Scientific Research and Essays Vol. 5(24), pp. 3826-3833, 18 December, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Investigation of some physical and mechanical properties of concrete produced with barite aggregate

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Accepted 29 April, 2010

This study analyzed some physical and mechanical properties of concrete produced with barite ($BaSO_4$) aggregate supplied from Muş province of Turkey. Unit weight (UW), water absorption (%), ultrasound pulse velocity (UPV), Schmidt hardness (SH), modulus of elasticity (ME), compressive strength (CS), tensile strength (TS) and thermal conductivity (TC) of the concrete were analyzed. For the experiments, 6 series of concrete containing 0, 10, 20, 30, 40 and 50% volume of barite aggregate were prepared. To determine thermal conductivity coefficient, this ratio was increased to 100%. Experimental results for normal concrete and barite concrete were compared.

Key words: Concrete, barite, heavyweight concrete, thermal conductivity.

INTRODUCTION

Heavyweight concretes have been produced for a long time. These types of concretes were first used to enhance the safety of particular buildings having the tendency of sliding and which had no safety against overturning (Osma, 2002). With the development of nuclear energy and particularly for protection from fatal rays such as neutron and γ, which have the ability to penetrate objects, heavyweight concrete began to be used as a shield. Heavyweight concretes are also used in nuclear shelters and in the walls of X-Ray rooms. Heavyweight concretes are produced for their resistance to nuclear radiation, not for their weight (Temur, 2004). Concretes with a specific gravity greater than 2600 kg/m^3 are called heavyweight concretes while the aggregates with a specific gravity of greater than 3000 kg/m^3 are called heavy aggregates (Akkurt, 2008). Barite ($BaSO_4$) is the most common heavy aggregate used for heavyweight concrete. Barite occurs at 90% pureness in nature and can be used as crushed stone. The main function of barite in concrete shields is to produce a concrete which can be processed at maximum density, with adequate structural strength and to determine physical, chemical, thermal and structural properties (Kilincarslan et al., 2006).

As the barite ore that occurs in Turkey has high specific gravity and abundant reserves, it can be ideal choice for use as an aggregate in concrete. The barite aggregate used in this study was supplied form Muş province, which has a visible reserve of approximately 755.000 tons and non-visible reserve of approximately 2.49 million tons. Several previous studies have examined the mechanical, physical and chemical properties of different types of concrete produced with barite aggregate. Kilincarslan et al. (2006) determined the effect of barite aggregate content on the mechanical and physical properties of heavyweight concrete. Akkurt et al. (2008) investigated the effect of freezing and thawing on the mechanical and physical properties of concretes containing various proportions of barite aggregate. Akkurt et al. (2005) compared the radiation shielding properties of concrete containing normal weight aggregates against those containing various amounts of barite. El-Sayed Abdo (2002) reported the theoretical calculation of both the total mass attenuation coefficients for gamma rays and the effective removal cross-sections for fast neutrons. Topçu (2003) conducted a work on heavyweight concrete mixtures at different w/c ratios, which were prepared in order to determine the most favorable w/c ratio (0.40) of heavyweight concrete produced with barite aggregate.

In the literature there was no detailed study on the mechanical, physical properties and thermal conductivity

