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Elevated temperature performances of light-weight cementitious composites produced with waste rubber aggregate

Atık kauçuk agrega kullanılarak üretilen hafif çimento bağlayıcılı kompozitlerin yüksek sıcaklık performansları

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Abstract

In this study, lightweight concrete was investigated by using perlite (Pe), pumice (Pu), and waste rubber aggregates (R). The changes in compressive strength of lightweight concrete were investigated, while ultrasonic pulse velocity and density properties were compared after high-temperature exposure (300, 500 ℃). In this context, 11 different types of mixtures were produced. Combinations were formed by keeping the w/c ratio constant. As a result of the experiments, increases in compressive strength were determined at 300 ℃ in general. The compressive strengths of concretes produced using waste rubber aggregates were lower than concretes using pumice and perlite aggregates. It was determined that concrete made using waste rubber exhibited more ductile fracture during compression loading.

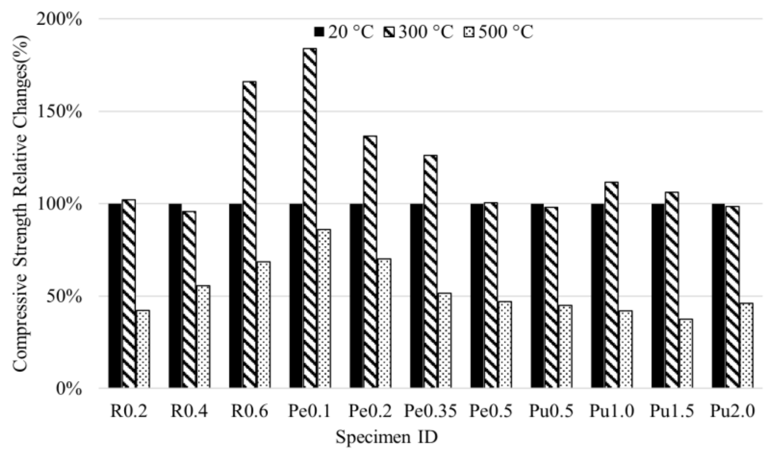
Keywords: Lightweight concrete, Waste rubber aggregate, Elevated temperature.

Öz

Bu çalışmada perlit (Pe), pomza (Pu) ve atık kauçuk agregaları (R) kullanılarak üretilen hafif betonların performansları incelenmiştir. Hafif betonun basınç dayanımındaki değişimler incelenirken, yüksek sıcaklığa (300, 500 ℃) maruz kaldıktan sonra ultrasonik ses geçiş hızı ve yoğunluk özellikleri karşılaştırılmıştır. Bu kapsamda 11 farklı karışım üretilmiştir. Kombinasyonlar s/ç oranı sabit tutularak oluşturulmuştur. Yapılan deneyler sonucunda genel olarak 300 ℃ sonrasında basınç dayanımında artışlar tespit edilmiştir. Atık kauçuk agrega kullanılarak üretilen betonların basınç dayanımları, pomza ve perlit agrega kullanılarak üretilen betonlara göre daha düşük olmuştur. Kauçuk atığı kullanılarak yapılan betonun basınç yüklemesi sırasında daha sünek kırılma gösterdiği belirlenmiştir.

Anahtar kelimeler: Hafif beton, Atık kauçuk agregası, Yüksek sıcaklık.

Graphical Abstract



1 Introduction

Lightweight concretes produced using lightweight aggregates have different properties, such as low density, fire resistance, and earthquake resistance. These concretes can be used in high-rise buildings and bridges due to their lightweight [1]. Compared to natural aggregate, lightweight aggregates have lower density and higher absorbency due to several characteristics. The engineering properties of lightweight concrete are also quite different from standard concrete. Lightweight concrete structures have advantages such as high strength, low thermal conductivity, and better heat, and sound insulation at the same weight ratio. However, due to internal porosity, the water in the cement paste may be absorbed by the lightweight aggregate and cause workability and strength losses. In addition, the excess water absorbed by the aggregate, apart from the water required for the hydration of the cement, can be an advantage for internal curing when used correctly [2]-[4].

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Lightweight concrete production using lightweight aggregate is a standard method. It is possible to obtain lightweight concrete using waste rubber aggregate instead of normal concrete aggregate. Studies [5],[6] revealed that the use of rubber aggregates to reduce concrete's brittleness and brittle structure compared to other materials. Approximately 6.5 billion tons of plastic and waste rubber are generated in the world every year. These wastes pose a significant environmental risk as they do not degrade for a long time [7]. For this reason, researchers have conducted different studies to dispose of this material. It is known that elastic and highly deformable rubber and rubber parts contribute to concrete properties [7]-[10]. Using waste rubber that harm the environment, both lightweight and environmentally friendly concrete can be obtained. Studies about lightweight concrete produced using rubber have increased in recent years [7]-[11].

