

# CASTOR OIL-BASED BUILDING MATERIALS REINFORCED WITH FLY ASH, CLAY, EXPANDED PERLITE AND PUMICE POWDER

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*This paper reports the results of a study conducted to evaluate the influence of class C fly ash (FA), clay (C), expanded perlite (EP), pumice powder (PP) and epoxidized castor oil (ECO) on the density, thermal conductivity, compressive strength, tensile strength, abrasion loss and water absorption of building material. Density, thermal conductivity, compressive strength and tensile strength decreased with the increase of ECO and FA as replacement for building material. These properties also decreased with increasing process temperature. The addition of clay in the building material had an increasing effect on these properties. The addition of clay decreased abrasion loss and water absorption as a function of replacement percent. The minimum thermal conductivity and maximum water absorption observed for the sample made with minimum clay and maximum FA-ECO ratios processed at the highest process temperature. The maximum compression-tensile strengths and minimum abrasion loss observed for the sample with maximum clay and minimum FA-ECO ratios processed at the lowest process temperature.*

## INTRODUCTION

Clay is a naturally occurring material composed primarily of fine-grained minerals. It is an inexpensive natural mineral that has been used as filler for rubber and plastic for many years. Clay can be chemically modified to make the clay complexes compatible with organic monomers and polymers [1]. Chemical and structural modification of material during firing generally improves mechanical strength and durability of bricks [2].

The Turkey currently produces approximately 15 million tones of coal fly ash each year from 15 coal fired power stations. The major waste management options currently used for fly ash are disposal in land fill or ash lagoons. Significant negative environmental impacts are associated with both of these methods [3]. Approximately 5% of Turkey fly ash is currently utilized as a partial replacement for cement in concrete, as a substitute raw material in cement manufacture, for grouting and stabilizing mine workings and as a fill material in general and structural civil engineering applications [4].

Perlite is obtained from pumice, which is a glassy form of rhyolitic or dacitic magma [5]. Expanded perlite (EP) has been used in constructional elements such as brick, plaster, pipe, wall and floor block; however has not been industrially used in concrete yet [6]. Approximately, 4.5 billion tones of the total 6.6 billion tones of perlite

reserve are located in Turkey [7]. Generally, admixtures such as silica fume and fly ash has been used in concrete to improve mechanical properties [8]. The natural perlite powder has a significant pozzolanic effect and is a good active mineral admixture for concrete [9, 10]. Demirboğa et al. [11] reported results of an extensive laboratory study evaluating the influence of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. They concluded that the addition of mineral admixtures increased the compressive strength of concrete produced with lightweight expanded perlite aggregate.

Pumice is a highly porous glassy volcanic rock. Due to this porous structure, most pumice pieces, when dry, will float on the water, that is, their specific gravity is less than 1 [12, 13]. The most of the pumice production is consumed by construction industries. The advantages include heat and sound insulation, fire resistance, and ease of cutting, shaping and nailing [12- 14]. Yazıcı et al. [15] also investigated high temperature resistance of pumice mortar and they have found that the pumice aggregate mortar gain a compressive strength value of 41% at 600 °C, while conventional natural river sand mortar lost 39% of their strength.

Unsaturated triglyceride oils such as soybean, crambe, linseed and castor oil constitute one major class of renewable resources [16]. The main composition of these triglyceride oils is saturated and unsaturated fatty

acids. They can be polymerized to form elastomeric network and promise alternative material resources to petrochemical derived resin [17]. Directly using these fatty acid or their derivatives from some chemical modifications are emerging applications which include painting, coating, varnishes, cosmetics and more recently polymer and composites. Among the renewable triglyceride oils, castor oil (CO) is attracting increased attention for industrial application. India is the world's largest exporter of castor oil; other major producers are China and Brazil. The castor oil is a versatile vegetable oil due to its unique composition in which the main component is the 12-hydroxy -9-cis-octadecenoic acid, the so-called ricinoleic acid, which represents 90 % of its fatty acid content. The rich chemistry of raw castor oil is attributed to its structure (one double C C and one -OH group per fatty acid chain), which makes it a good starting material for a wide range of applications [18]. The castor oil is suitable for use in isocyanate reactions to make polyurethane elastomers [19], polyurethane millable [20, 21], castables [22, 23], adhesives and coatings [24- 26], interpenetrating polymer network from castor oil-based polyurethane [27, 28] and polyurethane foam [29, 30]. If dehydrated castor oil is epoxidized, the product can be evaluated in poly (vinyl) compounds as a plasticizer/stabilizer [31].

In this study, the possibility of using ECO, FA, C, EP, and PP as raw materials for the production of building material was investigated experimentally. The thermal, mechanical and physical properties of productions were measured according to relevant standards and the results were compared to the values of other investigation.

Table 1. Physical and chemical properties of ECO.

Properties	ECO
Appearance at normal temperature.....	Thin to brown liquid
Brilliance.....	< (Pt-Co) : 372
Acid value .....	(KOH/g) : 3.01 mg
Iodine value.....	144.4 [mg I <sub>2</sub> per 100g]
Oxirane value .....	% 9.93
Thermal conductivity coefficient.....	0,151 W/mK
Density (25 °C) .....	0.976-0.997
Saponification number.....	190-195
Flow point .....	5 °C
Boiling point .....	155 °C
Ignition point.....	316 °C
Viscosity.....	40 Centipoise (at 40°)
Refractive index (25 °C/de) .....	2.07
Melting point in water (25 °C) .....	< % 0.0273
Loss on heating .....	< % 0.6
Weight per equivalent.....	161.8 g
Resin .....	133.3 g
Crosslinker .....	9.89 g
Pigment .....	76 g
Additives (Catalyst, antioxidant, flow agent and anti-foaming agents).....	12.3 g

## EXPERIMENTAL

### Raw materials

The materials used in the research are as follows:

**2.1.1 .ECO:** Epoxidized castor oil was used as received commercially from Konsan Inc. (Adana, Turkey). It was used as a chemical additive to improve the engineering properties of samples. Fig. 1, 2 and 3 show the remarkably constant composition of castor oil fatty acids, the fundamental structure of castor oil and the epoxidation of castor oil, respectively. Table 1 shows physical and chemical properties of ECO. Table 2 gives the <sup>1</sup>H NMR chemical shifts for both CO and ECO. <sup>1</sup>H NMR spectrum of the ECO revealed that 75% conversion of the double bonds to epoxide groups had taken place.

**2.1.2. FA:** In the study, an industrial waste Afşin Elbistan FA produced in Afşin Elbistan thermal power station in eastern Turkey was used in samples due to its pozzolanic reactivity. Afşin Elbistan FA is a lignite coal and approximately 4 million tons of FA is produced per year in the area. Color, density, thermal conductivity coefficient and natural moisture content of Afşin Elbis-

