

Review Article

INVESTIGATION OF THE MECHANICAL BEHAVIOR EFFECT OF RUBBER POWDER COMPOSITION ON THE MORTAR MADE OF PORTLAND-COMPOSITE CEMENT (PCC) WITH AN ENVIRONMENTAL APPROACH

Mehran Mohammadi¹, Mostafa Farhadi Ghoyounlu^{2*}

¹ Faculty Member of the Department of Civil Engineering, Faculty of Engineering, Bojnourd University, Iran

² B.Sc. Student of the Department of Civil Engineering, Faculty of Engineering, Bojnourd University, Iran

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Abstract

Rubber as a waste can be used in the form of powder to improve the mechanical properties of mortar. In this experimental study, the effect of rubber powder application on mortar made from Portland-Composite Cement (PCC) with environmental approach was investigated in the application of corroded tire waste as well as the reduction of clinker consumption. Since cement and sand mortar is not as reinforced as concrete, it is important to improve its tensile and bending behavior in addition to compressive strength. For this experimental study, about 300 samples were made in two stages without rubber powder and with 5% rubber powder. Despite the slight decrease in the resistance of the samples with rubber powder to those without rubber powder, the samples containing the rubber powder reached their final strength sooner, were lighter, and behaved better when fractured. Adding rubber crumbs to the concrete improved some of the mechanical properties such as higher energy absorption of the concrete, better ductility, and resistance to cracking.

Keywords: Rubber Powder, Portland-Composite Cement, Cement and Sand Mortar, Mechanical Behavior of Mortar.

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INTRODUCTION

In recent decades, the global growth of the automotive industry and the increasing use of automobiles as the main vehicle have increased tire production. This has created huge reserves of used tires [1]. Tire waste management and disposal is one of the major environmental concerns in many countries. Accumulation of these wastes is dangerous because it not only has a potentially negative environmental impact, but it also poses a risk of fire and provides breeding grounds for rats, insects, and mosquitoes. Waste tire management is increasingly becoming an environmental, health and aesthetic problem that is not easily solved. The use of waste tires as a concrete additive is a possible solution for disposal [2]. The global growth in the use of motor vehicles is increasing every year. One solution is to replace rubber powder with concrete aggregates to recycle rubber and help protect the environment. Of course, rubber concrete yields less compressive strength, but its acceptable strength and durability make it useful where high compressive strength is not required [3]. The use of waste tires in asphalt-concrete blends made with Portland cement has attracted the attention of engineers. In civil engineering, due to economic, technical, and environmental benefits, the recovery of crumb rubber in the asphalt-concrete mix has been successful [4]. Adding rubber particles to the concrete pavement can be useful for improving some properties such as high flexibility, low porosity, and low unit weight. Recycling crumb rubber in pavements may help reduce waste while reducing the need for natural aggregates. Rubber powder concrete can be used for some projects such as low traffic pavement, rural roads, and pedestrian areas. However, the optimal amount of tire used depends on the technical requirement and the destination of the project [5]. Adding a 5% aggregate of rubber powder to the concrete increases the corrosion resistance of the sulfate significantly. The use of rubber powder of waste tire can increase the durability of self-consolidating concrete. The best compressive strength of self-consolidating concrete made of rubber powder was when 5% of the rubber powder of waste tire passed through the sieve No. 50 was added [6]. Investigation of post-cracking behavior of concrete blended with rubber powder - replaced by coarse aggregate with rubber crumbs - had a positive effect on energy absorption and demonstrated energy flexibility indicators for concrete blended with rubber powder [7]. Further research is needed to

determine the optimization of particle size, percentage of rubber, type of cement, and the use of chemical and mineral additives on the properties of concrete combined with rubber powder [8].

Therefore, in accordance with previous research in this experimental study, the effect of rubber powder composition on the behavior of mortar made of Portland-composite cement was investigated.

MATERIALS AND METHODS

Portland-Composite Cement (PCC)

Portland-Composite Cement (PCC), Standard Code PM-A-32.5, is a hydraulic binder of the Portland cement family that is obtained by grinding and mixing Portland cement clinker with at least two types of additives including special limestone, high-grade natural pozzolan, slag (smelting furnace), inflatable ash (siliceous or calcareous), calcined pozzolan, cooked clay or shale or micro silica (silica fume) with an appropriate percentage of gypsum (crystalline calcium sulfate). The increased wear resistance of cement surfaces due to higher silica content in this cement has a direct effect on reducing physical erosion and extending the life of cementitious components. Due to the low heat generated by the reaction of water with this cement, the resulting heat gradually dissipates as the cement mortar becomes stiff and prevents the cement surface from cracking. The application of this cement eliminates the undesirable phenomenon of concrete efflorescence and prevents the carbonization of concrete and the penetration of harmful chemical agents such as sulfates and chlorine ions into the cemented parts. As a result, it reduces the disintegration of the cementitious material as well as reduces the phenomenon of bleeding and shrinkage of the mortar.

