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USAGE OF THE PLASTIC WASTES AS AN AGGREGATE IN CEMENTITIOUS MIXTURES

ÇİMENTOLU KARIŞIMLARDA PLASTİK ATIKLARIN AGREGA OLARAK KULLANIMI

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ABSTRACT

Due to its many advantages, polymer materials have a wide range of usage areas. There are some processes that must be applied to polymer wastes within the legal framework. Recycling is one of these processes. However, because it is a difficult and costly process, it becomes attractive to reuse these wastes. From this perspective, evaluating the feasibility of polymer wastes in cementitious mixtures as raw materials will be very useful research. In this study, cementitious mixtures containing plastic wastes in different proportions were studied. Mechanical properties were investigated by using plastic waste in two ratios with aggregate substitution in cementitious mixtures. As a result, it has been observed that some mechanical properties could be improved with the use of plastic wastes whose specific gravity is much lower than aggregate. The improvement in mechanical properties varies according to the type and amount of plastic wastes. Namely, it has been observed that 50% of the substitution of polystyrene and polycarbonate wastes and 10% of thermoplastic elastomers and electrical cable wastes increase some of the mechanical properties. It has been determined that the gradation of plastic wastes directly affects these properties such as fresh state properties and toughness of the cementitious mixtures. It is envisaged to obtain improved fresh state properties and high mechanical properties where the raw materials have more appropriate gradation.

Keywords: Construction materials, mechanical properties, mortars, reuse, wastes

ÖZET

Birçok avantajı bir arada barındırması sebebiyle polimer malzemeler çok geniş kullanım alanına sahiptir. Polimer atıklara yasal çerçevede uygulanması gereken birtakım işlemler mevcuttur. Geri dönüşüm de bu işlemlerden biridir. Fakat zor ve maliyetli bir süreç olması sebebiyle atıkları yeniden kullanma cazip hale gelmektedir. Bu perspektiften bakılınca polimer atıkların çimentolu karışımlarda hammadde olabilirliğinin değerlendirilmesi oldukça faydalı bir araştırma olacaktır. Bu çalışmada, plastik atıkları farklı oranlarda içeren çimentolu karışımlar üzerinde çalışılmıştır. Çimentolu karışımlarda agrega ikamesiyle iki oranda plastik atık kullanılarak mekanik özellikler incelenmiştir. Sonuç olarak; özgül ağırlığı agregadan oldukça düşük olan plastik atıkların kullanımı ile bazı mekanik özelliklerin geliştirilebileceği görülmüştür. Mekanik özelliklerdeki gelişim, plastik atığın türü ve miktarına göre değişiklik göstermektedir. Şöyle ki; %50 oranında ikame yapıldığında polistiren ve polikarbonat esaslı atıkların, %10 oranında ise termoplastik elastomerlerin ve elektrik kablosu atıklarının mekanik özelliklerinden bazılarını arttırdığı görülmüştür. Karışımların taze hal özellikleri ve tokluk gibi mekanik özellikleri plastik atıkların gradasyonunun doğrudan etkilediği tespit edilmiştir. Hammaddelerin daha uygun gradasyona sahip olduğu çalışmalarda geliştirilmiş taze hal özellikleri ve yüksek mekanik özellikler elde edilmesi öngörülmektedir.

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Anahtar Kelimeler: Atıklar, harçlar, mekanik özellikler, yapı malzemeleri, yeniden kullanım

INTRODUCTION

It is an inevitable fact that plastic waste is a major factor that increases environmental pollution. Waste management is a very important process that includes all types of wastes. Waste Management Hierarchy is used in accordance with the waste legislation (Atık Yönetimi Mevzuatı, 2016; Atık Yönetimi Yönetmeliği, 2015). According to this hierarchy;

- The generation of waste should be prevented.
- If it could not be prevented, it should be ensured that it occurs in the least amount.
- Wastes should be reused as much as possible.
- Unusable wastes should be recycled.
- In cases where recycling is impossible, energy recovery should be provided from wastes.
- The last method to be preferred is the disposal of the wastes by various methods.

