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Investigating the Effect of Natural Pozzolans on Mechanical Properties of Roller Compacted Concrete

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Abstract

Roller Compacted Concrete (RCC), is a concrete with zero slump, which is used in damming and road pavement. Roller Compacted Concrete Pavement (RCCP) bear heavy traffic loads and severe weather conditions. This type of concrete is due to its economic and environmental capabilities, including reduced construction and maintenance costs, longer durability and longer lifetime, as well as environmental compatibility. This paper presents the results of laboratory studies on the effect of natural pozzolan (zeolite) on the mechanical properties of RCC specimens. In this study, cement materials of 320 kg/m^3were used The rheological performance test (VeBe) and compressive and tensile strengths at the age of 7, 14 and 28 days and the flexural strength tests at 14 and 28 days were performed on the specimens. The results show that the higher amount of pozzolan reduced concrete efficiency (the time of VeBe increased). In addition, the compressive, tensile and flexural strength of the samples are decreased, significantly. However, reducing resistance does not mean compliance with the requirements of the Code.

Key words: *Roller Compacted concrete, Zero Slump, Road pavement, Mechanical properties, VeBe test.*

1. Introduction

The Roller Compacted Concrete Pavement (RCCP) is a type of zero-slump concrete that contains dense aggregates and cementitious matrix of materials. The performance of RCCP over the past years has shown that it can be used as durable material for pavement construction, in such a way that heavy traffic loads and weather conditions can be achieved with a series of low maintenance operations.

One of the first uses of RCCP was to build a runway in Yakima, Washington, DC by the US Army Corps of Engineers in 1942. In 1985, a RCCP shutter was launched at 36,000 square meters at the Portland International Airport. The advantages of choosing a RCCP in the airport's parking were less susceptibility to casting oil, less maintenance costs, lack of problems with the next meeting as well as economic benefits. [1] Haque studied the effects of fine-grained sand and kaolinite clay on the strength of RCCP and concluded that fine grained sand reduces the compressive strength of RCCP and the use of kaolinite also results in a significant reduction in the compressive strength. [2] Qasrawi etc. focused on the characteristics of RCCP under warm weather conditions at the Middle East region. [3] Ameri etc. investigated the effect of using slag of Isfahan steel convertor as a substitute for aggregate on RCCP. They replaced the slag with 0, 25, 50, 75, and 100 substitutions of natural fine grained particles and examined the compressive strength for mixed mixing designs. The results show that the replacement percentage of 25% can be optimum in the compressive strength test. [4] In two separated studies, Shekarchizadeh and colleagues studied the permeability of the RCCP and compared it with other concrete properties.[5,6] Vahidifar etc. examined the effect of microsilica and pumice on the performance of RCCP. The results showed that pumice reduced and micro-silica increased the stability and compressive strength of specimens compared to

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control samples. [7] In addition, Nile etc. investigated the effect of natural pozzolan, wind ash and microsilica in salt-scaling resistance of non-air-entrained of RCCP. The results showed that wind ash and microsilica decrease the time of its application. Furthermore, the compressive strength of microsilica increases compressive strength and natural pozzolan and wind ash reduces compressive strength. [8]

Madhkhan etc. examined the effect of polypropylene fibers containing metal and propylene fibers on mechanical properties of RCCP. They show that use of metal fibers increased the compressive strength due to its overlap. [9] Abiri and Miri studied the effect of limestone powder on mechanical properties of RCCP. The results showed that the use of limestone up to 5% increases the compressive strength and tensile strength. However, it decreases the compressive strength and tensile strength by increasing the percentage of lime. [10]

In this paper, an experimental study on the effect of natural pozzolan (zeolite) on the mechanical properties of RCC specimens was carried out. The reasons for choosing natural pozzolan (zeolite) for this study are as follows:

1- Various local cement factories in Iran are based on the production of pozzolanic zeolite cement. Therefore, the use of other pozzolans, in spite of existing equipment, reduces the capacity of cement production, resulting in economically inefficient will come with.

2- Access and transportation of this type of pozzolan is more convenient and cost-effective compared to other pozzolans.

