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The Assessment of Engineering Properties of Concrete Containing Ceramic Waste

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Abstract. Reusing waste from construction and demolition is one of the most important purposes in the world and our country. One of the industries with much waste having the possibility to be reused is ceramic industry. The aim of this thesis is to do laboratory study on some engineering properties of concrete produced through ceramic waste as aggregate. The waste, first, converted to powder and then replaced by part of sand used in concrete with different percentages. After obtaining optimum percentage, tests including compression, tensile strength, modulus of elasticity and shrinkage were performed. Result of this study showed that using ceramic powder waste as a partial replacement for sand can improve its concrete engineering properties.

Keywords: Concrete, Ceramic Powder, Compression Strength, Tensile Strength, Modulus of Elasticity, Shrinkage

1. INTRODUCTION

Reducing environmental pollutions resulting from concrete industry and taking care for natural resources as investments of future generations are the reasons for using waste in concrete. Another reason is that concrete construction works in all over the world increase the need for increased production of concrete thereby increasing primary materials of concrete ingredients. Thus, growing production of cement and clinker cause much natural resources and raw materials such as limestone, sand, clay and iron ore to be used and much greenhouse gases such as Co2, No and Co to be produced. Furthermore, aggregates which are also natural resources existed in the earth, are subject to growing demand to construct concrete structures and maintaining these valuable resources for future generations is another requirement. However, notable point is that concrete structures have many advantages in comparison with other structures and that they can be exploited comprehensively in all over the world. Now a solution should be found to use these resources properly and let the future generations use them, too. Thus, using waste in concrete can be one solution.

However, there left two other important issues, which we should study. First, to what extent can we use waste in concrete? Second, how strong and durable is concrete made of waste compared to usual one? To answer it is required to study concrete made of waste and the present study tries to find possible answers by examining basic elements of concrete.

In a recent study on using ceramic waste, F.Pacheco Torgal et al. [2] studied pozzolanic action in relation with replacing crushed ceramic waste as coarse-grained and its powder as fine grained with a part of cement in concrete. They found that it is the best choice to replace the waste in concrete as a part of fine grained. Another research by V.lopez et al. [1] showed that replacement of ceramic waste, which powdered into white powder by Los Angeles test machine, as a part of sand in concrete can, resulted in satisfied production. Considering these studies, the present research tries to investigate engineering properties of concrete produced by using powdered ceramic waste as a part of its sand. Thus, compression strength test was conducted to indicate the optimum use of the waste and then the other mentioned tests was done according to the optimum usage.

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Properties of used materials

Manufactured gravel with apparent density of 2.7 gr/cm^3 in saturated surface dry form and water absorption of 1.75% was used. Grading of aggregate was in allowed range of ASTM-C33[6] as showed in figure 1. Sand with apparent density of 2.6 gr/cm^3 in saturated surface dry form and water absorption of 2.50% was used. Grading of sand was also in allowed range of ASTM-C33[6] as showed in figure 2. Type 2 cement with specific weight of 2.9 gr/cm^3 was used.

In this research, ceramic powder from the waste of ceramic floor finish was used. The powder was produced through placing ceramic waste in Los Angeles test machine for 5 hours with 10000 cycles. Figure 2 shows grading of this powder.

Figure 2 shows all related curves of grading cement, sand and ceramic powder and the grading of ceramic powder is obviously nearer to that of cement.

