Investigation of mechanical and durability properties of recycled aggregate concrete containing crumb rubber considering a new model of elastic modulus

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Abstract

Natural gravel and Sand are growing more and more expensive due to their scarcity. Therefore, replacing natural aggregates with recycled materials has been a concern of researchers. In this paper, crumb rubber was utilized to supersede a few of the aggregate in percentages of 5, 10, and 15 aggregate volumes. In concrete containing 15% rubber crumbs, 10% silica fume, and 10% zeolite were used along with crumb rubber. The findings of this investigation indicated that concrete containing 15% crumb rubber causes the greatest decline in compressive strength. Comparative to control concrete, compressive strength was decreased by 35% at 28 days and 36% at 7 days by substituting 15% of crumb rubber with aggregate volume. Additionally, it was discovered that the compressive strength of concrete containing 15% rubber crumbs raised by 23% and 33% at 28 days, and 21% and 34% at 7 days, respectively, when the mixture contained 10% zeolite and 10% silica fume. Also, the greatest recline in flexural strength, tensile strength, and modulus of elasticity was related to concrete containing 15% crumb rubber, which was improved by adding 10% pozzolan. Finally, an elastic modulus prediction model for this type of concrete (recycled aggregate concrete) is presented.

Keywords: Crumb rubber; Elastic modulus model; Silica fume; Zeolite; Mechanical properties; Concrete durability; Recycled aggregate concrete

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1. Introduction

A tire is made up of elastomeric compositions that contain steel fiber cord [1]. The disposal of old crumb rubber has been a severe environmental issue worldwide [2, 3]. Each year, millions of tires approach the end of their serviceable lives, resulting in a significant number of non-biodegradable solid waste in the environment [4]. There are several ways to get rid of scrap tires, including burning [5] and landfilling [6] or as mulch on sports fields and asphalt binder modifiers [7]. Stockpiled tires generate health, environmental, and economic difficulties due to pollution of the air, water, and soil [6, 8–10]. Tire burning, which was the most convenient and inexpensive approach to disposal, now creates significant fire dangers [9, 11–13].

Recognizing this issue, government institutions, business stakeholders, and the scientific community have banded together to find scientific solutions to recycle all types of waste materials [14]. Various waste materials are now being explored for recycling options [15, 16].

The utilization of discarded rubber in technology to create concrete, the commonly utilized material in buildings, and uses a considerable quantity of natural resources, has been one of the study paths in the latest years. It is a resource-saving and environmentally responsible way to utilize discarded crumb rubber as aggregates in cement concrete.

Numerous experiments have already been conducted to see if rubber could be utilized as a substitution for aggregates. The density of concrete is influenced by using crumb rubber as aggregates. With go up in the proportion of rubber crumbs in concrete, a diminish in terms of a weight unit of rubberized concrete has been observed [17–20]. According to several experimental research, this decline in the unit weight of concrete was caused by the low specific gravity of the rubber utilized [19, 21–24]. The potential of crumb rubber grains to trap air in their uneven surface pattern was blamed for the fall in density [25]. Nagrockiene and Girskas [26] discovered that raising the amount of zeolite in concrete boosts its density.

The workability of concrete with rubber crumb fibers declines when the percentage of crumb rubber fibers increases [27–30]. According to reports, zeolite can reduce the workability and setting time of traditional concrete [31]. Oikonomou and Mauridou [23] demonstrated that the workability of rubber reduces by up to 15% as the amount of rubber increases.

The compressive strength slowly declines, as the percentage of rubber particles in the concrete grows [2, 20, 32–35]. Coarse rubber crumbs and cement paste have a poorer connection than fine rubber crumbs and cement paste, according to Topcu [36], which impacts compressive strength. Sohrabi and Karbalaie [37], and Guneyisi et al. [13], at water to cement ratio (0.5), concrete's compression strength adding crumb rubber and silica fume was examined. If the substitution of crumb rubber does not account for more than 20% of the overall aggregate content, significant decreases in compressive strength could be prevented [30,38]. It was discovered that adding silica fume to the mix increased compressive strength. The rationale was that nanometric gaps in cement paste were filled, resulting in a denser structure. Tammana [35], showed that compressive strength decreased by 38%, at 28 days after increasing the aggregate replacement with rubber by 20%.

Adding scrap rubber tires in rubberized concrete affects its flexural strength. According to the literature, adding more crumb rubber increases flexural strength [22, 39–45]. The size of the waste rubber used determines this inconsistency in behavior [21, 32, 46, and 47]. Crumb rubber (CR) in concrete has low stiffness [48] and good suppleness [49] and is composed of particles of various sizes [50], cleanliness [51], contents [52], shapes [53], and CR surface finish quality [54] all influence the attributes of CR concrete (CRC).

When fine rubber aggregates were utilized instead of coarse rubber aggregates, Thiruppathi [55] reported a more significant decrease in the static elasticity modulus. According to Benazzouk et al. [56], rubberized concrete has a decrease in dynamic modulus of elasticity than control concrete. The ultrasonic wave absorption by concrete was attributed to the decline in the dynamic elastic modulus. According to several studies, elasticity modulus declines as the quantity of rubber components increases [30, 57–60]. Also, machine learning techniques such as artificial neutral networks have recently been employed in the context of structural engineering like prediction of structural behavior [61, 62] or material properties [63] including modules of elasticity, durability, and compression strength.

The most critical aspect in determining concrete durability is permeability. Ganjian et al. [29] carried out a test investigation to explore the influence of scrap crumb rubber on water permeability when using a constant W/C ratio (0.5). Water permeability was enhanced by substituting coarse aggregate with chipped rubber aggregates. The reduced connection between particles in the concrete mixture was attributed to the increased water permeability.

All studies used waste tire rubber of different sizes, but there was no exact information about residual rubber on each sieve. Therefore, in this study, 4.75, 9.5, 12.5, and 14.75 were employed, and the ratio of water to cement was continual. The effect of substituting 10% of the cement with silica fume and zeolite and substituting 5%, 10%, and 15% of the coarse aggregate with coarse crumb rubber was also examined. The present study evaluated mechanical properties, including compressive strength, flexural strength, tensile strength, modulus of elasticity, and durability, including electrical resistance, ultrasonic, porosity, and water absorption.

2. Experimental program

2.1. Material properties

Type two Portland cement, silica fume, and zeolite were consumed in this research. Table 1 exhibits the physical and chemical properties of cement, silica fume, and zeolite. This study divided coarse aggregate, fine aggregate, and sand for preparing concrete mixes. The maximum sizes of them were 19, 9.5, and 4.75 (mm), respectively. Coarse gravel, fine gravel, and sand with Density 2.69, 2.67, and 2.6, and water absorption of 2.63, 2.38, and 4.61 were used, respectively. An Iranian national guideline was used for mixing aggregates [64]. The selection of aggregate consumption range in this study has been made according to the national method of the Iranian concrete mixing plans [64]. This study used natural coarse aggregate, fine aggregate, and sand with a particle size distribution and a 19 mm maximal particle size to prepare concrete mixtures. Based on the grain-size distribution, the distribution curve is a combination of the results between curves A19 and B19.

Table 1. Cement's physical and chemical characteristics and pozzolans.

In this paper, the remaining rubber on the sieves was 4.75, 9.5, 12.5, and 14.75. The distribution curve with a density of 1.12 was used, and the ratio of water to cement was continual. Coarse waste rubber chips replaced percentages of 5, 10, and 15 of the coarse aggregate, and the influence of replacing 10% of cement with silica fume with a density of 2.27 and zeolite with a density of 2.7 with 15% of waste rubber was investigated. This article provides details on the mixing ratios in Table 2.

Table 2. Proportions of crude rubber and pozzolan in concrete containing crude rubber and pozzolan.

3. Experimental program

3.1. Testing of stone materials

Density tests were performed in a saturated state with a dry surface and water adsorption percentage of sand according to ASTM C128-88 [65]. Density tests were performed in the saturated state with dry surface and water adsorption percentage of coarse aggregates and fine aggregate according to ASTM C127-88 [66]. The standard test was performed to determine the water content of the aggregate by drying it according to ASTM C5666-89 [67]. This experiment was performed to calculate the laboratory humidity of aggregate before each sample was made to correct the amount of mixed water. Grain-size aggregate distribution by the standard was done according to ASTM C136-84a [68].