2. Experimental Program

2.1. Materials

The cement used in this research was Portland cement type II. Natural pozzolans were mixed from origin resources (volcanic, sedimentary, and organic). They contain high amounts of silica and aluminum, as well as existing oxides and a small amount of iron. The chemical and physical characteristics of the cement and natural pozzolan are given in Table 1 and 2, respectively. General requirements for aggregates are in accordance with the ISIRI 302 Standard. Particle size distribution of aggregates is given in figure 1. The final composite of aggregates was include natural sand and rock powder filler (specially passing through sieve #100). No superplasticizer and drinkable water are used in this paper.

Table 1. Chemical properties of cement and pozzolan used in this research

element name	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	IR	LOI
Cement (%)	21.05	4.81	3.84	62.44	1.99	3.2	0.74	0.26	0.43	1.89
Natural Pozzolan	75.33	13.23	1.86	2.01	0.04	1.6	1.14	1.92	-	2.6

Table 2. Physical properties of cement and pozzolan used in this research

Specifications	Type of experiment	Measured value	Acceptable range
Cement type2 Customizable, Blaine test	ISIRI 390	3165	Min 2800
Natural pozzolan Customizable, Blaine test	ISIRI 390	3760	-

Table 3. Granulation aggregates used

Sieve Size/ Passing Percentage	19 mm	9.5 mm	4.75 mm	2.38 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm
Gravel	100	48	2	1	0	0	0	0
Sand	100	100	89	61	39	25	14	3

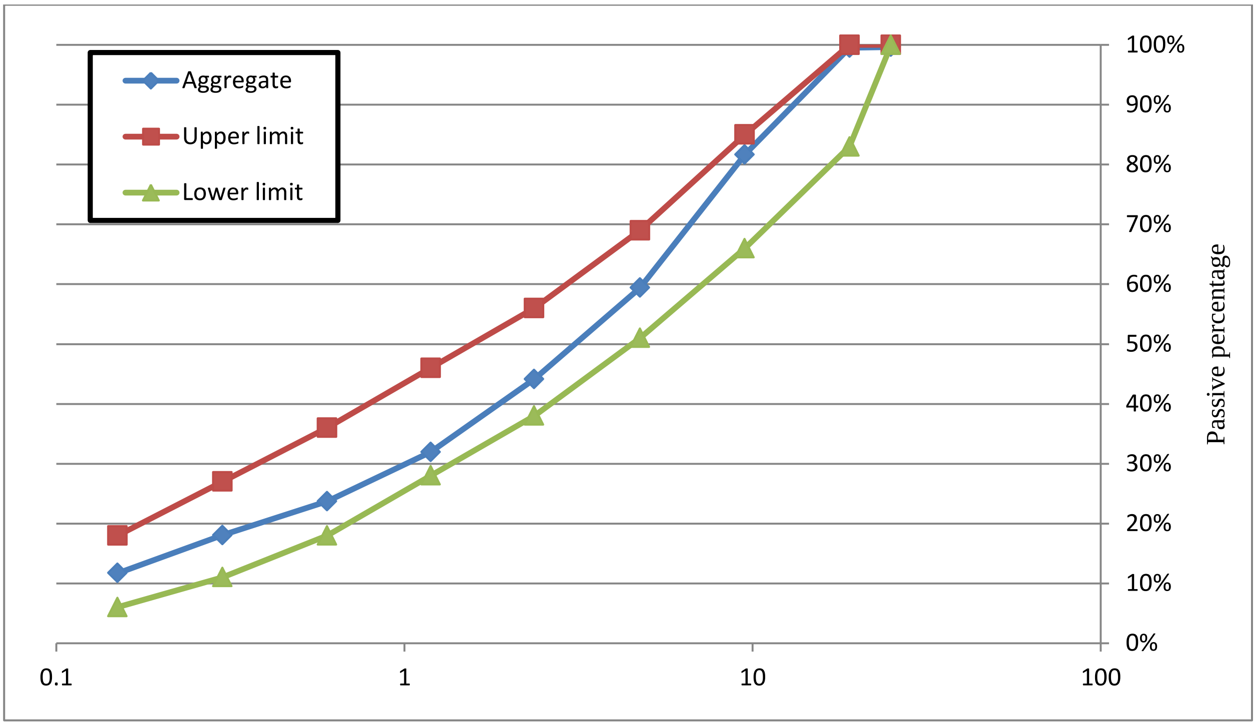


Figure 1. PSD of Granular aggregates according to ACI 211.3R Code

2.2. Mixing Procedure

In RCCP mixtures, the mixture must be produced in a suitable manner in such a way that optimal density is possible and the sufficient coherence of the mixture is provided in a way that does not become detached during the operation. On the other hand, the mechanical properties of RCCP bearings should also be satisfied. Therefore, the methods of RCCP mixing due to the stiffness of the mixture and its distinctive gradation are different from conventional concrete. The main differences in RCCP mixtures and conventional concrete pavements are:

• Roller compacted concrete pavements is not generally aerated (no vibrator is used).