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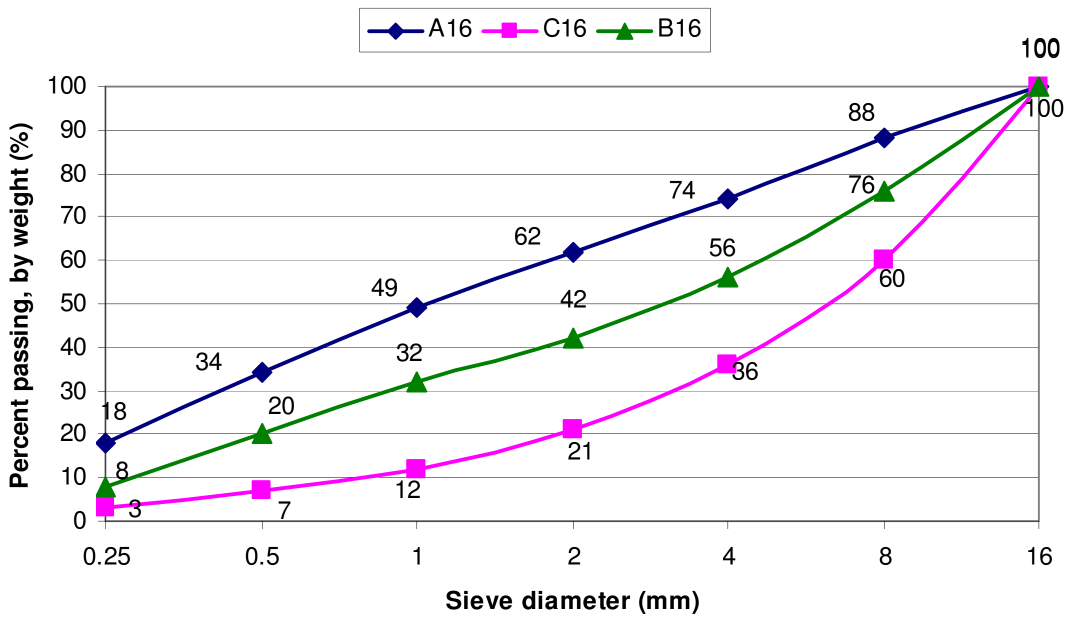

Figure 1. Granulometry curve of aggregates used in the experiments.

Table 1. Analysis of barite aggregate used in the experiments.

Constituent	Density (gr/cm^3)	$BaSO_4$	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SrO	PbO	MnO	Loss of ignition
Wt. (%)	4.35	94.24	2.23	0.30	0.13	0.04	0.15	2.61	0.00	0.00	0.14

Table 2. Chemical composition of the Portland cement (CEM I 42.5).

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl-	Loss of ignition	Insoluble ruin
Wt. (%)	19.3	5.57	3.46	63.56	0.86	0.13	0.80	2.91	0.013	2.78	0.42

Table 3. Physical and mechanical properties of the CEM I 42.5.

Time of setting (min)		Specific surface Blaine (cm^2/g)	Specific gravity (g/cm^3)	Compressive strength 28 days (MPa)	Volume expansion (mm)
Initial	Final				
119	210	352	3.15	52.7	1.00

of barite-containing heavyweight concretes. This experimental study investigated the mechanical and physical properties of concrete specimens produced by replacing natural coarse aggregate with barite aggregate at 0, 10, 20, 30, 40 and 50% by volume. Furthermore, the thermal conductivity coefficients of the concretes were calculated, which were obtained by increasing the barite ratio in the mixture to 100%.

EXPERIMENTAL STUDY

This experimental study used normal crushed stone aggregate and also barite aggregate supplied from Muş End. Diş Ticaret A.Ş. Grain diameter of the barite and crushed stone aggregates were arranged at 0-16 mm. The granulometry of both aggregates used in the experiments were formed according to the B16 curve, which is considered ideal at Turkish Standard 802 (Figure 1). The analysis of the barite aggregate is shown in Table 1. In unit weight experiments performed on these aggregates, the unit weight of barite aggregate was 4.0 gr/cm^3, and unit weight of normal aggregate was 2.60 gr/cm^3.

W/C ratio was taken as 0.60 to be obtained slump value of 5 cm and the dosages of the concretes were 400 g/dm^3. The properties of the CEM I 42.5 cement supplied from Elaziğ Altinova Cement Factory used in the study are given in Tables 2 and 3. Cube-shaped specimens with a volume of 1 dm^3 were prepared for

Table 4. Quantity of aggregates used in the experiments (gr/dm^3).

