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Utilization of Crushed Autoclaved Aerated Concrete as Aggregate in Concrete

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ABSTRACT

Recently autoclaved aerated concrete has been used in construction as filling material. Utilization of this material can solve insulation problem and also weight of the building is also reduced. After its use, although small in quantity, crushed autoclaved aerated concrete (CAA) are left over. In this study, both for insulation purposes and by applying lightweight concrete to reduce structural loads, reuse of CAA as aggregate in concrete production is aimed at. Concrete samples were produced using CEM I 42.5 Portland cement, river sand, crushed stones with 4-16 mm, 16-32 mm particle sizes and 0 %, 50 % and 100 % CAA instead of these two different kinds of crushed stones. On the concrete samples produced physical and mechanical experiments were performed and whether it is possible to produce concrete with adequate durability and strength was investigated. Decrease in strength and unit weights of the concrete were observed when CAA used.

INTRODUCTION

Concrete is a composite material produced through mixing coarse and fine aggregate, cement, water and some admixtures if necessary with appropriate ratios. In the past aggregates that constitute ¾ of the concrete composition were deemed to be filling materials and while aggregate gradation and amount were taken into consideration, its chemical and mineralogical structure does not have much importance. After concrete was handled and examined as a composite material composed of various phases, it was determined that beside cement mortar, mechanical features of the aggregate also effect concrete behavior. Consequently heavyweight concrete, lightweight concrete (LWC) and ordinary concrete concepts emerged [Alduaij et.al., 1999]

Aerated concretes produce by introducing air, or specially formed gas into cement slurry so that, after setting, a hardened mortar with a cellular structure formed. The slurry usually consists of a mixture of cement and siliceous material such as sand or pulverized fuel ash. There are two main methods of foaming the cellular structure. One of them is the addition of powdered aluminum or zinc, which combines with lime in the cement to generate hydrogen gas. The other method called as foam generating method, using a foaming agent in concrete. In case of first method, the aluminum or zinc powder is added to the cement slurry during mixing. Within a few minutes hydrogen gas begins to evolve causing the slurry to raise, the action continuing for an hour or so the slurry then sets to form a material consisting of a multitude of closed bubble holes surrounded by hardened cement mortar [Eq. 1].

$$2Al + 3Ca(OH)_2 \rightarrow 3CaO.Al_2O_3 + 3H_2 + 3676\ Kcal/kg\ Al \qquad \text{Eq.1}$$

One of the ways to reduce the mass or dead weight of a structure is the use of lightweight concrete in the construction. LWC can easily be produced by utilizing natural lightweight aggregate or air entraining in the concrete. One of the methods of producing LWC is to use light aggregate instead of normal concrete aggregates. ln cases where the use of lightweight aggregate is limited, the production of semi LWC is under consideration [Dilmore and Neufeld, 2001].

In LWC production, instead of calcareous aggregate used in ordinary concrete production, various types of aggregates with low specific and unit weights and high water absorption rates are used. There are many advantages of using LWC instead of conventional concrete in reinforced concrete buildings. The most important advantages are namely, as a result of their reduced unit weight, maintaining economy in the reinforcement elements which are under bending; decrease in foundation sizes; improvement in earthquake behavior; resistance against fire; providing insulation against noise and heat. However, there are also some disadvantages of this material such as having lower mechanical strength and higher immediate and late deformation; necessitating greater care in production and placement compared to ordinary concrete. Although use of LWC is preferred in most of the developed countries in order to benefit from the stated advantages, we know that this concrete is not used as commonly as the ordinary concrete. On the other hand, autoclaved aerated concrete (AC) is a light, elastic, contemporary building material durable against earthquake and fire with a very high heat insulation capacity because of the millions of pores in it. AC, 84 % of volume of which is dry air and dry unit volume weight of which is 400 kg/m3, is naturally a construction material that provides heat insulation not necessitating any other insulation material [Atan, 1973].

Porous structure of AC and its lower alkaline necessitates taking preventative measures against corrosion of steel. As pH degree in AC is between 10-11 and the alkali amount is lower than concrete. Besides it is not hazardous for public health. It is necessary to know the content of heavy metals in a building material for environmental and health considerations. In this respect, AC is harmless in terms of heavy metals and provides the conditions demanded by standards [Corinaldesi et. al., 2002].