• Roller compacted concrete pavements has less water content. Mainly in road works, in order to create sufficient density in the RCCP. This concrete is sufficiently dry to withstand the weight of the vibrating roller through which it passes. At the same time, it is necessary that this type of concrete is sufficiently moist so that the cement paste during mixing and during condensation can be well spread among aggregate particles.

• Roller compacted concrete pavements has less cement paste content. (less cement content will make the plan more economical)

• Roller compacted concrete pavements requires more granular grains to achieve proper granulation. In addition, as noted in the aggregate section, it is recommended that the maximum amount of sand should be limited to 19 mm in order to achieve the desired surface quality. On the other hand, different methods have been proposed for the mixing of pavement roller concrete mixes. These methods can be divided into two general categories of concrete and earthy. In all concrete methods, the ratio of water to cement materials is considered in order to achieve the compressive strength. In addition, the components of the mixture are determined in such a way that the mixing efficiency is suitable for compacting with the vibrating roller. This performance is based on the psychological test by determining the time required for the overloaded sample density and in the vibrational state (uncorrected time).

One of the fundamental considerations when using the mix design methods described in ACI207-5.R, which uses the psychological tests, is to select the correct volume ratio of the paste to the volume of the paste (past volume) or in short (PV). Roller concrete mixes The heads must have sufficient dough volume to fill the gap between aggregate particles. In this study, four mixing schemes were used to achieve optimal mixing plan. Table 3 shows the mixing scheme used in this study and Figure 1 shows the gradient plot for the mixing scheme.

Due to the rigidity of RCCP compared to ordinary concrete, the method of making roller concrete samples varies with the method of making concrete samples. The methods that have been used up so far include two broad categories. In a sample method, the roller concrete is dampened inside the mold and on the vibration table, under overweight and in layers. In another method, the specimens are made by means of compression blows, in several layers. In various studies, according to the first method (density with a vibrating table), the number of layers varies between a layer tile. The vibrating table used should meet the requirements of Standards 254 and ASTM D 4253 or ASTM C 192. In this test, it should be noted that complete build-up of roller concrete samples is difficult to use with a vibrating table. This lower density is more common in a laboratory, especially when a low amplitude vibration table is used under overhead. Condenser-condensed specimens can have similar densities of pavement samples, which should then be used when making the sample. [12-14]

In this study, a mixer was used to prepare mixtures. For better mixing, first, all the aggregates, cement and powders were mixed in the blender and mixed for 3 minutes. Then the mixture was gradually added and the blender was mixed for 7 minutes. In order to create a density in roller concrete samples, a 10 kilogram (including rods and plate) and a rod and a plate connected to it (weighing 3 kg) weighing 10 kg were used (totaling 13 kg). The molds were bonded in three layers. The compression time of each layer was considered to be 10 seconds. After preparation of concrete and molding, the surface of the samples was covered with wet beak for 24 hours. Then the samples are expelled from the mold and the curing continues until reaching the desired ages by being placed in the limewater saturation basin.

Figure 2. Roller Compacted Concrete condenser view

Table 3. The ratio of mixed components (kg/m^3)

Mixture	Cement	Natural Pozzolan	Gravel	Sand	Stone powder	Water
RCCP1	320	0	700	1100	85	93
RCCP2	260	60	700	1100	85	93
RCCP3	190	130	700	1100	85	93
RCCP4	130	190	700	1100	85	93

2.3. Experimental programs

Roller Compacted Concrete Pavement in new condition should be able to bear the weight of the roller to compact it, hence the concrete is very rigid and dry, its water content is much less than ordinary concrete. Therefore, routine psychological determinations and efficiencies such as slump testing for this type of concrete are not applicable. The method used to measure the efficiency of the roller concrete has been corrected by the psychological determination of the test.