Rubber powder

Tires are often crushed for landfill or for the production of tire chips and rubber powder. Most tire crushing equipment is removable and can be easily moved from one warehouse or landfill to another. This crushing process turns the tire into smaller pieces. There are a number of applications for scrap tires, including their use in rocks and breakwaters, playground equipment, erosion control, highway crash barriers, guard posts, and noise barriers. They are also used in asphalt mixes as

well as in fuel in cement kilns and paper mills [9]. Their results showed that concrete powders have better slip rubber strength, reduced fatigue crack and longer design life than conventional concrete mixes [10]. In another study, the effect of substitution of 5%, 7.5%, and 10% by weight of coarse grains was investigated using crushed rubber and powdered rubber. Their results showed that in general, the compressive strength decreased with an increasing percentage of rubber replacement in concrete. Although with 5% cement replacement by rubber, the decrease in compressive strength was less (less than 5%) with no significant change in other concrete properties, the highest reduction was observed at 7.5% and 10% replacement for both types of rubber used. The tensile strength of concrete decreases with an increasing percentage of rubber replacement in concrete. The most important reason for the incompatibility between rubber and pulp matrix is that bonding plays a key role

in reducing tensile strength. The tensile strength of concrete containing crumb rubber (replacement for aggregates) is lower than that of concrete containing rubber powder (replacement for cement) [11]. Replacing rubber with cement in concrete reduced their bending strength at both degrees. Adding this amount of rubber did not have much effect on the modulus of elasticity and compressive strength [1]. Oywars et al., by replacing 3.5 and 5 vol% of recycled rubber in a cement matrix, observed that adding this amount of rubber did not have much effect on the compressive strength and modulus of elasticity [12]. In this study, the effect of replacing 5 wt% of sand with rubber powder on mortar behavior was investigated. The rubber powder was passed through sieve No. 8 and the sand used was incubated for 24 hours in the oven and then sifted through a sieve. The gradation diagram of sand and rubber powder and their composition is shown in Figures 1 and 2.



Figure 1. Rubber powder in combination with sand and cement

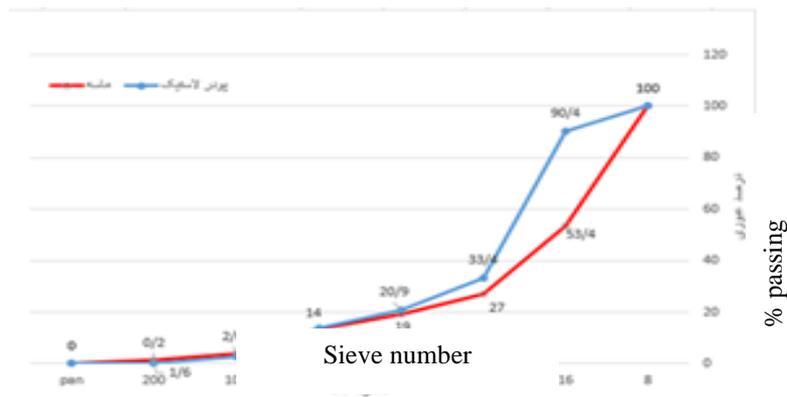


Figure 2. Gradation diagram of sand and rubber powder

Theoretical Basis of Tensile, Pressure and Bending Tests

The basic equations for determining the compressive, tensile and bending stresses based on the basic equations of materials strength are as follows and summarized in terms of sample dimensions and other test specifications:

Compression

To determine the compressive stress in the test specimens according to Figure 3a and the dimensions of the compressive specimen with sides $a = 5$ cm, we have:

$$\sigma_c = \frac{F}{A} = \frac{F}{a^2} = 0.04F \quad (1)$$

where σ_c are the compressive stress, F is the maximum fracture force of the specimen, and A is the cross-sectional area of the specimen.