With the use of different aggregates in concrete, the high-temperature performances of the concrete also change [12]-[14]. It has been reported that hydration products deteriorate at high temperatures of 400-450 °C [15]. Kök et al. [16] reported that the high temperature of 300 °C contributes to the compressive strength of the cementitious series, while there is a loss of strength at 500 °C. It was determined in studies that the performance of lightweight concrete produced using lightweight aggregate at high temperatures is better than concrete made using normal aggregate [14],[17],[18]. Due to the low density of waste rubber, it can be used in producing lightweight concrete, and high-temperature performance is among the parameters to be examined. Li et al. [19] used rubber wastes instead of fine aggregate (1%-4%) in a concrete mixture. They stated that the ideal amount of rubber (1%) prevents scattering compared to control mixtures after high temperatures. Mousa [20] investigated the performance of waste rubber material at temperatures between 300 °C and 800 °C by using it as an aggregate. As a result of the study, the losses for the mechanical performance were higher when rubber was used in high amounts. Marques et al. [21] examined the mechanical performances of concrete produced using recycled rubber aggregate by applying 400 °C, 600 °C and 800 °C temperatures. The researchers stated that the mechanical performance decreased with increasing rubber amount and temperature.

This study compared the mechanical, transmission, and density performances of pumice, perlite, and waste rubber aggregate. In this study, it was aimed to produce lightweight concrete by using waste rubber aggregates as aggregate in concrete. In this way, waste rubber, which causes environmental pollution as waste, will be evaluated. Concrete samples with similar densities were produced using three different aggregate types in different amounts. Mixtures prepared in 11 different series were exposed to air and two high temperatures (300 °C and 500 °C). The void content and ultrasonic pulse velocity (UPV) performances of the mixtures were measured before high-temperature exposure. The mechanical performances of the samples exposed to 300 °C and 500 °C high temperatures and samples kept in ambient conditions were compared.

2 Materials and methods

2.1 Materials

In the production of the samples, CEM I 42.5R (Aşkale Cement in Erzurum/Turkey) type cement was used as a binder. Pumice (D_{max}=2 mm), waste rubber (D_{max}=2 mm), and micronized perlite aggregates were used to produce lightweight composites. The chemical and physical properties of the cement material are presented in Table 1.

Table 1. Chemical properties of cement.

Property (%)	Cement
Al_2O_3	4.2
CaO	60.2
Fe_2O_3	3.1
K_2O	0.8
MgO	3.1
MnO	0.1
Na_2O	0.3
P_2O_5	0.1
SiO_2	20.7
TiO_2	0.4
SO_3	2.7
LOI	2.05

In the preparation of the mixtures, the target density was between 1.2 g/cm^3 and 1.6 g/cm^3, and the amount of material used in the mixtures was prepared in line with this target. For the favorable workability of the perlite samples, a superplasticizer additive was used in the mixtures. The amounts of materials used for the mixtures are given in Table 2 (by weight).

Table 2. Amounts of materials used in the experiments (by weight).

Series	Cement	Pumice	Perlite	Waste Rubber	Water
Pu0.5	1	0.5	-	-	0.4
Pu1.0	1	1	-	-	0.4
Pu1.5	1	1.5	-	-	0.4
Pu2.0	1	2	-	-	0.4
Pe0.1	1	-	0.1	-	0.4
Pe0.2	1	-	0.2	-	0.4
Pe0.35	1	-	0.35	-	0.4
Pe0.5	1	-	0.5	-	0.4
R0.2	1	-	-	0.2	0.4
R0.4	1	-	-	0.4	0.4
R0.6	1	-	-	0.6	0.4

2.2 Methods

The study used cylindrical molds with a diameter of 45 mm and a height of 90 mm to prepare the samples. While preparing the mixtures, firstly, the powder material was mixed. Cement mortars were produced by adding water to the powder mixture. The prepared samples were removed from the molds after 24 hours and kept in the curing environment until the 28th day when the tests were applied. The density and UPV tests were performed on samples before the mechanical examinations. Three samples were produced from each sample mixture, and the results were averaged in all experiments. The mechanical performances of light mortars exposed to different high temperatures were determined. The schematic representation of the applied high-temperature process is given in Figure 1.