AC is a non-flammable construction material and has a superior performance against fires. Because of its low thermal conductivity heat transfer in the material occurs slowly and this makes the AC durable against fire. Not only on the AC surface which is affected by the fire but also on the other surface temperature is lower compared to the ordinary concrete. That’s why; AC has also the function of protecting the other materials in buildings. Moreover LWC provides resistance against fires that might occur during an earthquake. During a fire the crystal water present in the AC plays an important role in reducing the temperature. As a result of the porous structure of AC the steam runs without causing dispersion or leaving broken parts. During a fire, temperature in AC is much lower than that of the ordinary concrete. Temperature is effective on only one face and only about 5 mm deep, on the other side of the AC temperature is not effective. As a result AC is able to protect the reinforcement materials in it very well [Ersoy, 2001; Lo and Cui, 2004].

The aim of this study is to realize LWC production with use in certain ratios of lightweight CAA aggregate obtained from AC fragments instead of the aggregate used in ordinary concrete types. Physical and mechanical properties of the concrete that embodies both the advantages of lightweight concretes and the superior features of CAA were examined.

MATERIALS AND METHOD

Experimental study

The mixture rates were determined through absolute volume method. The cement dosages were taken as 300, 350 and 400 kg/m^3 . The volume and weight of the material used in the mixtures are given in Table 1. Using CEM I 42.5 cement, sand, 4-16 mm (F) and 16-32 mm (C) grain-sized crushed stones and instead of these two different crushed stone CAA with 0 %, 50 % and 100 % ratios used for preparing cylindrical and cubic concrete samples were produced. For each set among fresh concrete experiments wet unit weight and workability experiments were performed. The concrete samples produced were kept under standard curing conditions (in 21 ± 1°C with lime saturated water). At the end of 28 days, among non-destructive tests ultrasound, resonance frequency, surface hardness, among destructive ones compressive strength, splitting tensile compressive strength tests were applied on the concrete samples.

Table 1. Mixture proportions of concrete containing CAA for 1m^3

Concrete type	Sand (kg)	CS I (kg)	CAA (F) (kg)	CSII (kg)	CAA (C) (kg)	Water (kg)	Cement (kg)
C 300-0	739	581	0	581	0	170	300
C 300-50	739	581	0	291	73	170	300
F 300-50	739	291	72	581	0	170	300
C 300-100	739	581	0	0	146	170	300
F 300-100	739	0	144	581	0	170	300
C 350-0	721	568	0	568	0	170	350
C 350-50	721	568	0	284	71	170	350
F 350-50	721	284	71	568	0	170	350
C 350-100	721	568	0	0	142	170	350
F 350-100	721	0	141	568	0	170	350
C 400-0	705	555	0	555	0	170	400
C 400-50	705	555	0	278	68	170	400
F 400-50	705	278	69	555	0	170	400
C 400-100	705	555	0	0	136	170	400
F 400-100	705	0	138	555	0	170	400

Materials

Cement. In production of the experimental concrete samples CEM I 42.5 Portland cement was used. The properties of the cement obtained from the factory are listed in Table 2.

Table 2. Properties of CEM I 42.5 Portland cement used in tests

Chemical Analyses (%)		Physical Properties	
SiO_2	20.96	Specific Gravity	3150
Al_2O_3	5.58	Fineness (cm^2/g)	3315
Fe_2O_3	3.69	Compressive Strength (MPa)	
CaO	63.97	2 days	21.9
MgO	1.69	7 days	38.3
SO_3	2.84	28 days	45.1
LOI	1.15		

Water. The water used in the concrete mixture is the regular tap water of Eskişehir. The water used has a sulphate content of 5.8 mg/lt , hardness of 3.9 mg/lt and pH of 6.3.

Aggregate. Eskişehir-Osmaneli sand and Söğüt Zemzemiye crushed stone were used. The grading curve pertaining to the aggregate is given in Figure1.