As a result, the reuse of the wastes becomes extremely significant when the generation of waste could not be completely avoided. The use of composites containing plastic wastes in various construction areas such as sewer pipes, pavements, cementitious mixtures (mortar, brick, concrete, paver block etc.) for different applications, roads, furniture production is available in scientific studies within the scope of reducing the usage of plastic wastes (Mahmood and Kockal, 2021; Zulkernain et al., 2021; Tuna Kayılı et al., 2020).

According to the literature, it was seen that a wide variety of wastes (such as plastics) in concrete or mortar were used for different purposes and the use of these materials developed especially mechanical and various other properties in certain ways and amounts of use (Almeshal et al., 2020; Bahij et al., 2020; Kockal and Camurlu, 2020; Mahmood and Kockal, 2020; Gu and Ozbakkaloglu, 2016). In a study on concrete blocks, ductility increased in the use of PET (polyethylene terephthalate) waste as a fiber. It was found that the flexural strength of this waste increased from 3 MPa to 6 MPa. Concrete that becomes more ductile is known to be more resistant to freeze-thaw (Chowdhury et al., 2013). In a study in which waste rubber was substituted up to 100% with coarse aggregate at various ratios in concrete, both the compressive strength and the modulus of elasticity were calculated by static pressure test on the 7th and 28th days. Dynamic impact test was also carried out with New Jersey type barriers prepared with these mixtures. The compressive strength and modulus of elasticity decreased, and the amount of energy absorption increased by rising the waste amount. Moreover, increasing the amount of energy absorption reduces the impact and the risk of occupant injury resulting from the accident (Atahan and Sevim, 2008). In another study made with six different concrete mixtures containing rubber particles, static pressure test and dynamic impact test were performed in the same way. However, in this study, the energy absorption amount was measured by performing the impact test by placing a certain weight on the cylindrical concrete samples with the Instron Dynatup 9250 HV device. As a result the compressive strength and modulus of elasticity decreased, while the amount of absorbed energy increased at higher amount of rubber particles (Atahan and Yücel, 2012). In a study on concrete including PET wastes as an aggregate, the wastes were used in three different shapes and sizes, and the effect of the shape and size of PET-aggregate on mechanical and fresh state properties was investigated. It was concluded that workability of the concrete mixtures was highly affected by of the shape and size of PET-aggregate. It has been observed that the decrease in compressive strength with the addition of PET waste was as low as 5% in some mixtures with workability suitable for reducing the w/c ratio (Saikia and De Brito, 2014). In another study on cement mortars incorporating PET wastes, these wastes were used as longitudinal reinforcement and as fiber having different L/D ratios. The maximum compressive strength was obtained by the sample having PET waste as fiber with L/D ratio of 2 with the value of 38.4 MPa (Yilmaz, 2021).

Plastic wastes could be used as fibers in cementitious mixtures as well as used as aggregates. It is known that concrete, in which polymer-based wastes are used as aggregate, will show lightweight concrete properties. In this case, it becomes more likely to obtain a concrete that can provide thermal and sound insulation (Meng et al., 2018; Chowdhury et al., 2013). In a study in which rubber crumbs were used, it was observed that the sound insulation value of the concrete increased considerably as the amount of these waste aggregate increased. The best results were obtained in lightweight concrete, in which rubber particles were used as 75% (Zhang and Poon, 2018).

In this study, the mechanical and physical properties of the cementitious materials obtained with the usage of one or more types of plastic wastes together were examined. It was aimed that cementitious mixtures containing plastic wastes with improved mechanical properties could perform better under the impact than those without plastic wastes. In the future studies, suitable mixtures for a concrete barrier will be determined by using these plastic wastes.

MATERIALS AND METHODS

Materials

The materials used in the cementitious mixtures were ordinary Portland cement (CEM I 42.5 R), fine aggregate (0-4 mm, crushed limestone), a superplasticizer type of chemical additive, nine different types of plastic wastes and also tap water. The specific weights of these initial materials are given in Table 1. The types and some specifications of the plastic wastes are given in Table 2.

