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RESEARCH ARTICLE

The Effects of Tragacanth Addition on the Thermal and Mechanical Properties of Lightweight Concretes Mixed with Expanded Clay

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Abstract

The effects of adding tragacanth, which is a natural resin, as expanded clay aggregate and binder to specimens on the thermal and mechanical properties of lightweight concretes has been examined in this study. Expanded clay with diameters of 4 - 8 mm and by proportion 5%, 10% and 20% of cement's weight was added to specimens in the study. As a binder, by addition of 1% tragacanth to cement at the rate of 1%, new lightweight concrete specimens with densities varying between 867 kg/m^3 to 1452 kg/m^3 were produced. Tragacanth with the same proportions of mixture was prepared in pure specimens in order to compare. Water / cement ratio was kept constant in all mixtures. At the end of a drying time of 28 days, thermal conductivity, specific heat capacity, compressive strength, modulus of elasticity, water absorption and drying quantities of specimens were confirmed. As a result, decrease of thermal conductivity, density and compressive strength of specimens was seen through adding tragacanth and raising the amount of expanded clay.

Keywords

Expanded clay · tragacanth · thermal conductivity · lightweight concrete

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1 Introduction

The majority of energy consumption in buildings takes place by conduction in structure units such as walls, the roof or upholstery. Decrease of thermal conductivity of these types of structure units provides an important utility in terms of energy consumption. Lightweight concrete can be produced by using lightweight aggregates [1]. Lightweight concretes are preferred due to their low density features, low thermal conductivity and architectural flexibility [2, 3].

Studies to produce low density concrete have focused on the incorporation of lightweight aggregates of different types into the cement [2, 4, 5]. Industrial and municipal waste and natural or artificial aggregates are materials used in the production of lightweight concrete [6–10].

Aggregates are divided into two parts as natural (pumice, perlite, vermiculite etc.) and artificial (fly ash, expanded perlite, expanded clay etc.) [3].

By producing reinforced concrete structures with the porous aggregates, both thermal conductivity and dead loads can be reduced. Porous aggregates have low thermal conductivity due to their resistance to exposure to heat transfer of inert gases in the pores within. Also, increasing the pore amount in same volume reduces the mass of the material thus causing remission of structure [11].

Expanded clay, whose raw material is clay, is widespread in nature. Expanded clay has the feature of expansion because when it is exposed to high temperatures, gas-filled pores are formed with the release of gases in the chemical structure. In this way, the volume can be raised by one and a half to six times the initial volume. It has a sintered solid outer shell. Products like lime, coke and fuel should be added to increase the expansion into clay mud. The expansion process is performed in rotary kilns at temperatures of 1000°C and 1300°C [12].

In the expansion process, the expansion amount depends on the thermal process. Thus, aggregates in the range of 300 to 800 kg/m^3 density and of different piece diameters can be produced with different temperatures and cooking times [13].

Expanded clay is widely used not just in the production of skyscrapers, bridges, piers and platforms as part of their lightweight concrete; it can also be used in buildings as concrete brick, plaster and filler materials too. Instead of soil in greenhouses and green roof buildings, it can provide a natural growth medium for plants. As aggregate in the construction of asphalt roads, it is used in filling uneven rough fields in geotechnical. Forces on the lateral surface are reduced in sealants because it is lightweight. It is convenient as an overload to pipelines and to provide thermal insulation through filling around hot water and steam lines [14]. It is also used in the filtration of waste and clean water [15].

Tragacanth, used as a binder, is a type of gum that is obtained by drying the resin leaking from a thorny plant, tragacanth (*Astragalus*), under natural conditions [12].

Tragacanth is acidic polysaccharide that has a complex structure containing trace amounts of starch and cellulose. It has high viscosity properties due to the high content of fucose, xylose, and galacturonic acid and methoxy groups [16]. Chemically, tragacanth consists of two parts. The first portion is called trangacanthic acid or bassorin, and forms about 60% to 70% of tragacanth. The second portion, which is called tragacanthine, is the small water-soluble part [17]. Tragacanth is used in the chemical, pharmaceutical and food industries [18].

