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Investigation of usability of limonite aggregate in heavy-weight concrete production

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ABSTRACT

Limonite ($Fe_2O_3 \cdot xH_2O$) is a soft or brown, hard iron mineral, usually in yellow colour. It is also used as a pigment since it contains iron ore. It is believed that it can also be used in the production of heavy concrete due to its 60% iron ore content. In this paper, an experimental study was carried out on radiation shielding properties and certain physical and mechanical properties of normal and limonite reinforced concrete. For this purpose, with the normal concretes prepared according to standards, amounts of aggregates were reduced at the rates of 20%, 40%, 60%, 80% and 100% by volume respectively, and heavy concrete mixes were prepared that were obtained by adding limonite at the same rates in their place. With limonite reinforcement, compressive and flexural strength of the concrete produced decreased, water absorption amount increased and their radiation permeability significantly decreased.

1. Introduction

A radiation dose above the maximum permissible limit is very dangerous for human beings (Demir et al., 2007). Unfortunately, nuclear plants are established in order to fulfil the increasing energy need, and we are compulsorily faced with radiation-emitting devices to keep pace with evolving technology. Thus, we need to know the hazards of radiation and take precautions in order to be affected by these effects at a minimum level. Lead or heavy aggregates are generally used in order to be protected from the hazardous effects of radiation. As the negative effects of the lead on human health are also known, protective shields can be created by using elements such as barite, hematite, siderite, limonite, ilmenit, serpentine containing iron ore, which are generally of a high intensity (Topcu, 2003).

Overall, heavyweight concrete has been used where it is necessary to reduce the thickness of radiation shielding, generally due to space considerations (Demir et al., 2011; Yılmaz et al., 2011; Gencel et al., 2010, 2011; Acevedo and Serrato, 2010; Mahdy et al., 2002). Demir et al. (2011) experimentally found that the linear attenuation coefficients (μ) decrease with the increasing photon energy for their concretes and the linear attenuation coefficient depends on photoelectric effect and Compton scattering at this energy. He also concluded that barite was effective at 663 keV. Yılmaz et al. (2011) measured the attenuation coefficients of gamma rays of 12 concrete samples with and without supplementary cementitious materials, at energies of 59.5 and 661 keV. According to Lee et al. (2007) the aggregate of concrete plays an essential role in modifying physical-mechanical properties of concrete; it also significantly affects shielding properties of concrete (Aïtcin, 2004; Aitcin, 2003; Bakhsh, 2001; Esen and Yilmazer, 2010; Kilincarslan et al., 2006). Esen and Yilmazer (2010) conducted physical and mechanical experiments on concrete samples they produced with barite aggregate. An increase in the values of unit weight, modulus of elasticity, ultrasound pulse velocity (UV) and thermal conductivity was determined depending on the increase in the rate of barite; and a decrease was determined in the values of Schmidt hardness (SH), water absorption (%), compressive strength and tensile strength. In general, a number of theoretical and experimental studies have been conducted on heavy concretes (Demir et al., 2010; Akkurt et al., 2006; Bashter et al., 1996b, 1997; Bashter, 1997; Mollah et al., 1992; Kaplan, 1989; Kan et al., 2004; Un and Demir, 2013; Maslehuddin et al., 2013; González-Ortega et al., 2014; Singh et al., 2014; El-Sarraf et al., 2013; Dahiru, 2008; Abo-El-Enein et al., 2014; Field et al., 2015; Ouda, 2014).

In addition, the shielding properties were measured for different types of concrete (Bashter et al., 1996a; Dealmeid et al., 1974; Fillmore, 2004; Rockwell, 1956; Schaeffer, 1973; Etherington, 1958; ACI 359-07, 2007; Esen and Yilmazer, 2011; Kansouh, 2012; Akkurt et al., 2011; Kaur et al., 2012; Basyigit et al., 2011; Ramadan et al., 2006; Abdo, 2002; Abdo and Megahid, 2001). Barite was mostly used in the studies carried out. Among these studies, Esen and Yilmazer (2011) examined the X-ray and radioisotope energy absorption capability of the heavy

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concrete produced using barite, and observed that the density and the capability to absorb the energy of the concrete with an increasing rate of barite increase. Kansouh (2012) produced and examined a new serpentine concrete as a reactor biological shield. According to him, Ilmenite–limonite concrete is a better reactor biological shield. New serpentine concrete is a better reactor fast neutrons shield than ordinary and hematite–serpentine concretes. Serpentine concrete has lower properties as a reactor total gamma rays shields. Also, the radiation shielding properties of high strength concrete were investigated (Mesbahi et al., 2011; Al-Humaiqani et al., 2013; Chakraborty et al., 2001; Ferraris, 1999; Mostofinejad et al., 2012; Aïtcin and Neville, 1993; Shah and Ahmad, 2003). Al-Humaiqani et al. (2013), carried out an experimental study on the gamma ray radiation shielding properties of normal and heavy high performance concretes (HPCs). In this research, it was observed that the compressive strength of heavy HPCs plays an important role in enhancing the attenuation of gamma rays. The compressive strength and attenuation of gamma rays in heavy weight HPCs have a near to linear relation.