Table 1. The Specific Weights of the Initial Materials

Initial Materials	Specific Weight (g/cm^3)
Fine aggregate (0-4 mm)	2.61±0.01
Portland cement (CEM I 42.5 R)	3.11±0.02

Table 2. Plastic Waste Materials and Their Some Specifications

Type of Plastic Waste	Code	Specific weight (g/cm3)	Shape	Utilization areas of this materials
Polycarbonate	K	1.141	Like as crushed aggregate	Plastic demijohn, medical equipment's, spectacle lens, roof covering
Polyethylene	P	0.928	Round	Bottle cap, carrier bag
ABS	A	1.009	Cylinder	Car parts, bumper
Polypropylene	R	0.875	Cylinder with hole	Plastic chairs, yoghurt case, vase
PVC	V	1.162	Crushed	Pipe, window, cable
Polystyrene (Crystal)	T	1.007	Round	Plastic glass and plate
Polystyrene (Antishock)	S	1.052	Crushed	Fridge, washing machine, styrofoam
TPE	E	0.962	Crushed	Shoes sole, power cable
Waste of power cable	B	1.490	Finely chopped	Power cable

Methods

The mixtures were prepared by 10 and 50% of waste by volume for each waste and several wastes were used together to determine the combined of the wastes. Furthermore, hybrid mixtures were prepared on the same principle at the total ratio of 50%. Certain details of the mixtures are given below:

- The amount of cement: 380 kg/dm3
- Water/ cement ratio: 0.5 (constant)
- Chemical admixtures: Fosroc Gantre 738 S (Polycarboxylate based admixture)
- The amount of chemical admixture: It was determined as a percent by the amount of cement according to the flow diameter of cementitious mixtures. (in the range of 0.8-1.6%)

The fresh consistency of the cementitious mixtures was determined by measuring the flow diameters according to EN 1015-3. In order to decide the waste being more suitable as construction material, 7-day mechanical properties of the mixtures were examined. As a result of these mechanical tests flexural strength, compressive strength and toughness were found. The flexural and compressive strengths of the hardened samples were calculated according to the equations 1 and 2 respectively as described in the European standard of EN 196-1. Toughness values were calculated from the area under the load vs. displacement graph of the compressive strength tests via a software program and the relative toughness values are given in Table 4. Modulus of elasticity of the hardened samples were calculated by the equation 3 as described in European standard of EN 12390-13. Also, the relative modulus of elasticity values are exhibited in Table 4 according to the results obtained by the mentioned equation.

$$\sigma_f = \frac{3 \times F \times l}{2 \times b \times d^2} \quad (1)$$

σ_f : Flexural strength (MPa)
l: Distance between two supporting pins (mm)
b: Width of specimen (mm)
d: Thickness of specimen (mm)

$$\sigma_C = \frac{F}{A} \quad (2)$$

σ_C : Compressive strength (MPa)
F: Maximum load (N)
A: The cross section of the area of the material resisting the load (mm^2)

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \quad (3)$$

σ_1: the stress at the unit deformation value of 5×10^{-5} (MPa)
σ_2: 40% of the maximum stress (MPa)
ε_1: the unit deformation at the stress value of σ_1
ε_2: the unit deformation at the stress value of σ_2

RESULTS

The fresh consistency of the cementitious mixtures was determined by measuring the flow diameters. The flow diameters and the amount of the amount of chemical additives (%) to achieve the specified consistency were given in Table 3. Due to the segregation problems experienced in high consistencies, the flow diameters have been tried to be kept between 10 and 15 cm. However, in some mixtures, fluidity could be achieved at a consistency of higher than 15 cm.