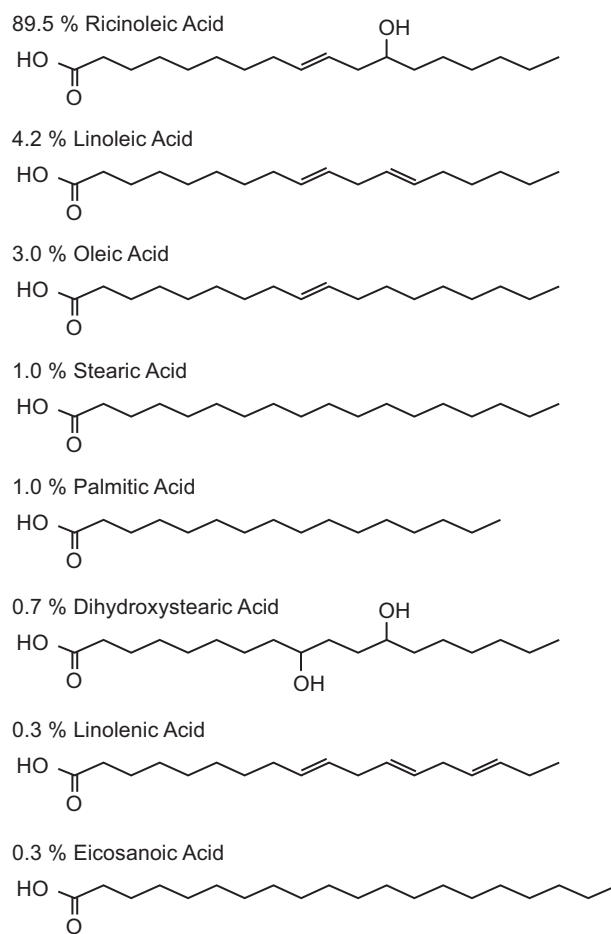


Figure 1. The remarkably constant composition of castor oil fatty acids.

tan FA were light grey, 1.5 g/cm<sup>3</sup>, 0.511 W/mK and 0.002, respectively. According to ASTM C618, Afşin-Elbistan FA can be classified as Class C fly ash due to its chemical composition. The chemical compositions of Afşin Elbistan FA, C, EP, PP used in this study are given in Tables 3.

2.1.3. C: Clay was purchased from Aslan Corporation (Eiaziğ, Turkey). It was used as a natural material to improve the engineering properties of samples. The density and thermal conductivity coefficient were 2.24 g/cm<sup>3</sup>, 0.93 W/mK, respectively.

2.1.4. EP: Expanded perlite is mainly composed of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub>. EP is one of the most feasible materials as an economical building material for incorporation of fatty acids. Moreover, the principal property of EP is the low thermal conductivity [32]. It was used to decrease thermal conductivity of the samples and

supplied from Izper Company (Izmir-Turkey). Table 4 shows the physical characteristics of the EP.

2.1.5. PP: The pumice that was used in this investigation was hand picked from Ahlat region in Bitlis, Turkey. It was in the form of 3-7 cm lumps. All the pieces were light colored: white or pinkish white. It was crushed, screened, and then stored in glass bottles. It was used in samples due to its pozzolanic reactivity. Table 5 shows the physical characteristics of the PP.

Table 4. Physical characteristics of EP.

Colour.....	White
Melting point.....	1300 °C
Specific heat.....	0.20 kcal/kg °C
Unit weight.....	2.3 g/cm <sup>3</sup>
Density.....	0.213 g/cm <sup>3</sup>
Thermal conductivity coefficient.....	0.114 W/mK
Sound insulating.....	18 db (125Hz)

Table 2. <sup>1</sup>H NMR Spectral Assignments for both CO and ECO.

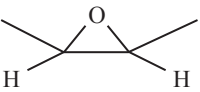
Assignments	Chemical Shift (δ, ppm)	
CH <sub>2</sub> = CH <sub>3</sub>	1.3	1.0-1.8
CH <sub>2</sub> CH = CHCH <sub>2</sub>	2.0-2.2	-
COCH <sub>2</sub>	2.3	2.3
	-	2.9-3.1
CH <sub>2</sub> OCO	4.0-4.4	4.0-4.4
(O)CH <sub>2</sub> CH(O)CH <sub>2</sub> (O)	5.2-5.3	5.2-5.3
CH <sub>2</sub> CH = CHCH <sub>2</sub>	5.3-5.7	-

Table 5. Physical characteristics of PP.

Colour.....	Pinkish white
Fineness (m <sup>2</sup> /kg).....	283
Residue on 75 mm sieve (%).....	2.45
Density.....	0.607 g/cm <sup>3</sup>
Thermal conductivity coefficient.....	0.217 W/mK

Table 3. Range of chemical composition (%) of obtained FA, C, EP and PP.

	FA	C	EP	PP
SiO <sub>2</sub>	21.33	43.645	70.3	60.82
Al <sub>2</sub> O <sub>3</sub>	4.025	20.259	13.2	16.73
Fe <sub>2</sub> O <sub>3</sub>	2.606	12.954	-	7.04
CaO	36.480	10.150	2.4	4.44
MgO	1.032	1.534	1.60	1.94
Na <sub>2</sub> O	-	-	4.0	5.42
K <sub>2</sub> O	-	-	6.1	2.25
FeO	-	-	2.2	-
TiO <sub>2</sub>	-	-	0.20	-
Ignition loss	29.798	9.650	-	1.36
Unknown	4.729	1.808	-	-

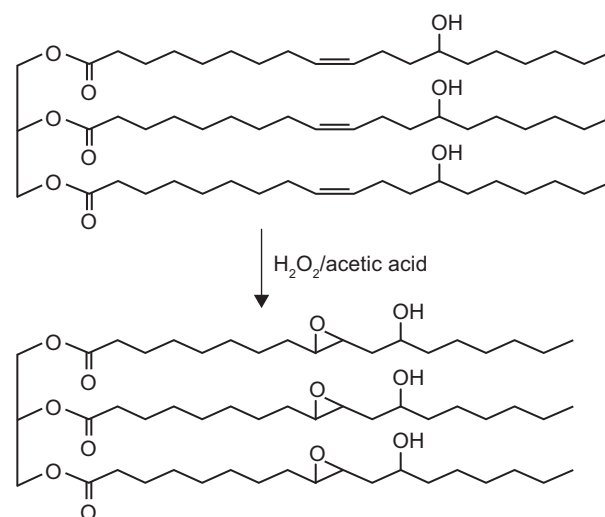


Figure 3. Epoxidation of castor oil.

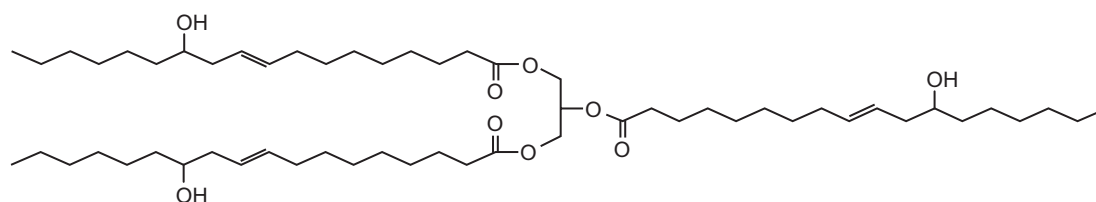


Figure 2. The fundamental structure of castor oil.

### Sample mix design

In order to investigate the effect of different FT and raw material contents on thermal, physical and mechanical properties of samples, mixtures were prepared in twelve different material ratios and in three different FT as 170, 190 and 210°C. The FA, C, EP and PP were used as base materials for producing the samples. The ECO was used as binder in samples. The standard mix compositions were determined from the pretrial. The mix proportions and sample codes at all temperatures were listed in Table 6. The powder samples were first blended in plastic bags to get better homogeneity. After this, the powder materials were mechanically mixed with ECO in an auto-mixer machine (Toni-Technique mortar mixer 5 l) for a total of 5 min. Care was taken to avoid non-mixed residues remaining on the upper edges of the mixing bowl after the mixing process. 100 × 100 × 100 mm cube and 150 × 60 × 20 mm prism were used for the determination of compressive strength-abrasion loss% and thermal conductivity coefficient-water absorption%, respectively. Precautions were taken to ensure homogeneity and full compaction. The test samples of prism and cube were cast using an internal and external vibrator. After casting, all test samples were finished with a steel trowel.