3.2. Test for slump

ASTM C143 [69] was used to conduct the slump test.

3.3. Unit weight of fresh concrete

The density of fresh concrete was established in accordance with ASTM C138 [70].

3.4. Test of compressive strength

In this study, in line with BS 1881-116: 1983 [71], compressive strength tests were performed on a square standard material of 10 *10 *10 cm on days 7 and 28.

3.5. Tensile strength test

The Brazilian technique or halving in accordance with ASTM C496-90 was used in the experiment to estimate the tensile strength of models that are 20 cm in height and have a 10 cm diameter [72].

3.6. Testing of the flexural strength

Testing of the flexural strength of concrete was performed using a simple beam method and loading in the middle point according to ASTM C293-07 [73]. For this purpose, concrete samples with dimensions of 40 * 10 * 10 cm were made.

3.7. Testing the elastic modulus

Testing the elastic modulus of samples that are 20 cm in height and have a 10 cm diameter by the pressure method was performed according to BS EN 1992-1-1 [74].

3.8. Ultrasonic test

Ultrasonic testing of cubic samples with dimensions of 10 * 10 * 10 cm was performed according to ASTM C597 [75].

3.9. Electrical resistance test

Electrical resistance test of cubic samples with dimensions of 10 * 10 * 10 cm was performed according to ASTM C1760 [76].

3.10. Water absorption and porosity testing of concrete

This experiment was carried out in accordance with ASTM C642 [77]. The results of 3 cubic tests of concrete were averaged to determine the percentage by weight of water absorption at the age of 28 days.

4. Results and discussions

4.1. Workability (fresh concrete)

Table 3 indicates the difference in density and slump of the specimens compared with the concrete without shredded rubber, silica fume, and zeolite. The slump gradually reduces, as the percentage of shredded rubber in concrete rises. Slump declines and prevents the consistency of concrete due to the constant quantity of water used in the combination and the increase in the quantity of crumb rubber. The decreased inter-particle friction between the rubber and other components could be the cause of the reaction [30]. When crumb rubber was mixed with concrete, the density of the material decreased due to the particular gravity of shredded rubber becoming less than that of natural aggregates [32, 49]. This reduction was slightly improved when pozzolan was replaced by cement in the rubber concrete mix.

Table 3. Slump test results and specific weight.

4.2. Compressive strength

Figure 1 shows the trend of changes in compressive strength. The samples were examined at seven and 28 days of age. It has been noticed that when the quantity of rubber crumbs raised, the compressive strength of the concrete containing rubber reduced. Compressive strength declined by 6%, 18%, and 35% at 28 days after increasing the aggregate replacement with rubber crumbs by 5 %, 10%, and 15%, respectively, comparison to the control mix samples. There was also a decline at the age of seven days. Compressive strength is reduced because of the formation of porosity, which may have arisen due to rubber particles. Cracks from around the crumb rubber in concrete containing crumb rubber while loading and these materials might speed up the failure of the matrix of cement and crumb rubber. Grains of crumb rubber might be considered porosity in the rubber concrete mix, increasing porosity and lowering the strength [78]. Figure 2 shows that the compressive strength was improved by adding silica fume and zeolite to the rubber concrete mix. Replacing 15% rubber with aggregate containing 10% silica fume and zeolite revealed that the compressive strength rose by 33% and 23%, respectively, at 28 days compared to CR15%. This decrease was also seen at the age of seven days. This increase is due to the filling properties of silica fume and zeolite by refined grains and also creating good adhesive between rubber crumbs and the cement matrix.

Figure 1. Compressive strength of crumb rubber concrete at 7 and 28 days.

Figure 2. Compressive strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

4.3. Flexural strength

Seven and 28 days of flexural strength of crumb rubber concrete are indicated in Figure 3. It has been discovered that as the quantity of crumb rubber in the concrete grows, the flexural strength of the concrete falls. A reduction of 6%, 13%, and 27% in flexural strength was observed when 5%, 10%, and 15% rubber aggregate was used in place of coarse aggregate, respectively, at the age of 28 days compared to the control mix samples. This decrease was also seen at the age of seven days. The decreased flexural strength is a weak connection between the cement paste and the rubber pieces [28]. By replacing 15% rubber with aggregate containing 10% silica fume and zeolite, it was observed that the flexural strength rose by 10% and 11%, respectively, on days 28 and 7, rose by 21% and 13%, respectively contrasted to CR15%, it shows figure 4.

Figure 3. Flexural strength of crumb rubber concrete at 7 and 28 days.

Figure 4. Flexural strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

4.4. Tensile strength

Figure 5 shows the results of 7 and 28 days of tensile strength testing with and without crumb particles rubber at various amounts. As seen in the graph, the tensile strength declines as the percentage of waste rubber replaced develops. The tensile strength is lowered by around 27%, 14%, and 21% in samples containing 5%, 10%, and 15% rubber crumbs at 28 days, respectively, contrasted to the control mix samples. This decrease was also seen at the age of seven days. The decrease is because as the crack expands, the pressure separates the surface between the rubber particles and the cement paste. Therefore, the rubber acts as a hole, leading to rapid concrete deterioration. By enhancing the interfacial transition zone (ITZ), pozzolans including silica fume and zeolite can strengthen the bond between the rubber and the binder, preventing strength loss [79, 80]. The findings indicate, 10% SF and 10% ZE improved the tensile strength of concrete including 15% crumb rubber at the age of 28- days by 13% and 9%, respectively, and at the age of 7-day by 12% and 2%, respectively compared to CR15%. It is shown in figure 6.

The results indicated a special relationship between compressive and tensile strength, figure 7. As the compressive strength decreased, the tensile strength decreased, and vice versa. In CR15%, the compressive strength was reduced by 35% and the tensile strength by 21%. Lower reduction of tensile strength than compressive strength can be assumed that rubber as a soft material can act as a barrier against the growth of cracks in concrete. Also, in CR15%SF10% compressive and tensile strength rose by 33% and 13% contrasted to CR15%.

Figure 5. Tensile strength of crumb rubber concrete at 7 and 28 days.

Figure 6. Tensile strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 7. Relationship among 28-day compressive strength and 28 days tensile strength of concrete containing shredded rubber, silica fume, and zeolite.

4.5. Modulus of elasticity

As illustrated in Figure 8, the rise of rubber particles in concrete affects the modulus of elasticity of the concrete mixtures. A reduction of 5%, 8%, and 15% at 28-day was noticed in the elastic modulus aggregate comparison to the control mix samples when 5%, 10%, and 15% coarse aggregate and fine aggregate were substituted with rubber aggregate, respectively. This decline can be explained to the fact that the small holes in the rubber granules, which are usually made with water, cause cavities in the mixture; as the volume of the rubber increases, the porosity increases, and the bend and curvature increase, resulting in a decrease in stiffness and modulus of elasticity. Pozzolans can be used to compensate for this decrease. Because pozzolans have filler properties and fill porosity, the elastic modulus is improved. As shown in figure 9, the modulus of concrete elasticity improvement is 5%, 6% for CR15%SF10% and CR15%ZE10% at 28-day compared to CR15%, respectively. The results of the researchers [29, 81] also confirm this.

Figure 10 shows the relationship between the modulus of elasticity and porosity of 28-day concrete containing rubber particles, silica fume, and zeolite from this study. The modulus of elasticity decreases with increasing porosity. The results showed that CR15% had more porosity and less modulus of elasticity than the other samples; adding 10% pozzolan to this mixture improved porosity, and modulus of elasticity was observed.

Figure 8. Modulus of elasticity of crumb rubber concrete at 7 and 28 days.

Figure 9. Modulus of elasticity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 10. Relation between modulus of elasticity and 28 days porosity of concrete containing crumb rubber, silica fume, zeolite.

