe₂O₃           | 3.4    | 9       | Mass stability (mm)               | 2      | -       |
| CaO             | 62.7   | 12.53   | Setting period start (min)        | 153    | -       |
| Free CaO        | 1.09   | -       | Setting period stop (min)         | 188    | -       |
| MgO             | 1.02   | 4.33    | 90 μ sieve (%)                    | 0.2    | -       |
| SO₃             | 2.21   | 0.39    | 45 μ sieve (%)                    | 12.8   | -       |
| Na₂O            | 0.18   | 2.75    | 2 day-strength (MPa)              | 30.2   | -       |
| K₂O             | 0.41   | 2.5     | 7-day strength (MPa)              | 51.1   | -       |
| PbO             | -      | -       | 28-day strength (MPa)             | 62.2   | -       |
| BaO             | -      | -       |                                   | -      |         |
| Sb₂O₃           | -      | -       |                                   | -      |         |
| ZrO₂            | -      | -       |                                   | -      |         |
| SrO             | -      | -       |                                   | -      |         |
| TiO             | -      | -       |                                   | -      |         |
| CeO₂            | -      | -       |                                   | -      |         |
| Cl⁻             | 0.01   | -       |                                   | -      |         |
| Insoluble residue | 0.6   | -       |                                   | -      |         |
| Ignition loss   | 2.15   | 0.54    |                                   | -      |         |
Cement. CEM I 42.5-R was used as cement in all experiments. The chemical, physical, and mechanical analyzes given by the manufacturer's factory which produced this cement are shown in Table 1.

Fly ash. Çayırhan Thermal Power Plant fly ash was used in all experiments. Fly ash properties are given in Table 1.

Chemical Admixture. Superplasticizing concrete admixture was used in all experiments in order to provide proper workability without risk of decomposition or increasing the mixing water.

Water. Tap water in Kocaeli University, Materials of Construction Laboratory was used as the mixed water for all the concrete specimens prepared in this study.

Concrete. In this study, 4 series concrete was produced by replacing natural sand with WECR in 5%, 10%, and 15% of the total aggregate volume. The produced concrete series are coded as follows according to the ratio of rubber aggregate in total aggregate volume:

C = Control concrete without rubber aggregate.
WECR-5 = Concrete with rubber aggregate of 5%.
WECR-10 = Concrete with rubber aggregate of 10%.
WECR-15 = Concrete with rubber aggregate of 15%.

| Materials            | Weight (kg) |
|----------------------|-------------|
|                      | C | WECR-5 | WECR-10 | WECR-15 |
| Cement               | 300| 300    | 300     | 300     |
| Water                | 155| 155    | 155     | 155     |
| Fly Ash              | 60 | 60     | 60      | 60      |
| Chemical admixture   | 3.90| 3.90  | 3.90    | 3.90    |
| Natural sand         | 360| 317    | 273     | 230     |
| Crushed sand         | 517| 517    | 517     | 517     |
| Crushed stone 5-12   | 470| 470    | 470     | 470     |
| Crushed stone 12-20  | 512| 512    | 512     | 512     |
| WECR                 | -  | 26     | 52      | 78      |
| Total                | 2378| 2361  | 2343    | 2326    |

The concrete mix ratios for concrete of 1 m³ are shown in Table 2. 150x150x150 mm cubes, 150x300 mm cylinder, and 100x100x400 mm beam concrete specimens were prepared for the experiments. Unit weight, water absorption, workability, compressive strength, flexural strength, ultrasonic pulse velocity, and abrasion tests were carried out on the samples. The slump value of fresh concrete for workability was determined, and the physical and mechanical properties of the hardened concrete were determined for 3 days, 7 days and 28 days.

3. Experimental work and discussions

Workability. The slump test was used to determine the workability of the concrete and the test was carried out according to TS EN 12350-2 [29]. The slump values were given in Table 3.
Table 3. Values for the amount of slump in fresh concrete

| Concrete  | C   | WECR-5 | WECR-10 | WECR-15 |
|-----------|-----|--------|---------|---------|
| Slump, mm | 150 | 170    | 175     | 185     |

When the table is analyzed, it is seen that value of slump increases with the increase of the content of WECR in the concrete. The use of WECR at low ratios (up to 15% of the fine aggregate volume fraction) reported to increase slump of concrete as similar to the research introduced by Khaloo et al. in 2008 [24]. Some research support also this result [16-18]. It has been observed that WECR considerably reduces cohesion and causes increase in slump value in the concrete because of its round shape and hydrophobic structure.