Tension

To determine the compressive stress in the test specimens according to Figure 3b, we have:

$$\sigma_t = \frac{F}{A} = \frac{F}{bt} = 0.16F \quad (2)$$

where σ_t is the tensile stress, F is the maximum fracture force of the specimen, A is the cross-sectional area of the specimen, b is the width of the papillary briquette specimens at its minimum (waist circumference), and t is the specimen thickness, which is 2.5 cm for both.

Bending

To determine the maximum bending stress in the test specimens according to Figure 3c, we have:

$$\sigma_{\max} = \frac{M_{\max} C}{I} \quad (3)$$

where M_{\max} is the maximum bending of cross-section, σ_{\max} is the maximum stress value at the cross-sectional area in the form of tensile or compressive stress, C is the distance between the farthest tensile or compressive strands of the bending axis, and I is the moment of inertia around the bending axis of the beam.

The maximum bending value of cross-section is obtained from the following formula:

$$M_{\max} = \frac{PL}{4} \quad (4)$$

where M_{\max} is the maximum bending anchor in the loaded specimen similar to Fig. 3c, P is the amount of load applied, and L is the distance of the supports.

Given that the beam is made of $16 \times 4 \times 4$ cm, the beam cross-section is square (with dimension d) and its moment of inertia is obtained by the following formula:

$$I = \frac{bh^3}{12} = \frac{d^4}{12} \quad (5)$$

Combining equations 3, 4 and 5 results in:

$$\sigma_{\max} = \frac{12PLd}{8d^4} = \frac{3PL}{2d^3} \quad (6)$$

where P is the amount of load applied, L is the distance between the supports, and C is the distance between the farthest tensile or compressive strands of the bending axis.

Then, according to the dimensions of the standard beam cross-section made of cement and sand mortar in the laboratory, which is a square with sides of 4cm, it can be written:

$$\sigma_{\max} = 0.0234375PL \quad (7)$$

Since, according to the figure, the span in the test device was 10, the formula would be completed as follows:

$$\sigma_{\max} = 0.234375P \quad (8)$$

It should be noted that if the standard of 12 cm span is defined, the formula will be as follows:

$$\sigma_{\max} = 0.28125P \quad (9)$$

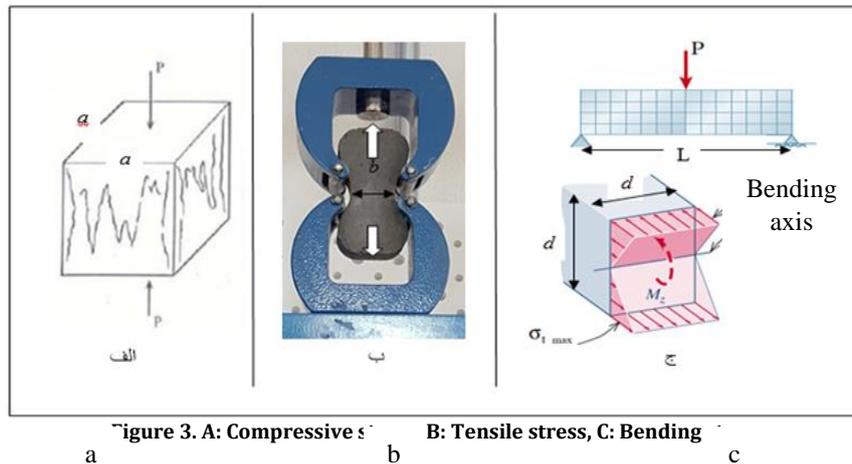


Figure 3. A: Compressive stress, B: Tensile stress, C: Bending

Test reports and mix design

In this study, the Iranian National Standard INSO 706-2 and American standards C348 ASTM, C190 ASTM as well as European standards EN 197-1:2000 and CRD-C 260-01 were used. According to the standard recommendation, a sand-cement ratio of 3:1 was used in the mixing design of samples, but different designs of water-cement ratio from 0.6 to 0.75 were prepared in this study (Table 1). Also in the design, mixing was repeated by adding rubber powder 5 wt% sand. In Table 1, mixing schemes A to D are the control mix designs and the A1 to D1 mix designs are target mix designs that are repeated with rubber powder. First, this ratio of water to cement has been less studied in previous studies, and in this study, more fluid

mortars have been investigated. Secondly, it is emphasized that this ratio of water to cement is not permitted in the manufacture of concrete but is prevalent in the manufacture of mortar. As the tensile specimens were manufactured, compressive specimens were fabricated with that mixing design to investigate their different loading times and how their strength increased. Also, compressive samples and tensile papillary briquettes were molded in triplicate to meet the minimum number of standards per loading life. In addition, additional specimens were also provided to replace the specimen if lost for any reason. For example, according to standards, if the resistance of the samples is more than 15% different from the average resistance of the other similar