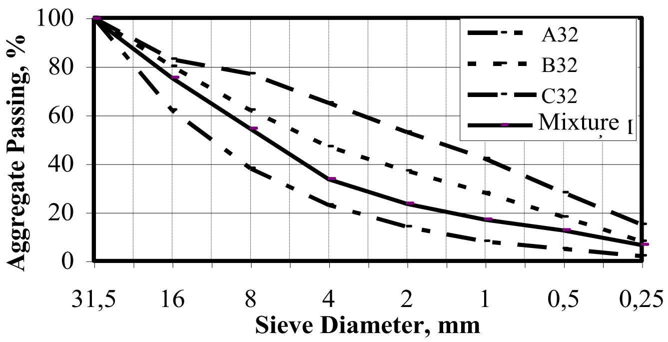

Fig. 1. Grading curve of aggregate mixture from Eskişehir-Osmaneli

Crushed autoclaved aerated concrete (CAA). The lightweight aggregate used in the study was the CAA fragment leftovers from the constructions of Eskişehir Osmangazi University construction area. The unit weight of the CAA fragments was determined as 385 kg/m3. Their water absorption percentage is very high. That's why before mixing the particles were saturated with water. The CAA fracture aggregate was classified in two sizes. The aggregate used in the mixture was sieved between 4-16 and 16-31.5 mm sizes and prepared for use.

EXPERIMENTAL RESULTS

At the end of 28 days, among non-destructive tests ultrasound, resonance frequency, surface hardness, among destructive ones compressive strength, splitting tensile strength tests were applied on the concrete samples. Their hardened unit weights, ultrasonic pulse velocities, dynamic modules of elasticity, compressive strength depending on surface hardness, splitting tensile strength and compressive strength values were determined. Also, capillary water absorption amounts, in weight and in volume of the samples produced were determined. The σ–ε diagrams of the concrete samples were drawn. The results of unit weight experiment and slump tests are given in Table 3. As seen from Table 3 it was observed that when CAA is used in concrete unit weights decrease with rates reaching up to 12 %. Slump values have shown irregular variation.

Table 3. Unit weight and slump test results of fresh concrete containing CAA

Concrete type	Δfresh (kg/dm^3)	Slump (cm)	Concrete type	Δfresh (kg/dm^3)	Slump (cm)	Concrete type	Δfresh (kg/dm3)	Slump (cm)
C 300-0	2350	10	C 350-0	2386	12	C 400-0	2357	8
C 300-50	2287	5	C 350-50	2159	4	C 400-50	2216	11
F 300-50	2290	6	F 350-50	2282	3	F 400-50	2263	5
C 300-100	2084	3	C 350-100	2065	6.5	C 400-100	2074	7
F 300-100	2065	7	F 350-100	2112	9	F 400-100	2074	7

Results of water absorption experiments are given on Figure 2 and 3. When Figure. 2 is examined it was observed that water absorption as per weight ratios of the concrete samples varies between 2.04-6.86 %. With CAA addition, water absorption as per weight ratios of the concrete samples increased. Especially in the concrete samples produced with 4-16 mm CAA the mentioned increase amount reached 200 %. When Figure 3 was examined it was observed that water absorption as per volume rates of the concrete samples varied between 4.27-11.11 %. With use of CAA their water absorption as per volume has shown an increase rate reaching 100 %. Because CAA absorbs more water compared to crushed stone with use of CAA water absorption rates of the concrete samples have increased.