Table 3. Flow Diameters of the Cementitious Mixtures

Sample Code	The Plastic Waste Type	The amount of plastic waste (%, by volume)	The amount of chemical additives (%)	Flow Diameter (cm)	Experimental Unit Weight of the Cementitious Mixtures (kg/m³)
C	----	----	0.8	15	2170.57
İP50	Polyethylene	50	0.8	20.5	1682.45
İK50	Polycarbonate	50	0.8	10.75	1706.64
İA50	ABS	50	0.8	12.25	1679.70
İR50	Polypropylene	50	1.0	12.3	1663.25
İV50	PVC	50	1.6	15.25	1697.30
İS50	Polystyrene (anti shock)	50	1.6	13.25	1663.25
İE50	TPE	50	1.2	11.25	1664.10
İT50	Polystyrene (crystal)	50	1.0	18.75	1674.56
İK10	Polycarbonate	10	1.0	11.25	2059.30
İA10	ABS	10	1.1	13	2041.05
İS10	Polystyrene (anti shock)	10	1.0	12.65	2200.54
İP10	Polyethylene	10	1.2	12.25	2182.10
İT10	Polystyrene (crystal)	10	1.1	13.75	2154.10
İR10	Polypropylene	10	1.4	14	2168.97
İV10	PVC	10	1.2	13.25	2143.99
İE10	TPE	10	1.2	12.25	2206.87
İB10	Power cable	10	1.4	11.5	2210.54
İAV50	ABS and PVC	50	1.6	11.25	1766.13
İPV50	Polyethylene and PVC	50	1.2	12.25	1757.30
İAE50	ABS and TPE	50	1.6	11	1730.83

The flexural strength, compressive strength, relative toughness values and relative modulus of elasticity of all the cementitious mixtures are given in Table 4.

Table 4. Mechanical Test Results of the Cementitious Mixtures

Sample Code	The Plastic Waste Type	The amount of plastic waste (%, by volume)	Flexural Strength (MPa)	Compressive Strength (MPa)	Relative Toughness (MPa)	Relative Modulus of Elasticity (MPa)
C	----	----	10.67	40.05	100	100
İP50	Polyethylene	50	4.52	12.49	34.7	62.5
İK50	Polycarbonate	50	6.93	25.44	140.4	67.3
İA50	ABS	50	7.15	22.31	73.3	75.5
İR50	Polypropylene	50	5.56	18.20	48.9	72.6
İV50	PVC	50	4.01	7.61	37.5	57.3
İS50	Polystyrene (anti shock)	50	8.09	27.63	138.9	75.2
İE50	TPE	50	3.60	6.05	57.9	29.4
İT50	Polystyrene (crystal)	50	7.61	25.09	74.0	71.1
İK10	Polycarbonate	10	11.02	34.09	105.3	84.8
İA10	ABS	10	11.90	32.20	102.3	73.3
İS10	Polystyrene (anti shock)	10	11.45	35.36	100.6	83.0
İP10	Polyethylene	10	11.17	30.75	72.0	85.2
İT10	Polystyrene (crystal)	10	10.78	32.52	92.4	80.1
İR10	Polypropylene	10	11.51	33.09	120.3	87.0
İV10	PVC	10	10.03	27.34	87.5	78.1
İE10	TPE	10	10.56	28.11	142.3	71.6
İB10	Power cable	10	11.46	25.66	211.7	61.4
İAV50	ABS and PVC	50	5.90	11.12	53.2	47.3
İPV50	Polyethylene and PVC	50	4.07	9.62	40.4	69.1
İAE50	ABS and TPE	50	5.60	11.38	40.2	61.5

It could be seen from Figure 1 that the two highest relative toughness values (among the mixtures containing 50% waste) are 140.4% and 138.9% belonging to İK50 and İS50, respectively. As could be clearly detected from the graph, the best two values were higher than the toughness value of the control sample.