samples, they will be eliminated. Also, samples with obvious disadvantages should not be tested. If less than two acceptable results are obtained after removing the defective specimens and the unacceptable results, further testing shall be performed. Also, the dimensions of the specimens should be controlled so that the difference with the standard is less than 2%. Portland-composite cement made in the Bojnourd cement plant was used. In the case of sand, according to the mortar grading standard, the sands were first passed a sieve No. 8. Then, during its overall inspection of the aggregate cleanliness and health of all mixing designs, the sand was kept in the oven for at least 24 hours to obtain the moisture content of the

aggregates and not to affect the mixing design. Before filling the molds, they were covered with a thin layer of oil and then the molds were placed on a metal plate. Then the molds were filled without pressure and raised. For compaction, the mortar was firmly pressed with the thumb and this was repeated 12 times for each briquette. After pressing the mortar into the molds, the excess mortar was lifted onto the surface by a trowel and smoothed. The mold was covered with laminated glass or metal plate. Then the mold and plate were taken, and they were turned around the longitudinal axis of the mold and then the top plate that was previously under the mold was removed, and the pressing and straightening operation was then repeated again.

Table 1. Mixing designs

Water to cement ratio (W:C)	Sand to cement ratio (S:C)	Water (gr)	Cement (gr)	Sand (gr)	Rubber powder (gr)	Mixing designs
		W(gr)	C(gr)	S(gr)	R(gr)	
0.6	3	1920	3200	9600	-	A
		1920	3200	9600	480	A1
0.65	3	2080	3200	9600	-	B
		2080	3200	9600	480	B1
0.7	3	2240	3200	9600	-	C
		2240	3200	9600	480	C1
0.75	3	2400	3200	9600	-	D
		2400	3200	9600	480	D1

After molding, the test specimens were kept in the mold for 24 hours at room temperature above 50%. The upper surfaces of the specimens should be exposed to humid air (without splashing water). The samples were removed from the mold after 24 h and placed in a clean water tank. Water should never be on the testes, and the distance between them should not be less than 5 mm. If the mortar is not tight enough within 24 hours, the exit time should be delayed so as not to threaten their destruction. It should be noted that the geometric dimensions of standard mortar compressive specimens are 5 × 5 × 5 cm with a contact force of 25 cm² and the standard ASTM papillary specimens are 2.5 × 2.5 cm in the thinnest section and have a cross-section of 6.25 cm². The mold should be placed on a horizontal floor in a humid environment or in a humid chamber without delay. The humid air should be present on all sides of the mold. Open the molds without damaging the test. A rubber or plastic hammer or any other suitable device can be used to remove the specimen. The air temperature at the test site should be between 20 and 27.5 °C. To test the tensile strength of the cement mortar, briquette samples were removed from the water and sand or other loose grains in contact with the surface of the specimens were clamped to the device. The clamp retaining surfaces should be clean and lubricated to determine the bending and tensile strength of the cement mortar. The position of the test device shall be such that the clamps can rotate freely on the axles. The briquette specimens were carefully placed in the clamps, respectively, and were

continuously applied until they were broken (Fig. 4b). In the case of compressive strength apparatus, pre-mortar specimens were tested for testing: homogeneity of the sample, no porosity, honeycombing; Or concave concrete surfaces of the concrete under test, parallel to the sample surface to the permissible level and no crack and cracked capillaries, as well as wet surfaces during the test and no dry surface. After checking the above, the samples were tested on the relevant devices (Fig. 4a). For bending specimens, the prism, measuring 4 × 4 × 16 cm, was dried after exiting the water, and loose grains and particles attached to surfaces of specimens, contacting the supports and points of loading. They were cleaned. The surfaces were controlled by a straight glass blade and, if there was significant curvature on the surfaces, they were removed by abrasive grinding or the sample was removed. The specimen was inserted into the device's jaw so that the smooth surfaces adjacent to the molds would contact the device's jaws. The longitudinal centerline of the specimen should lie directly above the middle point of the two supports. The loading device was adjusted so that the loading blade was perpendicular to the length of the prism and parallel to its upper surface. The center of the loading blade of the device should be located directly above the centerline of the specimen and in the middle of its mouthpiece. It should be ensured that the contact between the loading blade of the device and the sample is continuous when applying the load (Fig. 4c).