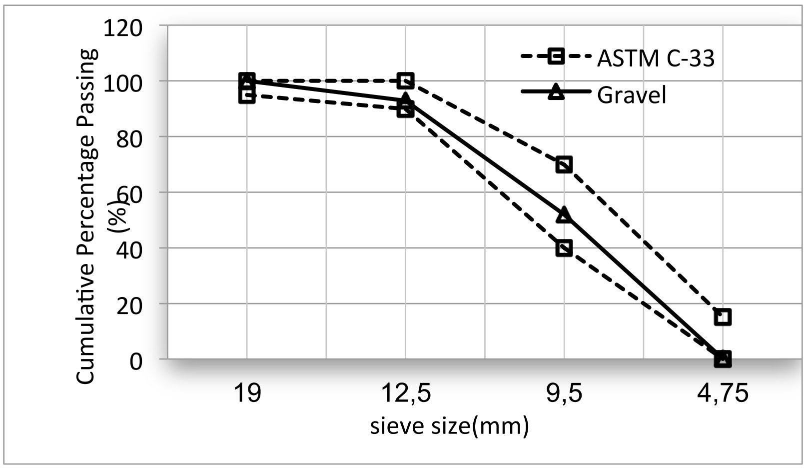

Figure 1. Curve of sand grading

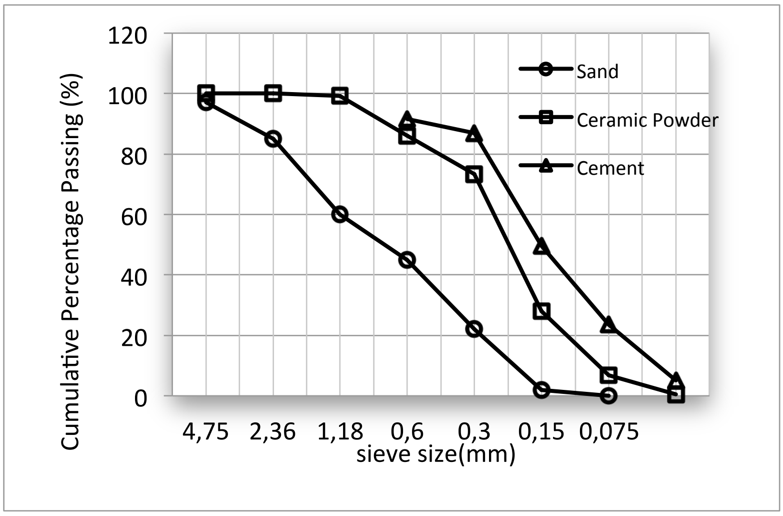

Figure 2. Curves of cement, sand and ceramic powder grading

Design of developed mixtures

Different types of concrete with diverse percentages of ceramic powder were developed and compared with usual concrete with cement content of 400 kg per cubic meter. Water-cement ratio was also given as 0.45. The highest rate of lubricant in C50 sample was 2.4%. The slump of the samples was 6-7, according to ASTM-C143standard.[8] Table 1 shows the properties of control concrete and samples having ceramic powder.

Different percentages of ceramic powder were replaced with partial sand used. Mixing materials in concrete mixer was done in this manner: first, gravel and sand were poured in mixer and mixed completely, and then cement and ceramic powder along with water and lubricant were added into the mixture. The mixing process continued about 4 minutes.

Table 1. Features of developed mixtures.

Specimen Name	Material weight Kg/cm^3					W/C
	Water	Gravel	Sand	Cement	Ceramic Powder	
C0	180	1092	728	400	0	0.45
C10	180	1092	655.2	400	72.8	0.45
C20	180	1092	582.4	400	145.6	0.45
C30	180	1092	509.6	400	218.4	0.45
C40	180	1092	436.8	400	291.2	0.45
C50	180	1092	364	400	364	0.45

Method of experiments

Cubic frames with dimensions of 15x15x15 cm were used to do compression test with ASTM-C39 standard.[9] Tensile test was done with ASTM-C496 standard [10] by a cylinder frame with 15 cm in diameter and 30 cm in height. A cylinder frame with 15 cm in diameter and 30 cm in height was used to indicate modulus of elasticity in ASTM-C469[12] standard and shrinkage test was conducted in ASTM-C157[11] in which standard bar used for compaction. The concrete was poured in the frame in three layers each of which received 25 hits to make it consolidated. All frames opened after 24 hours and sampling of all experiments was conducted in experimental conditions according to ASTM-C192 standard.[7].

Table 2. Test results of compression strength of cubic samples of control concrete with different percentages of ceramic powder (maintained in wet condition)

Specimen Name	Strength Of 7 day-old (MPa)		Average Strength Of 7 day-old (MPa)	Strength Of 28 day-old (MPa)		Average Strength Of 28 day-old (MPa)
	Specimen a	Specimen b		Specimen a	Specimen b	
C0	31	31.6	31.3	39.6	38.7	39.2
C10	25	26.2	25.6	40	39.5	39.8
C20	35.4	33.1	34.3	39.4	40	39.7
C30	36.7	37.8	37.3	43.6	47.4	45.5
C40	36.4	37.8	36.9	47.6	47	47.3
C50	35.5	36.1	35.8	43	44.2	43.6

Samples, which should be treated in wet condition, were put in water basin but the samples, which should be kept in dry condition, were left at the experimental environment.

