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A comparative study on the thermal conductivities and mechanical properties of lightweight concretes

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A R T I C L E I N F O

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A B S T R A C T

Thermal conductivity of the materials used in buildings is one of the major factors affecting the heat transfer. Higher thermal conductivity of building walls results in higher heat losses, and in order to maintain the same temperature inside a building, energy consumption for heating or cooling increases. To reduce the heat loss, thus decrease the energy usage, materials with lower thermal conductivities should be preferred. Lightweight concretes can be used for this purpose. However, the properties of these concretes may vary depending on the materials used. The main objective of this experimental study is to compare the properties of lightweight concretes produced with different lightweight aggregates. Lightweight concretes in a wide range of unit weights from approximately 300–1800 kg/m^3 were prepared in the experimental program. Some properties of the concretes containing pumice and expanded polystyrene beads were obtained. Properties of concretes with expanded perlite and autoclaved aerated concrete determined in previous studies are also included in comparisons and discussion. The test results showed that, depending on the amount and type of lightweight aggregate, unit weight of concrete can be reduced and concretes with various physical and mechanical properties of can be achieved. Thermal conductivity was reduced with the use of lightweight aggregates and for all the lightweight concretes considered, a good relationship was obtained between thermal conductivity and unit weight of concrete. Reductions in the compressive strength and modulus of elasticity of concretes have been obtained with decreasing concrete unit weights. The reduction in strength was more for the concrete containing expanded polystyrene beads.Results showed that strong relationships exist between modulus of elasticity and unit weight of concrete. Results showed that strong relationships exist between modulus of elasticity and unit weight of concrete.

1. Introduction

Heating and cooling costs of a building during its life span form a major part of its operating costs. Heating and cooling also occupies an important role in energy consumption. New energy lines are needed for most countries for increasing demand. It is expected that both economical and environmental constraints will increase in the coming years and one of its effects on construction industry is to achieve more energy efficient buildings and construction materials [1]. There may be several ways to reach this goal and one of the major methods of obtain such buildings is to improve their thermal insulation properties. Insulation against environmental conditions and improving the energy efficiency of buildings is becoming increasingly important. The insulation properties of the buildings are one of the most important factors affecting both the operating cost and thermal comfort. Reduction of the heat loss in buildings decreases the consumption of energy, thus, reduces the cost of both heating and cooling [2]. As a result of the lower use of energy, improvements in thermal insulation also affect sustainability.

The importance of insulation has been much neglected in Turkey and until recently there was no legal obligation for the insulation of buildings. However, a new legislation came into effect in 2011, which requires new buildings to be constructed satisfying certain criteria regarding thermal insulation [3]. In addition, the importance of insulation on the heating and cooling costs has also been better understood in Turkish society in recent years and the insulations of many existing buildings in the country are being improved. Because ordinary brick walls do not satisfy the thermal properties required, thermal insulation materials are applied externally onto the walls for both existing buildings and new constructions. This approach means increased workmanship, scaffolding, and cost for

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Table 1
Aggregate grading.

Aggregate type	Percentage passing						
	Sieve size (mm)						
	16	8	4	2	1	0.5	0.25
Natural sand	100	100	100	96	82	54	18
Limestone aggregate	100	71	22	0	0	0	0
Pumice	100	70	20	0	0	0	0

the new constructions. To reduce the cost of workmanship, and improve the thermal properties of building walls, many innovative products are now being introduced into the market. These products include materials such as lightweight concrete infilled hollow bricks, sandwich of brick-lightweight concretes or panels of lightweight concretes. A common property of almost all of these products is that they contain lightweight concrete obtained by different aggregates or methods. The main characteristic of lightweight concretes is their higher porosity. Most of the pores are enclosed pores, which provide high thermal insulation. As a result, lightweight concrete is a suitable material for thermal insulation of structures [4]. Because of their higher porosity, the mechanical and physical properties of the concretes are different than those of normal concrete. Many factors may affect the properties of lightweight concretes.