The results of this study were made a comparison to the international codes in Table 4 to understand the research method better and review the data gathered. Codes had a reduced forecast than the research's outcomes, as seen in Table 4. The NBR 6118 code has the best forecast for the modulus of elasticity among the proposed codes. Other codes cannot accurately predict the elastic modulus of rubber concrete mixes.

Table 4. Comparison of the research results conducted with the elasticity modulus of different codes.

4.6. Modeling the modulus of elasticity of crumb rubber concrete mixes

A model for estimating the modulus of elasticity of crumb rubber concrete mixes was presented following the formula using mini-tab software and laboratory data (1).

$$E_c = 9.25 + 3.835\sqrt{Fc}$$ Equation 1

Ec: Modulus of elasticity (Gpa)

Fc: Compressive strength (Mpa)

To better understand the process in this research and check the model obtained, a comparison of the laboratory results (E), and the final solution of this model (Ec) is presented in figures 11-12.

Figure 11. The relationship of Ec in this research with the research of others [82–84].

Figure 12. Comparison of the laboratory results (E) and the final solution of this model (Ec) in this research with the research of others [82, 84, 85].

4.7. Ultrasonic wave speed

Figure 13 depicts the method of altering the speed of ultrasonic waves in 10 * 10 * 10 cm concrete specimens as the proportion of crumb rubber varies. The transmission speed is reduced when crumb rubber is added. In a body with high porosity, the wave velocity is low. When the porosity is low, the wave velocity is high. The results exhibited that the ultrasonic reduced as the amount of rubber increased. A 12%, 40%, and 65% reduction was observed in ultrasonic when 5%, 10%, and 15% coarse aggregate was substituted with rubber aggregate at 28 days compared to the control mix samples. An ultrasonic improvement was observed by adding pozzolan to the samples, as shown in figure 14.

Figure 13. Ultrasonic of crumb rubber concrete at 7 and 28 days.

Figure 14. Ultrasonic of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

4.8. Electrical resistivity test

7-day and 28-day electrical resistivity of waste rubber concrete is shown in figure 15. Electrical resistance rises as the amount of shredded rubber in the mixture rises. Because rubber is a dielectric material, rubber particles in the concrete act as an insulator, stopping electricity from flowing between the two measuring electrodes [60]. An important change in the increased electrical resistivity was noticed [45], as shown in figure 16.

Figure 15. Electrical resistivity of crumb rubber concrete at 7 and 28 days.

Figure 16. Electrical resistivity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

4.9. Water absorption test and Porosity test

The amount of rubber in the concrete impacts its porosity, which has an effect on its water absorption capacity [29]. As the percentage of shredded rubber in concrete was raised, the porosity and water absorption increased Table 5. Because rubber particles are non-polar, air bubbles can be trapped on their surfaces. As a result, the cement-aggregate interface becomes more porous and absorbent. According to Mohammed et al. [29], replacing 10% of the cement with silica fumes results in more than un-reacted silica fume in the matrix. Due to its micro filling capabilities, this can fill air gaps within the rubber concrete's microstructure, reducing water absorption [45]. Adding silica fumes to the concrete samples helped reduce porosity and water absorption Table 4.

Table 5. Results of % water absorption test and % porosity.

5. Discussions

Slump decreased by 3%, 7%, and 15% increasing the aggregate replacement with crumb rubber by 5 %, 10%, and 15%, respectively, compared to the control mix samples. The slump was improved by adding silica fume and zeolite to the rubber concrete mix. Replacing 15% rubber with aggregate containing 10% silica fume showed that the compressive strength rose by 47% compared to CR15%. A reduction of 1% and 4%, in flexural strength was observed when 10% and 15% coarse aggregate was substituted with rubber aggregate, respectively, to the control mix samples. They were improved by adding silica fume and zeolite.

Compressive strength was reduced by 20%, and 36% at 7 days after increasing the aggregate replacement with crumb rubber by 10%, and 15%, respectively, in comparison to the control mix samples. They were improved by adding silica fume and zeolite. It is possible to explain the reduction in compression strength of concrete incorporating tire rubber particles by three major factors:

- In contrast to the surrounding cement paste, rubber particles are more deformable, which results in cracks close to the rubber particles, which resemble cracks that appear around air voids in typical concrete [28].
- As a result of the cement paste and crumb rubber's poor adhesion [86].
- Last but not least, due to the potential of a diminution in concrete matrix density, which is a function of aggregate density, size, and hardness.

Compressive strength of rubber concrete is assumed to be influenced more by the deformability and soft aggregate-like properties of tire rubber particles than by either of the other two effects. The observation that tire rubber particles of different sizes appear to have a considerable influence on the compressive strength of a tire lends support to this theory. As tire rubber particles become larger, rubber concrete's compressive strength decreases. As a result, tire rubber particles can be described as soft aggregate components that develop tensile stresses at their surfaces and next to the cement paste when the rubber concrete mixe is put under compressive stress [25].

Flexural strength decreased by 15% and 29%, and Tensile strength declined by 13% and 22% when 10% and 15% coarse aggregate were substituted with rubber aggregate, respectively, at the age of 7 days compared to the control mix samples. Tensile strength and flexural strength were improved by adding silica fume and zeolite to the rubber concrete mix.

A reduction of 5%, 8%, and 15% at 28-day was observed in the modulus of elasticity (E) when 5%, 10%, and 15% coarse aggregate was substituted with rubber aggregate, respectively. The modulus of elasticity was improved by adding silica fume and zeolite to the rubber concrete mix.

Ec decreased by 2% and 7% when 5% and 10% coarse aggregate was substituted with rubber aggregate, respectively, compared to the control mix samples. There is a direct relationship between Ec and E. As Ec decreased, E also decreased. This study shows the relationship of Ec in this research with the research of others. Gupta and other researchers [84], showed a reduction of 23% and 11% in Ec when 5%, 10%, and aggregate were substituted with rubber aggregate, respectively.

A 13% and 41% reduction was observed in ultrasonic when 5% and 10% coarse aggregate was substituted with rubber aggregate at 7 days compared to the control mix samples. An ultrasonic improvement was observed by adding pozzolan to the samples.

Electrical resistivity rose by 7%, and 26% at 7 days after increasing the aggregate replacement with crumb rubber by 5 %, and 10%, respectively, in comparison to the control mix samples. By replacing 15% rubber with aggregate containing 10% silica fume and zeolite, the electrical resistivity increased by 32% and 36% on days 7, respectively, contrasted to CR15%.

Water absorption increased by 1% and 22%, and porosity rose by 8%, and 20% at 28 days after increasing the aggregate replacement with rubber crumbs by 5%, and 10%, respectively, in comparison to the control mix samples. The samples were improved by adding silica fume and zeolite.

6. Conclusion

This paper investigated the mechanical properties of concrete containing crumb rubber and mineral additives silica fume and zeolite. The following items can be concluded according to this article's parameters and values.

1. In this research, the workability of rubber concrete mix reduced when the quantity of crumb rubber rose.
2. When using crumb rubber concrete, the compressive strength diminishes as the quantity of shredded rubber rises, it reduces the adhesive between crumb rubber and the cement, resulting in quick concrete rupture during loading. Also, tensile strength showed a reduction with a rise in the percentage of rubber crumbs content. However, the strength improves when zeolite and silica fume are used in place of some of the cement.
3. When the quantity of shred rubber in the mix increases, the flexural strength decreases because fissures exist, causing poor bonding between the constituent materials. The strength of a structure improves when zeolite and silica fume are used in place of some of the cement.
4. The ultrasonic testing results indicated that the porosity in concrete containing crumb rubber increased; thus, the modulus of elasticity decreased with rising porosity. In rubberized concrete mixes, a decrease in static modulus of elasticity suggests increased flexibility, which may be considered a good gain.

5. The water absorption of concrete containing rubber particles rises as the substitution amount increases. Greater water penetration has resulted from the formation of voids and fractures because of the larger surface area of shredded rubber.

COI Statement

The authors of this study declare that they have no conflict of interest.