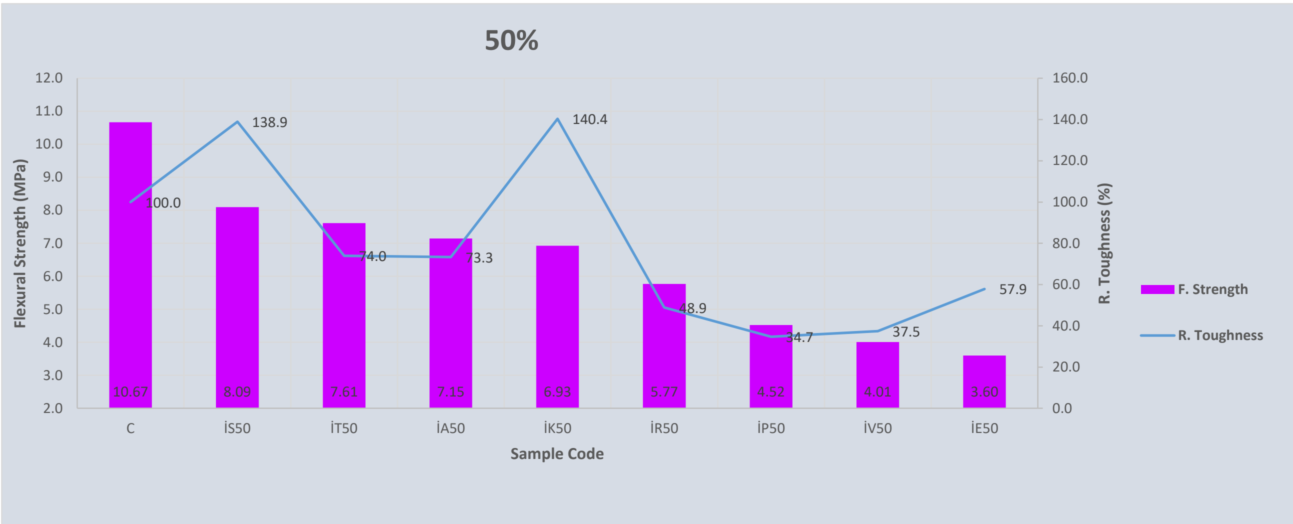

Figure 1. Flexural Strengths and Relative Toughness Values of the Cementitous Mixtures Including 50% of Waste

The flexural strength and relative toughness values of the cementitious mixtures having 10% of plastic waste are compared in Figure 2. First of all, it has been observed that the use of 10% plastic wastes had more positive effect on toughness than the use of 50% plastic wastes. However, with a value of 211.7%, the relative toughness of the sample of IB10 is higher than the whole samples (including 50% and hybrid studies). Unfortunately, 50% of this waste (power cables) could not be studied. There was a very high amount of segregation and the mixture could not be placed in the molds.

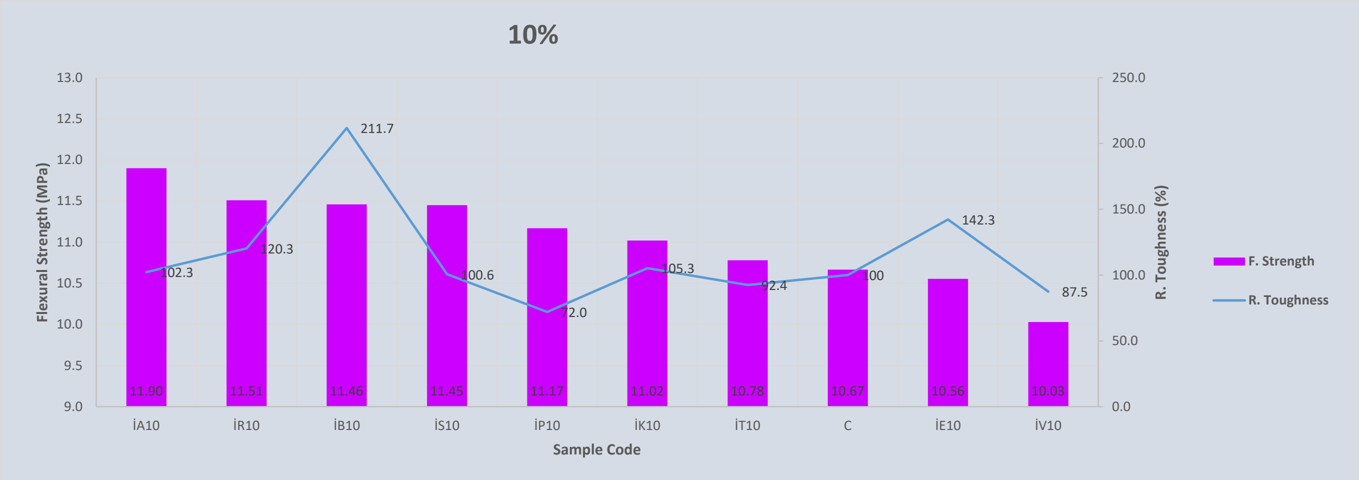

Figure 2. Flexural Strengths and Relative Toughness Values of the Cementitious Mixtures Including 10% of Waste