Limonite mineral, which is heavily extracted in Turkey especially in Malatya Hekimhan region, can be used in the production of heavy concrete as it contains a high rate of iron ore. Many studies were carried out on heavy weight concrete in the literature and it was mentioned that limonite aggregates can be used in concrete production; however, no such study collectively examining the mechanical, physical and radioactive properties of the concrete produced using limonite was encountered. For this purpose, results were obtained and examined by putting concrete samples at different mixing rates and sizes that were prepared and poured in accordance with the standards through physical and mechanical experiments.

2. Experimental study

The limonite mineral to be used in heavy concrete production was supplied as a rock mass and render graded by crushing. Chemical components of limonite were determined (The chemical analysis experiments were carried out at Elazıg Altınova Cement Industry Inc. For this, the samples were first passed through the breaker. The product is dried at 105 °C until reaching constant weight. 40 gr sample was milled for 100 s in the Herzog grinder with +7 Spectromelt C20 (grinding aids). In the Persian device, the sample is grinded by inserting the ring to the ring, and the sample is pressed at a certain pressure. The pressed sample was applied to XRF 9900 Xray device and analysed chemically); and the chemical analysis results of this mineral were shown in Table 1 and the experimental results of the sieve analysis of the limonite aggregate were shown in Table 2.

Local river bed aggregate was used as a normal aggregate. The maximum grain diameter (D_{max}) was chosen as 16 mm. According to TS 706 EN 12620 (2009), attention was paid to keep the grading curve between the curves A16 and C16 in order for the cavity of the mixture to be low and compasity to be high. PÇ 42.5(CEM I 42,5 R) type cement, of which physical and chemical properties are shown in Table 3, was used in the study.

Limonite mineral was first put through physical experiments, and the dry weight (W_d), saturated dry surface weight (W_{ssd}), underwater weight (W_w), dry specific weight (δ_d), dry surface saturated specific weight (δ_{ssd}), visible specific gravity (δ_a), water absorption percentage (W_a) and porosity (p) of the aggregates were determined. Porosity and water absorption rate was calculated according to TS EN 1936 (2010). Values obtained as a result of the experimental studies are shown in Table 4 below.

Mix ratios were calculated in the light of these data and the water/cement (W/C) rate was determined as 0.40 as a result of the Slump test conducted on the experiment concreting prepared, the amount of slump being 5–10 cm. Considering that the mix to be made will be heavy concrete, Sikament FFN super plasticizer at a rate of 1.5% of the amount of cement was added into the mix in order to prevent the segregation of heavy aggregates. In all mixes, the dosage of cement was taken as 400 kg/m^3. Concrete mix rates prepared are shown in Table 5. The concrete mortar prepared considering the mixing ratios were placed in moulds prepared in the sizes of 10 × 10 × 10 cm and 4 × 4 × 16 cm in order to determine their mechanical and physical properties and in plate shaped, oiled moulds 30 × 30 × 2 cm in size in

Table 1
Chemical analysis results of limonite mineral (Dogan, 2012).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss of Ignition	Undetected Article
Limonite	3.31	3.85	60.65	3.39	5.85	15.90	7.04

Table 2
Sieve analysis results of the limonite aggregate to be used in the experiment (Dogan, 2012).

Sieve No	Remaining on the Sieve (g)	Cumulative Remaining on the Sieve (g)	Remaining Cumulative %	Passing Cumulative %
16	0	0	0	100
8	736.1	736.1	24.58	75.42
4	890.5	1626.6	54.32	45.68
2	480.8	2107.4	70.38	29.62
1	357.6	2465	82.32	17.68
0.5	238	2703	90.27	9.73
0.25	146.2	2849.2	95.15	4.85
Container	145.3	2994.5	100.00	0.00

Table 3
Physical and chemical properties of PÇ 42.5 (CEM I 42,5 R) cement (Dogan, 2012).

Chemical Composition (%)		Physical Properties of the Cement	
SiO_2	19.3	Specific gravity (kg/m^3)	3150
Al_2O_3	5.57	Outlet Start (min.)	119
Fe_2O_3	3.46	End of outlet (min.)	210
CaO	63.56	Volume expansion (mm)	1.00
MgO	0.86	**Specific Surface of the Cement (Blaine)**	
Na_2O	0.13	Cement (m^2/kg)	352
K_2O	0.80	**Compressive Strength of the Cement (MPa)**	
SO_3	2.91	2 days	27.2
Cl^-	0.013	7 days	42.4
Loss of ignition	2.78	28 days	52.7
Insoluble residue	0.42		
Free CaO (%)	1.22		

Table 4
Physical values of the aggregates (Dogan, 2012).

	Physical Values	
	Normal Aggregate	Limonite Aggregate
Wa(%)	2.04	11.42
P(%)	5.45	27.65

Table 5
Mix design for 1 m^3 limonite-reinforced concrete (Dogan, 2012).

	Control	L20	L40	L60	L80	L100
Cement (kg)	400	400	400	400	400	400
Water (kg)	160	160	160	160	160	160
Normal Aggregate (kg)	1953	1563	1173	780	390	–
Siderite Aggregate (kg)	–	461	923	1390	1850	2313