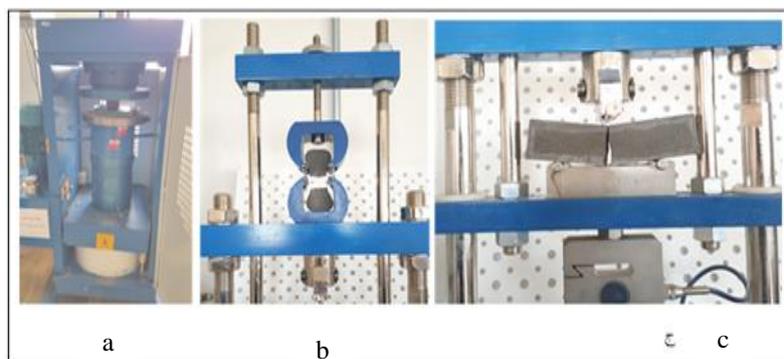


Figure 4. Loading on (a) pressure (b) tensile (c) bending specimens

Diagrams and their analysis

Maximum force was obtained after compressive, tensile and bending tests at 7, 14 and 28 days and at least 3 at each shelf life. Based on formulas 1, 2 and 8, the values of compressive, tensile and bending stresses were calculated. Drawing diagrams of compressive, tensile and bending stresses in different mixing schemes resulting from the difference of water to cement ratio. Figures 5 and 6 show the 28-day resistance for the mean of 3 fractured compressive, bending, and tensile samples in 4 different control and target mixing schemes based on Tables 1 and 2. As is known, the stress variations are linearly

related to the W / C ratio. By comparing them with each other, it was indicated that with increasing ratio of water to cement decreased in both series. However, by calculating the linear regression equation in all 3 graphs, it is clear that for the control samples the linear relationship in compressive stress with the correlation coefficient $R^2 = 0.99$ is more accurate than the tensile equation with $R^2 = 0.98$. Also bending specimens with correlation coefficient $R^2 = 0.94$ indicates that the pattern of decreasing resistance is somewhat out of linear state but can also be considered linear (Figure 5).

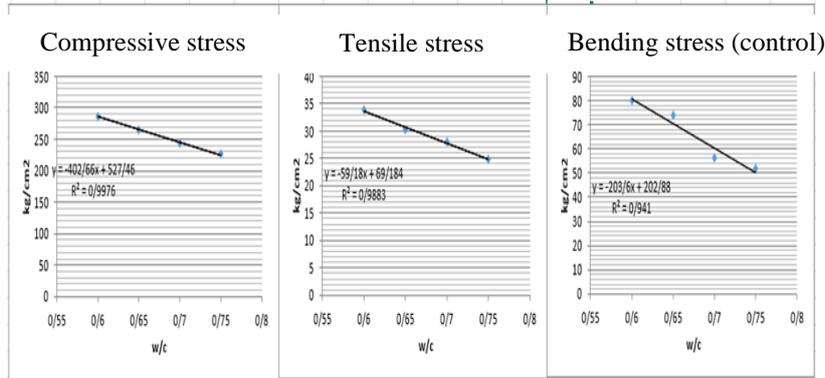


Figure 5. Diagrams of (a) compressive (b) tensile (c) bending stresses with different W:C ratios for control samples.

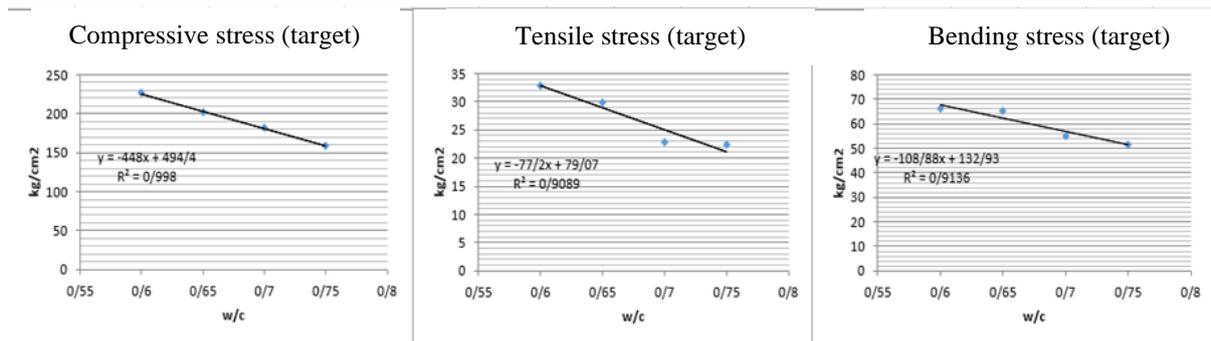


Figure 6. Diagrams of (a) compressive (b) tensile (c) bending stresses with different W:C ratios for target samples.