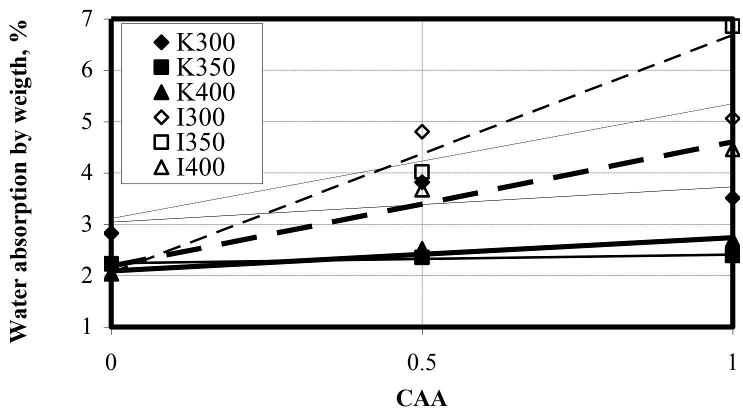

Fig. 2. Water absorption tests results of concrete containing CAA

Capillarity coefficients of the concrete samples determined at the end of capillary water absorption experiment are shown in Figure 4. Capillarity coefficients of the concrete samples vary between 2.6x10-6 – 4.41x10-6 cm^2 /s. Together with the increase in CAA rate, a great change in capillarity coefficients of the concrete samples took place. Capillarity coefficients of the concrete samples increased with rates reaching up to 200 %. That's reason is that when CAA is used, although the volume is the same, the pore rate in it increases as 84 % of the structure of CAA consists of pores. Because the CAAs do not have regular shapes in concrete production, they create more pores during placement and compaction and water can run more easily in the concrete, as a result capillarity coefficient has increased.

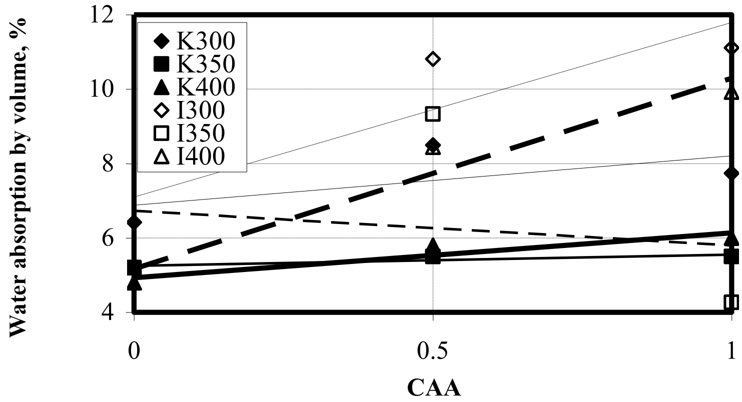

Fig. 3. Water absorption tests results of concrete containing CAA

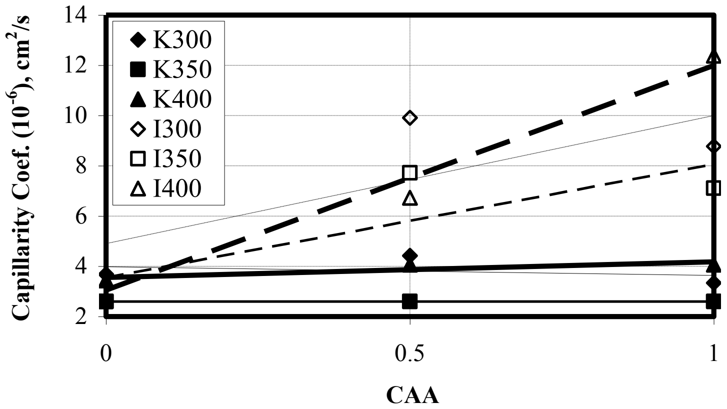

Fig. 4. Capillarity coefficients of concrete containing CAA

Hardened unit weights of the concrete samples are shown in Figure 5. It was observed that unit weight of the samples have varied between 2426-2036 kg/dm^3. With the increase of CAA rate in the concrete samples produced hardened unit weights decreased till 16.1 %. That's reason is that specific weight of CAA is smaller than the specific weight of crushed stone.

Among the non-destructive hardened concrete experiments resonance frequency test was performed and its results are shown on Figure 6. A resonance frequency of the produced concrete samples varies between 2.86-3.01 kHz. In case of 16-4 mm CAA use in concrete resonance frequencies have increased with a rate reaching up to 4 %. The concrete samples dynamic modulus of elasticity values, which were calculated depending on their ultrasound transfer times, and unit weights are shown in Figure 7. The calculated E-modulus values vary between 27.47-56.89 GPa. Together with the increase in CAA ratio used in concrete the dynamic E-modulus value has decreased with a rate reaching 52 %. The explanation for this decrease could be as follows: CAA does not have regular shapes and as result porosity in concrete increases.