The uncorrected timing test includes the use of the standard VeBe equipment at 3600 rpm. In this method, the mixture of roller concrete is poured into a standard cylindrical container of 9 liters, and then overhead weighs 13.3 kg, and vibration starts.. Its duration is a period from the onset of vibration to the expiration of the paste from inside the concrete and its appearance around the plate. Details of this experiment are presented in ASTM C1170. The laboratory's research considers the unplanned time of about 30 seconds suitable for the roller compacted concrete mixtures.

Preventing the phenomenon of aggregate, aggregate removal from concrete for roller compacted concrete is one of the most important issues and is one of the main requirements in the mixing plan of this type. In addition to the dryness of the mixture, the low amount of cement materials in terms of controlling thermal problems is a factor in the expansion of the separation in this type of concrete. The problem of water draining in conventional concrete and ordinary concrete pavements is one of the things that need to be considered and controlled. Although RCCP does not occur due to the low water content of the mixing water phenomenon, it can be considered as one of the most important issues in the design of mixed cement mixtures. But in general, the problems caused by the formation of a weak layer on the concrete surface due to water drainage in this type of concrete are not problematic and can be considered as the advantages of this type of concrete. These tests for RCCP are usually seen visually and according to the experience of the workshop.

Although flexural strength is mainly the basis for designing roller compacted concrete pavements, but due to the difficulty in the preparation of flexural specimens, especially in the control of the quality of roller concrete, in many cases the relationship between flexural strength and compressive strength is determined or assumed and The mixing plan is based on compressive strength. The compressive strength of the RCCP for the construction of the pavement is significantly higher than the resistance intended for the roller compacted concrete used in the damping. Obviously, for a mixture of RCCP, increasing the amount of cement material or reducing the proportion of water to cement materials, the strength of the mixture increases. Another point to note is the increase in the strength of roller concrete over time, which is similar to conventional concrete due to the development of the process of hydration of cement. In this study, a compressive strength test was carried out on cubic samples of 10 × 10 × 10 cm and tested according to ASTM C39 standard. In order to perform the tensile test, cylindrical specimens with a diameter of 15 cm and a height of 30 cm were performed according to ASTM C496 standard. As well as flexural beam samples of 10 * 60 * 60 * cm were used to perform the flexural strength test according to ASTM C78 standard. Tests for compressive and tensile strength at the age of 7.14.28 days and flexural strength at the age of 14 and 28 days. At each age of each specimen, 3 specimens were cracked for compressive strength and two specimens for tensile and flexural strength. These tests for roller concrete are usually seen visually and according to the experience of the workshop. [16-18].

3. Results and Discussion

3.1. Performance Measurement (VeBe)

The results of the test of performance measurement are as figure 4.

As the results of table 4 show, in the case of performance testing, the ASTM standard accepted acceptable range of 30-45 seconds and some others 45-60 seconds, and in the book of Roller Concrete Procedures, the Research Center of Road Research, Housing and Urban Development The number is 20-30 seconds. If the test of this test is 354, all samples will meet the requirements of the Code. By examining the results of the test, it can be concluded that the RCCP2, RCCP3, RCCP4 mixing time of the RCCP4 was 6%, 19.4%, and 26.84%, respectively. The results show that increasing the amount of pozolan consumed increases the time of onset. This is due to the high water absorption properties of pozzolan and also the porous zeolite structure which ultimately causes the dryness of the samples.

3.2. Compressive strength

According to the compressive strength results, at 7 days of age, samples containing pozzolan were less resistant than control samples. By increasing the amount of pozzolan from 20 to 60%, the compressive strength of the samples is reduced. So that samples containing 20%, 40%, 60% of pozzolan were resistant to control samples, respectively, 14.34%, 51.51%, 66.24%, respectively.

At 28 days of age, samples made with pozzolan had less compressive strength than control samples, so that samples containing 20%, 40%, 60% pozzolan were 24.36%, 43.45%, 70.79% Reduced resistance For example, in a study by Amir Soleimani Moghaddam and their colleagues on the study and comparison of the mechanical properties of concrete containing natural pozzolan, the results were obtained that natural pozzolan decreases the compressive strength of the specimens. The results of the compressive strength test is shown in Fig. 5.