From an economic and environmental viewpoint, materials used in a building's structure should be expected to be both natural and to decrease heat loss and gain. In this study the utility of expanded clay and tragacanth, which is a natural gum, have been investigated experimentally. In particular, we intended to decrease the thermal conductivity by adding tragacanth to lightweight concrete products. The properties of the new materials were investigated and the utility of these materials was discussed.

2 Experimental Study

2.1 Materials

Expanded clay with a diameter of 4 - 8 mm, which was used to produce new specimens, was obtained from Liapor Company, Austria. CEM IV/B (P) 32.5 R pozzolanic cement was added to a gum tragacanth-water solution as a binder to expanded clay, as shown in Fig. 1. 100 g of powder gum tragacanth was waiting to be dissolved in 5 l of water. It was dissolved and separated by stirring continuously for two days. Then bassorin, the insoluble part, was filtered out and the remaining part was added to the mixtures. Chemical components of cement and expanded clay are given in Tab. 1.

Tab. 1. Chemical analysis of cement and expanded clay

Components	Cement (%)	Expanded clay (%)
SiO_2	23.51	54.60
CaO	58.51	3.34
Al_2O_3	6.15	17.60
Fe_2O_3	4.00	6.90
MgO	2.27	4.00
SO_3	2.37	-
Cl	0.10	-
K_2O	-	3.58
Na_2O	-	0.71
Fire loss	2.04	7.81
Not available	0.72	-

2.2 Mixtures

Expanded clay with a diameter of 4 - 8 mm was mixed with cement in the proportions 5%, 10% and 20% of weight. Water to cement ratio in the mixtures was 0.5. Tragacanth was added to all mixtures by 1% of weight. Specimens into which no tragacanth was added were prepared in order to observe the effects of adding tragacanth. Mix proportions of samples are given in Tab. 2. For thermal conductivity and specific heat measurements, prepared mixtures were poured into sheet metal molds with sizes of 150 mm x 60 mm x 20 mm in accordance with measurement device probe sizes. 100 mm x 100 mm x 100 mm sized molds were used in order to detect mechanical properties. As shown in Fig. 2, specimens with six distinct mixtures and two different sizes were generated. Specimens were left at room temperature for 28 days in order to dry.

2.3 Experimental study

The thermal conductivities and specific heats of specimens were detected by Isomet 2104 portable heat transfer analyser, which makes measurements by using the hot wire method according to Norm (DIN) 51046. Measurements were made on different parts of the specimens five times and the averages of these measurements were used in the study. Measuring device detected thermal conductivity coefficient in the range between 0.04 W/mK and 6 W/mK with 5% precision and volumetric heat capacity in the range of 4.0×10^4 J/m^{3}K and 4.0×10^6 J/m^{3}K with 15% precision. The temperature was between 22°C and 25°C during measurement. Thermal diffusivity of specimens whose thermal conductivities, specific heats and densities were known was determined by calculating with the equation below:

$$a = \frac{k}{\rho . c} \tag{1}$$

a represents heat transfer coefficient (m^2/s), k represents heat conductivity coefficient (W/mK), ρ represents density (kg/m^3) and c represents specific heat (J/kgK).

A device that can apply force up to 3000 kN for compressive stress testing was used. (The lower plate was fixed and the upper plate moved to apply the compressive force.)

3 Results and discussion

3.1 Unit weight

As shown in Fig. 3 and Tab. 3, the densities of the samples decreased with increasing clay content in the mixture. As expected, owing to the pores in the structure of expanded clay, increasing amounts of expanded clay in the unit volume of the mixture lead to a decrease in density. Also, as shown in Fig. 3, tragacanth addition to the mixtures decreased the density. The


(a) (b)

Fig. 1. a) Expanded clay b) Leaf tragacanth

Fig. 2. Samples

density of the sample with 5% tragacanth was 19.6% lower than the tragacanth-free sample. In a similar fashion, the densities of samples with 10% expanded clay and 20% expanded clay content were 13.2% and 23.8% lower, respectively.

Weight reduction due to decreases in concrete density leads to decreases of the stress that acts on the building components. Therefore, reduced building weight may improve the strength of the building against earthquakes [19]. The reduced building weight may also allow a reduction in reinforcement steel and reinforced concrete cross-sectional areas leading to reduced costs. Furthermore, reducing the amount of cement required per unit volume will have a contribution to sustainable environment [20].