UPV and density results for lightweight concrete samples prepared in the laboratory using three different aggregate types were examined after 28 days. Samples kept in the laboratory environment were exposed to two different high temperatures at the end of 28 days.

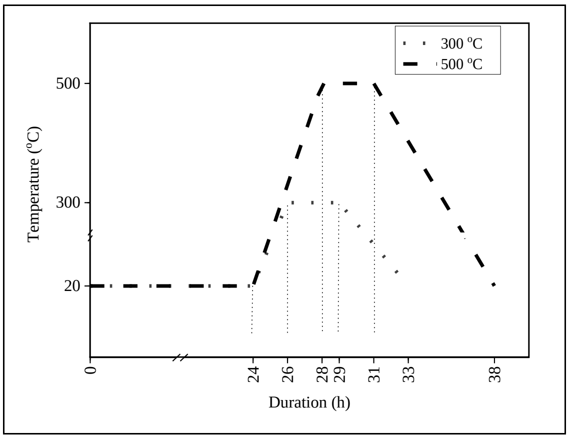


Figure 1. The process of elevated temperature exposure.

The mechanical performance changes in three different environments in total were examined. Ultrasonic pulse velocity tests were calculated by the ASTM C597-16 Standard using Equation (1) below.

$$v = \frac{\mathrm{L}}{\mathrm{t}}\ x\ 10^3 \qquad (1)$$

v : Ultra pulse velocity (km/s),
L : Distance between the surfaces of the sample (m),
t : Time recorded on the ultrasonic device (μs).

3 Results and discussion

The curves showing the relationships between the density and UPV of concretes produced using perlite, pumice, and waste rubber aggregate are shown in Figure 2. The highest UPV transition values were obtained at 3.25 km/sec in samples containing pumice aggregates. Figure 2 shows that UPV values generally decreased with the increase in perlite and waste rubber aggregate content. With the rise in the pore and void structure in the sample, decreases were observed in the density, and as a result, the UPV results also decreased. In concretes containing pumice aggregate, no significant increase in density values could be obtained with the increase in aggregate amount (0.2 g/cm³). For this reason, the difference between the UPV results was not as significant as the samples containing perlite and waste rubber aggregate (0.06 km/sec).

The compressive strength results and relative strength changes of the samples before and after elevated temperatures are shown in Figure 3. When the changes in the compressive strength of the samples were examined after different temperature effects, the highest strength was 59.8 MPa in the samples with perlite aggregate exposed to 300 °C temperature. The highest increase rate was approximately 84% in the samples containing perlite aggregate. The study obtained the lowest compressive strengths in the samples containing waste rubber aggregate. The strengths of the samples produced using waste rubber aggregate decreased with the increase in rubber waste aggregate content. The low hardness and low strength of rubber aggregates are believed to be the main cause of strength reductions [7]. With the increase in the use of waste rubber aggregate, more significant decreases were observed in UPV values compared to densities. The studies determined that the UPV of the concrete increased with the increase in the amount of rubber aggregate. Khaloo et al. [10] in their research stated that the increase in rubber material improves concrete sound insulation.