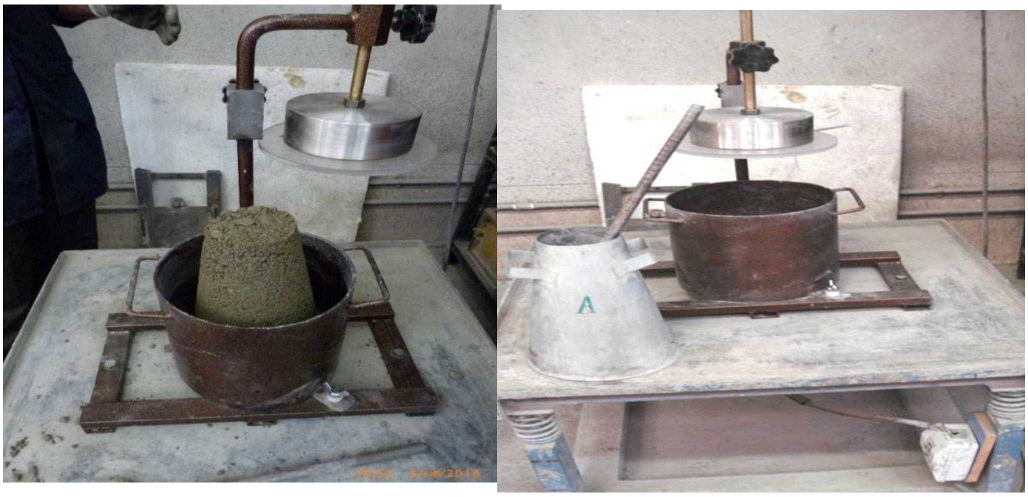


Figure 3. VeBe device

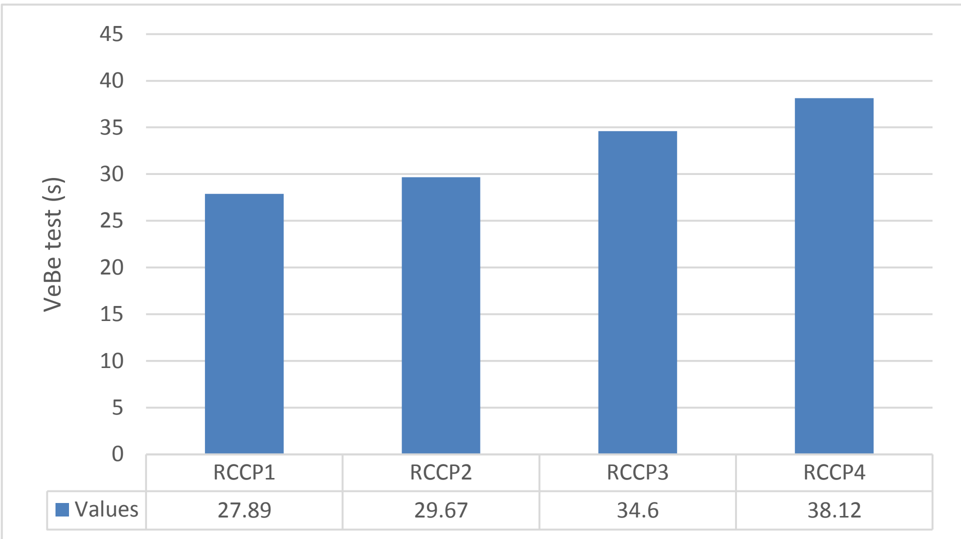


Figure 4. Results of the VeBe Performance Test (S)