Two cubic samples were developed for each 3, 7, 14, 28, 42, and 60 day-old ages in both wet and dry conditions to do compressive strength test.

While doing tensile test, two cylinder samples were made for each 7, 14, 28, and 42, day-old ages and the samples kept in wet conditions. In order to indicate the modulus of elasticity cylinder samples, which kept in wet conditions, were used and two samples were used for each age. The experiment was conducted for each 7, 14, 28, and 42, day-old ages. Demec machine and jack were also used simultaneously in a way that when concrete strain reached 50×10^{6} primary stress P_1 was read from the jack, and when it reached 40 % of the same force with tensile strength of cylinder sample the strain was measured from the gauge of the device. Thus, with above mentioned data one can calculate secant modulus of the concrete easily.

A prismatic sample was used to indicate shrinkage degree of the concrete. For this reason, two resulted samples were kept in dry condition. The shrinkage degree was read by Demec machine for each 3, 7, 14, 28, 42, 60, 90, and 120 day-old ages.

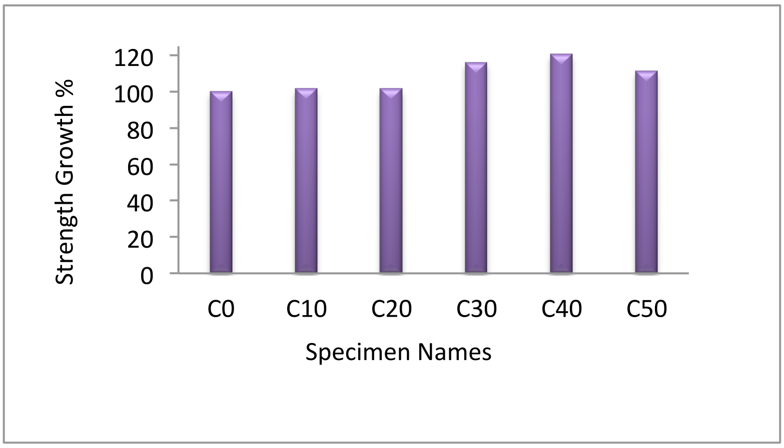

Figure 3. Ratio of compressive strength of samples with ceramic powder to control sample.

Results and their analysis

Compressive strength

Table 2 shows results from compressive strength in 7 and 28 day-old ages for samples with ceramic powder and control concrete.

As it seen, by increasing ceramic powder as a partial replacement for sand in concrete, its compressive strength increased gradually according to the age of the concrete. Only in C10 sample compressive strength of 7 day-old was less than control concrete but this decreased strength compensated by 28 day-old age and finally reached strength higher than control concrete.

By increasing ceramic powder as a partial replacement for sand in concrete, workability of concrete decreased significantly because of water absorption. In this case, without using lubrication phase it is not possible to form cement paste and homogeneous mixture. Thus, the rate of lubrication can be increased depending on the increasing ratio of the powder. The highest permissible value of lubricator was used in C50 sample according to the manufacturer company. The 28 day-old strength of this sample, however, was lower than that of C30 sample. Therefore, given the fact that using too much lubricator may result in implementation issues and the compressive strength of 28 day-old sample of C50 was lower than that of C30 sample, we considered C40 sample with 40% replacement of ceramic powder to sand as the optimum percentage. In figure 3, we considered compressive strength of control sample with the age of 28 days old as basic strength and then compared it with the strength of other samples with different values of ceramic powder replaced for sand. Figure 4 shows the results of compressive strength of C40 sample in the ages of 3, 7, 14, 28, 42, and 60 days old in both wet and dry conditions.