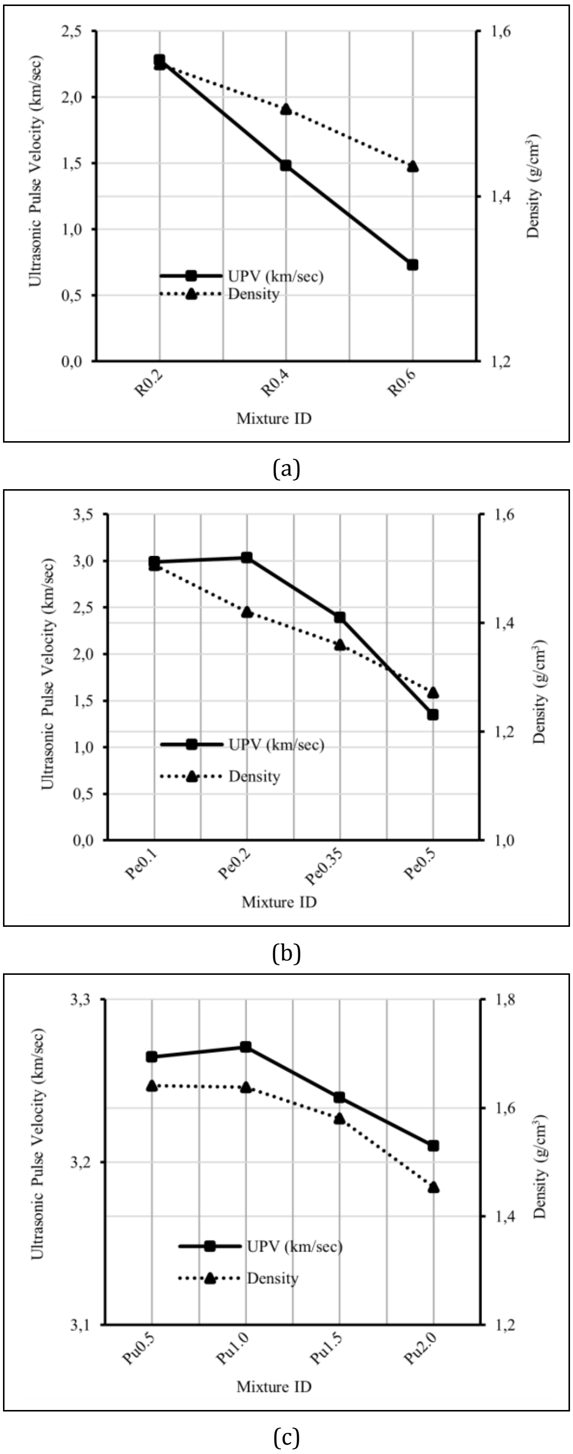
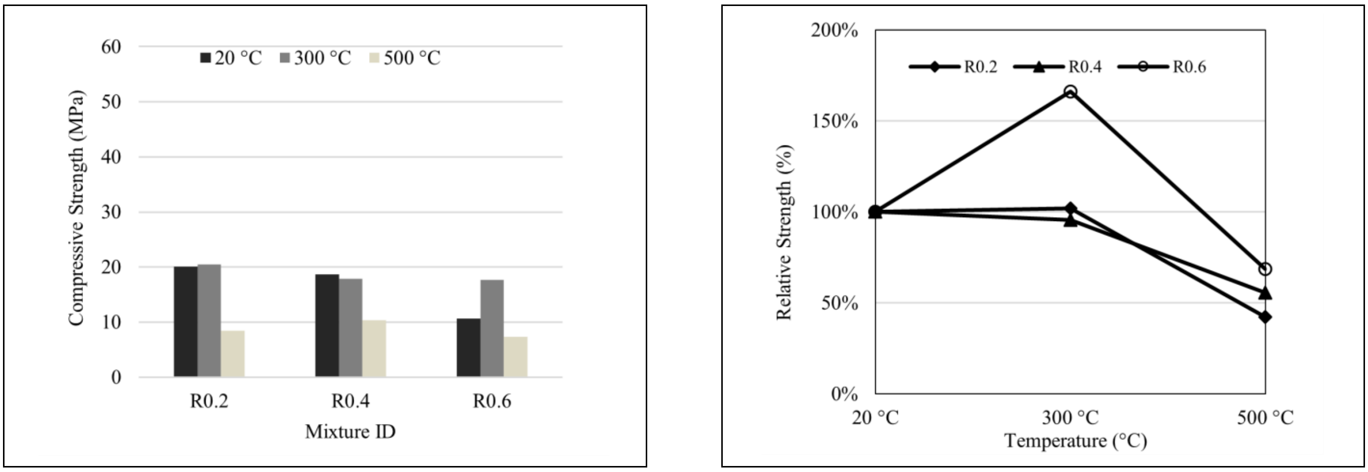
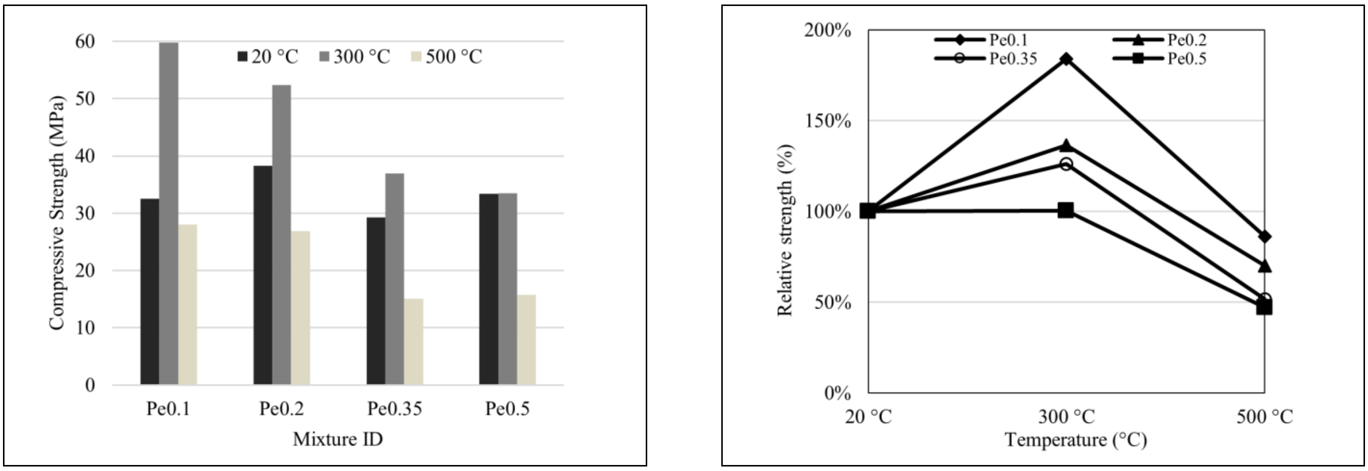