	C	B10	B20	B30	B40	B50	B100
Barite aggregate	0	260.4	520.8	781.2	1041.6	1302	2604
Normal aggregate	1687	1517.5	1348.9	1180.2	1011.7	843	0

Figure 2. Thermal conductivity coefficient measurement device with hot wire method.

analysis of unit weight, water absorption percentage, modulus of elasticity, ultrasound pulse velocity (UV), Schmidt hardness (SH) and compressive strength. Each series contained 6 specimens. In addition, 40 x 40 x 160 mm specimens were prepared for tensile strength experiments 60 x 150 x 20 mm specimens were produced for measuring thermal conductivity coefficient. The specimens were prepared in a laboratory and were released from the molds after 24 h. The specimens were then cured in lime-saturated water at 22ºC for 28 days. The water-saturated weights of the specimens were determined before they were transferred to a drying oven at 80ºC. The specimens were removed from the drying oven and allowed to reach room temperature. The dry weights were determined and unit volume weights were calculated according to Archimedes' principle. Three specimens were used to measure ultrasound pulse velocity (UV) and Schmidt hardness (SH) values. The remaining specimens were subjected to compression tests. Unlike the specimens described above, the specimens that were produced for tensile strength and thermal conductivity experiments underwent a 28-day curing period and were kept at room temperature prior to experiments.

Since the aim of this study was to investigate the physical and mechanical changes in concretes after increasing the barite ratio in the mixture, control samples (C series) were produced. The whole aggregate amount calculated for this purpose was normal aggregates. The amount of barite aggregate used in the experimental concretes was calculated according to the absolute volume method. According to this method, normal aggregate volume in the mixture was decreased by 10% and instead 10% barite aggregate was added and B10 series concrete were produced The experimental series were termed B10, B20, B30, B40 and B50 series, containing 10, 20, 30, 40 and 50% barite, respectively. To calculate thermal conductivity coefficients, barite ratio was increased to 100%. The amounts of aggregates used in the concrete mixture which was prepared according to ACI 211.1 Keleştemur and Yildiz (2009), Keleştemur et al. (2009) are given in Table 4.

Elasticity module was calculated with the following formula;

$$E = 10\,\frac{V^2 \rho}{g} \tag{1}$$

Where V is ultrasound pulse velocity (km/s), E is modulus of elasticity (MPa), ρ is density (kg/m^3) and g is acceleration due to gravity (9.81 m/s^2) (Kilincarslan, 2006).

Thermal conductivity coefficients were measured using the Hot Wire method with the Shotherm QTM device indicated in Figure 2. In the Hot Wire method, the heater wire on the probe is placed between the well-insulated material whose thermal conductivity is known and the specimen inside the probe. The device performs the necessary calculations and with its built-in micro computer and the display indicates the numerical thermal conductivity of the material for a certain temperature value (Yilmazer, 2009).

RESULTS AND DISCUSSION

The results of unit weight, water absorption, ultrasound pulse velocity (UV), Schmidt hardness (SH), modulus of elasticity, compressive strength and tensile strength experiments performed on concrete specimens using different ratios of barite aggregate are given in Figures (3 to 9). Figure 3 shows the changes in barite aggregate ratio and unit volume weight. As indicated in the Figure, the unit volume weight increased in proportion to the barite content. The average unit volume weight of concretes containing 50% barite was measured as 2728 kg/m^3. Considering that the concretes with a unit volume weight greater than 2600 kg/m^3 are called heavyweight