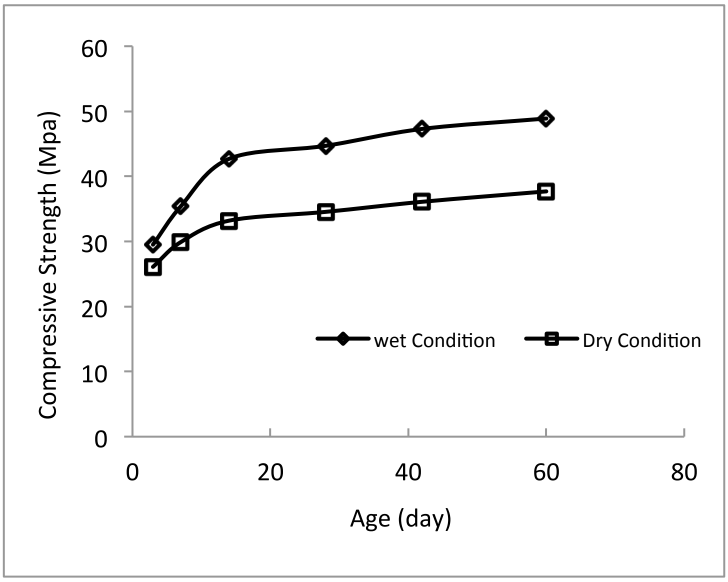

Figure 4. Compressive strength of C40 cubic sample in different ages.

In figure 5, we considered compressive strength of 28 days old sample as basic strength and then compared it with the strength of other age ranges of concrete. Lopez et al. [1]used this comparison, too.

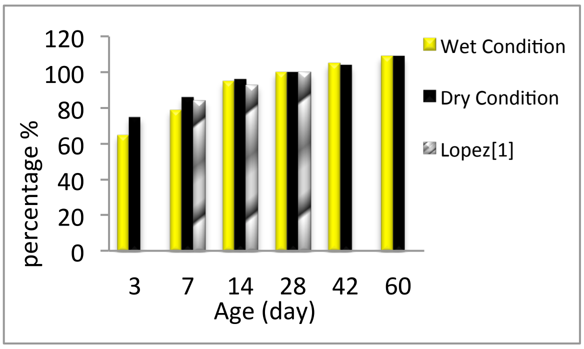

Figure 5. Comparison of compressive strength of C40 sample with different ages with that of 28 day-old sample

Tensile strength

Table 3 shows the results from tensile strength test on C40 sample with different age ranges and control concrete. Figure 6 shows the relation between tensile and compressive strength dealing with the sample having ceramic powder and control concrete along with the optimum line resulted from the experiments and their equations. As seen in figure 6, difference between these two curves is 5% at most and there is no significant difference between the sample with ceramic powder and control concrete. Lopez et al. [1]have also seen no significant difference between the sample with ceramic powder and control concrete.

Table 3. Results from tensile strength test of sample C40 and control concrete.

Specimen Age (day)	Tension strength of Control Concrete (MPa)	Tesile strength of C40 (MPa)
7	1.84	2.16
14	2.26	2.70
28	2.54	2.88
42	2.83	2.97

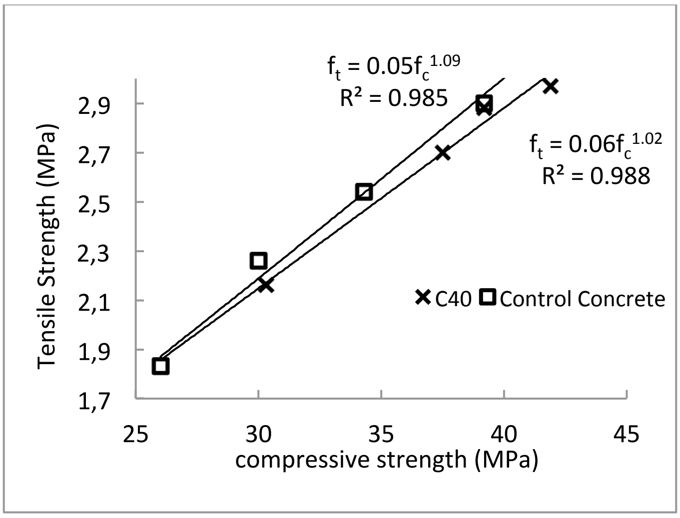

Figure 6. Relation between tensile and compressive strength dealing with control concrete and C40 sample

Figure 7 shows the ratio of tensile to compressive strength in different range of ages dealing with C40 sample and the research by Lopez et al.[1] The results of compressive test of cubic samples transformed into cylinder samples according to the method described in "Design and Performance of Concrete Buildings", Department of Comprising and Developing National Building Laws, 2009. The figure shows that the ratio is about 7%.