### Preparation of the test samples

Firstly, the samples were predried at temperature 100°C for 12 h. The predried samples were exposed to firing at temperatures 170, 190 and 210°C for 12 h in laboratory type electrically heated furnace, respectively. Furnace was turned off after holding period of 30 min.

The standard temperatures were determined from the pretrial. When process temperature was lower than 170°C, the sample wasn't completely dry. When process temperature was above 210°C, deformation of sample begins; its structure starts to crack, at the same time partial fracture in sample happens. The twelve samples were fired at each firing temperature (170, 190 and 210°C). The total sample number was thirty six. The samples fired at three different FT were pulled up slowly from mould and they were tested in the laboratory.

### Methods

A quick thermal conductivity meter (QTM 500) based on DIN 51046 hot-wire method was used to measure the thermal conductivity. Variac (power supply) was used to supply constant electrical current to the resistance. QTM 500 device is a product of Kyoto Electronics Manufacturing, Japan. Measurement range is 0.02-10 W/mK. Measurement precision is ± 5 % of reading value per reference plate. Reproducibility is ± 3 % of reading value per reference plate. Measuring time is standard 100-120 s. The thermal conductivity coefficient was determined by using Eq. (1) [33].

$$k = K \frac{l^2 \ln(t_2/t_1)}{V_2 - V_1} - H \quad (1)$$

where  $K$  and  $H$  are the constants of the Shotherm-QTM apparatus that are taken as  $252 \times 10^{-4}$  and  $33 \times 10^{-3}$ , respectively.

Each measurement was repeated three times and at three different locations for each sample. The thermal conductivity coefficient,  $k$ , was computed by using the average of these nine  $k$  values.

Table 6. The mix design and codes for samples at all temperatures.

	ECO								
	170°C			190°C			210°C		
	% 40	% 45	% 50	% 40	% 45	% 50	% 40	% 45	% 50
% 60 C									
% 30 FA									
% 5 EP	C1	C2	C3	C4	C5	C6	C7	C8	C9
% 5 PP									
% 50 C									
% 40 FA									
% 5 EP	C10	C11	C12	C13	C14	C15	C16	C17	C18
% 5 PP									
% 40 C									
% 50 FA									
% 5 EP	C19	C20	C21	C22	C23	C24	C25	C26	C27
% 5 PP									
% 30 C									
% 60 FA									
% 5 EP	C28	C29	C30	C31	C32	C33	C34	C35	C36
% 5 PP									



The mechanical tests were performed in the Ministry of Public Works and Settlement, Construction Department Laboratories (Elazığ, Turkey). The density, water absorption, compressive strength and abrasion resistance were evaluated for each sample using test procedures described in the TS 699 (1987) standard. The results were appraised using equations from TS 699.

The density was measured by weight and volume measurements.

The compressive strength of samples was tested using a Turkish Beskom Material Testing Machine (Compressive Testing Machine) Model BC100. The maximum rate of pressure applied for this compressive testing machine was 200 t. Results were obtained using a computer connected to the compressive testing machine (Fig. 5a) shows the compression strength test of the products.

The tensile strength of samples is determined by Eq.(2) [4].

$$F_{Tensile} = 0.35 \sqrt{F_{compressive}} \quad (2)$$

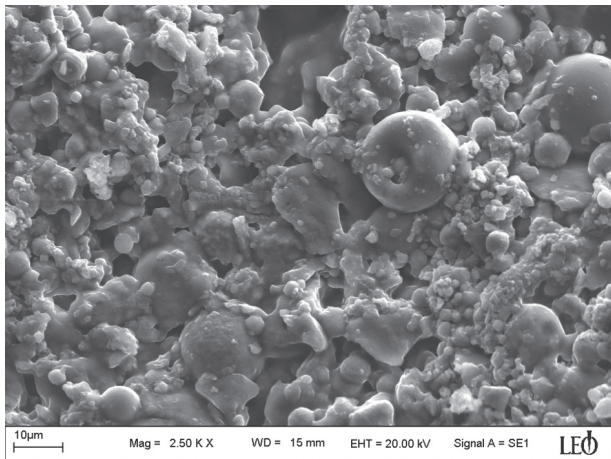


Figure 4. SEM photo of fired sample with 50 % ECO, 60 % FA, 30 % C, 5 % EP, 5 % PP.

The abrasion resistance was measured with volume loss of samples for each group. Abrasion resistance test was done by using Bohme Surface Abrasion Test Method. Loss volume of sample due to surface abrasion was calculated. Fig. 5b shows the abrasion test of the products. The abrasion loss values were determined by using Eq. (3) [4].

$$\% \text{ Abrasion loss} = [(First \text{ mass} - Last \text{ mass}) / First \text{ mass}] \times 100 \quad (3)$$

The moisture content of each sample at the times of testing was recorded. The samples were placed in a water tank that has the capacity to submerge the whole samples at room temperature of  $20 \pm 2^\circ\text{C}$ . After  $\frac{1}{3}$ ,  $\frac{2}{3}$ , 1, 2, 3, 4, 5, 6, 7, 8 and 24 hours the samples were removed from the tank. The surface water on the samples was wiped of with a damp cloth. The percentage weight gain of samples was measured at different time intervals. The rate of water absorption of each sample was calculated by weight difference between the samples immersed in water and the dry samples using the following equation:

$$WA = [(M_w - M_D) / M_D] \times 100 \quad (4)$$

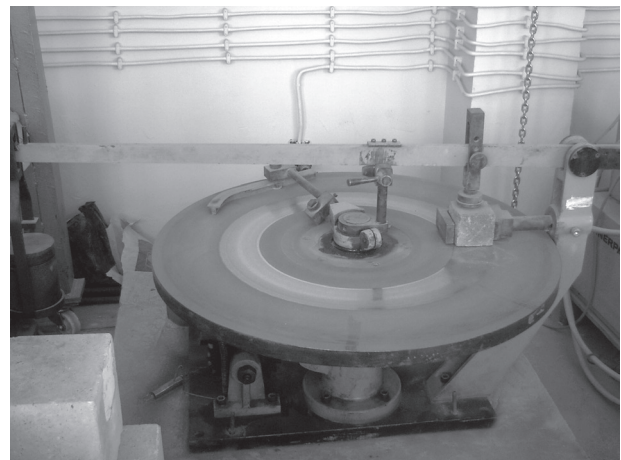
## RESULTS AND DISCUSSION

### Density

Density is one of the important parameters, which can control many physical properties in lightweight building material and it is mainly controlled by the amount and density of lightweight building material. The density-ECO percent relation in the samples at all FT was presented in Fig. 6. By incorporating the FA, C and ECO at different volume percentages in a sample, a wide range of sample densities can be produced.



a) the compression strength test



b) the abrasion test

Figure 5. The tests of the products developed from ECO, FA, C, PP and EP.