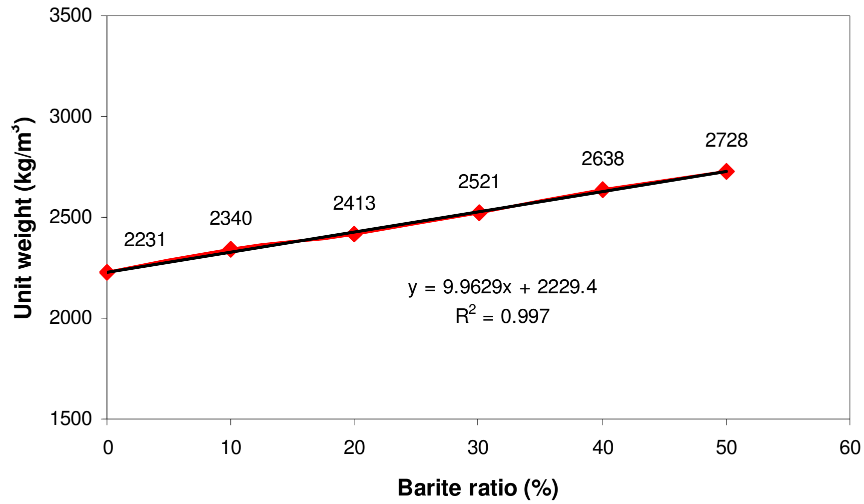

Figure 3. Graph showing change of barite ratio and unit volume weight .

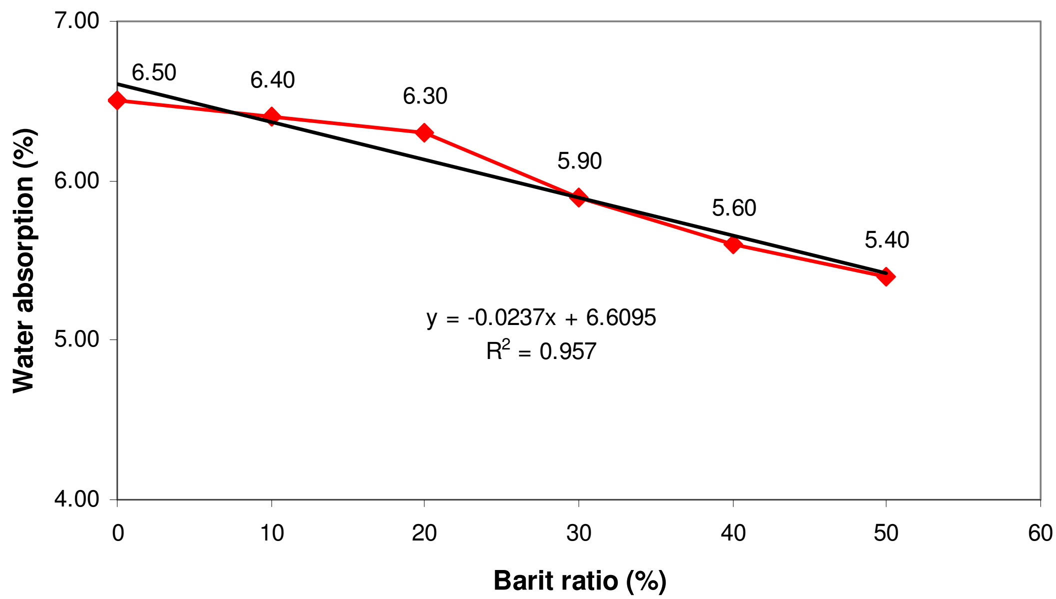

Figure 4. Graph showing water absorption percentage of concrete according to change of barite ratio.

concretes, the concretes over B40 can be called heavyweight and the concretes below B40 can be called moderate weight concretes.

Figure 4 indicates the change between barite aggregate and water absorption percentage. As indicated in the Figure, as the barite ratio in the mixture increased, water absorption percentage decreased, which indicates that barite aggregate has low water absorption characteristics. Figure 5 indicates the barite ratios and the changes in UPV values for all concrete types. As indicated in the Figure, as the barite ratio increased, UPV value also increased. This results from the fact that barite aggregate has a high density. Figure 6 gives the change of barite ratios and Schmidt hardness values for all concrete types. As indicated in the Figure the maximum Schmidt hardness value of 31.60 was recorded in samples 10% barite content. In concrete specimens with a barite content of 50%, Schmidt hardness value was measured as 29.30. This value is slightly higher than the value of the control specimen.