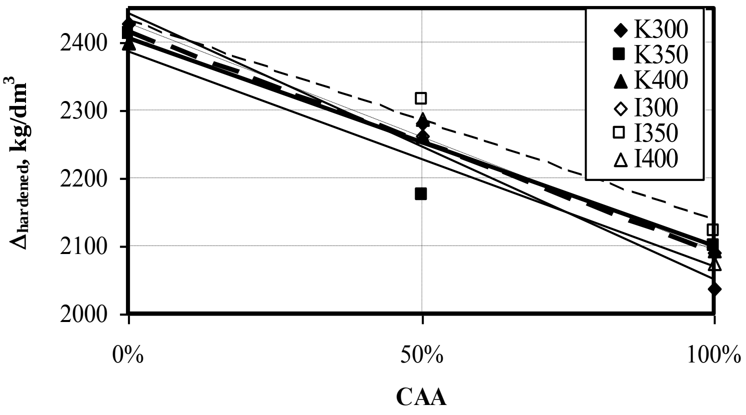

Fig. 5. Unit weight tests results of hardened concrete containing CAA

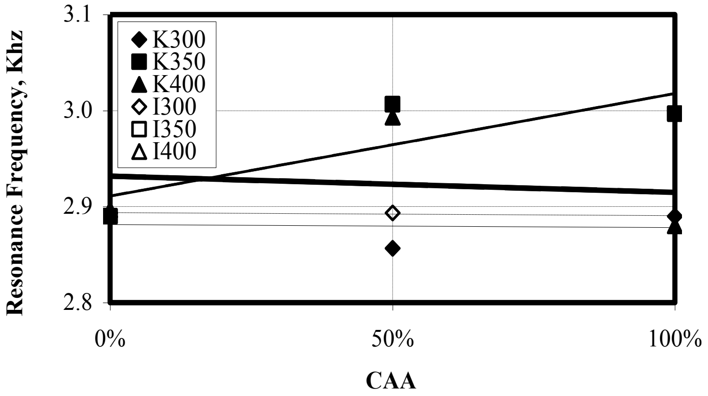

Fig. 6. Resonance frequency tests results of concrete containing CAA

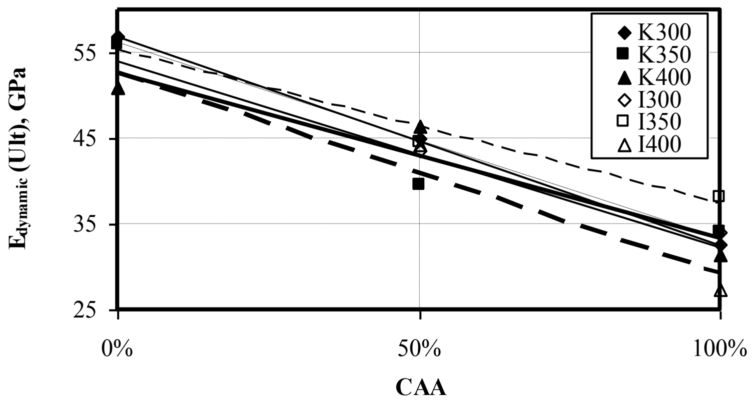

Fig. 7. Dynamic E-modulus of concrete containing CAA

The estimated compressive strengths obtained from surface hardness experiments applied on the concrete samples produced are given on Figure 8. The estimated compressive strengths of the concrete samples vary between 22.7-36.6 MPa. It was observed that this variation is irregular in the samples with CAA. The reason for this could be as follows: CAA creates irregular pores in the concrete and in case these pores are close to the surface they affect surface hardness value and thus the estimated compressive strength. Splitting tensile strength values of the concrete samples are shown on Figure 9. These values vary between 1.74-4.56 MPa. Use of CAA in concrete the splitting tensile strength values have decreased with values reaching 62 %. The reason for this could be as follows: CAA is large, and does not have a regular shape and that's why creates more pores in one section. In case load is applied on such a section the splitting tensile strength decreases as a result.