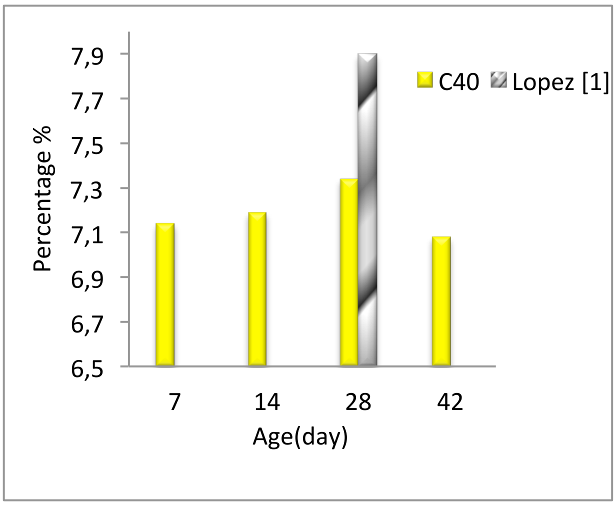

Figure 7. Ratio of tensile to compressive strength in C40 sample.

Assessing tensile strength

According to ACI committee 363[13], the assessment of concrete tensile strength on the concrete split basis defined as following:

$$f_{SP} = 0.59\sqrt{fc} \qquad (1)$$

Where f_S equal tensile strength of concrete based on cylinder samples for strengths from 21 to 83 mega Pascal. Figure 8 shows the results from tensile strength test on C40 sample and the research by Lopez et al.[1] and the mentioned relation.

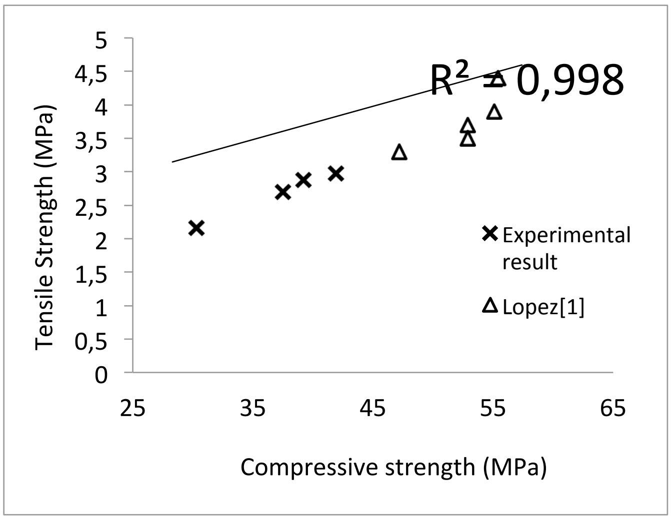

Figure 8. Comparing results from experimental tensile strength and ACI relation with compressive strength.

As seen in the figure, the relation developed by ACI assessed the values of tensile strength higher unbiasedly based on compressive strength. Thus, we modified the relation as following in order to improve the assessment of tensile strength.

$$f_{SP} = \alpha \times (\, 0.59\sqrt{f_c}\,) \qquad (2)$$

Where the quantity α calculated as 0.81, given the numbers mentioned on this dissertation and the research by Lopez et al[1]. Figure 9 shows the results of tensile strength test on C40 sample and the research by Lopez et al.[1] with the modified relation of ACI.

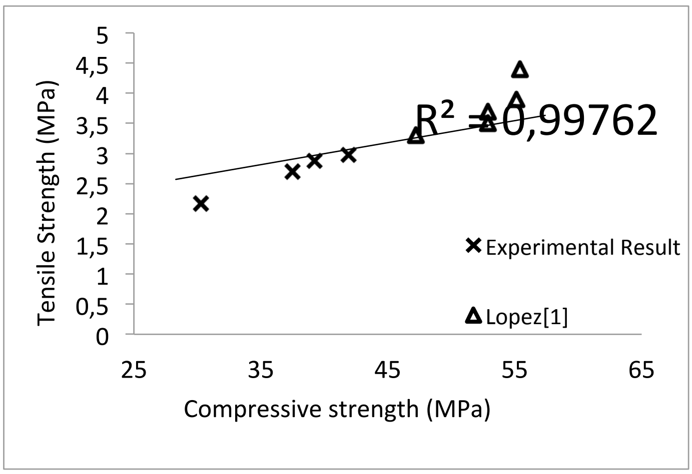

Figure 9. Comparing the results from experimental tensile strength and modified relation of ACI with compressive

As seen in figure 9, by inducing modification factor the precision of assessing tensile strength of the concrete improved significantly. Considering figure 8, maximum error of ACI relation to assess tensile strength based on compressive strength was 33 %, but in figure 9 with modified ACI relation, maximum error reached 19 %. It is worth to note that it is required to study more samples containing ceramic powder to calculate the quantity α.