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Biographies

Ali Akbar Shirzadi Javid was born in Iran. After graduation from Buali Sina University in Civil Engineering, he continued his studies on Construction Engineering and Management at the Iran University of Science and Technology and received his MSc and PhD in 2010 and 2014, respectively. He then joined the Iran University of Science and Technology.

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Figure 1. Compressive strength of crumb rubber concrete at 7 and 28 days.

Figure 2. Compressive strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 3. Flexural strength of crumb rubber concrete at 7 and 28 days.

Figure 4. Flexural strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 5. Tensile strength of crumb rubber concrete at 7 and 28 days.

Figure 6. Tensile strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 7. Relationship among 28-day compressive strength and 28 days tensile strength of concrete containing shredded rubber, silica fume, zeolite.

Figure 8. Modulus of elasticity of crumb rubber concrete at 7 and 28 days.

Figure 9. Modulus of elasticity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 10. Relation between Modulus of elasticity and 28 days Porosity of concrete containing crumb rubber, silica fume, zeolite.

Figure 11. The relationship of Ec in this research with the research of others.

Figure 12. comparison of the laboratory results (E) and the final solution of this model (Ec) in this research with the research of others

Figure 13. Ultrasonic of crumb rubber concrete at 7 and 28 days.

Figure 14. Ultrasonic of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Figure 15. Electrical resistivity of crumb rubber concrete at 7 and 28 days.

Figure 16. Electrical resistivity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Table 1. Cement's physical and chemical characteristics and pozzolans.

Table 2. Proportions of crude rubber and pozzolan in concrete containing crude rubber and pozzolan.

Table 3. Slump test results and specific weight.

Table 4. Comparison of the research results conducted with the elasticity modulus of different codes.

Table 5. Results of % Water absorption test and % porosity.

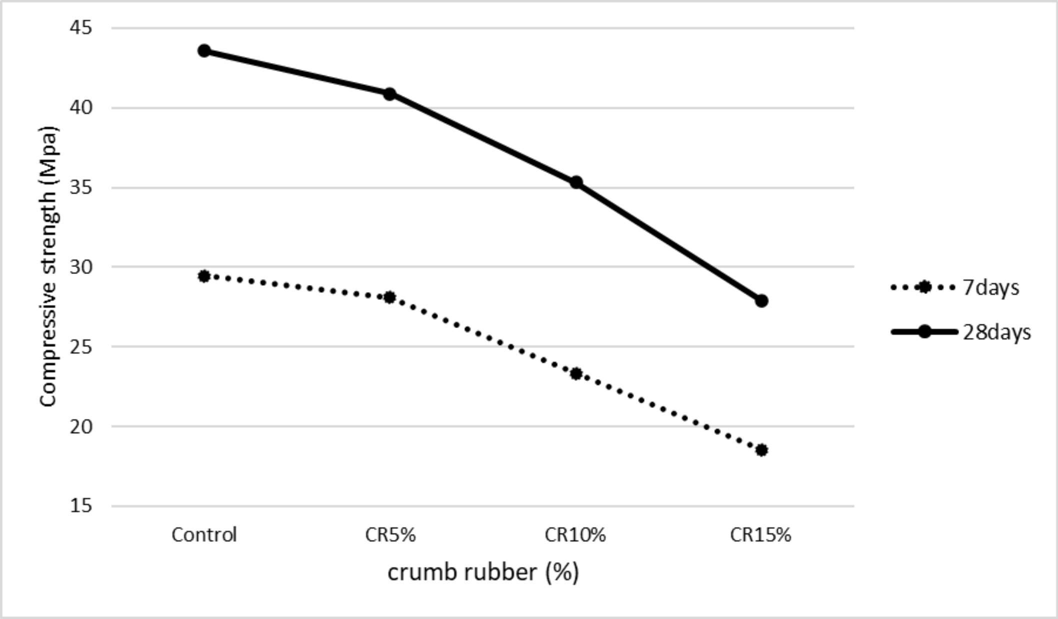


Figure 1. Compressive strength of crumb rubber concrete at 7 and 28 days.

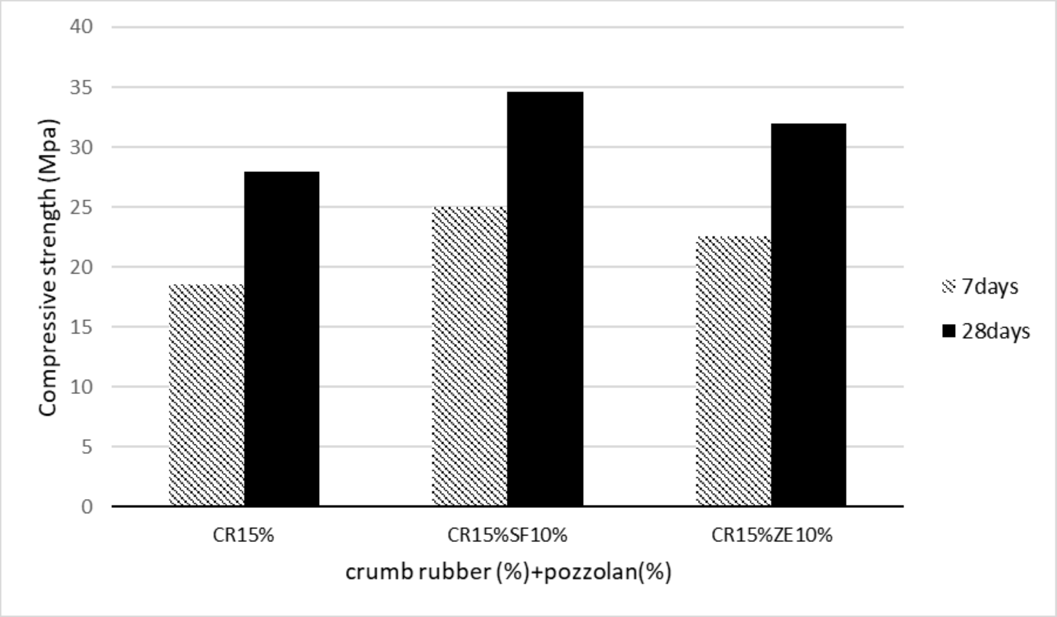


Figure 2. Compressive strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

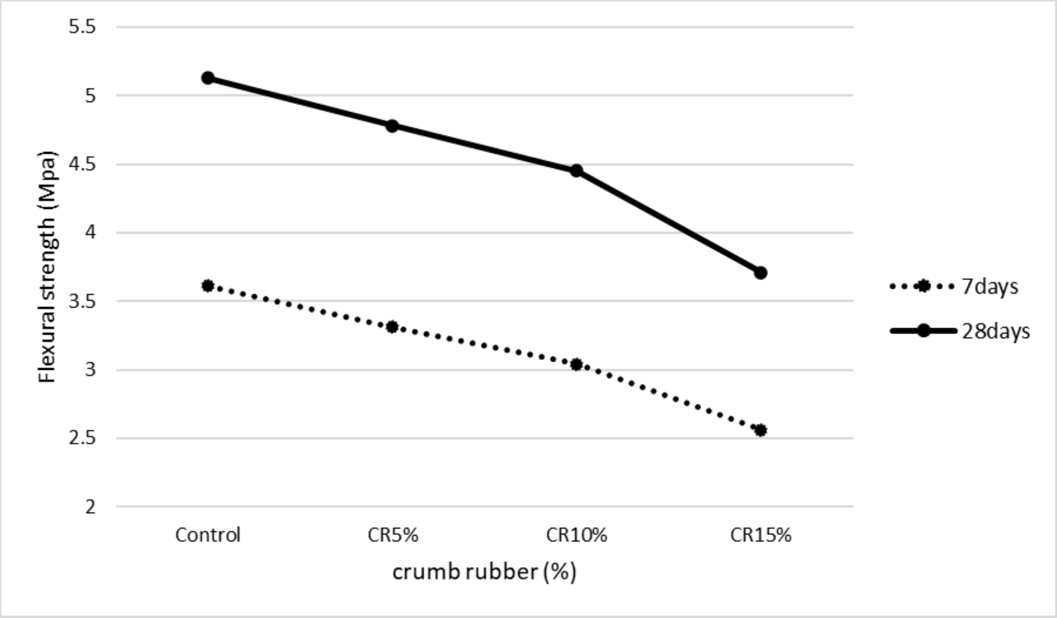


Figure 3. Flexural strength of crumb rubber concrete at 7 and 28 days.

