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Investigation on abrasive wear of concrete containing hematite

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Many concrete structures such as dams, canals, roads and floors are required to have abrasion resistant. Aggregates play an important role on strength characteristics and abrasion resistance of concrete. Also compressive strength has a decisive influence on abrasion. In this study, hematite is used as replacement aggregate for the purpose. This study investigates effects of different concentrations (10-50% replacement) of hematite on mechanical properties of concrete. Water/cement ratio and cement content is kept constant as 0.42 and 400 kg/m^3, respectively. It was observed that hematite – a material with higher density and higher hardness than cement – will increase both the compressive strength and the wear resistance depending on hematite content in the mixture. Concrete mixes with adequate workability have been produced. Correlation between hematite content-compressive strength and wear loss is equated, and the equation representing wear as a function of cement content and hematite content provides a high agreement with the experimental results.

Keywords: Wear testing, Concrete, Cement, Hematite, Mechanical properties, Wear resistance

Concrete pavements have been widely used in many countries in the world as an alternative to the asphalt pavements. The rigidity of the pavement slab and its ability to distribute loads and high compressive strength makes concrete desirable material[1]. So, Wear resistance of floor constructions from mortar and concrete with cement binders is very important for their service life, especially in industrial enterprises such as pavements, concrete highways, airfield runways, parking lots, hydraulic structures, tunnels and dam spillways etc. However, the abrasive resistance of infrastructure made with cement concrete is very important for their service life[2]. Deterioration of concrete surfaces occurs due to various forms of wear such as erosion (wearing by abrasive action of fluids containing suspended solids), cavitations (wearing by implosion of vapour bubbles in high-velocity fluid flow), and abrasion[3] (wearing by repeated rubbing or frictional processes). Although wear itself is difficult to define, it is described as the so-called sliding wear occurring due to repetitive scraping, rubbing, skidding or sliding of objects on its surface[4-6]. And wear originates from multiple sets of complex interactions on microscopic scale between surfaces that are in mechanical contact and slide against each other[7].

Abrasive wear is known to occur in pavements like floor and concrete highway by foot and vehicular traffic, hydraulic structures and other surfaces upon which friction forces are applied due to relative motion between the surfaces and moving objects. The resistance of concrete to wear is influenced by variables such as strength, aggregate properties, surface finish and type of hardeners or toppings. It is well establish that concrete wear resistance increases with increasing compressive strength and tensile strength[8,9]. Bechyne[10] reported that a certain relationship between the compressive strength and wear characteristics of concrete exists. The tensile strength of concrete is generally assumed to be zero in concrete design. But in design of some structures, the tensile strength must be known. This is a crucial design parameter especially in structures such as concrete dams, airfield runways, concrete roads and pavements, and other slabs[11]. A large number of previous studies have indicated that concrete abrasion resistance is primarily dependent upon compressive strength of the concrete. The factors such as cement content, water-to-cement ratio (w/c), type of aggregate and their properties affect the concrete strength. Therefore, these factors have an important influence on abrasion resistance of concrete. According to American Concrete Institute (ACI) Committee 201, the compressive strength of concrete

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that will be subject to abrasive forces should not have a compressive strength less than 30 MPa[6,12]. As mentioned, there are many factors affecting abrasion resistance of concrete. The flow chart in Fig. 1 shows parameters on the abrasive wear of concrete composites and the manufacturing processes contributing to the abrasion resistance[13].

In order to develop concrete with high abrasion resistance, it is desirable to use material having hard surface, paste with low porosity and high strength[14]. Abrasion resistance of concrete depends a great deal on the hardness of the aggregates. Thus, the aggregates used in concrete, which will subject to abrasive forces, should have enough hardness and resistance[6]. Concrete with high strength and resistance to wear is made possible by reducing porosity and microcracks in concrete[15].

This research was carried out to evaluate the performance of hematite and its content in concrete with respect to strength and abrasion resistance. Concrete strength and abrasion resistance were determined at various levels of hematite replacements with the limestone-based aggregates. The results obtained in this investigation would be useful in establishing mixture proportions for wear resistant concretes.

Materials and Methods

Cement

In this study, the cement used in all the concrete mixtures was a normal Portland cement which corresponds to CEM II/A-M (P-LL) 42.5N Portland cement. Physical and mechanical properties and chemical analysis of cement are presented in Tables 1 and 2, respectively.