Indicating modulus of elasticity

Table 4 shows the test results from indicating modulus of elasticity on C40 sample in different range of ages by considering its compressive strength. Figure 10 shows the relation between tensile strength and modulus of elasticity for both concrete having ceramic powder and control concrete. The compressive strength of the cubic samples were transformed into cylinder ones according to the method described in "Design and Performance of Concrete Buildings", Department of Comprising and Developing National Building Laws, 2009 [16].

Table 4. Test results from indicating modulus of elasticity on C40 sample.

Concrete Age (day)	Compressive Strength (MPa)	Modulus of elasticity (MPa)
7	30.3	2.56
14	37.5	2.7
28	39.2	2.78
42	41.9	2.86

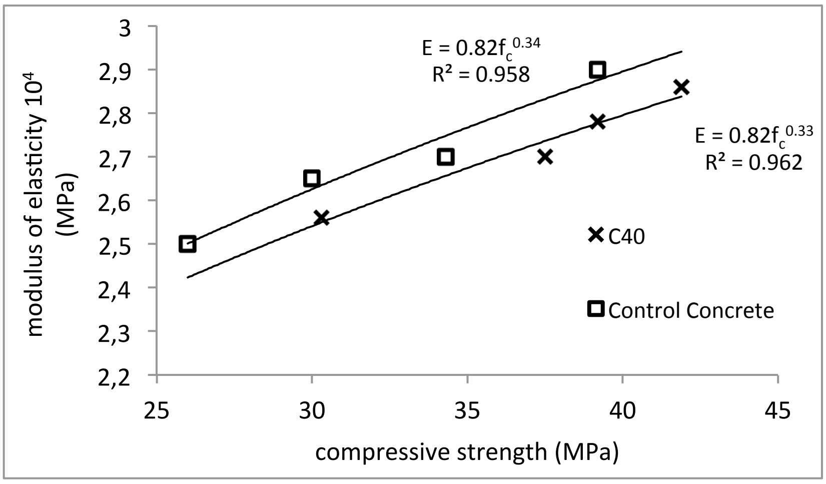

Figure 10. Relation between compressive strength and modulus of elasticity for C40 sample

As seen in figure 11, the modulus of elasticity of the concrete having ceramic powder was 3.4 % less than control concrete. Given this trivial difference, it seems that the existence of ceramic powder in concrete may not cause a significant difference in its modulus of elasticity.

Assessment of the modulus of elasticity

The modulus of elasticity which assessed by ACI is in line with the square root of the compressive strength. ACI 318-99[14] suggests the following relation to assess the modulus of elasticity of the compressive strength for normal concretes:

$$E_c = 4733 \sqrt{f_c} \qquad (3)$$

Where f_c is compressive strength (MPa), and E is the modulus of elasticity (MPa).

ACI 363-92[13] suggests the following relation for the concretes with strength between 21 to 83 MPa:

$$E_c = 3320\sqrt{f_c} + 6900 \quad (4)$$

Figure 11 shows the results of relation between modulus of elasticity and compressive strength tests on C40 sample as well as suggested relations by ACI with the values developed by Madandoust, RAhmat (2003)[15] for the concrete with high strength and the values developed by Mazloom (2008)[3] for normal and control concrete.