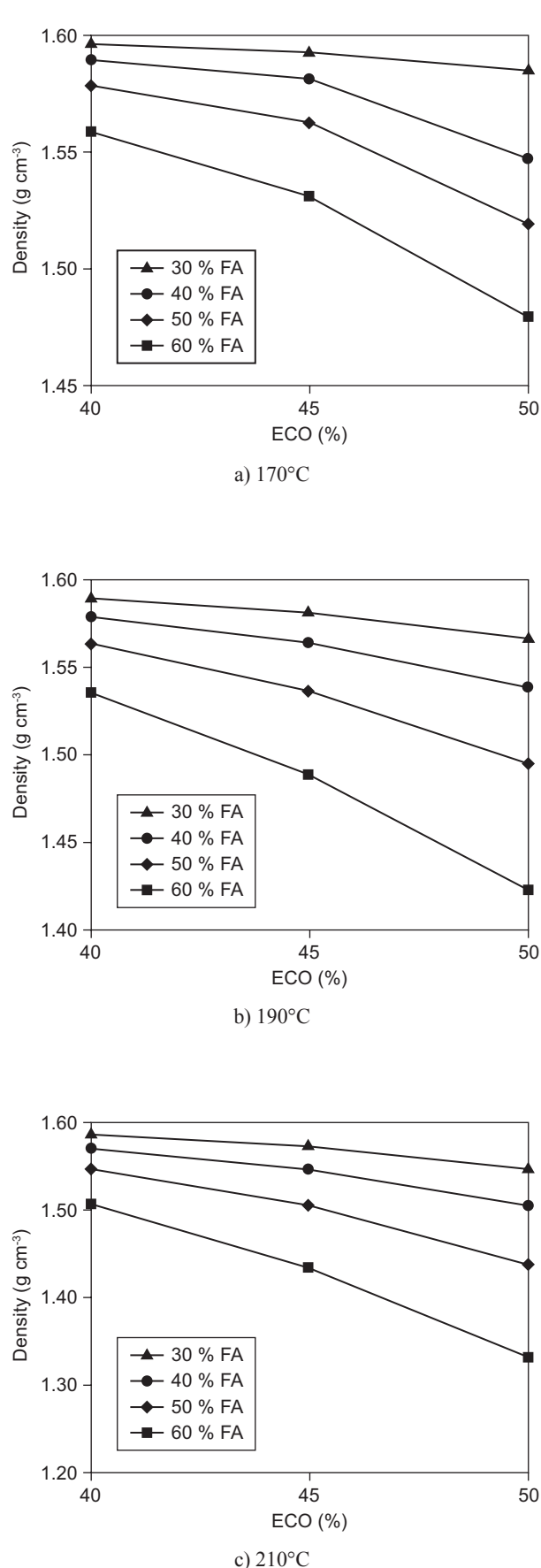


Figure 6. The density- ECO percent relation in the samples.

The density values of samples with FA-C-EP-PP/ECO as partial replacement of FA were determined to be between 1.596 and 1.331 g/cm<sup>3</sup>. The density of samples decreases with an increase in FA ratios. The lower density of sample due to FA is probably related to the higher air content that results in less density and partly to the amorphous structure of FA, as indicated in Ref. [11]. All of the samples were exposed to the different FT such as 170, 190 or 210°C for 12 h in a digital-controlled electrical oven. The density decreased with an increase in firing temperature. The lowest density value of samples was found as 1.331 g/cm<sup>3</sup> for the sample (sample code: C36) with a 60% FA /30% C / 5% EP/ 5% PP ratio and 50% ECO processed at 210°C. At 170 and 190°C, the density of the samples increased 2.52% (sample code: C3) and 1.40% (sample code: C6), compared to the corresponding the sample (sample code: C9) with 30% FA and 50% ECO processed at 210°C, respectively. The samples were revealed the highest density values with FA content of 30% for all process temperatures. For 40, 50 and 60% FA, the reductions were 7.44, 11.50 and 13.85%, respectively, compared to the corresponding the sample with 30% FA. These values were determinate for the sample (sample code: C9) with 50% ECO processed at 210°C.

#### Effect of C and FT

The results show the negative effect of C on the sample for low density. This is because the particle sizes of C are bigger than FA, thereby leading to a decrease in the pozzolanic reaction between the SiO<sub>2</sub> and CaO<sub>2</sub> in the sample. The highest density value was measured in the sample (sample code: C1) produced with 40% ECO processed at 170°C, which contain highest (60%) amount of C. For 50, 40 and 30% C, the density values of the samples were decreased 0.43, 1.12 and 2.38%, respectively, compared to the corresponding the sample (sample code: C1) with 60% C and 40% ECO processed at 170°C. The density of C7 sample was 1.585 g/cm<sup>3</sup> compared to 1.331 g/cm<sup>3</sup> for the C36 sample. Thus the density of the C36 sample was 16.02% of the C7. The analysis of results indicates that, in all mixes at 170, 190 and 210°C, increasing the C content in the sample increased the density. For 170°C and 190°C, the density values were increased about 1.00-1.42 % and 1.58-6.46 %, respectively, compared to the samples at 210°C.

#### Effect of ECO and FT

The density values are inversely proportionate with the percentage ECO replacement. The density dramatically decreases with an increase in the replacement level of ECO. The reason for this is that the chemical structure of ECO is chemical interaction with

other ingredients, thus increasing the ECO ratio results in a decrease in density. The maximum decreases were obtained in the samples produced with 50% ECO. The high FT has an important influence on the low density development of samples with ECO. However, as the FT of sample increases, a decrease in density is naturally inevitable. When ECO ratio (for sample with 60% C at 170°C) was increased from 40 to 45, and 50, density decreased 0.25%, and 0.68%, respectively. While the sample's density with code C7 (ECO ratio:40%) was 1.585 g/cm<sup>3</sup>, the density of samples that is made up of 45% and 50% ECO replacement for sample C8 and sample C9 was 1.572, 1.545 g/cm<sup>3</sup>, respectively. Reduction in the density due to ECO was 0.82% and 2.52% for 45% and 50% ECO replacements, respectively.

#### Thermal conductivity

Building material of low thermal conductivity is useful for the thermal isolation of buildings. There was a reasonably good relationship between thermal conductivity and density. Lu-Shu et al. [34] also reported that thermal conductivity increased with increasing density. There are numerous studies [35, 36] reporting that increase in density results in higher thermal conductivity coefficient. The reduction in density of concrete by means of mineral admixture is probably related to the lower specific gravity. Bouguerra et al. [37] reported that the thermal conductivity of lightweight concrete changes considerably with porosity. Differences in the apparent density and the effective thermal conductivity of concretes arise from differences in their porosity. In other words, voids filled with air contribute nothing to the weight of concrete, while the overall conductivity of a porous concrete is the result of the thermal conductivity of the silicate structure and that of the air contained in it. It is for this reason that the thermal conductivity of concrete is related to its density. Thermal conductivity depends on density and on the mineralogical composition of the raw materials mixture used.