Aggregates

Aggregates typically constitute 70-80 wt% of concrete. So aggregate type, size and gradation plays an essential role in modifying concrete properties. Reference concrete was produced as plain concrete (PC) using limestone-based aggregates with three different grain sizes: up to 3 mm crushed stone I (CSt-I), up to 7 mm natural river stone (NRS) and

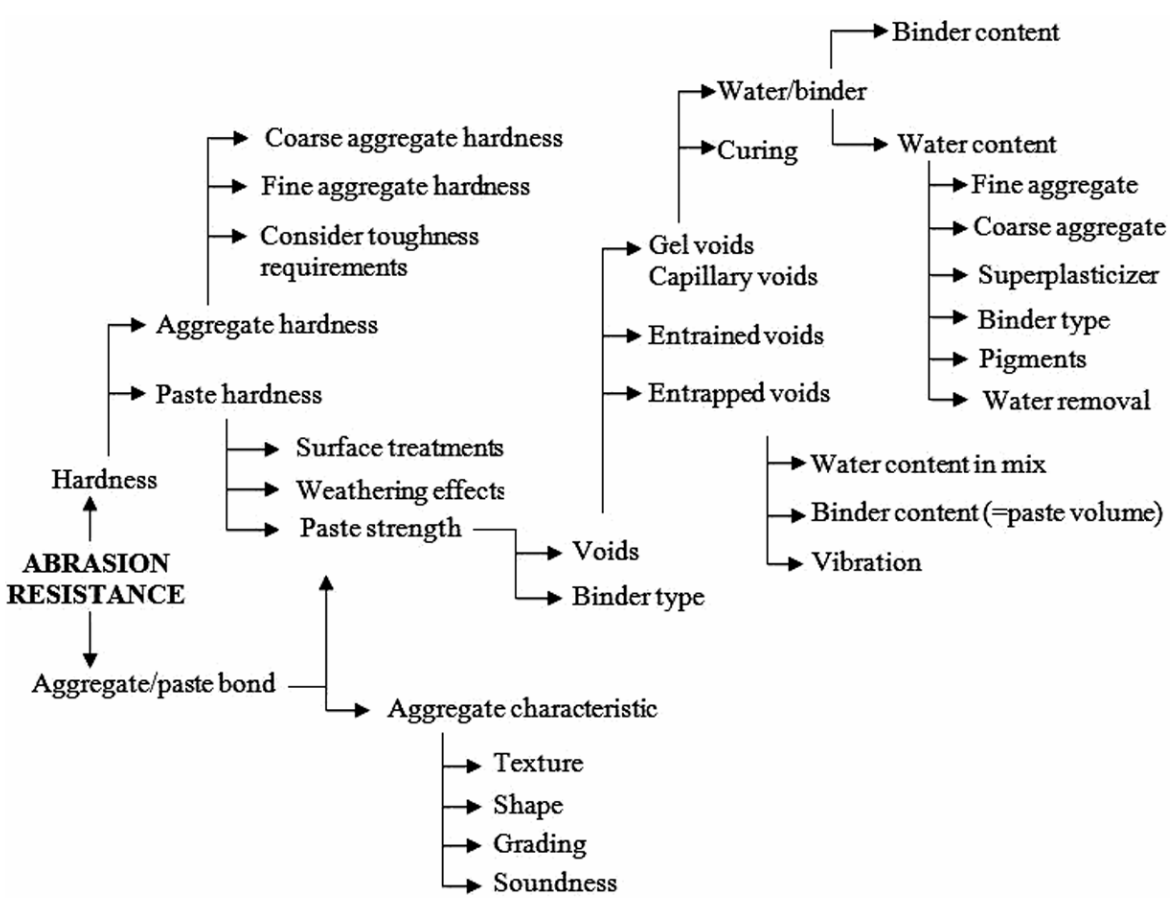

Fig. 1 – Various parameters affecting abrasion resistance of concrete

Table 1 – Physical and mechanical properties of Portland cement

Compressive strength (MPa)			Flexural strength (MPa)			Initial setting time (min)	Final setting time (min)	Le Chatelier (mm)	Specific gravity	Blaine (cm^2/g)
2 Days	7 Days	28 Days	2 Days	7 Days	28 Days					
22.5	36.6	47.8	3.7	5.6	6.9	145	195	1	3.15	4150

Table 2 – Chemical analysis of Portland cement (wt%)

Total SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Cl	LOI*	Free CaO	Total Admixture
22.9	5.32	3.63	55.83	1.99	2.62	0	4.2	0.82	19.45

*Loss of ignition

7-15 mm crushed stone II (CSt-II). The aggregates were obtained from Atabey quarry in Isparta, Turkey, graded, washed and cleaned of clay and silts. To reduce difficulties of producing, mixing and placing of concretes and to prevent segregation of heavyweight aggregate in the fresh concretes, the maximum aggregate size was selected as 16 mm diameter. The results of aggregate sieve analysis are shown in Fig. 2.

Unlike PC, the main feature of heavyweight concrete is the inclusion of metallic fillers- usually ilmenite, magnetite, hematite etc. In this work, hematite was adopted as a replacement for concrete aggregates. It was obtained from Hekimhan region in Malatya, Turkey.