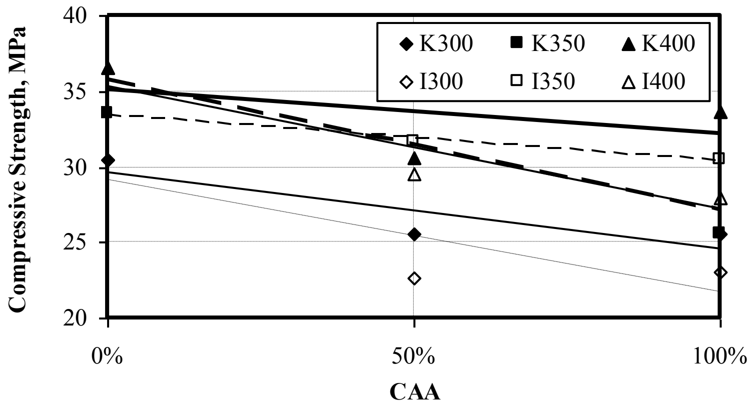

Fig. 8. Compressive strengths determined from surface hardness of concrete containing CAA

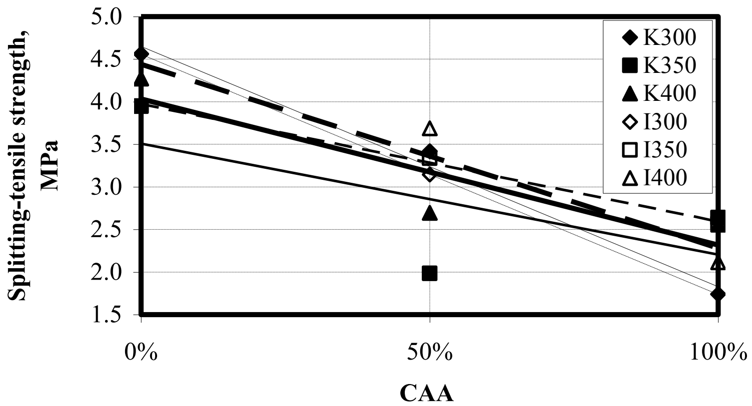

Fig.9. Splitting-tensile strength tests results of concrete containing CAA

Compressive strengths of the concrete samples are given in Figure 10. Compressive strengths of the samples vary between 11.37-40.84 MPa . With use of CAA in concrete it was observed that compressive strengths fall with rates reaching 72 %. The reason for that could be again CAA which increases the pore amount in concrete, and aggregate phase strength of which is lower than that of the crushed stone. As per the shrinking amounts in return to compressive loads σ–ε diagrams of the concrete samples are given in Figure 11. When Figure 11. is examined it was observed that with use of CAA straining decreases. On the other hand deformations have increased with 300-350 dosages and decreased with 400 dosage with use of CAA. When the toughness of the concrete samples was examined decrease was observed together with CAA use. The toughness of the concrete samples calculated using their σ–ε diagrams are shown in Figure 12. When Figure 12. was examined it was observed that with 300 dosage and with CAA used toughness of the concrete samples decrease with rates reaching 40 % and with 400 dosage toughness increase with CAA use. The highest toughness value was obtained in the concrete samples produced with 400 dosage cement. Because of the low compressive strength of CAA, toughness of concrete has decreased.