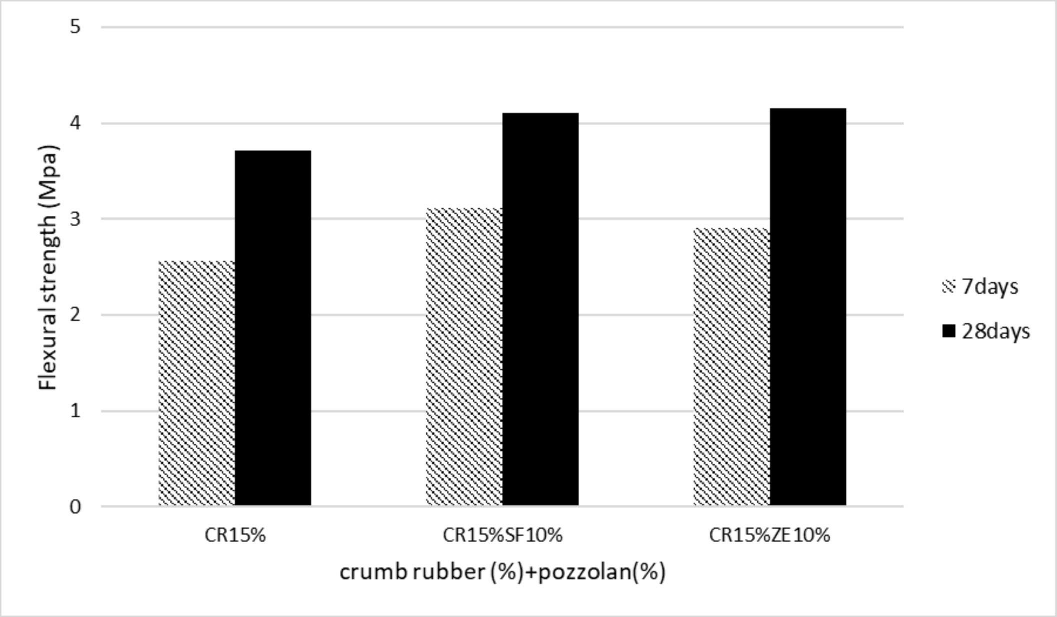


Figure 4. Flexural strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

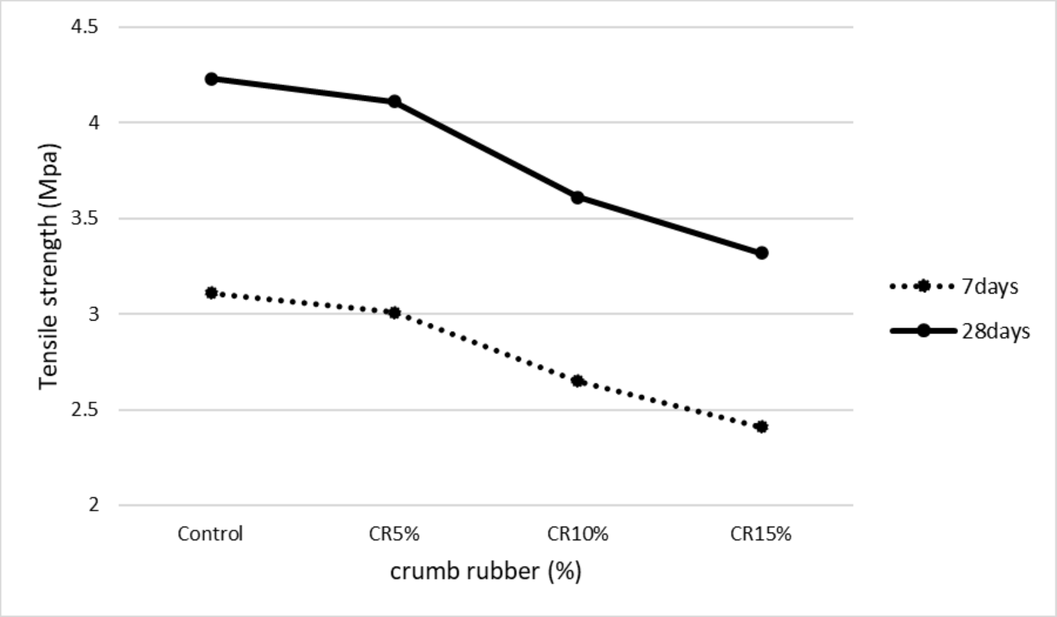


Figure 5. Tensile strength of crumb rubber concrete at 7 and 28 days.

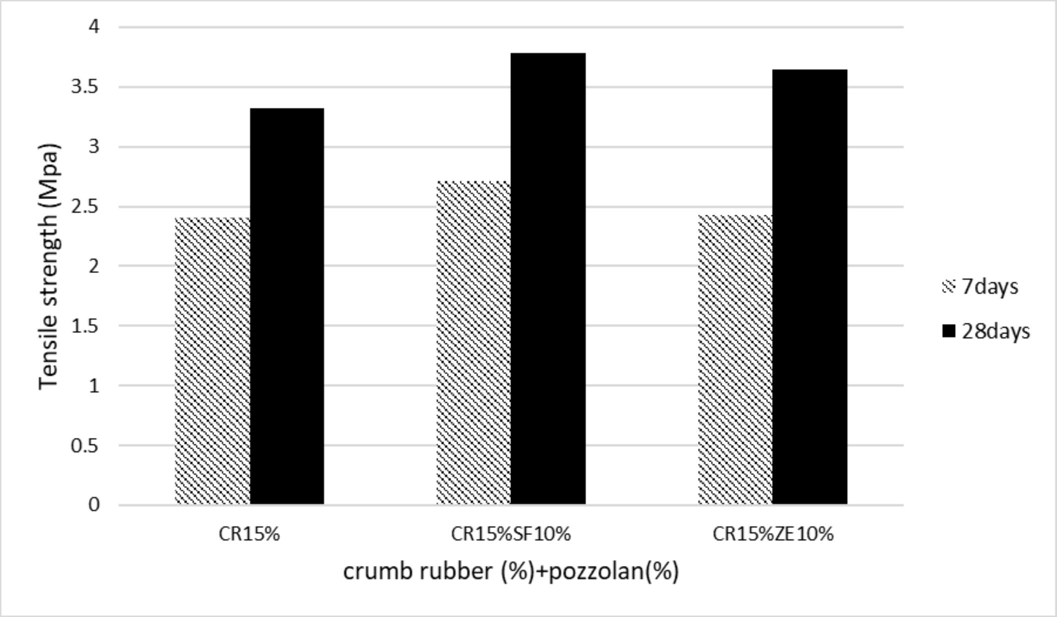
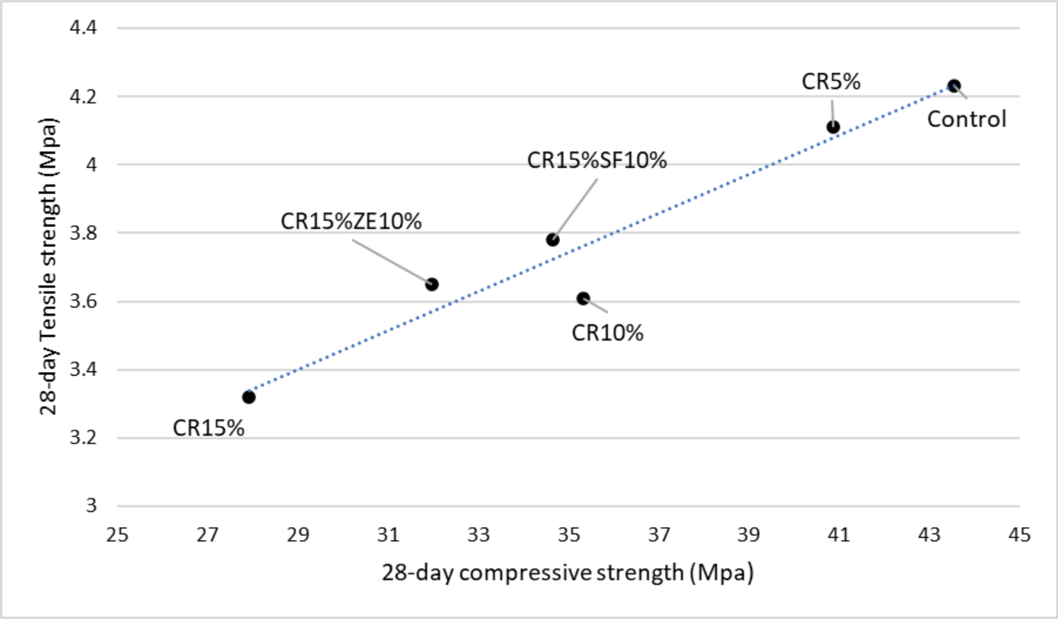


Figure 6. Tensile strength of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.