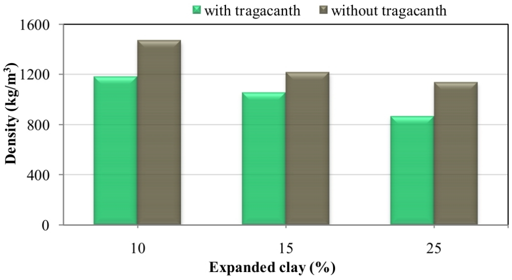

Fig. 3. Density variation according to expanded clay ratio

3.2 Determination of thermal conductivity, specific heat and thermal diffusivity

In previous studies, a strong relationship has been found between thermal conductivity and density. Thermal conductivity is reduced by decreases in density [4–6, 21–24]. As seen in Fig. 4, thermal conductivity decreases with the increase of expanded clay amounts in the mixtures. The decrease of thermal conductivity with increasing expanded clay amounts is caused by increasing porosity. As a significant consequence, adding tragacanth into the mixtures decreased thermal conductivity. The thermal conductivity of the sample with 5% tragacanth content was 27.7% lower than the tragacanth-free sample. By increasing the tragacanth content, the difference between the thermal conductivities of the samples with and without tragacanth content increased. The sample with 20% expanded clay content had 35.2% lower thermal conductivity than the tragacanth-free one. Artificial pores formed in the tragacanth-added samples because of the loss of water content during desiccation, which caused larger porosity and therefore additionally decreased thermal conductivity coefficients. In Fig. 4, a strong relationship can be seen between thermal conductivity and density in samples with tragacanth content ($R^2 = 0.997$).

Concrete is assumed to be an uncompressible substance. Therefore, specific heat varies with temperature [25]. The higher the specific heat value of a substance, the higher the en-

Tab. 2. Mix proportions

Specimen code	105	110	120	205	210	220
Expanded clay: Cement	5:100	10:100	20:100	5:100	10:100	20:100
Tragacanth (%)	0	0	0	1	1	1
Water/Cement	0.50	0.50	0.50	0.50	0.50	0.50

Tab. 3. Thermal and mechanical properties of the mixtures

Specimen code	105	110	120	205	210	220
Density (kg/m^3)	1472	1217	1139	1183	1056	867
Thermal conductivity (W/mK)	0.418	0.368	0.332	0.302	0.263	0.215
Specific heat (J/kgK)	1073	1282	1315	1200	1317	1362
Compressive strength (MPa)	9.88	7.72	6.16	5.46	3.97	1.48
Thermal diffusivity (mm^2/s)	0.265	0.236	0.222	0.213	0.189	0.182

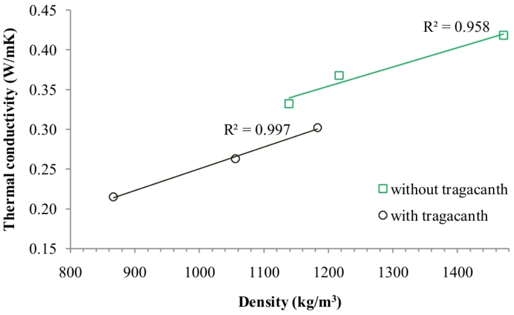

Fig. 4. Relation between thermal conductivity and density

ergy requirement for temperature increment of unit mass. In Fig. 5, specific heat increase owing to decrease of density is shown. Upon the addition of tragacanth to the mixtures, specific heat increase was raised. The specific heat of the sample with 5% expanded clay content was 11.83% higher than the tragacanth-free sample. The specific heat values of the samples with 10% and 20% expanded clay content were 2.73% and 3.57% higher than the tragacanth-free mixtures, respectively. Preferring structural members with higher specific heat will be advantageous.