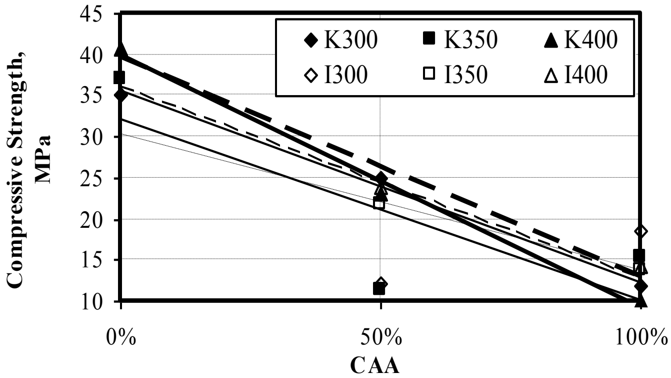

Fig. 10. Compressive strength test results of concrete containing CAA

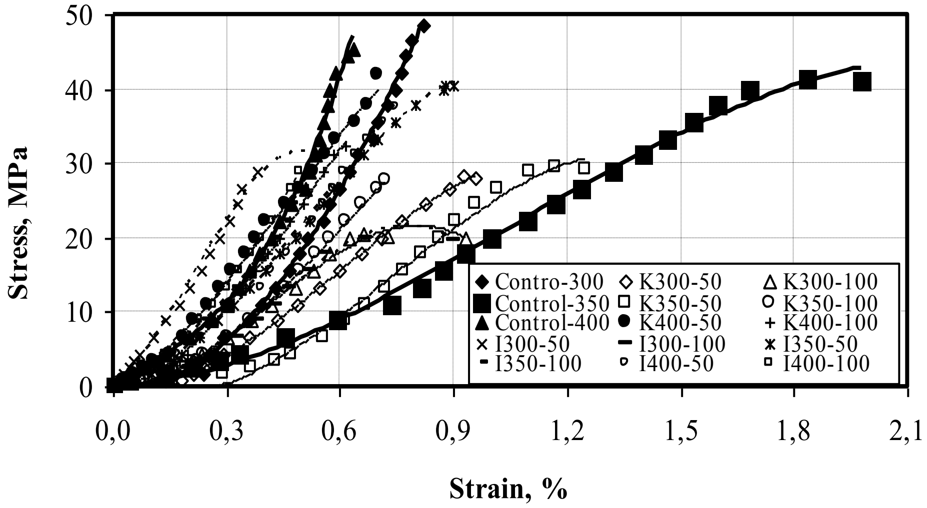

Fig. 11. σ−ε curves of concrete containing CAA

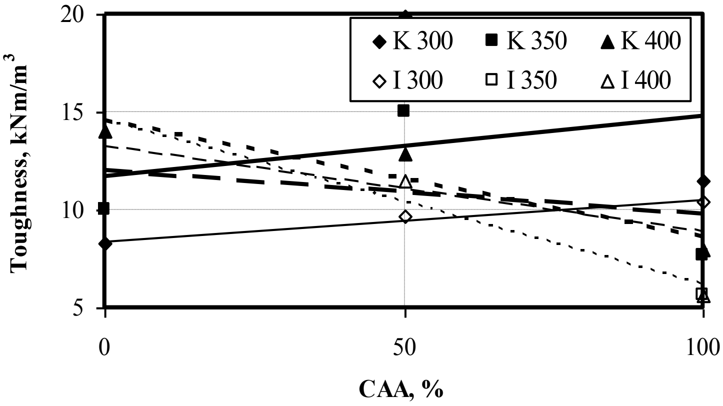

Fig. 12. Toughness of concrete containing CAA

ANALYSIS OF CAA CONCRETE USING COMPOSITE MATERIALS RULES

The modules of elasticity were determined using the σ–ε diagrams of the produced CAA concrete. The modules of elasticity for the concrete sets produced using coarse composite material models [Topçu,1998] were calculated and the results are shown in Figure 13 and 14 It may be observed in Figure 13 and 14 that the experimentally determined modulus of elasticity values decreased due to use of CAA and lessening of the dosage. This decrease was observed as 72 % when CAA was used. The modulus of elasticity of the concrete decreases for CAA is less brittle compared to crushed stone and it easily molds since 80 % of it is composed of air pores. When Figure 13 and 14 are studied it is observed that the closest values to the experimentally obtained modulus of elasticity values were calculated through Popovics model. Moreover, the remotest results were obtained using Illston model [Topçu, 2005; Topçu and Avcular, 1997].