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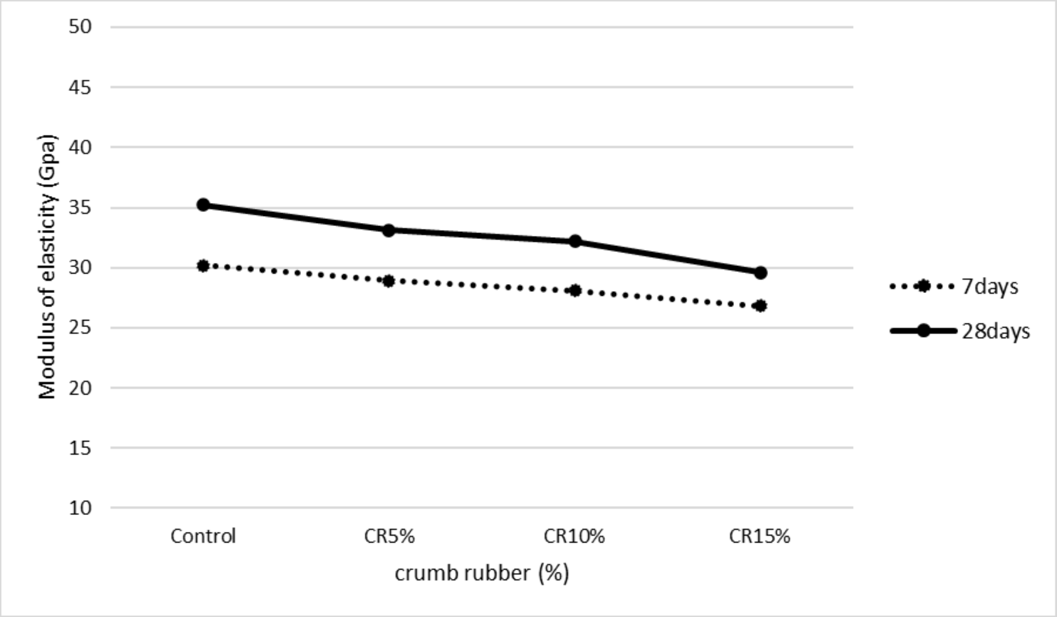

Figure 8. Modulus of elasticity of crumb rubber concrete at 7 and 28 days.

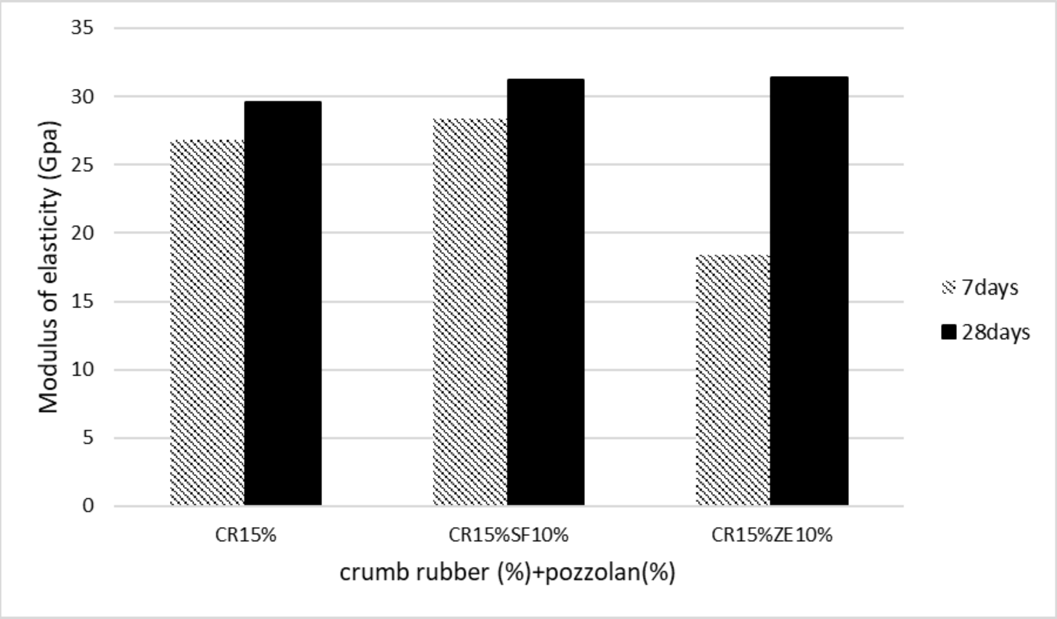

Figure 9. Modulus of elasticity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

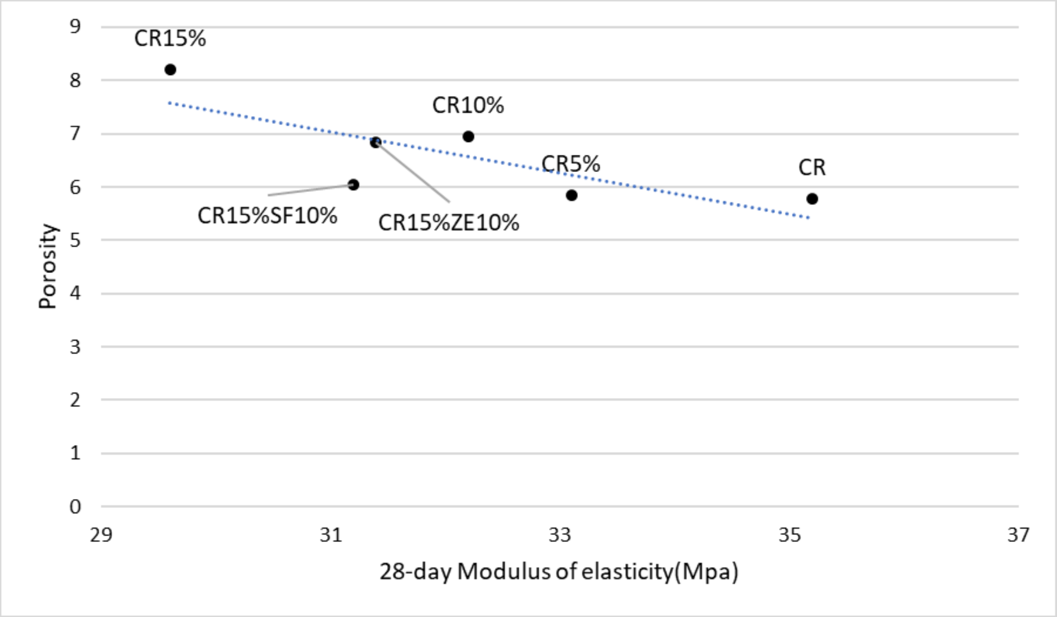

Figure 10. Relation between Modulus of elasticity and 28 days Porosity of concrete containing crumb rubber, silica fume, zeolite.