The test results of all waste types were evaluated within themselves:

- The studies done with polyethylene were indicated that the toughness decreased as the waste increased. It was observed that the strength of the mixtures firstly increased at 10% and decreased again by 50%.
- It was resulted that both the toughness and flexural strength decreased as the amount of PVC increased.
- In the studies with ABS; when the amount of waste increased from 0 to 10%, toughness increased by 2% and the flexural strength increased at 10%. Also, it has been determined that both of them decreased at 50%.
- It was observed that the strength remained almost constant and the toughness increased by 40% with the use of 10% of TPE. While the ratio of TPE was 50%, both strength and toughness decreased. Another important point here was that when the ratio of TPE was 50%, there were quite problems during placement and removal from the molds.
- In the samples containing polypropylene, when the amount of waste increased from 0 to 10%, the strength and toughness increased. Both of them fallen at the amount of 50%.
- The toughness decreased as the amount of polystyrene (crystal) increased.
- Besides that, it has been determined that the best mechanical results, especially the toughness values, were obtained from the mixtures including polystyrene (anti-shock) and polycarbonate in the use of relatively high amount of these wastes. The results of these mixtures were compared with the results of the control mixture in Fig. 3 and 4. When the amount of polystyrene (anti-shock) increased from 0 to 10%, the toughness remained almost constant according to Figure 3. But it was increased by 40% when the amount was risen to 50%. (despite reduced flexural strength). As could be detected from Figure 4, the toughness increased as the amount of polycarbonate increased.
- When the modulus of elasticity values of all mixtures given in Table 4 were examined, it was observed that all the samples including wastes were lower than the control sample. Furthermore, the modulus of elasticity decreased with the increase in the amount of wastes. The main reason for this is that the elasticity modules of plastic wastes used instead of aggregate originated by limestone are lower than the aggregate. It was observed that PVC, TPE and power cable wastes decreased their elasticity modules at a higher ratio than the other ones.

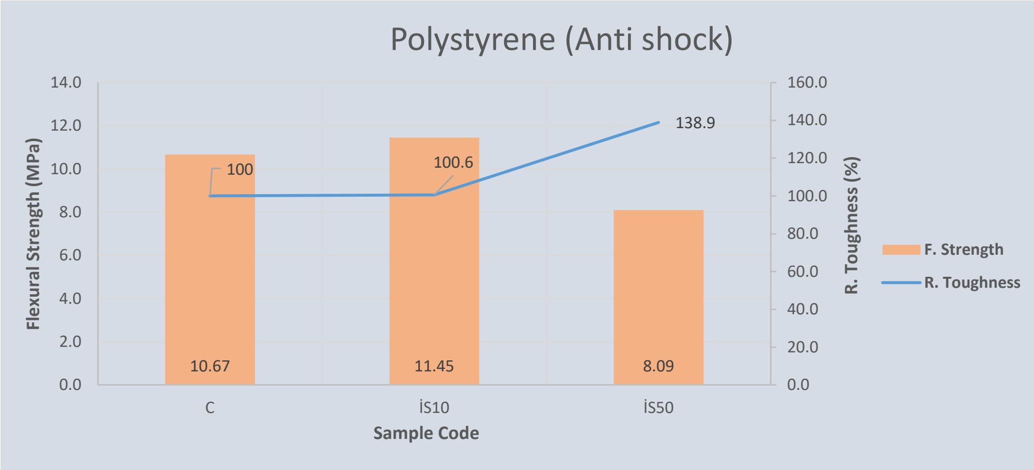

Figure 3. Flexural Strengths and Relative Toughness Values of the Cementitious Mixtures Including Polystyrene Waste