Dry Unit weight and water absorption. The dry unit weight of hardened concrete was determined according to TS EN 12390-7 [30]. The percentage of water absorption and the dry unit weight of hardened concrete is shown in Table 4.

Table 4. Dry unit weight and water absorption in hardened concrete

| Concrete  | C   | WECR-5 | WECR-10 | WECR-15 |
|-----------|-----|--------|---------|---------|
| Dry Unit weight, gr/cm³ | 2.35 | 2.25   | 2.22    | 2.10    |
| Water absorption, %  | 3.28 | 3.68   | 6.41    | 7.04    |

Unit weight of the WECR is lower than that of the fine aggregate. Therefore, there is a steady decrease in the dry unit weight of the concrete values as seen in Table 4 when the amount of WECR in the concrete increases. In addition, WECR increases water absorption by the rate of participation as in the study presented by Grinys et al.[10]. The WECR is likely to increase water absorption because of the increase in gaps [24].

Compressive strength. Cube specimens with dimensions of 150x150x150 mm were used in the compressive strength tests made according to TS EN 12390-3 [31]. 5 samples of 3, 7 and 28 days were crushed in compression test machine and the averages of them were found. The test results are given in Figure 3. As shown in Figure 3, there is a regular decrease in compressive strength as the amount of WECR in the concrete increases.

![Figure 3. Compressive strength-time relationship in the concrete.](image-url)
Flexural strength. In order to find the flexural strength in accordance with TS EN 12390-5 [32], the specimens were tested with four point loading tests.

In the study, 100x100x400 mm prismatic concrete specimens were loaded up to failure as shown in Figure 4 after 3, 7 and 28 days curing and flexural strengths were found. The results of flexural strength of 100x100x400 mm prism specimens are given in Figure 4.

When Figure 5 is examined, it is seen that the flexural strength decreases as the amount of WECR in concrete increases, similar to the graph of compressive strength in Figure 3. It was seen that adding more 5% WECR reduced the difference between 7 and 28 days. Decrease in flexural strength was slowed down by 15% WECR addition. The flexural strength does not increase in accordance with the pressure strength at 28th day.

Ultrasonic Pulse Velocity (UPV). This test is based on the measurement of the passing time of sound velocity in the material according to TS EN 12504-4 [33]. The ultrasonic sound device measures how
long the sound wave passes through a distance between the two opposing surfaces of the concrete (Figure 6-a,b). The relationship between the calculated wave velocity value and the compressive strength can be found approximately.

In this study, 100x100x400 mm prismatic concrete specimens were used to obtain UPV value of concrete. UPV values were found on the prismatic specimens at the end of the days 3, 7, and 28 before the flexural strength test. The relationship between the compressive and flexural strengths with UPV values of 3, 7 and 28 days are shown in Figure 7.

![Figure 6. UPV test](image)

![Figure 7. UPV-compressive and flexural strength relationship for types of concrete](image)
R² values in Figure 7-a clearly shows that there is a strong of linear relationship between the UPV with the compressive (R²=0.9792) and flexural strength (R²=0.8687) of control concrete. WECR increases both void and adherence loss in concrete. Therefore, the value of R² decreases gradually due to the increase in the amount of WECR and the weakening of the graphical relationship in Figure 7-b, c, d. It has been noticed that flexural strength weakens this relationship because the flexural strength does not increase in accordance with the compressive strength from 7th day to 28th day.

Especially, the relationship of UPV- flexural strength lost with R²=0.6261 in Figure 7-b, and the relationship of UPV-compressive strength lost with R²=0.6905 in Figure 7-d shows that UPV-compressive strength relationship is stronger than UPV-flexural strength relationship in Figure 7-a,b,c,d.

Ultrasonic pulse velocity in concrete significantly decreases with increasing WECR because of porous composition as in the study carried out by Khaloo et al [24]. The UPV values reduce to 4.1 levels for 15% WECR in Figure 7.d., they are in the 4.8 km/s range for C in Figure 7.a,

**Modulus of Elasticity.** Concrete is a non-elastic material because it is a composite composed of brittle and different phases. However, it may exhibit elastic properties under small stresses. Theoretically, this corresponds approximately to a value between 20% and 35% of the compressive strength. The σ-ε relation used to explain the elastic behavior of concrete can be determined by experimental methods.