Since approximately 75% of the concrete volume is occupied by aggregate, the properties of aggregate greatly affect performance of concrete [5]. Natural or artificial lightweight aggregates can be used for producing lightweight concretes. The studies on these aggregates focus mostly on a particular aggregate [6–13]. Properties of lightweight aggregates are usually presented as intervals in reference manuals and codes [14]. However, such comparisons based on literature do not provide actual data for a particular material, it is not always clear which criteria these intervals are based on, and as a result may cause misleading conclusions. In addition, the results may not always be comparable due to the differences in mixture proportioning. Although there many studies available on the effects of various materials and mixtures on the properties of lightweight concretes, direct comparisons of lightweight concretes are very limited.

The main objective of this study is to provide more data on the effects of some lightweight aggregate concretes from the mechanical properties and thermal conductivity points of view. In the experimental program, the natural normal weight aggregates were partially replaced by the pumice and expanded polystyrene beads at various replacement ratios. For a better discussion, the results obtained were evaluated together with the results from previous studies including autoclaved aerated concrete and expanded perlite obtained by the same authors.

2. Experimental details

2.1. Materials

In this study, two lightweight concrete series were produced in which pumice and expanded polystyrene beads were used as aggregates. Same ordinary portland cement (CEM I 42.5 R) and same superplasticizer was used in all the mixtures. An air entraining admixture was also included in some concretes. The same locally available natural sand and limestone coarse aggregate were used in the mixture series and their particle size distributions are shown in Table 1.

The test results obtained using pumice and expanded polystyrene beads were discussed together with those of the mixtures containing expanded perlite, and the properties of the expanded perlite are given in a previous study performed by the authors [6].

2.1.1. Pumice

Pumice is light-colored aggregate with a particle density in the region of 700–900 kg/m^3. The pumice used was obtained from Nevsehir which is located in the central region of Turkey. Unit weight of the pumice was 406 kg/m^3. Water absorption of the pumice at 30 min was measured as 15% by weight. Experience showed that in some cases, pumice particles with higher density may exist in low amounts in the pumice aggregates. Therefore, to ensure a homogeneous lightweight aggregate, only the particles that floated on water were used in the mixtures. Particle size distribution of the pumice is shown in Table 1. As seen in these results, its particle distribution is not the same as that of the normal weight aggregates. Thus, when the pumice content increases, the aggregate gradation in concrete is slightly modified for each replacement ratio.

2.1.2. Expanded polystyrene

The expanded polystyrene beads used in this study had particle sizes of 2–4 mm, 4 mm, and 4–8 mm. Polystyrene is expanded with an industrial process and the expansion amount affects both the size and the unit weight of the polystyrene beads. As the particle size increases (due to more expansion), the density of this material is reduced. Thus, the unit weights of expanded polystyrene beads used in the study were 54, 22 and 13 kg/m^3. In order to have similar grading to those of the other aggregates, combinations of these different particles were used. All the expanded polystyrene beads were spherical in shape. The water absorption of the expanded polystyrene beads at 1day was measured as 0.7% by volume. Since the polystyrene particles do not absorb water, and have smooth surfaces compared to other lightweight aggregates, there is no need for pre-absorption water and they require less water during the production of lightweight concrete.

Expanded polystyrene boards are the most common and widely used materials for the thermal insulation of buildings in Turkey. When a new thermal insulation material is introduced into market, its effectiveness is compared mostly to such boards because it is well known that their thermal conductivities are very low. Concrete mixtures containing only expanded polystyrene beads as aggregates were prepared in the study. To compare the thermal conductivity of the lightweight concretes produced with the polystyrene beads and also other lightweight aggregates, polystyrene boards were included as reference materials in the study. Expanded polystyrene boards obtained from the same producer were used in the experimental study for a better comparison and discussion of the thermal diffusivity of the lightweight concretes produced. Four different expanded polystyrene boards having unit weights between 16 and 30 kg/m^3 were used for this purpose.

2.2. Mixtures

In the experimental study, two different series of concrete mixtures were prepared, the details of which are given below. In addition to these mixtures; results from a previous study with expanded perlite aggregates, obtained by the same authors, were also included in the discussions. The properties of the mixtures containing expanded perlite are given elsewhere [6].

2.2.1. Mixtures containing pumice

In this series, seven concrete mixtures having different unit weights were prepared by using pumice, natural sand and limestone coarse aggregate. Their mixture proportions are given in Table 2. Effective water/cement ratio was 0.43 and kept constant