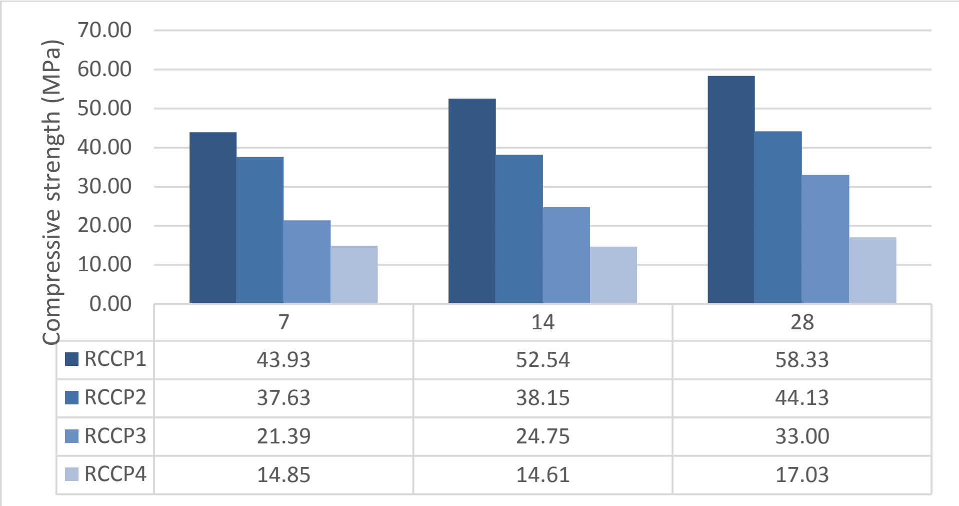


Figure 5. Compressive strength results (MPa)

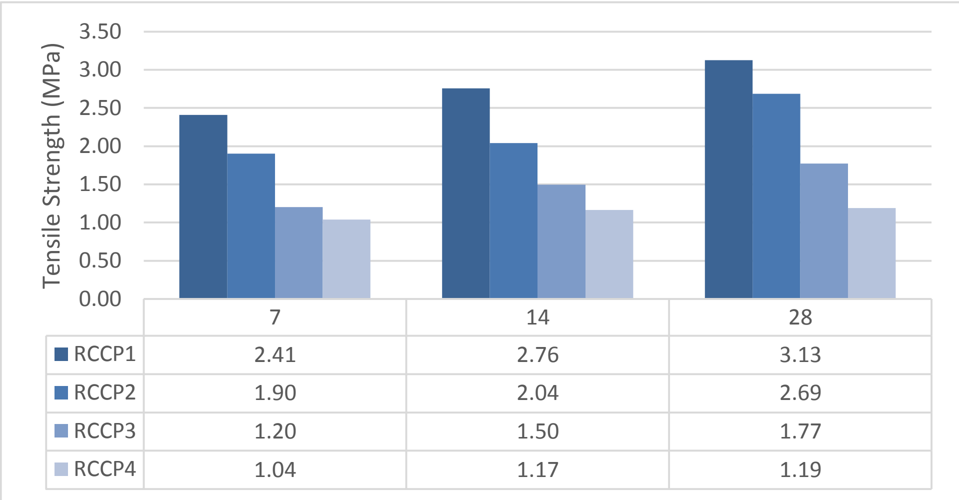


Figure 6. Tensile strength results (MPa)

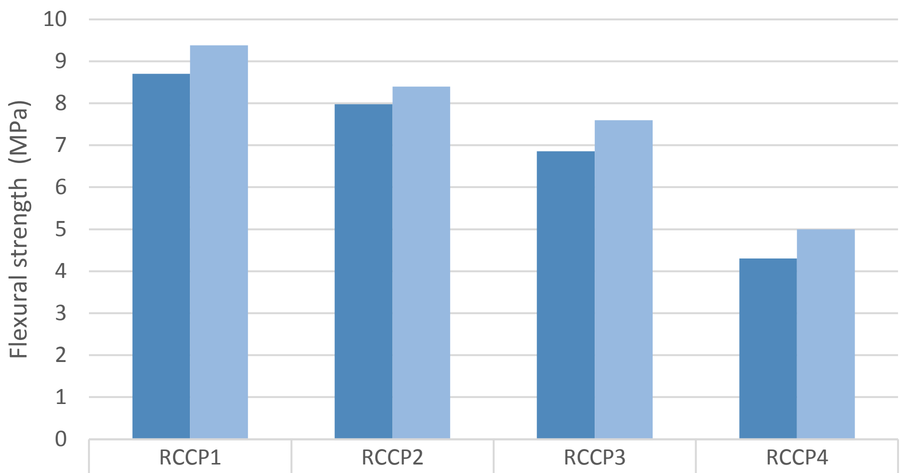
3.3. Tensile strength

Although the concrete is usually not designed to withstand direct tensile stress, knowing the tensile strength of the concrete is valuable in estimating the extent to which the Turks develop. To determine the tensile strength, two half-tensile strengths of 15 * 30 cm standard specimens were used to form and compress it, such as pressure specimens. The samples made after the desired treatment periods are placed between the plates of the machine with its axis horizontal, and then the load is increased so that the rupture is made in two half-folds on the plate, including the vertical diameter of the sample. For each the design of the mix is two cylindrical specimens for 7 days resistance and two specimens for resistance of 28 days.