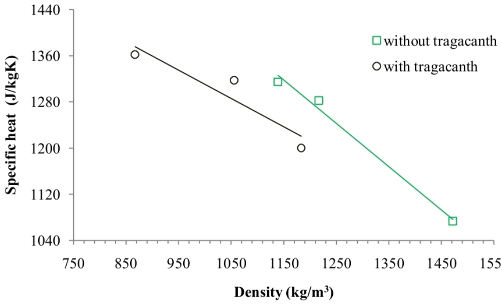

Fig. 5. Effect of density on the specific heat of tragacanth adding concrete mixtures

Another thermal property of the materials is thermal diffusivity. Thermal diffusivity indicates the diffusion rate of the heat through the substance. Lower thermal diffusivity means that most of the heat is stored and only a small amount of heat is conducted. As shown in Fig. 6, thermal diffusivity decreases when density decreases. Thermal diffusivity of the tragacanth-free samples was higher. The thermal diffusivity of the mixture with 5% expanded clay content was 19.6% lower than the tragacanth-free mixture. As a desired result, the thermal diffusivity decreased with the addition of tragacanth.

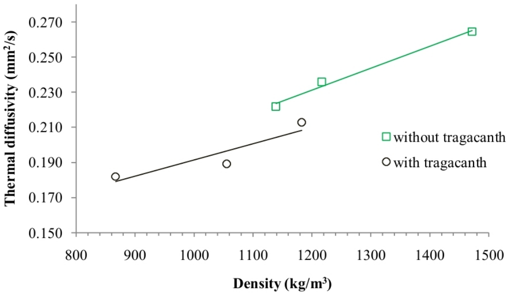

Fig. 6. Effect of density on the thermal diffusivity of tragacanth adding concrete mixtures

3.3 Compressive strength

Fig. 7 shows the effect of density on compressive strength. With the increase in density, compressive strength also increases. In the mixture with an increasing amount of expanded clay that causes a decrease in density, compressive strength is decreasing. Also, adding tragacanth to the mixtures significantly weakened the compressive strength. In 1139 kg/m^3 density, while the compressive strength of the mixture including 20% expanded clay without tragacanth was 6.16 MPa, the compressive strength of the mixture including 5% expanded clay with tragacanth was 5.46 MPa.

The density and compressive strength of the mixture containing 5% expanded clay and with tragacanth were lower than the density and compressive strength of the mixture containing 5% expanded clay and without tragacanth, 19.6% and 44.7%, respectively. The compressive strength of the mixture containing 10% expanded clay with 1056 kg/m^{3}density was 27.3% lower than the mixture containing 5% expanded clay. The compressive strength of the mixture containing 20% expanded clay was 62.7% lower than the mixture containing 10% expanded clay. In the mixtures with the addition of tragacanth, as expanded clay ratio increased, the compressive strength decreased more. From the results obtained, it can be said that concrete formed from mixtures cannot be used as a carrier element in construction.

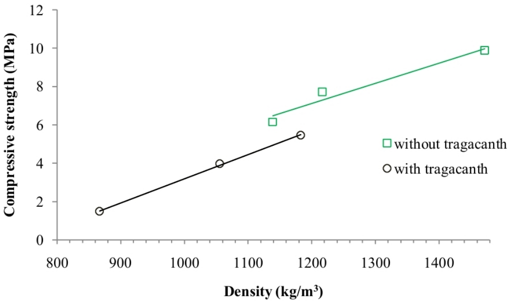

Fig. 7. Effect of density on the compressive strength of tragacanth adding concrete mixtures

3.4 Modulus of elasticity

Elasticity module plays an important role in determining the elongation and deformation of concrete construction elements. It is mostly calculated by theoretical methods [4, 26]. In this study, the following equation proposed by the Turkish Standards Institute and giving better results has been used [27].

$$E = 3.25(f_{ck})^{1/2} + 14 \qquad (2)$$

In this equation, E is the elasticity module (GPa), and f_{ck} is the characteristic compressive strength (MPa). Fig. 8 shows the change in the elasticity module with density. As shown in the figure, as a result of increasing the expanded clay ratio in the mixtures, the elasticity module decreases with a decrease in density. The lower densities of the samples with tragacanth caused their elasticity modules to be less than the elasticity modules of the mixtures without tragacanth. The mixture containing 20% expanded clay with tragacanth was 18.5% lower than the mixture without tragacanth.