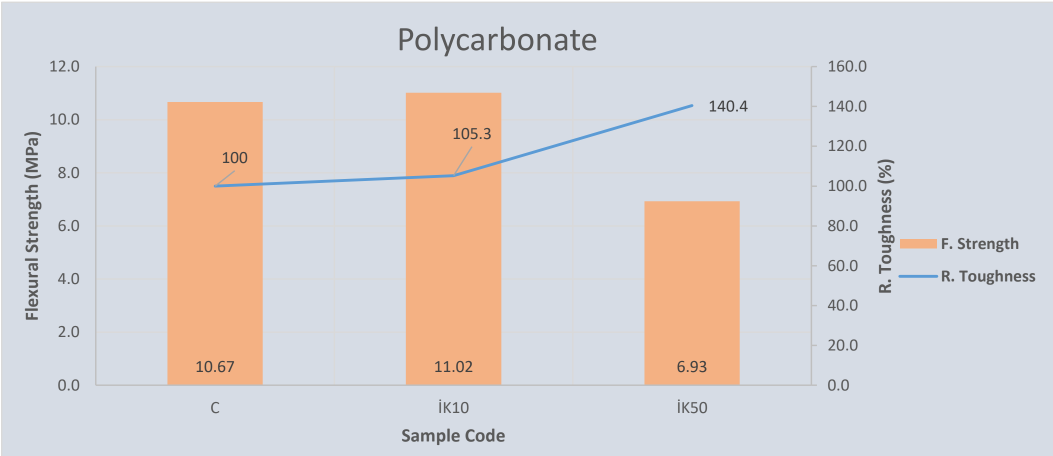

Figure 4: Flexural Strengths and Relative Toughness Values of the Cementitious Mixtures Including Polycarbonate Waste

Due to the low positive contribution of the use of the wastes of polyethylene, PVC, ABS and TPE to the mechanical properties, the hybrid mixtures were prepared and examined like as the other mixtures. The results were given in Figures 5, 6 and 7. In hybrid mixtures, contrary to expectations the strength and toughness values were obtained at a point close to the average strength and toughness values of both wastes.

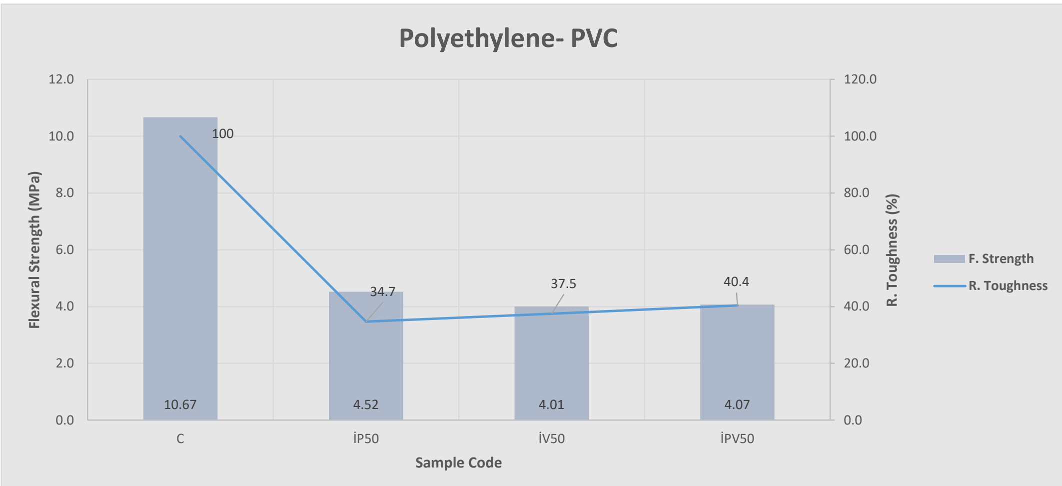

Figure 5. Flexural Strengths and Relative Toughness Values of the Hybrid Cementitious Mixtures with Polyethylene and PVC