As indicated in Figure 7, modulus of elasticity values of concrete specimens increased in parallel to the increase in barite ratio. Due to the increase of density and UPV value, modulus of elasticity also increased. Figure 8 indicates the changes in compressive strength values of the concrete specimens according to the change of barite

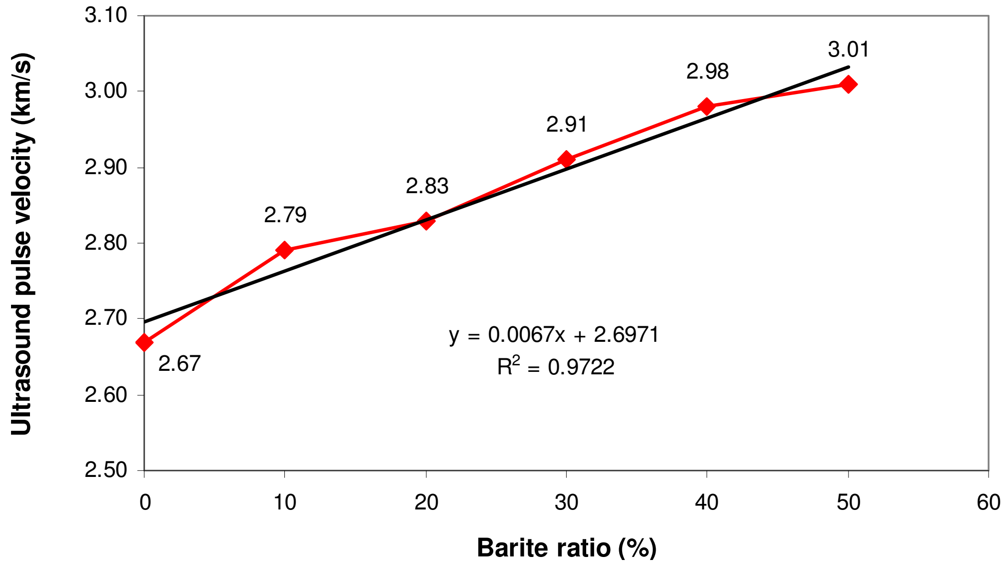

Figure 5. Graph showing change of barite ratio in concrete and ultrasonic pulse velocity.

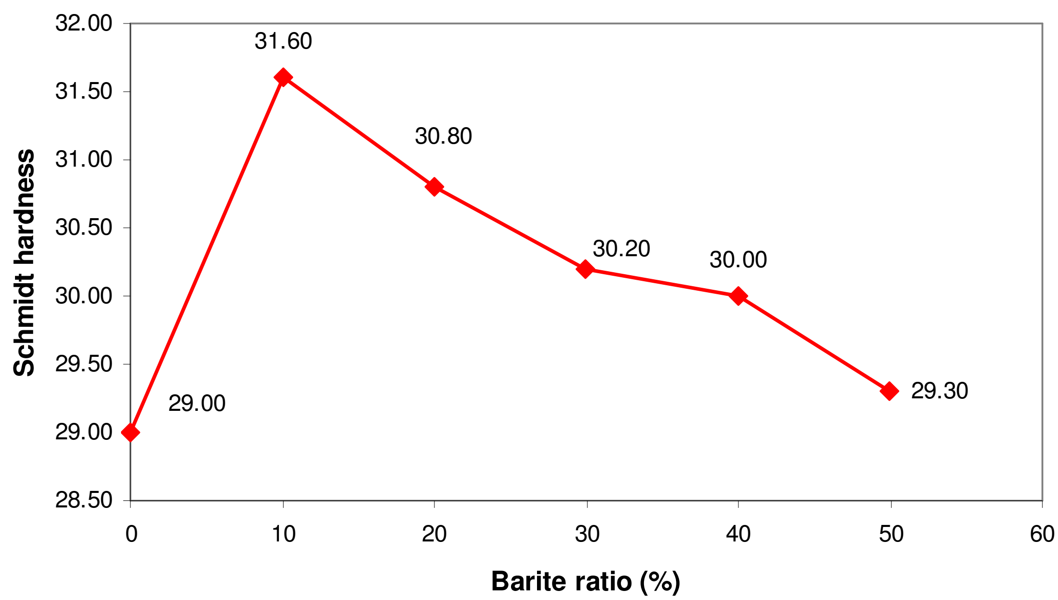

Figure 6. Graph showing change of barite ratio in concrete and Schmidt hardness.