#### Effect of FA and FT

The influence of the different FA-ECO ratios on the thermal conductivity of sample at all FT is shown in Fig. 7. It can be seen from Fig. 7 that the thermal conductivity of sample decreased with an increase in FA ratio. The reason for this is that the high FA replacement caused reductions in density drastically. Since the thermal conductivity is related to the density. FA (40%, 50% and 60% replacement of C) decreased the thermal conductivity of sample with 50% ECO processed at 170°C, other conditions being constant, and the reductions were 3.27%, 9.81% and 21.49%, respectively, compared to the corresponding C3 sample with 30% FA. This is probably related to the increase of porosity due to the addition of FA replacement in

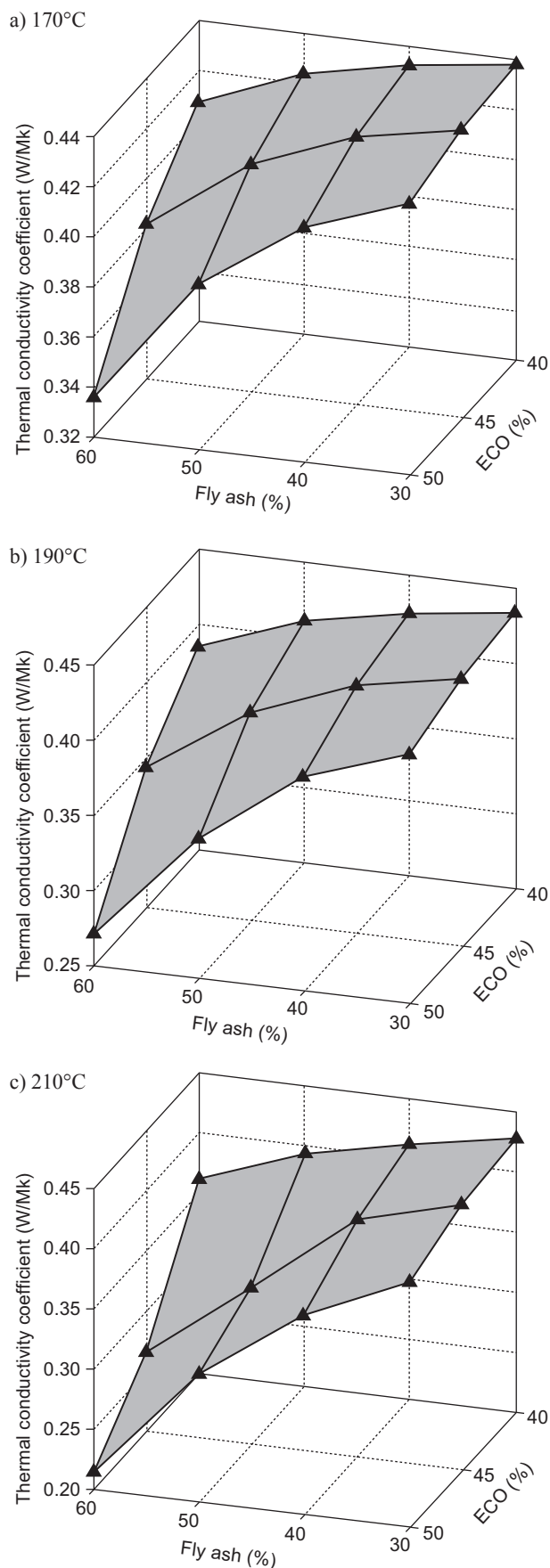


Figure 7. The thermal conductivity coefficient - ECO percent relation in the samples.

sample, the lower density of FA, and partly to the amorphous structure of FA. The experimentally obtained values of the thermal conductivity of sample are in good agreement with earlier findings [38-40]. In addition, the reduction in this study is more than those of the earlier studies. Because the percentage of the mineral admixture replacement in sample of previous study [41] is higher than 31%, reductions in thermal conductivity due to FA were higher than that of EP and PP. This is probably due to lower density of EP and PP. Lower density results in porous and lower density of sample. Reduction in density causes a reduction in thermal conductivity. As shown in Fig.6, the thermal conductivity of samples was increased about 1.14-19.04% at 190°C and 2.28-36.11% at 210°C, compared to the samples processed at 170°C. Reductions were partly due to the density. The lowest thermal conductivity value reached 0.215 W/mK when the samples were added 60% FA and 50% ECO processed at 210°C. The lowest density was obtained for this value of thermal conductivity coefficient. At a density between 1.596 and 1.331 g/cm<sup>3</sup>, the sample has a thermal conductivity of 0.438-0.215 W/mK according to TSE standards. The maximum reduction in thermal conductivity of sample occurred at the maximum FA replacement.

#### Effect of C and FT

The thermal conductivity of the sample was raised linearly with increase of mass fraction of C additive. The highest value of thermal conductivity coefficient is determined at the sample produced with 60% C ratio and 40% ECO processed at 170°C as 0.438 W/mK. The thermal conductivity coefficient is decreased, when the C per cents decrease at every three process temperatures (170°C, 190°C and 210°C). As expected, the thermal conductivity decreases with increasing of the process temperature. The highest values of thermal conductivity coefficients are determined at 170°C, while the lowest values of thermal conductivity coefficients are obtained at 210°C among all of the samples. This is probably related to the increase of porosity due to the high process temperature.

#### Effect of ECO and FT

The thermal conductivity decreases with increasing of mass fraction ECO of samples. In our study, the ECO decreased thermal conductivity up to 50.91% due to the reduction of the density of sample. The thermal conductivity of samples were increased about 5.60-40.60% with ECO content of 40% and 4.03-19.17% with ECO content of 45%, compared to the samples produced with 50% ECO (sample code: C9) processed at 210°C. ECO has great influence on the thermal conductivity of samples. When ECO increased from 40% to 50%, thermal conductivity of the sample with 30% FA was

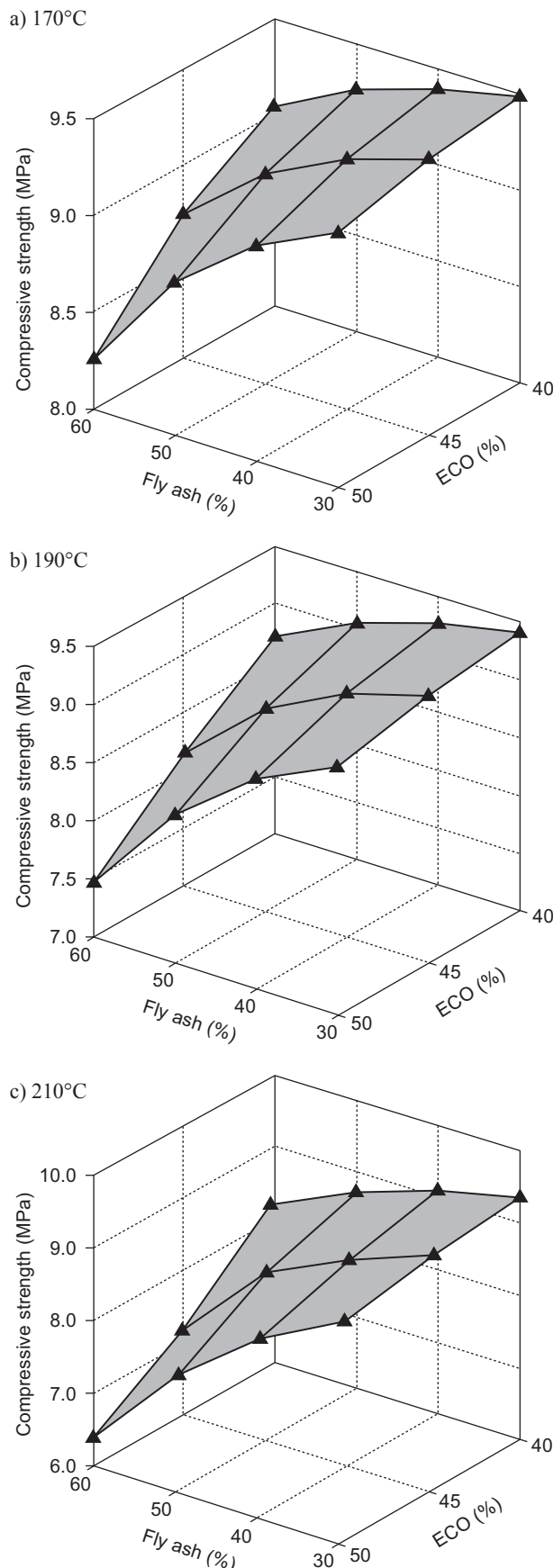


Figure 8. The compressive strength - ECO percent relation in the samples.



increased by 2.28%, 3.92%, and 5.60% for 170°C, 190°C and 210°C, respectively. The thermal conductivity of the samples with 60% FA was lower than those with 30% FA at increment ratio from 40% to 50% ECO. This is due to the porousness development chemical property of ECO, which results in lightness. Similar results were also reported by Balo et al. [38-41] for samples with epoxidized sunflower oil, epoxidized soybean oil, epoxidized palm oil, epoxidized linseed oil and epoxidized olive oil. Thermal conductivities of some types of construction materials used at present [52] and the most useful of the samples with FA-C-EP-PP/ECO are given at Table 7.