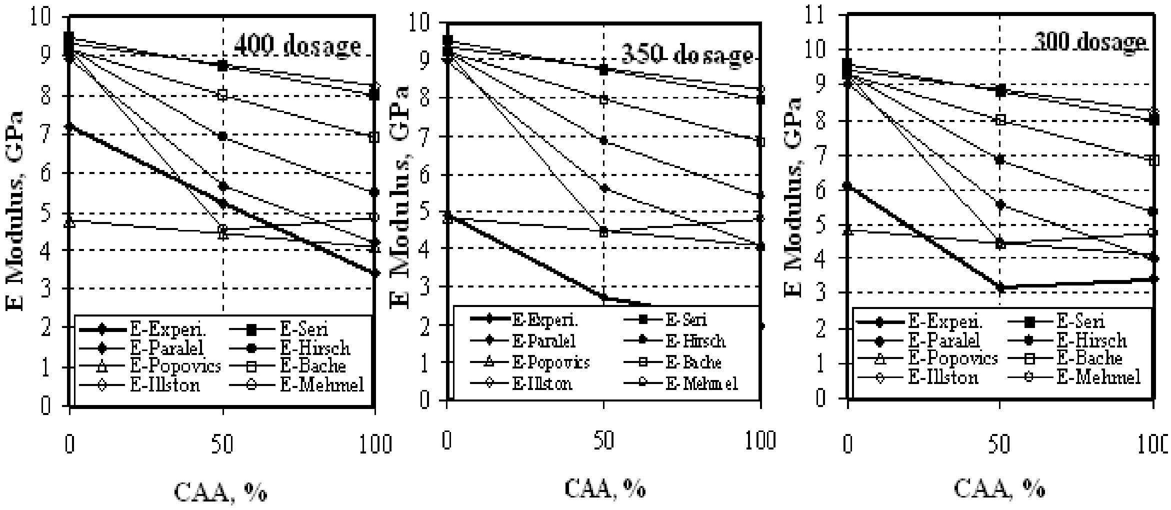

Fig. 13. E- modulus of concrete containing CAA (32-16mm)

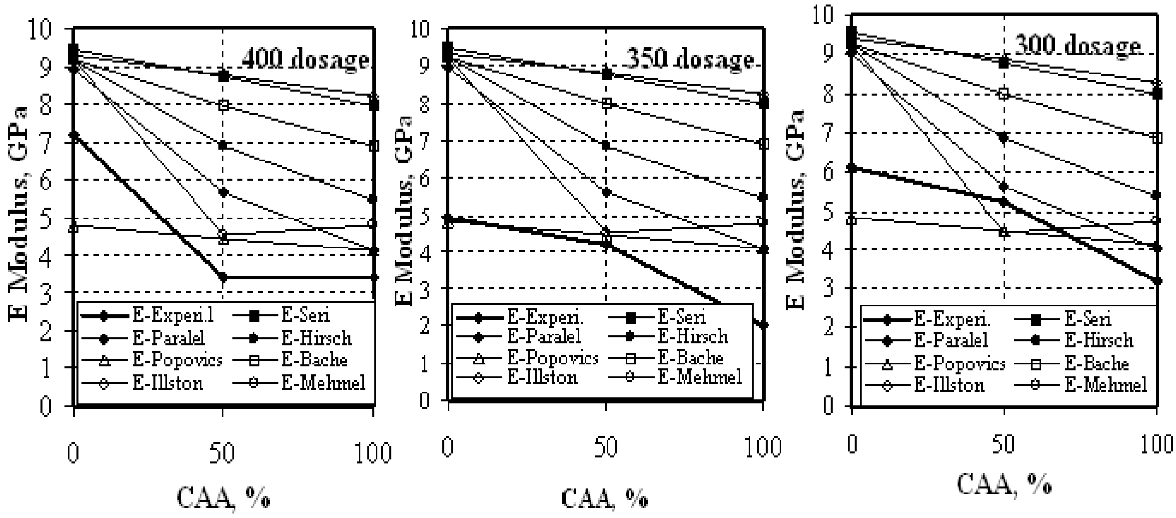

Fig. 14. E-modulus of concrete containing CAA (16-4 mm)

CONCLUSIONS

The following general conclusions can be drawn from the study provided in the paper:

- As a result of the conducted experiments, a decrease about 16 % was observed in the unit weight of the concrete when CAA was used instead of coarse aggregate.
- When CAA was added the compressive strength and splitting tensile strength resistance of the concrete decreased about 72 %. Along with these, the water absorption in weight and in volume rate increased by 100 and 200 %, respectively.
- The pores within the CAA resulted in great reformation. The highest toughness values were obtained by 400 dosage cement dosage with CAA concrete due to both the compressive strength and deformation.
- The mathematical results closest to the modulus of elasticity values experimentally determined in view of composite material rules were given by Popovics model. According to these results, CAA should not be added to the concrete in full instead of coarse aggregate. For instance, as shown in Fig. 10, CAA can be used instead of coarse aggregate in concrete mixtures of 350 and above dosages in order to obtain C 20 quality concrete, while 4-16 mm CAA should be used at the rate of 75 % for 300 dosages, and 16-32 mm CAA should not be used.
- The use of CAA in concrete mixture has environmental advantages since it makes use of leftover crushed AC. Moreover, the unit cost of concrete would decrease. CAA should be regained economically.
- Furthermore, it is suggested that CAA should be used as insulation material, in LWC production and in architectural concrete production.

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