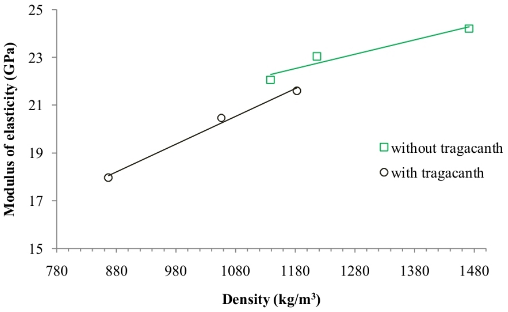

Fig. 8. Effect of density on the modulus of elasticity of tragacanth adding concrete mixtures

3.5 Water absorption

After determination of the dry weight of the samples, they were kept in water (24 hours) by immersing into the water until there was no change in their weight. Water in the concrete is important because it damages the construction elements with freezing and thawing cycles during the cold seasons. Therefore, the water absorption of concrete should not exceed certain values. As shown in Fig. 9, the water absorption rate increased when density decreased. It was discovered that the mixtures with tragacanth retained more water; increasing the amount of expanded clay enhanced the rate of water absorption. With the increase in the amount of expanded clay, increasing the amount of water absorption can be considered to be due to wider aggregate adhesion surfaces. The water absorption ratio of the mixture containing 20% expanded clay with 867 kg/m^3 density and tragacanth was 34.1% more than the mixture containing 20% expanded clay without tragacanth.

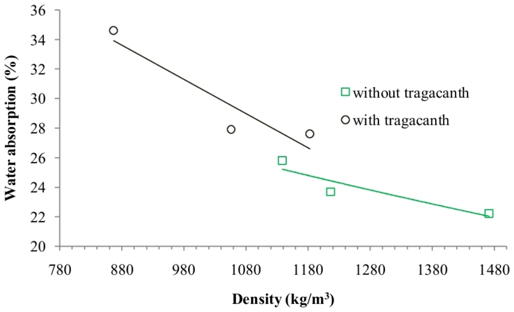

Fig. 9. Effect of density on the water absorption of tragacanth adding concrete mixtures

3.6 Ultrasonic pulse velocity

The velocity of ultrasonic sound varies depending on the porosity of the material. The porosity varies depending on density. For this reason, the velocity of ultrasonic sound varies depending on density and compressive strength [28]. In Fig. 10, the change in the velocity of ultrasonic sound with amount of expanded clay and tragacanth can be seen. The addition of tragacanth to the mixtures decreased the velocity of ultrasonic sound.

An increase in the amount of expanded clay in the mixtures decreased the density and the compressive strength and also the velocity of ultrasonic sound. The velocities of ultrasonic sound of the mixtures with tragacanth varied between 1389 - 1587 m/s and the velocities of ultrasonic sound of the mixtures without tragacanth varied between 2083 - 2564 m/s.

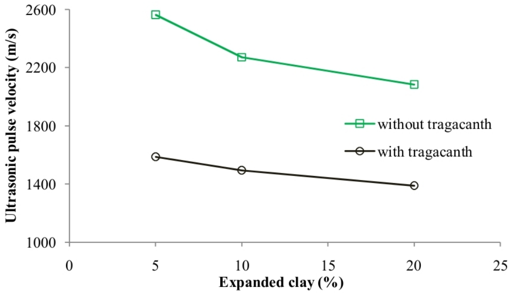

Fig. 10. Ultrasonic pulse velocity and expanded clay rate

4 Conclusions

In the study, it was ascertained that in the mixtures with expanded clay aggregate and the addition of tragacanth, increasing the amount of expanded clay reduced the density and thermal conductivity, but at the same time also decreased the compressive strength values. Adding tragacanth to the mixtures was improved thermal conductivity about 30%. Thermal conductivity and density of the mixture can be reduced by adding tragacanth. A strong correlation between thermal conductivity and density has been seen. Specific heat and thermal diffusivity values?? with the addition of tragacanth to the mixture give better results than mixtures without tragacanth. The water absorption was increased by adding tragacanth to the mixtures. Ultrasonic sound velocity was increased because of air bubbles entering addition tragacanth. Compressive strength and module of elasticity were adversely affected by adding tragacanth to the mixtures. Using lightweight concrete mixed with expanded clay and tragacanth may be beneficial in both earthquake-resistant and low-energy consumption buildings. Since the tragacanth is an organic material, durability of the studied samples should be found. One of the issues that should be studied is how to improve the compressive strength.

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