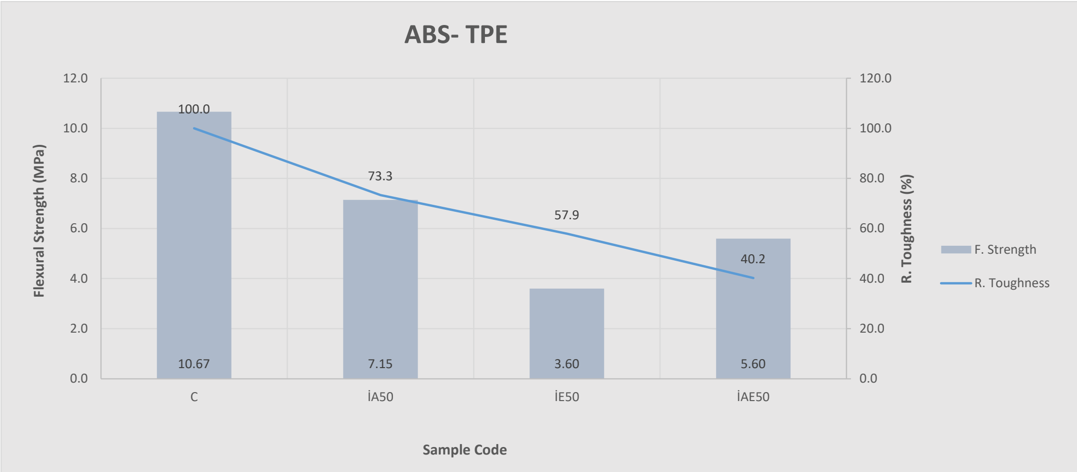

Figure 6. Flexural Strengths and Relative Toughness Values of the Hybrid Cementitious Mixtures with ABS And TPE

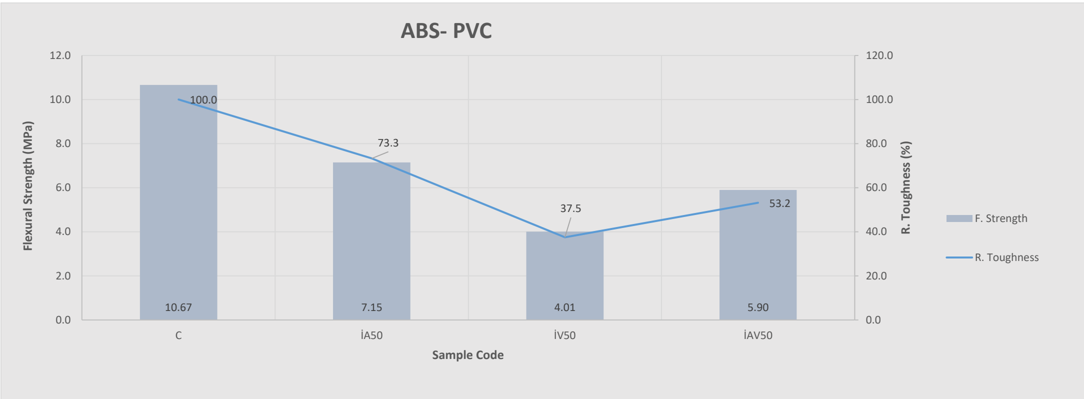

Figure 7. Flexural Strengths and Relative Toughness Values of the Hybrid Cementitious Mixtures with ABS and PVC

CONCLUSION

In this study, the cementitious mixtures made with nine different types of plastic waste were examined. It was aimed to increase the mechanical properties of traditional cementitious mixtures and to increase the durability of the materials made by these mixtures under the impact. It could be concluded that many of the plastic waste types have positive effects on toughness especially when used in low amounts such as 10%. Also, some of them contributed positively high amounts of usage (50%) like polystyrene (anti shock) and polycarbonate. Namely, it is vital that the samples of İS50 (0.0864 MPa) and İK50 (0.0873 MPa) have higher toughness values than the control sample (0.0622 MPa). Although, waste addition to these samples did not increase the flexural strength, it was observed that it increased the toughness.

In line with the results obtained, some suggestions for future studies are as follows:

- ABS, TPE and power cable waste seem to be suitable materials in low amounts of usage. At higher amounts, such as 50%, polystyrene (anti-shock) and polycarbonate wastes came to the fore, if the placement problems could be resolved.

- In order to overcome the placement and segregation problems, it is suggested that aggregate substitution should be made by paying attention to the size ranges of both the wastes and the aggregate seperately. In other words, plastic waste can be substituted with the same size range of the aggregate.

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