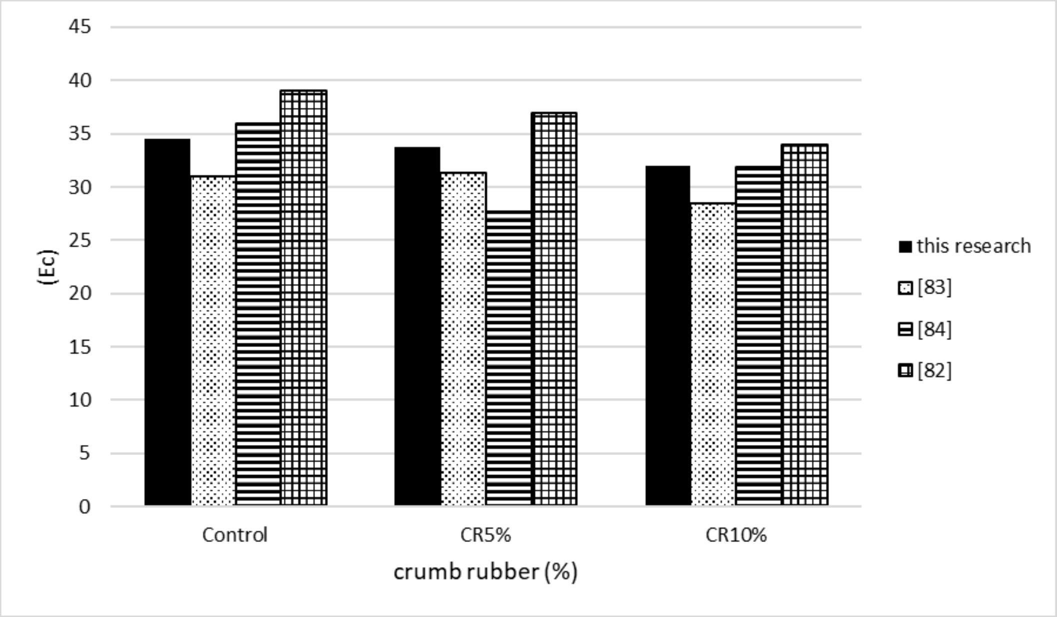

Figure 11. The relationship of Ec in this research with the research of others [82–84].

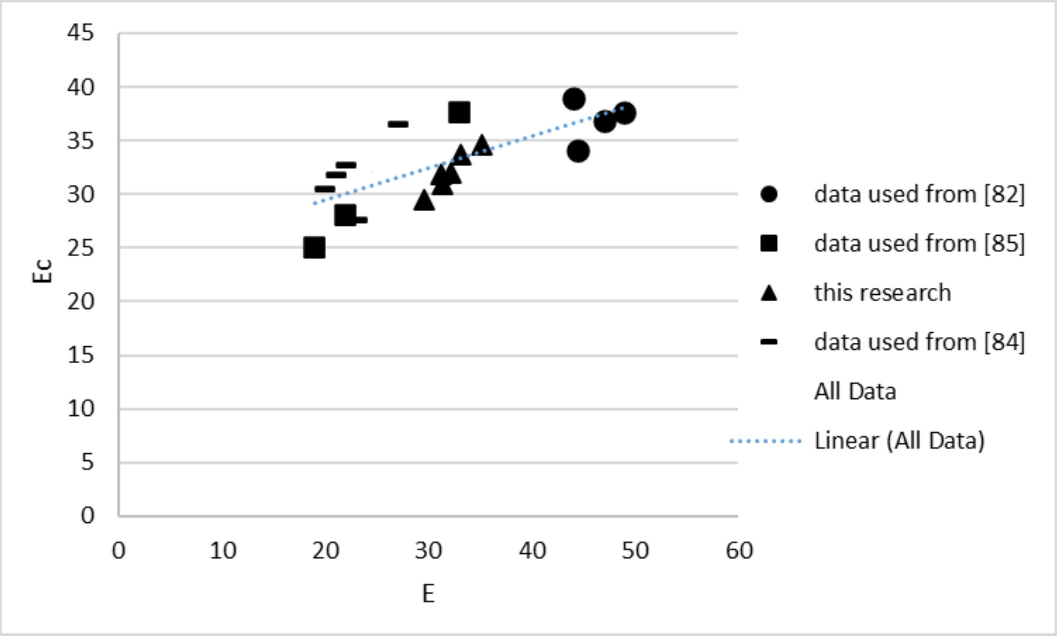

Figure 12. comparison of the laboratory results (E) and the final solution of this model (Ec) in this research with the research of others [82,84,85].

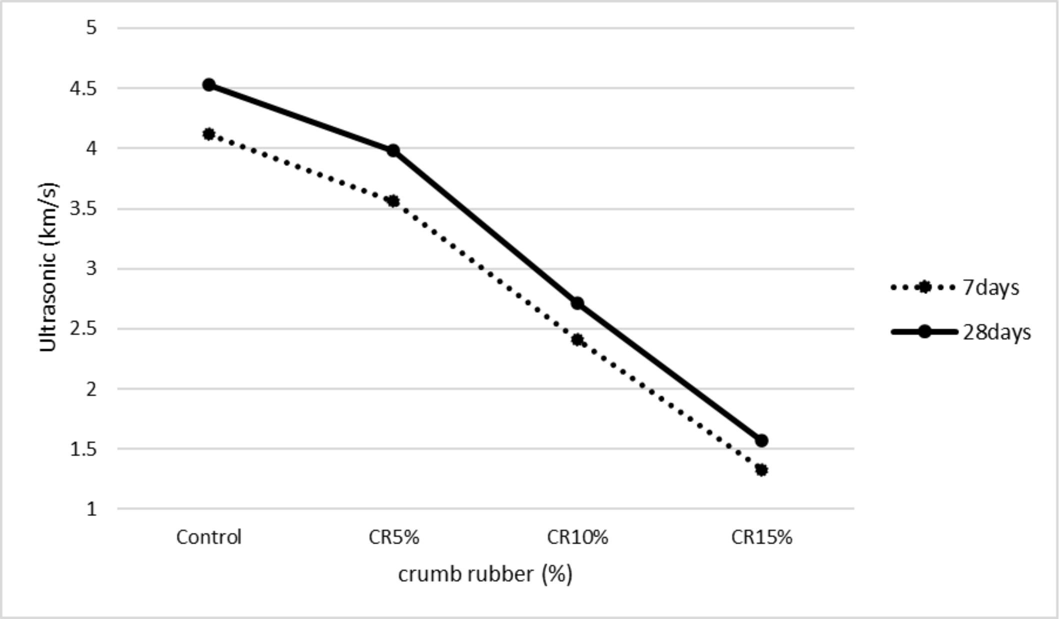

Figure 13. Ultrasonic of crumb rubber concrete at 7 and 28 days.