In figure 6, the tensile strength of the samples made with different positions of pozzolan is given.

According to the results of tensile strength, at 7-day age, samples containing pozzolan are less resistant than control samples. By increasing the pozzolan content from 20 to 60%, the tensile strength of the samples is reduced. So that the samples containing 20%, 40%, and 60% of pozzolan were resistant to the control samples, respectively, 12.24%, 41.91%, 56.43%, respectively.

At 28 days of age, samples made with pozzolan had less compressive strength than control samples, so that samples containing 20%, 40%, 60% pozzolan were 7.84%, 43.27%, 60.3%, respectively have resisted. figure 6.



	RCCP1	RCCP2	RCCP3	RCCP4
14	8.7	7.98	6.86	4.3
28	9.38	8.4	7.6	5

Figure 7. Results of flexural strength (MPa)

3.4. Flexural strength

For determination of bending strength, standard samples of 10 * 15 * 60 cm were used which are molded and compressed as compression and tensile samples. The samples made after the desired treatment periods were applied to two supports and applied force to the beam at two points, and then the load was increased to give the fracture two half-pieces in the sample. For each mixing plan, 2 barrel specimens for 14 days resistance and 2 samples for 28 days resistance are considered. Figure 7 shows the flexural strength of samples made with different pozzolan percentages.

According to the results of flexural strength, at 14 days of age, samples containing pozzolan are less resistant than control samples. By increasing the amount of pozzolan from 20 to 60 percent, the bending strength of the samples is reduced. So that samples containing 20%, 40%, 60% of pozzolan were resistant to 8.28%, 23.22%, 50.28%, respectively. At 28 days of age, samples made with pozzolan had less compressive strength than control samples, so that samples containing 20%, 40%, 60% pozzolan decreased 10.45%, 18.48%, 46.7%, respectively.

4. Conclusion

Considering the behavioral sensitivity of the roller concrete to the ratio of the constituents, and especially the amount of cement material, it is very important for the implementation and resistance to

these mixtures. In the current laboratory research, samples with different amounts of pozzolan as part of the cement used, and based on the results of laboratory research, the following conclusions can be made:

1. Based on what has been seen in practice, an increase in the amount of powdered stones used to supply fine grained materials results in an increase in the amount of water consumed due to its high water absorption.
2. Increasing the amount of fine-grained material as well as the cement content will increase the efficiency and reduce the unplanned timing of roller concrete. In addition, the results show that the aggregate type has a direct impact on the roller concrete performance time.
3. Comparison of the compressive strength and tensile strength of roller concrete samples shows that there is a good correlation between the compressive and tensile strengths. In addition, it can be concluded from the obtained relationship that there is a good parallelism between the relations between the Brazilian tensile strength and the flexural strength of the pavement roller concrete with conventional concrete.

4. In the case of compressive strength, according to 354 28-day resistance, samples should be at least 27.6 MPa. As the results of this study showed that RCCP2, RCCP3, RCCP3, RCCP3, RCCP3, RCCP3, and RCCP3 have been accepted and adhered to, in accordance with the rules of the 354 resistance of 28 days, and the only RCCP4 mixing plan does not comply with the requirements of the Code. The accuracy of the graphs shows that consumption of up to 40% can give the results of the accepted rules and with regard to the resistance process, the use of more than 40% of pozzolans will not bring desirable results and is not recommended.
5. The publication 354 for the 28-day tensile strength of 2.8 to 4.1 is desirable. The results of this study indicate that the results of the RCCP1 RCCP2 mixing designs are close to these numbers, but in the case of RCCP3, RCCP4 mixing designs, these results are far from acceptable for the publication period and are not acceptable. For the bending strength, the accepted range of 354 for sample results is 4.5 to 4.75 MPa for 28-day specimens. As the results of flexural strengths show that all samples of all four mixing designs have the minimum resistance required by the publication 354. In this case, it can be stated that the use of pozzolan up to 60% of cement consumes can meet the requirements of publication 354 for flexural strength.

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