![Figure 8. Modulus of elasticity test design](image)

Figure 8 shows the compressive test to find the modulus of elasticity on standard cylinder specimens of 150x300 mm according to ASTM C496 [34]. One scale dial gauge was used to find the vertical deformation of the concrete and to establish a relationship with the compressive resistance. One of the gauges seen in the Figure 8 is for horizontal deformation and was deactivated in this experiment. Modulus of elasticity were calculated with the help of experimentally obtained strength and vertical deformation data on 28 day specimens.
Table 5 shows the static modulus of elasticity values of the concrete. As the use rate of WECR% in concrete increases, the value of the modulus of elasticity steadily decreases. The value of 34146 MPa in the control concrete decreased to 24687 MPa with a decrease of 27.7% in the concrete containing 15% WECR. It has been understood that 15% WECR use in concrete is significantly reduced the modulus of elasticity by a loss of 27.7 while the WECR increase of 5% and 10% in concrete reduced the modulus of elasticity by 8.9% and 14.6%, respectively. This is as in the study by Grinys et al. (2015) [10].

| Concrete | C     | WECR-5 | WECR-10 | WECR-15 |
|----------|-------|--------|---------|---------|
| Modulus of elasticity, MPa | 34146 | 31111  | 29167   | 24687   |
| Decrease of modulus of elasticity (%) | 0     | 8.90   | 14.6    | 27.7    |

**Abrasion.** According to TS 2824 EN 1338 [35], cube specimens cured for 28 days in the size of 71x71x71 mm were subjected to the Bohme abrasion test. They were subjected to 16 cycles, each of which occurred 22 times. At the end of the experiment, reductions in the volume of the samples were determined. The test device used in the experiment is shown in Figure 9.

| Concrete | C     | WECR-5 | WECR-10 | WECR-15 |
|----------|-------|--------|---------|---------|
| Abrasion, cm³ | 6.67  | 7.2    | 8.9     | 10.1    |
| Increase of abrasion, % | 0     | 7.95   | 33.4    | 51.4    |

The results of the abrasion test on 71x71x71mm cube samples at the end of 28th days are given in Table 6. It is seen that C gives the best result. The abrasion increases due to WECR increase as in some studies [25-28]. The abrasion of WECR-5 was acceptable and close to C value at abrasion rate of 8% while the abrasion increases by WECR-10 and WECR-15 were observed to be much higher with 33.4% and 51.4%, respectively.
4. Conclusions
Taking into account the results obtained from the experiments in the study, it is possible to achieve the following results:

1. The use of WECR in the concrete increases the slump values because of its round and hydrophobic structure and poor adherence with cement paste.
2. A decrease in unit weight of concrete with WECR was observed due to the low specific gravity of the WECR.
3. For 3, 7 and 28 days samples, as the addition of WECR increased, the compressive strength of the concrete decreased considerably. The increase in WECR reduces the difference between 3, 7 days and 28th day specimens due to the decrease in adherence. On the other hand, this difference for C is increasing due to the more positive effect of the ultimate strength in the fly ash.
4. It has been observed that the flexural strengths are in good agreement with the compressive strengths for all samples. Increase of WECR in concrete gradually reduces strength.
5. UPV is in agreement with the strengths. $R^2$ values shows that a strong of linear relationship between the UPV with the compressive and flexural strength of control concrete. The value of $R^2$ gradually reduces by the increase of void and adherence loss in concrete due to the increase in the amount of WECR. The increase of WECR% reduces UPV values. It is seen that UPV-compressive strength relationship is stronger than UPV-flexural strength relationship. However, its main reason is that the flexural strength does not increase in accordance with the compressive strength at 28th day.
6. The modulus of elasticity in concrete decreases considerably due to the addition of WECR to the concrete. Especially, 15% WECR use in concrete is significantly reduced the modulus of elasticity.
7. The Bohme abrasion resistance decrease with use of WECR in concrete. In particular, the addition of more than 5% WECR in concrete causes seriously volumetric reductions.

According to the findings obtained from the study, it is possible to use WECR in terms of recycling by replacing them with fine aggregates up to 5%, taking into account the adverse conditions in concrete properties. However, the replacement of the plastic aggregate by more than 5% has a very negative effect in the concrete and it does not bring any advantage except for an increase in the slump value. In fact, this increase in slump value can be used as an advantage and it is possible to achieve a positive increase in mechanical properties by reducing the amount of water. By conducting a new research, it is perhaps possible to use WECR without too much reduction in mechanical properties.

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