#### Compressive strength

The compressive strength results of the samples made with FA-C-EP-PP/ECO were determined at 170°C, 190°C, 210°C and the results were given in Fig. 8. In general, all the samples produced developed satisfactory compressive strength ranging from 9.49 to 6.43 MPa at all firing temperatures.

#### Effect of FA and FT

Compressive strength is a function of unit weight. Gül et al. [43] and Şahin et al. [44] reported that the compressive strength decreased because the unit weight decreased with increasing FA ratio instead of normal aggregate. In this study, increasing the FA ratio is found to impact the compressive strength value of samples significantly. The FA reduced compressive strength of sample at all levels of replacement at 170, 190 and 210°C. Reductions were very high at high temperatures, but with decrease in firing temperature the reduction percent decreased. Reductions at compressive strength were 2.14%, 5.57% and 11.26% for 40%, 50% and 60%

FA, compared to the corresponding the sample with 30% FA and 50% ECO processed at 170°C, respectively. Reduction rate increased significantly with increasing firing temperature. This is due to pozzolanic and filler effect of fly ash. These observations are consistent with the results of other studies [45-47]. For example, Azhar et al. reported that addition of FA (20-30% by weight of cement) decreased the compressive strength up to 25% [47].

#### Effect of C and FT

Previous studies indicate that the density of sample increases with an increase in mass of C and hence results in a increase in compressive strength of the sample [43-52]. This behavior is due to the physical properties of C, since it has higher density than FA. Thus, the rate of gain of strength with C is also more gradual than that of FA. At 170°C, the compressive strength of sample (with 40% ECO) made with 30%, 40%, 50% and 60% C were 9.04, 9.26, 9.40 and 9.49 MPa, respectively. The compressive strength of sample decreased with decreasing C. Increasing the firing temperature resulted in a decrease of reduction values of compressive strength due to low density and increasing porous structure of sample.

#### Effect of ECO and FT

The compressive strength was reduced by as much as 32.24% with the addition of 50% ECO at all FT. Reductions in compressive strength at 170, 190 and 210°C for 45% and 50% ECO were 62%, 52% and 74%, 57%, compared to the corresponding the sample with 60% FA and 40% ECO, respectively. The firing temperature affected the decrease in reduction of compressive strength to a large extent. In addition,

Table 7. The thermal conductivity and density values for the different construction materials.

Type of the Construction Materials	Density (Kg/m <sup>3</sup> )	Thermal conductivity (W/m°C)
Cement Plaster	1850	0.72
Gypsum Plaste	1280	0.46
Perlite Plaster	610	0.19
Light Weight Concrete with Expand Perlite	1120	0.39
Normal Concrete	2240	1.40
Concrete with Normal Aggregate	1600	0.81
Concrete with Light Aggregate	1600	0.75
Gas (aerated) concrete	500	0.19
Porous concrete containing non-porous aggregate (gravel, etc)	1500	0.64
Porous broken - brick or slag concrete	1200	0.47
Pumice-stone concrete ,expanded clay concrete	800	0.29
Concrete with wood product aggregate	800	0.41
Glass- fibre resinfaced gypsum board	1200	0.49
Sample with ECO, FA, C, PP and EP	1331	0.58

compressive strength decreased with increase of ECO replacement percent. The compressive strength reduction observed was due to both chemical properties of ECO and low strengthens effects. The compressive strength of the sample is opposite to its density. In addition, the decrease in compressive strength is related to air-entrainment. The more the air voids ratio, the lighter the sample and the lower its compressive strength. The samples were obtained the highest compressive strength values with ECO content of 40%.

#### Tensile strength

The variation of tensile strength of samples depending on ratios FA-ECO in samples fired at 170°C, 190°C and 210°C is given in Fig. 9. The tensile strength values are obtained by using Eq. 2 and the compressive strength values. The interpretations of graphs connected with the tensile strength values are similar to the compressive strength values. The tensile strength values were varied between 1.078 and 0,887 MPa.

#### Abrasion loss

The abrasion loss of samples at different FT was presented in Fig. 10. At the lower sample strengths tested, the effect aggregate hardness on abrasion resistance is likely to more pronounced, given that the resistance to abrasion influenced by sample strength, aggregate properties, a quality of near-surface finish. The abrasion loss of all these samples was under 3.91%. It was obvious that the samples containing FA-C-EP-PP with 40% ECO processed at 170°C showed satisfactory results.

#### Effect of FA and FT

The addition of FA exhibited a reduction in abrasion resistance. The abrasion resistance was reduced by as much as 79% with the addition of 60% FA at different FT. The lowest abrasion loss value was measured in the sample produced with 40% ECO processed at 170°C [sample code: C1 (0.65%)], which contain lowest (30%) amount of FA. Addition of 60% of FA by mass is the optimum content that produced the highest increase in abrasion loss. The pozzolanic effect of high FA ratio reduces the abrasion resistance of the sample. When in-creasing the firing temperature, low abrasion loss obtained. For 30, 40 and 50% FA, the increases were 55.75%, 42.96% and 15.07%, respectively, compared to the corresponding the sample [sample code: C36 (3.91%)] with 60% FA and 50% ECO processed at 210°C.

#### Effect of C and FT

While the abrasion loss of samples that contain 30%C were 1.3%, 2.41% and 3.91% , on the other hand the abrasion loss of samples of those made up of 40% C