ratio. Average compressive strength was calculated as 56.72 MPa in control specimens. In the specimen containing 10% barite aggregate, compressive strength was calculated as 59.58 MPa. As the barite ratio increased, compressive strength tended to decrease. This might be related to the characteristic structure of barite aggregate or to the high w/c ratio. A previous study reported that as the w/c ratio increased, compressive strength decreased (Topçu, 2003). This result is consistent with the data obtained in the present study. Figure 9 indicates the change of tensile strength values depending on the barite ratio. In control specimens, tensile strength was calculated as 9.03 MPa; in the B10 series, tensile strength was measured as 9.23 MPa and in B50 specimens, this value was measured as 50.09 MPa. In the present study, it was found that compressive strength and tensile strength curves were parallel.

Figure 10 indicates the change in thermal conductivity coefficients according to the change of barite ratio in concert specimens. Unlike other mechanical and physical experiments, in the experiments on thermal conductivity of concrete specimens, the ratio of barite aggregate was

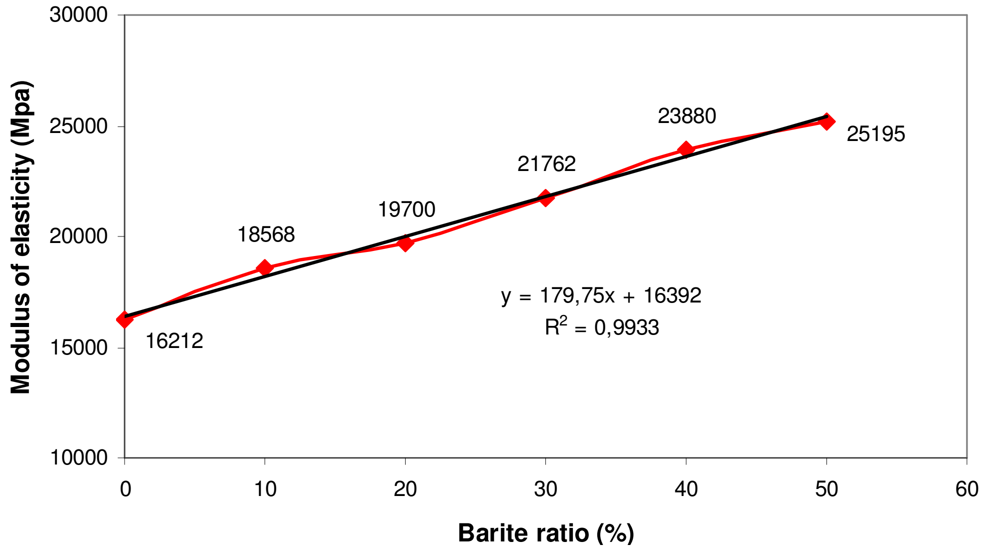

Figure 7. Graph showing change of modulus of elasticity in concrete according to barite ratio.