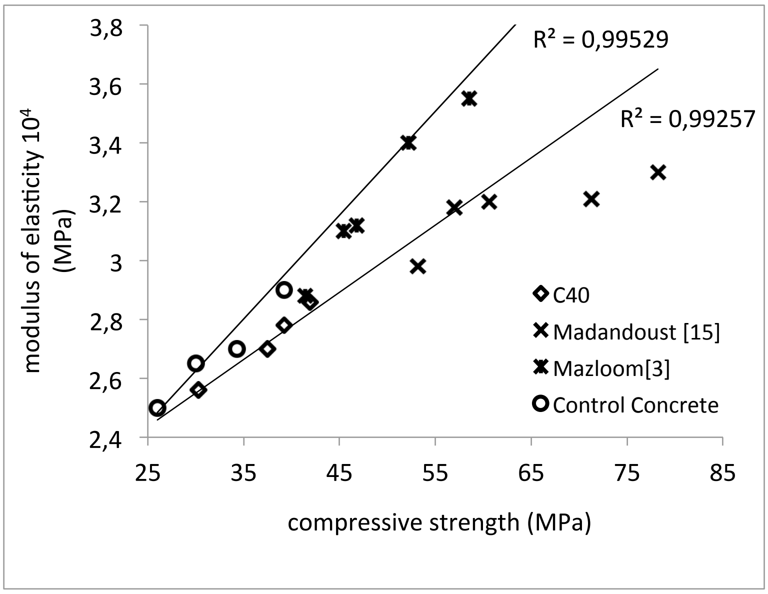

Figure 11. Comparing results of relation between modulus of elasticity and compressive strength tests on C40 sample with the relations of ACI

As seen in figure 11, the results of this study and the results from Madandoust, RAhmat (2003)[15] are closer to those of ACI 363-92[13] relation. Furthermore, the results from Mazloom (2008) [3]for both normal and control concretes are closer to those of ACI 318-99[14] relation. Thus, according to these results, we can conclude that ACI 363-92[13] relation can be used to indicate the modulus of elasticity of concretes having ceramic powder. On the other hand, the modulus of elasticity of concrete with ceramic powder was 3.4 % less than that of control concrete. Thus, considering this trivial difference it seems that the existence of ceramic powder in concrete cannot make significant difference in its modulus of elasticity.

Shrinkage test

The results from the gauge of Demec machine in certain range of ages and using them in relation 4 can indicate the value of shrinkage all of which shown in figure 13 for C40 sample along with the findings of other researchers for normal concretes. As seen in the figure and the studies by Bai et al., 2005[4] and Barr et al., 2003[5], the shrinkage in control concretes with 120 day-old age varies in the range of (626 – 700) $x10^{-6}$ and this value for the concrete with ceramic powder is 626 $x10^{-6}$. Figure 12 indicates that the value of shrinkage in the concrete with ceramic powder is less than normal concrete.

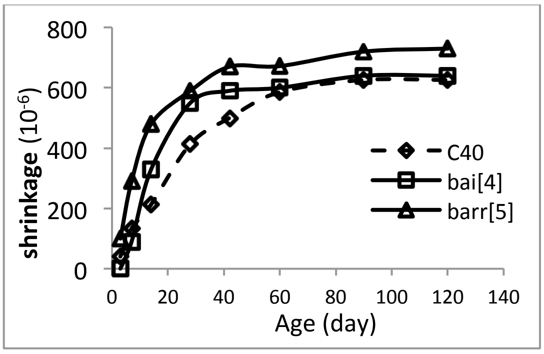

Figure 12. Comparing the value of shrinkage of C40 sample and those mentioned in the studies by Bai et al., 2005[4] and Barr et al., 2003[5].

2. CONCLUSION

- Using 40% ceramic powder instead of partial sand in concrete not only reduces its compressive strength in comparison with the sample without ceramic powder (control concrete) but also increases the compressive strength in 28 day-old about 20%.
- Existence 40% ceramic powder in concrete instead of sand does not cause significant change in tensile strength of concrete in comparison with the control concrete (they have 5% difference at most). The ratio of tensile strength to compressive strength in C40 sample with different range of ages is about 7%.
- Using the relation of tensile strength shows unbiased values for C40 sample, according to the compressive strength of ACI but, modifying ACI relation by coefficient of $\alpha = 0.81$ may result in significantly increased precision of the assessment and then it is possible to use this relation to assess tensile strength of C40 sample according to compressive strength.
- The trend of changes involving the relation of the modulus of elasticity with compressive strength of C40 sample follows ACI 363-92[13] relation and it is possible to use it to assess the modulus of elasticity of C40 sample with different range of ages. In addition, the modulus of elasticity of C40 sample is 3.4% less than that of control concrete.
- Conducting tests on shrinkage value of sample made of 40 % ceramic powder (C40) showed that the highest value of shrinkage was that of 90 day-old and was 626 micron with no significant growth afterwards. This Value of shrinkage was also less than normal concrete.
- The color of produced powder was red because of using iron oxide in producing this kind of ceramic, thus, the concrete produced from this powder shows completely its color on the first days but the color fades from it over time because of the effect of physical properties of cement on the powder.

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