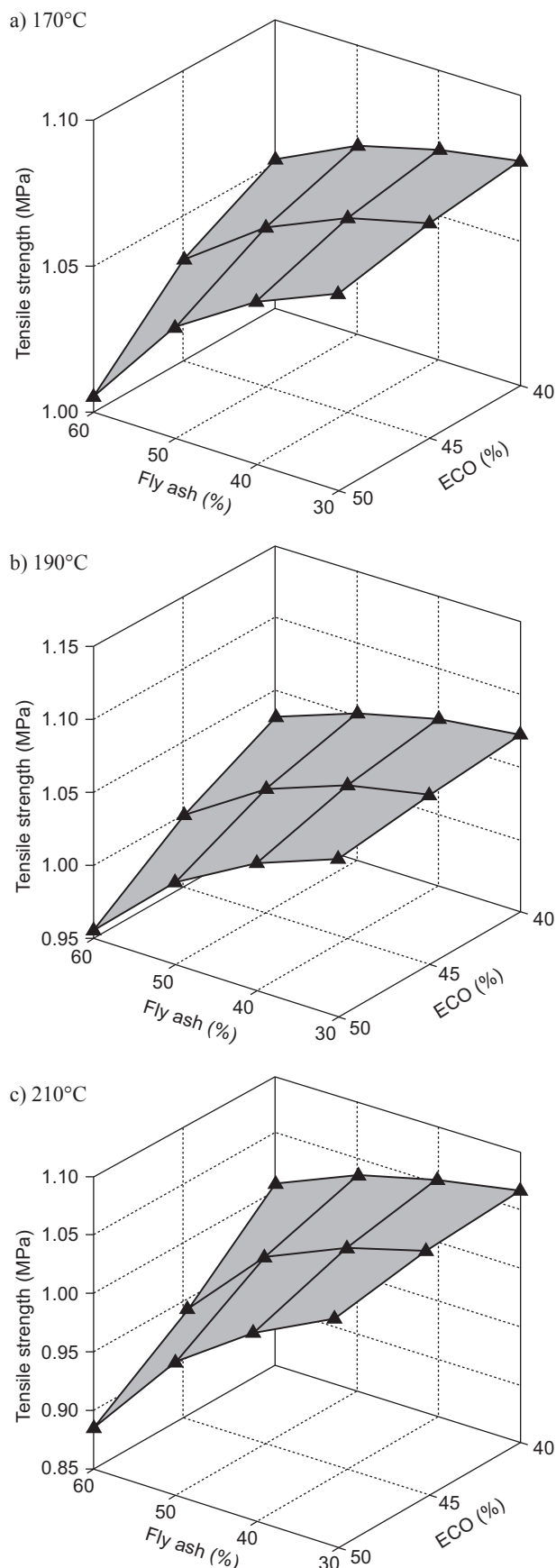


Figure 9. The tensile strength - ECO percent relation in the samples.

were 1.05%, 1.84% and 2.98%, of those made up of 50%C were 0.86%, 1.49% and 2.23% and of those made up of 60%C were 0.76%, 1.21% and 1.73% for the sample with 50% ECO processed at 170°C, 190°C and 210°C respectively. The abrasion resistance improvement in sample can be explained by low pozzolanic reactions at elevated temperatures in which less reactive form of silica in C shows low pozzolanic reaction that is normally remains reacted under low firing temperature.

#### Effect of ECO and FT

The abrasion resistance of samples decreased with an increase in ECO ratios. The reductions induced by 40%, 45% and 50% ECO replacement for sample processed at 210°C by mass on the abrasion loss were 35.67%, 25.62% and 15.07% for 30%FA ratio, 44.60%, 34.89% and 21.94% for 40% FA ratio, 55.75%, 42.96% and 23.78% for 50% FA ratio, compared to the sample with 60% FA, respectively. This behavior is due to the chemical properties of ECO. Under the conditions of high firing temperature, the chemistry of sample was substantially altered. This was caused an increase in porosity and reduction in abrasion resistance. The abrasion loss of samples was decreased about 49.21-66.75% at 170°C and 30.46-38.36% at 190°C, compared to the samples processed at 210°C, respectively.

#### Water absorption

The amount of water absorbed in a sample is indicative of its permeable pores [48]. These values depend on the extent of curing of samples and the duration of water absorption. If the curing conditions and the time interval for which different samples are exposed to water penetration are the same, then the water absorption values can give a comparative evaluation of the quality of the sample cover. Fig. 11 shows the influence of FA and ECO ratio on the water absorption as a function of FT. It is clearly shown from this figure that increasing the content of FA-ECO, the main source of porosity, leads to the increase of water absorption. The water absorption of the fired samples at all FT achieved the limits of TSE.

#### Effect of FA and FT

The test results showed that the water absorption values increases with an increase in FA ratios. The addition of FA in the ratios of 30%, 40%, and 50% by mass, when compared to the sample with 60% FA and 50% ECO, provided an increase of about 38.53%, 28.85% and 15.61% at 170°C, 39.57%, 30.06% and 16.46% at 190°C, and 40.72%, 30.96% and 17.57% at 210°C, respectively. Finally, the water absorption of the samples consistently increased up to the FA mass of 81.59%. This water absorption increase may be the indication of porous bonding between powder raw materials and ECO.

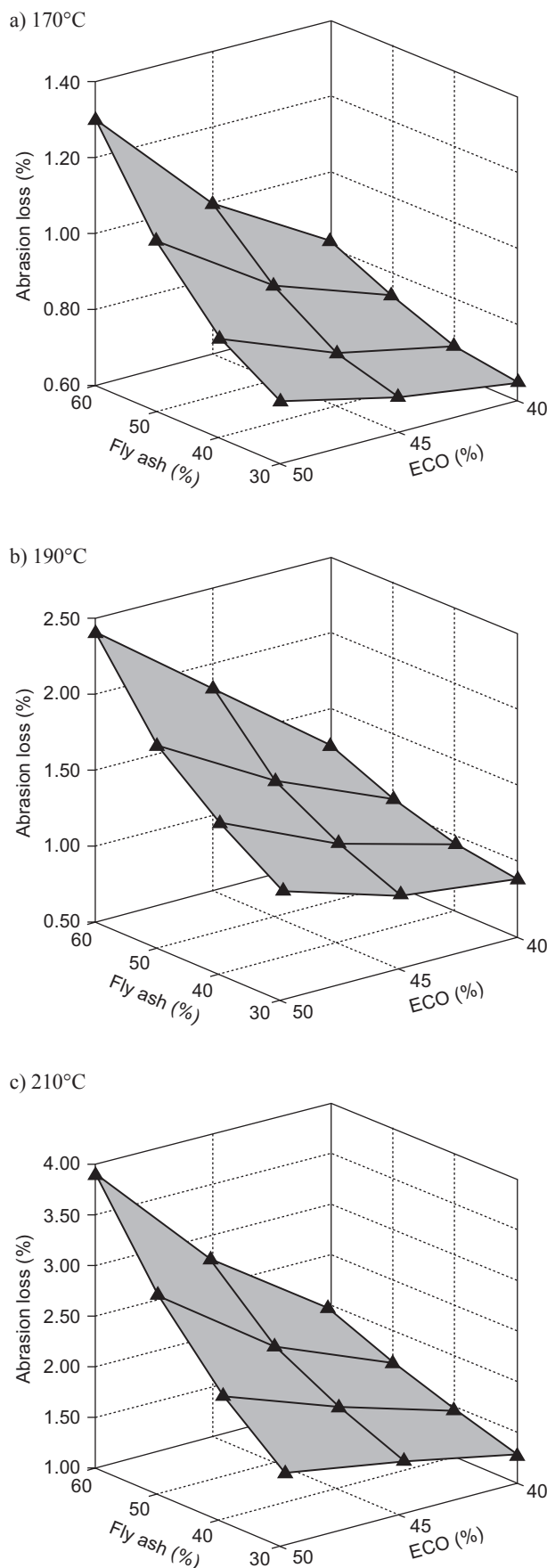


Figure 10. The abrasion loss - ECO percent relation in the samples.

This phenomenon also may contribute to the thermal conductivity decrease of the sample. The test results also indicated a relationship between the water absorption and thermal conductivity in the all FT.

#### Effect of C and FT

The measured absorption of water indicates the relative quality of near surface sample properties. The test results showed that an increase in C ratio resulted in a decrease of water absorption in all FT, and the addition of C has a major effect on the improvement of the compressive strength values. Water absorption property is an important factor affecting the durability of samples. The less water that infiltrates the sample, the more durable and resistant it is to environmental damage. So, the water absorption is measured to investigate the extent of densification in the fired body and also used as an expression to open pores. Increasing the C ratio from 40% to 50%, and 60% increases the water absorption by about 15.05%, 27.50% and 35.48% at 170°C, 15.31%, 27.95% and 36.31% at 190°C and 15.88%, 28.03% and 37.14% at 210°C, compared to the sample with 30% C and 40%ECO, respectively. This is probably due to C which has a high specific gravity. For sample with 60%C ratio and 50% ECO processed at 210°C compared to the sample processed at 170°C and 190°C were reduced the water absorption by 62.42% and 30.05%, respectively.