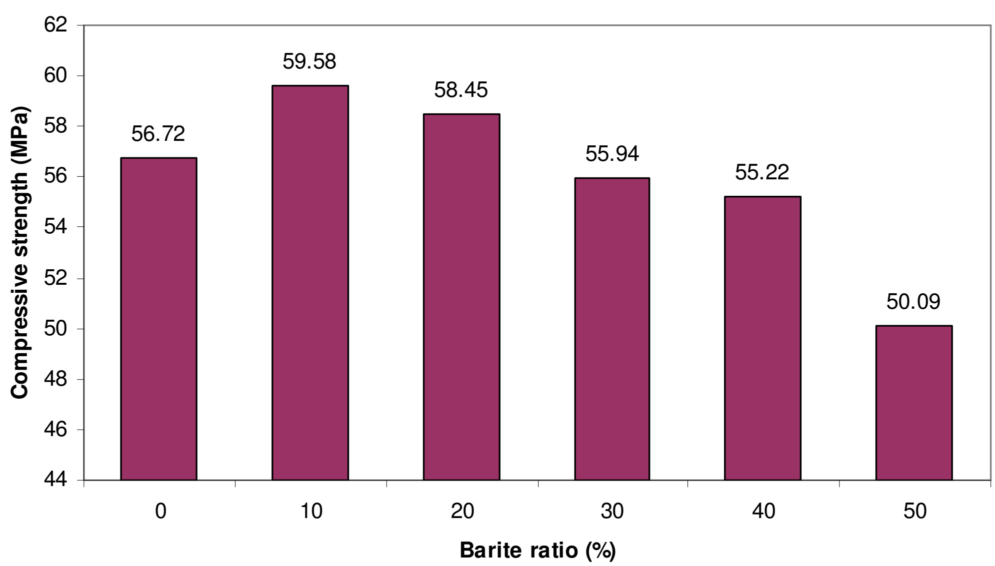

Figure 8. Graph showing change of barite ratio in concrete and compressive strength.

increased to 100%. As the barite ratio in the specimen increased, thermal conductivity coefficients also increased. When compared to the control specimens (Series C), thermal conductivity coefficient in B100 concrete increased by approximately 16%. Considering that the porous structure of the material slows thermal conductivity, it can be suggested that thermal conductivity coefficient and density are directly proportional. In this case, it would be expected that heavyweight concrete material, which has a low structural porosity and a high density, would have a high thermal conductivity coefficient. In a previous study (Temur, 2004), it was reported that the greatest temperature in the shield occurred in the inner surface as a result of a chain reaction, and that the temperature decreased from the inner surface to the exterior surface. Therefore, it was found that thermal tensions generated pressure in the inner surface and tension in the exterior surface. Thus, it was reported that concrete used for shielding should have a high thermal conductivity coefficient and a small expansion coefficient. The data obtained in the present study are consistent with the findings of this previous study. The energy absorbed during the reduction of all radiation by the shielding concrete (heavyweight

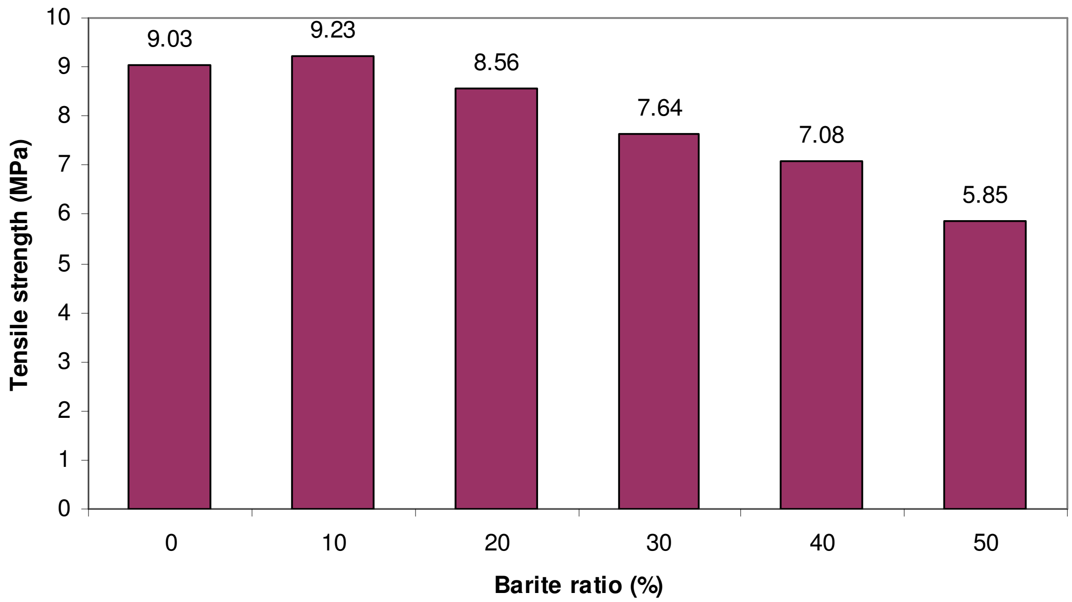

Figure 9. Graph showing change of barite ratio in concrete and tensile strength.