For target samples, the linear relationship in compressive stress with the correlation coefficient $R^2 = 0.99$ was more accurate than the bending equation with $R^2 = 0.91$. Also, the correlation coefficient value in the tensile equation was $R^2 = 0.9$, which is almost linear (Figure 6). As can be seen, the linear pattern in the control tensile equation is significantly different from the target tensile equation. This difference is smaller in the tensile sample equations. Therefore, for the highest tensile and bending and compressive strengths, the water-to-cement ratio must be 0.6 and lower water-to-cement values can be tested in future research. However, the amount of porosity and hardness of the mortar in question should also be taken into account.

For the target and control samples, a comparison was made between the mean tensile, compressive, and bending stresses over a 28-day life, summarized in Fig. 7. At first glance, by comparing diagrams A and B, it can be seen that the additive effect of rubber powder was significant in reducing compressive strength, but had less effect on tensile and bending stresses. A closer look reveals that, in the design of less water-soluble mixtures, the tensile strength is almost unchanged by the rubber powder additive. In bending strength, this is evident in the design of more water-soluble mixtures.

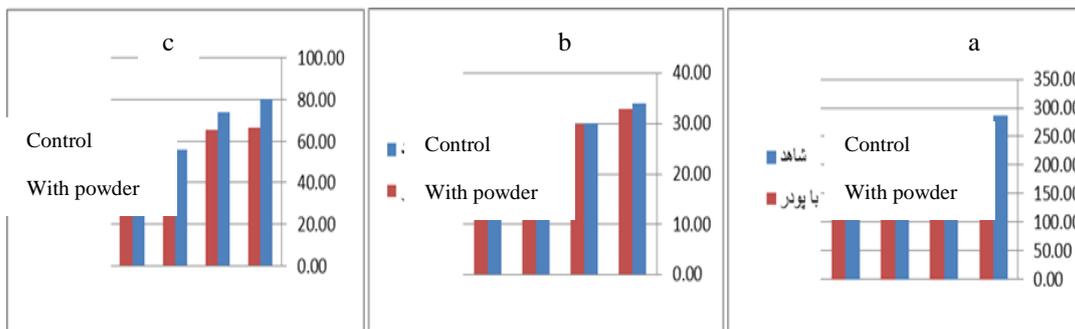


Figure 7. Diagrams of values of (a) compressive (b) tensile (c) bending stresses values for the control and target specimens over a 28-day life.

To compare the energy absorption state, the stress and strain diagrams of the compression test for the control and target states are shown in Fig. 8.

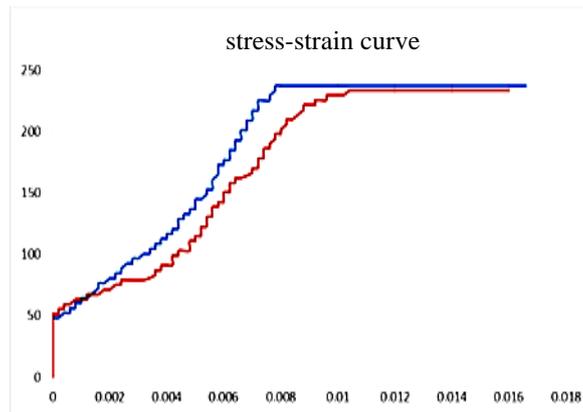


Figure 8. Stress and strain diagrams of control and target pressure samples over a 28-day life.

Control and target samples were identified by comparing the stress-strain curve. Despite less stress on the samples with powder, they had higher strain and exhibited softer loading behavior.

CONCLUSION

1. At higher water-to-cement ratios, the 7-day tensile strength difference with other lifetimes is more significant, thus as mortar water increases, it reaches its final strength more lately.
2. The growth of tensile, compressive and flexural strength is equal at different times and has no relation with water-to-cement ratio or mixing design.
3. In spite of less stress in the samples with powder, they have higher strain and exhibit softer loading behavior.
4. The effect of rubber powder additive is significant in reducing compressive strength but has less effect on tensile and flexural stresses.
5. The proposed mixing design for applying 5% rubber powder in cement sand mortar is less than 0.65 due to its tensile strength.
6. The amount of correlation in the samples with rubber powder decreased and the dispersion of the cultivars increased.

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