Hematite is a natural red, brown or black rock (see Fig. 3) that contains iron oxide. When pure it has the Mohs hardness between 5.5 and 6.5 and the specific gravity between 4.9 and 5.5 g/cm^3. However, physical properties of rocks in which hematite are the main constituent may vary considerably; the specific gravity of hematite ores can range between 3.2 and 4.3. Some ores are soft and produce dust that would make them a poor aggregate for heavy concrete. Hematite particles tend to be flaky, which is undesirable in regard to the workability of concrete[15].

Hematite was prepared as aggregate by crushing and grounding the ore in a laboratory mill, then sorting it via sieves into two groups of coarse (H_c) and fine (H_f) aggregates (Fig. 3). Specific gravity, water absorption and loose unit weight were determined according to ASTM C 127[16], ASTM C 128[17] and ASTM C 29[18] standards, respectively. Physical and mechanical properties of all aggregates are given in Table 3. The chemical composition of hematite is presented in Table 4.

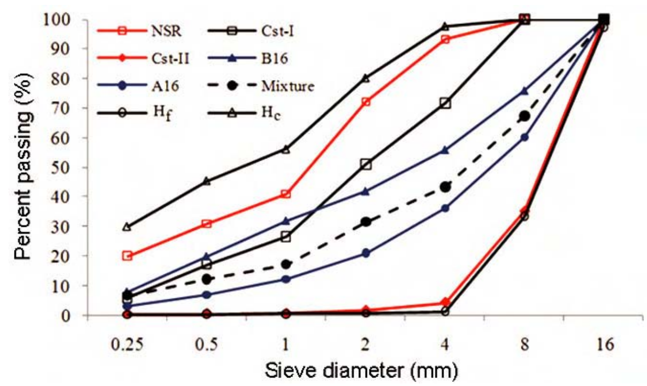

Fig. 2 – Grading curves of aggregates and mixture

Mix proportions

To investigate the effect of hematite aggregate on the abrasive wear behavior of concrete, plain concrete and concrete containing different proportions of hematite were investigated. The absolute volume method to obtain denser concrete was used in the calculation of the concrete mixtures.

The water content of mixture is very important. Partial segregation may occur when water content is higher. Water penetrates to the surface of concrete or mortar layer. A different zone of porosity is created, with maximal value at the surface, to minimal value at the bottom. Therefore, the upper part of the samples may have markedly lower wear resistance[19]. Also it is well-known that the higher the w/c ratio in concrete mixtures the lower the compressive strength. Thus, an increase in the w/c ratio adversely affects the abrasion resistance of concrete. The American Concrete Institute Manual of Concrete Practices (ACI 304-3R, 1989)[20] advises not to use Type III cement or accelerators so as to avoid high and rapid hydration and potential consequent cracking. After extensive trials, water/cement ratio the cement content were determined as 0.42 and 400 kg/m^3, respectively.