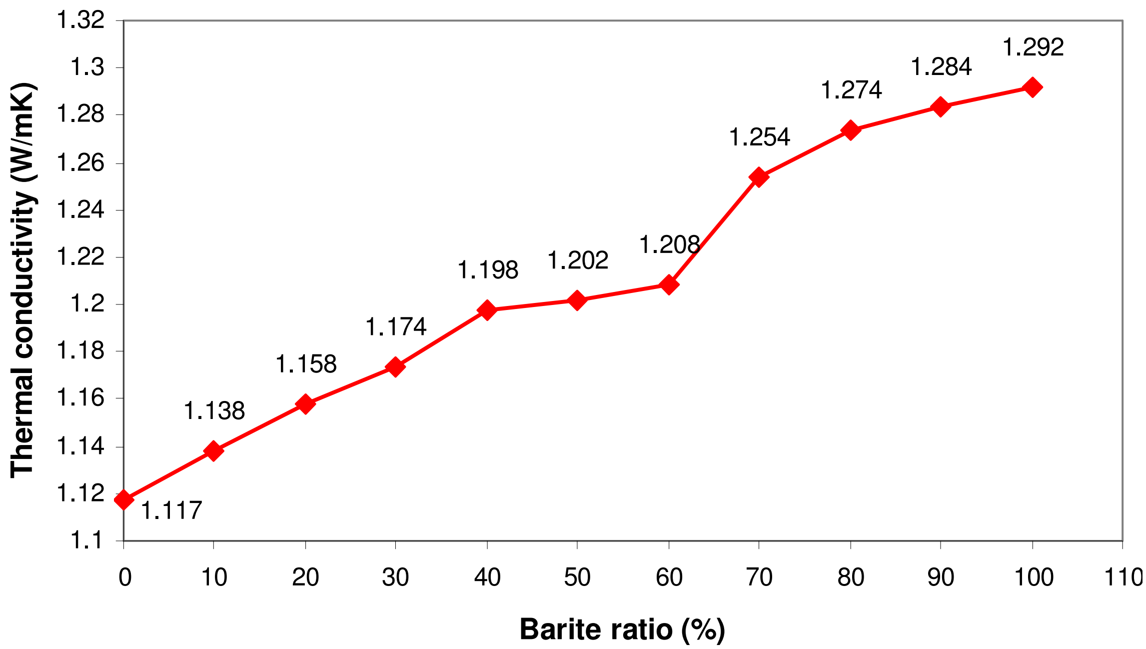

Figure 10. Graph showing change of barite ratio in concrete and thermal conductivity.

concrete) is converted to thermal energy, resulting in shielding concrete increasing in temperature. Since concretes that use heavy aggregates have a higher risk of decomposition, maintaining the homogeneity in these types should be given greater attention than when using conventional concretes. Because ductility is as necessary as resistance for the safety of the building, it is not appropriate to use heavyweight concretes in buildings other than in those structures that require a concrete curtain and increased weight for protection from radiation.

Conclusions

The experimental results indicated that the changes in barite aggregate ratio change physical and mechanical properties of the concrete. It was found that unit weight, modulus of elasticity, ultrasound pulse velocity (UV) and thermal conductivity coefficient values of 400 dosage barite aggregated concretes with a w/c ratio of 0.60 increased in parallel to the increase in barite ratio; however Schmidt hardness (SH), water absorption (%), compressive strength and tensile strength values were found to decrease with increasing barite content. Considering that, particularly in Turkey, known reserves of natural heavy aggregate are scarce and that artificial heavy aggregates are costly, the costs should be compared with those of conventional concretes before deciding to use heavyweight concretes produced with these aggregates.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support received from the Scientific Research Projects Administration Unit of Firat University. This study was conducted within project grant no. 2008/1556.

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