#### Effect of ECO and FT

According to the test results (for samples with 60% FA) increase in ECO ratio up to 71.47% by volume resulted in an increase of water absorption in all FT. Furthermore, the addition of ECO a major effect on the improvement of the water absorption values at 170°C when comparing that of the samples processed at 210°C. When compared to the samples with 30% FA that contain %60 C, increasing the FT at 170°C, 190°C, and 210°C for the samples with 60% FA, provided an increase in the water absorption by about 35.48%, 37.70% and 38.53% for 40% ECO ratio, 35.89%, 37.31% and 39.57% for 45 ECO ratio, and 37.14%, 38.95% and 40.72% for 50% ECO ratio, respectively. The water absorption increase in samples is due to the porous bond of ECO to the powder raw materials. The water absorption test results show that samples with low ECO had high strength. However, the strength was negatively changed as a result of the high addition of ECO.

#### S.E.M. analysis

S.E.M. (scanning electron microscope) was used to characterize the microstructure of samples (Fig. 4). The micrograph shows that the particles have a rough surface, with irregular shape and different sizes. According to SEM investigations (for sample with

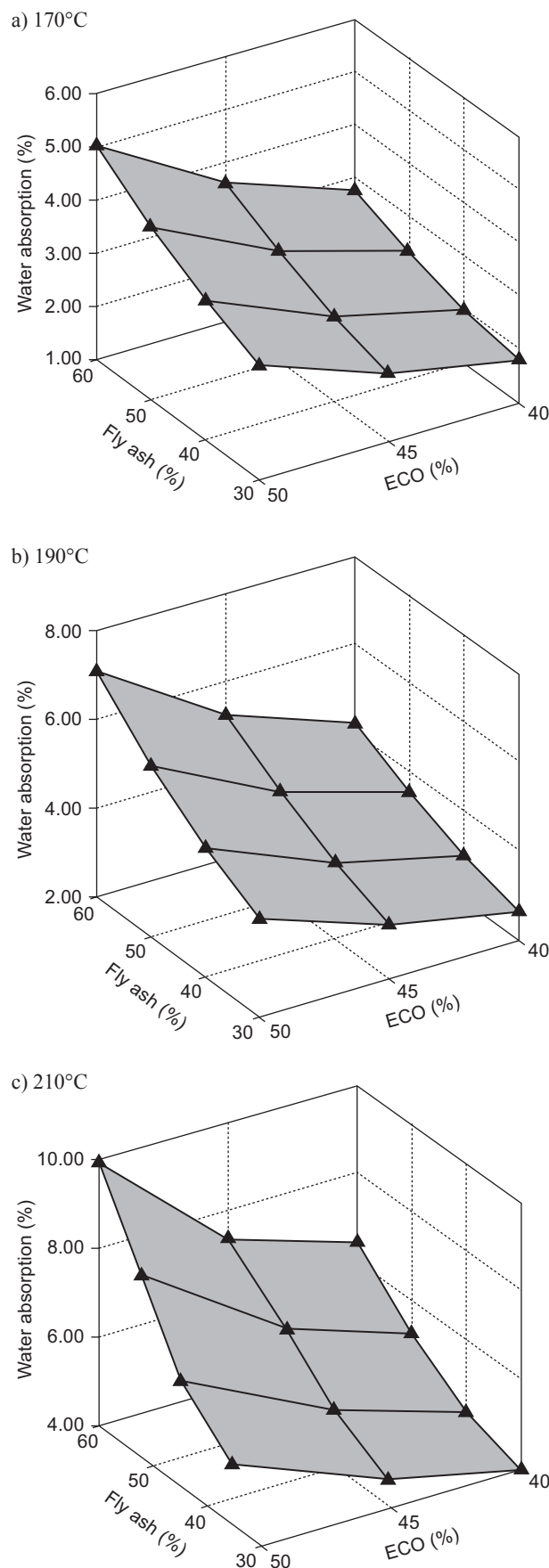


Figure 11. The water absorption and ECO percent relation in the samples.



50%ECO/60%FA/30%C/5%EP/5%PP and processed at 190°C), FA, EP and PP grains are between 1 and 3 mm and C grain thickness is between 20 and 30 mm. The SEM result shows that bond with sintering are developed among the C grains in the sample and can rarely be cavity. The cavities among the C grains are found about 3 mm. A combination is obtained among the grains of the FA, C, EP and PP. This combination is different from the C grains.

## CONCLUSIONS

The aim of this study was to evaluate the usability of FA-C-EP-PP/ECO as raw materials for building material. A basic experimental study on the thermal, physical and mechanical properties of samples containing FA-C-EP-PP/ECO as materials provided the following results.

1. FA and ECO together were effective admixtures for decreasing significantly both the compressive-tensile strength and the thermal conductivity of sample. The C alone increased all these values but decreased the water absorption and abrasion loss. The C provided tight bond among the particles, thereby increasing both the density and the thermal conductivity, in addition to increasing the compressive-tensile strength and decreasing the abrasion loss and water absorption.
2. The lowest value of the thermal conductivity, compressive-tensile strength and density in produces was obtained for sample (sample code: C36) produced with 60% FA- 30% C- 5% EP- 5% PP / 50% ECO. The lowest value of the abrasive loss, water absorption was determinate for sample (sample code: C1) produced with 30% FA- 60% C- 5% EP-5% PP / 40% ECO.
3. Densities decreased from 1.596 to 1.331 g/cm<sup>3</sup> with the increase of FA-ECO at all FT. The C decreased the density of samples.
4. There was a good relationship between density and thermal conductivity. Thermal conductivity of samples were increased with increasing of density at all FT. Thermal conductivity values were between 0.438 and 0.336 W/mK for 170°C, 0.433 and 0.272 W/mK for 190°C and 0.428 and 0.215 W/mK for 210°C. FA was more effective than ECO in the decreasing of the thermal conductivity of samples.
5. The highest compressive-tensile strength was obtained as 9.49 and 1.078 MPa, respectively. The low firing temperature (170°C) was more effective than high C ratio in the increasing of the strengths. FA-ECO and high FT (190°C and 210°C) had a negative effect on the strengths.
6. The thermal conductivity decreased when the water absorption of samples increased. The thermal conductivity was higher when the water absorption of samples was between 1.80% and 5.00% than those of the samples having moisture content between 5.00%

and 9.78%. There was an about relationship between the water absorption and thermal conductivity for all conditions.

7. The abrasion resistance of sample can be considerably improved with the addition of C. The abrasion resistance of sample containing high C decreases with increasing content of FA-ECO.

In this study we demonstrated that it is possible to utilize FA-C-EP-PP and ECO as alternative raw material resources for the production of the building material

## Nomenclature

$M_D$	Mass of the specimens after drying (g)
$M_W$	Wet mass of the specimens after being removed from the water tank (g)
$F_{Tensile}$	Tensile strength (MPa)
$F_{compressive}$	Compressive strength (MPa)
H	Constant of Shoterm QTM Aparatus
I	Current density in heater wire (A)
K	Constant of Shoterm QTM Aparatus
k	Thermal conductivity coefficient (W/mK)
$t_1$	Temperature of startup (K)
$t_2$	Temperature of finish (K)
$T_{avr}$	Average temperature (K)
$V_1$	The startup voltages of thermoelement (mV)
$V_2$	The finish voltages of thermoelement (mV)
WA	Rate of water absorption (%)

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