Figure 2. Relationship between density and UPV.
(a): Waste rubber. (b): Perlite. (c): Pumice.

It was stated that the water in the concrete is removed with exposure to 250 °C-300 °C temperature, and there is no structural damage. When the temperature reaches 300 °C, the water at the interfaces of the C-S-H gels evaporates [22]. Increases in compressive strength were determined in general for the samples exposed to 300 °C temperature. The reason for this increase may be that the temperature contributes to the hydration of the unreacted cement particles by acting as a catalyst for the evaporation of free water between the fracture surfaces [23].



(a)



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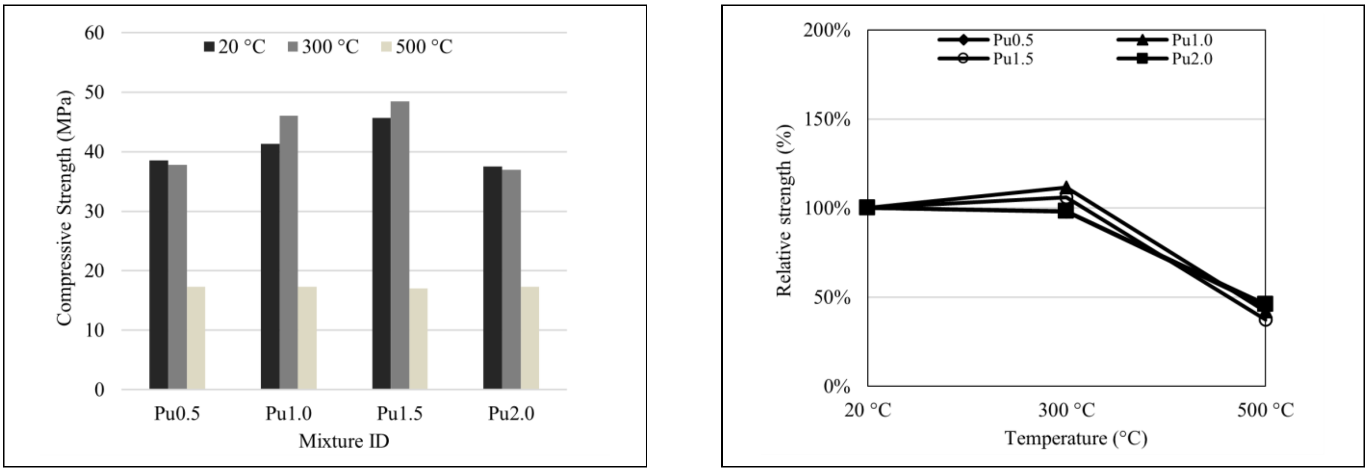

(c)

Figure 3. Compressive strength results of specimens. (a): Waste rubber. (b): Perlite. (c): Pumice.

Another effect that causes the increase in strength at 300 °C can be called the pozzolanic reaction. It may result from the hydrothermal reaction of CaOH liberated during the hydration reaction at this temperature with pearlite and pumice grains smaller than 75 µm [24],[25]. Significant strength losses were observed in all samples when the temperature reached 500 °C. Researchers attributed the strength losses to volume expansion caused by the conversion of the $Ca(OH)_2$ compound in the concrete structure to CaO at around 500 °C-600 °C [26],[27]. In addition, the deterioration of adhesion between the aggregate and the cement may be another reason due to the expansion of the aggregates in the concrete at these temperature levels and the shrinkage caused by water loss in the cement [26].