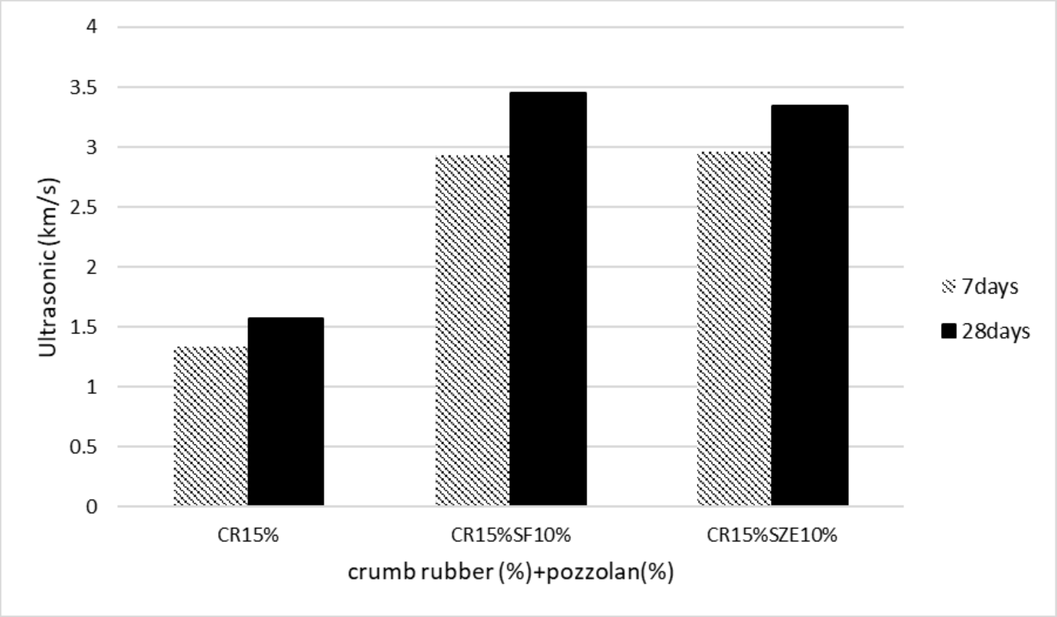

Figure 14. Ultrasonic of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

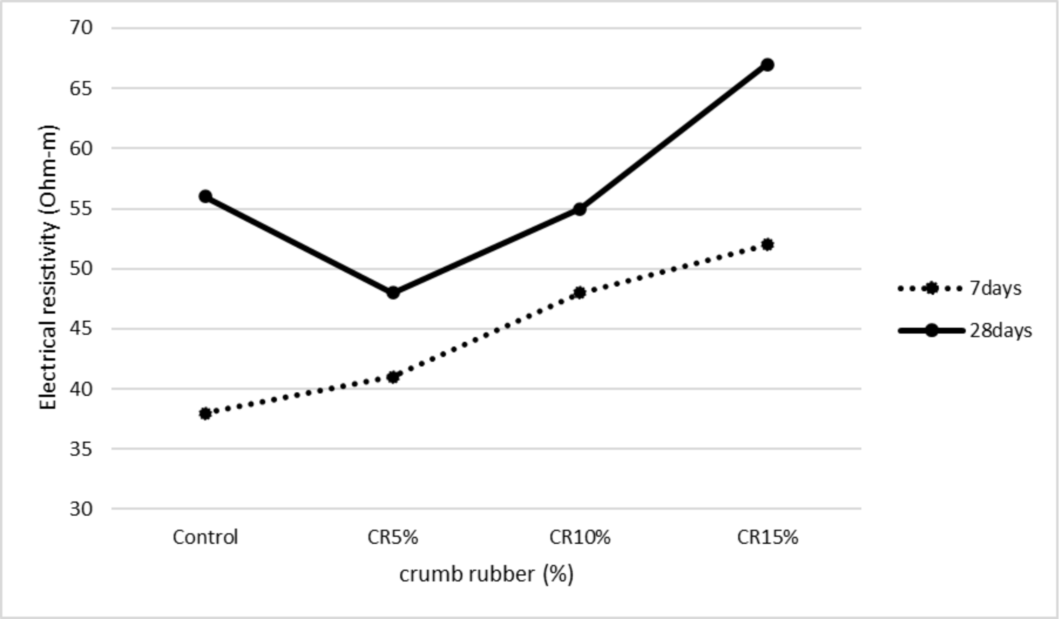

Figure 15. Electrical resistivity of crumb rubber concrete at 7 and 28 days.

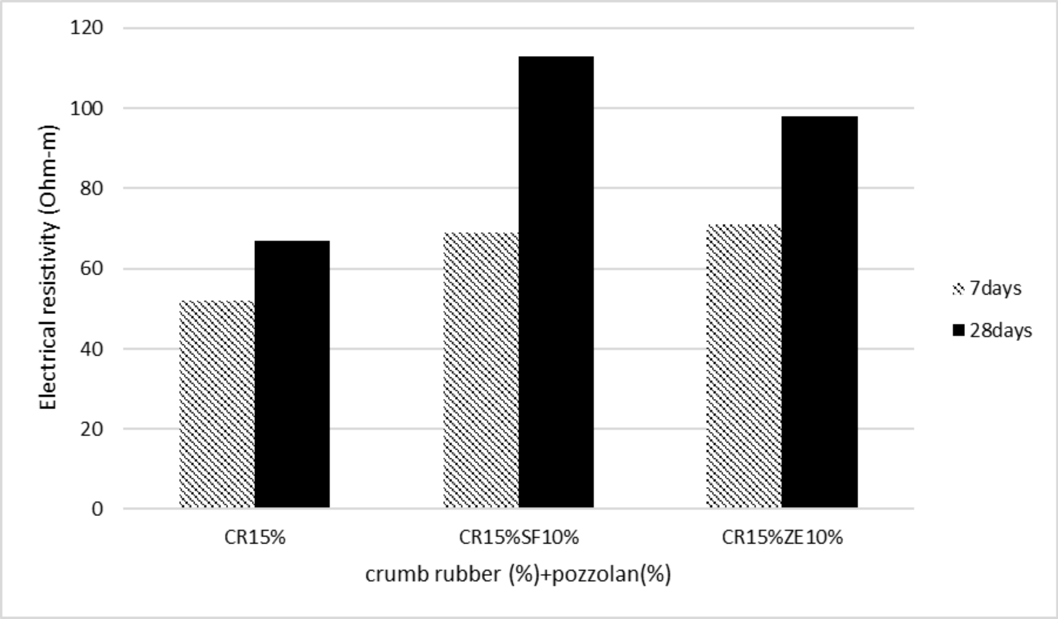

Figure 16. Electrical resistivity of crumb rubber concrete at 7 and 28 days + silica fume and zeolite.

Table 1. Cement's physical and chemical characteristics and pozzolans.

Chemical analyses	Portland Cement (%)	silica fume (%)	Zeolite (%)
SiO2	20.74	87.49	66.5
Al2O3	4.90	2.87	11.81
Fe2O3	3.50	1.27	1.3
CaO	62.95	1.55	3.11
MgO	1.20	1.31	0.72
Na2O	-	0.38	2.01
K2O	-	0.41	3.12
SO3	3.00	0.17	-
Loss of ignition	1.56	-	-
Insoluble residue	0.74	-	-
Specific gravity(kg/m^3)	3050	-	-
Specific surface area(kg/m^3)	2805	-	-

Table 2. Proportions of crude rubber and pozzolan in concrete containing crude rubber and pozzolan.

Mix ID	Cement (Kg)	Silica fume (kg)	Zeolite (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Sand (kg)	Rubber (kg)	W/C	Water (kg)
Control	420	0	0	547.68	544.83	707.17	0	0.4	225.88
CR5%	420	0	0	520.55	516.68	707.17	22.81	0.4	225.88
CR10%	420	0	0	493.15	489.49	707.17	45.62	0.4	225.88
CR15%	420	0	0	465.76	462.29	707.17	68.44	0.4	225.88
CR15%SF10%	324.70	95.3	0	465.76	462.29	707.17	68.44	0.4	225.88
CR15%ZE10%	306.61	0	113.39	465.76	462.29	707.17	68.44	0.4	225.88

Table 3. Slump test results and specific weight.

Mix ID	Slump (cm)	Specific weight (kg/m³)
Control	5.7	2391
CR5%	5.5	2368
CR10%	5.3	2354
CR15%	4.8	2284
CR15%SF10%	2.5	2307
CR15%ZE10%	4.6	2324

Table 4. Comparison of the research results conducted with the elasticity modulus of different codes.

Mix ID	Modulus of elasticity was performed	ACI 318-08[87]	CSA A23.3[76]	NBR 6118[77]
		$E_c = 4730(f'c)^{0.5}$	$E_c = 4500(f'c)^{0.5}$	$E_c = 5600(f'c)^{0.5}$
Control	35.2	31.21	29.7	36.96
CR5%	33.1	30.23	28.76	35.8
CR10%	32.2	28.11	26.74	33.28
CR15%	29.6	24.99	23.78	29.59
CR15%SF10%	31.2	27.84	26.48	32.96
CR15%ZE10%	31.4	26.74	25.44	31.66

Table 5. Results of % Water absorption test and % porosity.

Mix ID	% Water absorption	% porosity
Control	2.81	5.77
CR5%	2.85	5.85
CR10%	3.44	6.94
CR15%	4.19	8.20
CR15%SF10%	2.98	6.05
CR15%ZE10%	3.44	6.84