Compressive strength-deformation curves obtained as a result of 500 °C temperature application are shown in Figure 4. As can be seen from the figure, as a result of the high temperature, the fracture patterns of lightweight concretes containing pumice, and perlite aggregates occurred as a brittle fracture. The samples containing the highest creep behavior contained rubber aggregate showing more ductile behavior under load. Studies observed that the ductile behavior of concrete mixtures increases with the use of rubber materials [10]. If an aggregate can exhibit elastic behavior in the concrete mixture, the damage rate of the concrete decreases under loading. Even after high-temperature application, less damage can occur to the matrix thanks to the elastic aggregates in concrete. However, as the amount of other lightweight aggregates increases, strength increases at 300 °C, and strength losses increase at 500 °C. Due to its ductile and deformable structure, with the increase in the amount of waste rubber aggregate an increase in strength was observed at 300 °C temperature, and a decrease in strength loss compared to other lightweight aggregates was seen at 500 °C.

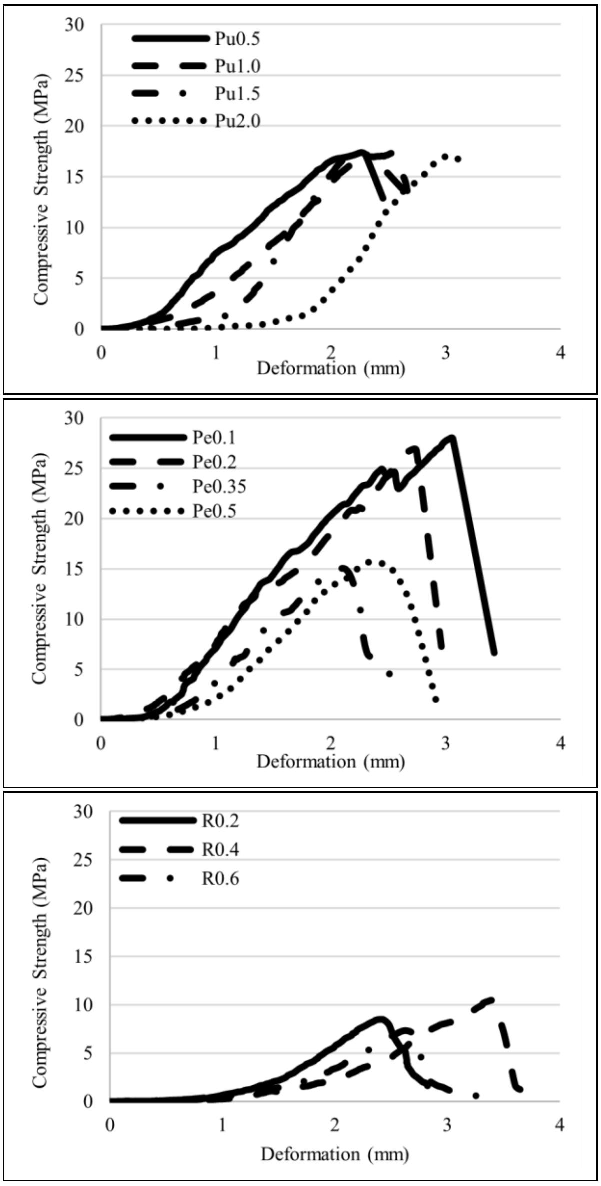

Figure 4. Compressive strength-deformation curves after exposure to 500 °C.

4 Conclusions

1. In lightweight concretes produced with waste rubber aggregate and perlite, decreases in UPV values were determined as the amount of aggregate increased,
2. Strength losses occurred in all aggregate types at 500 °C temperature,
3. Concrete produced using wastes of rubber exhibited ductile fracture after 500 °C temperature,
4. As the amount of waste rubber aggregate increased, the strength loss rates decreased at high temperatures, while the strength losses increased with the aggregate amount in general in the concretes produced with pumice and perlite aggregates.

5 Declaration of authors' contribution

In this article Nurullah ÖKSÜZER contributed to the stages of structure, introduction, materials and methods and general evaluation of the results.

6 Declaration of ethics committee approval and conflict of interest

"The article does not necessitate a research ethics committee approval".

"There is no conflict of interest issue with any person/institution throughout this paper work".

7 References

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