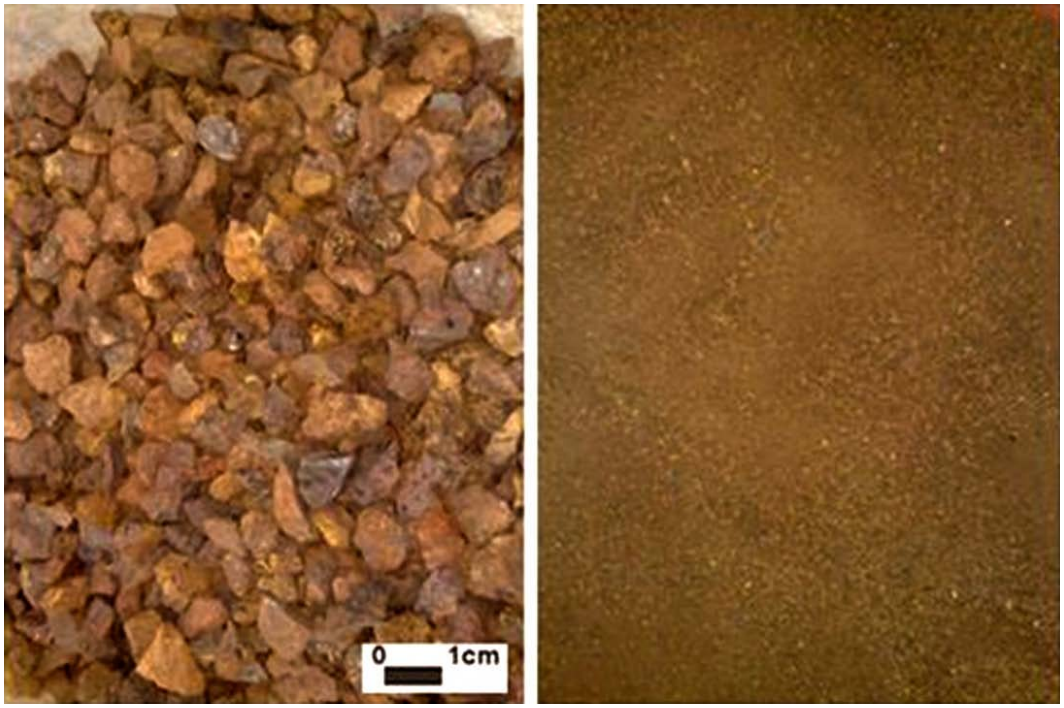

Fig. 3 – Coarse (left) and fine (right) hematite aggregates

Table 3 – Physical and mechanical properties of aggregates.

Aggregate codes	Specific gravity	Water absorption (%)	Loose unit mass (kg/m^3)
CSt-I	2.61	2.91	1913
NRS	2.63	3.13	1830
CSt-II	2.70	0.83	1676
H_f	3.75	2.35	1956
H_c	4.00	1.27	1733

Table 4 – Chemical composition of hematite (wt%)

Fe_2O_3	MnO	MgO	TiO_2	Al_2O_3	CaO	SiO_2	LOI*
81.13	0.14	1.55	0.03	0.57	4.8	4.2	5.82

* Loss of ignition = mass loss in a sample heated to 950°C

Table 5 – Mass of aggregates used (kg)

	PC	H10	H20	H30	H40	H50
CSt-I	445	391.2	347.7	304.2	260.8	217.3
NRS	447.5	387.4	344.4	301.3	258.3	215.2
CSt-II	920	826.4	734.6	642.8	550.9	459.1
H_f	0	121.6	243.1	364.7	486.2	607.8
H_c	0	129.4	258.8	388.1	517.5	646.9

Table 6 – Measured and estimated wear loss values and absolute relative errors for them

	PC	H10	H20	H30	H40	H50
Tested	6.62	3.48	3.08	2.75	2.41	2.32
Estimated	5.46	4.26	3.97	3.1	2.24	1.81
ARE(%)	18	22	29	13	7	22

To examine the effect of metallic aggregate, limestone-based aggregates (L) were replaced by hematite aggregate at 10% (H10=5% H_f +5% H_c), 20% (H20=10% H_f +10% H_c), 30% (H30=15% H_f +15% H_c), 40% (H40=20% H_f +20% H_c) and 50% (H50=25% H_f +25% H_c). Due to the high density of hematite, segregation is a danger. To avoid it, the preplaced aggregate method was used. The weights of the materials used in the mix design to obtain 1 m^3 of concrete are presented in Tables 5 and 6.

Mixing, curing and testing

The procedure for mixing heavy concrete is similar to that for conventional concrete. In a typical mixing procedure, the materials were placed in the mixer with a capacity of 56 dm^3 in the following sequence: first course aggregates, fine aggregates followed by cement, initially dry material mixed for 1 min and finally addition of 80% of water. After 1.5 min of mixing, the rest of the mixing water was added. All batches were mixed for a total time of 5 min; in order to prevent fresh concrete from segregation, the mixing duration was kept as low as possible. For each concrete mixture, a good workability and sufficient strength gain were achieved. Slump test (ASTM C 143) of the fresh concrete was performed for each mix, providing useful data to determine the workability and uniformity. Then six specimens for each concrete mixture were cast in molds and the molds were subjected to vibration. However, the high specific gravity of hematite is such that excess compacting vibration, which can cause segregation, must be avoided. After 24 h, the specimens were demolded and then cured in lime-saturated water at 20 ± 2°C temperature for 28 days prior to testing. It is well recognized that adequate curing of concrete is very important not only to achieve the desired compressive strength but also to make durable concrete.

Six series of specimens were made from the above six mixtures. The cubic specimens of 150×150×150 mm were primarily used for compressive strength. Flexural strength is done according to ASTM 293-94 after 28 days of curing. Demoulded unit weight test was carried out according to ASTM C 138 at 28 days.

Samples of 70×70×40 ±1.5 mm were used to determine wear resistance of concrete at 28 days according to Turkish standard specifications (TS 699). Although this standard is highly recommended for abrasion of natural stones, this standard is applied on concrete specimens as an alternative of ASTM C779. Many other researchers have used this methods and obtained reliable results[14,19,21,22].

In compliance with TS 699, the abrasion system had a steel disc with a diameter of 750 mm and rotating speed of 30±1 cycles/min, a counter and a lever. Abrasion test apparatus is shown in Fig. 4. In the test procedure, 20±0.5 g of abrasion dust was spread on the disc, the specimens were then placed, the load of 5 kg was applied to the specimen and the disc was rotated for four periods, while a period was equal to 22 cycles. After that, the surfaces of the disc and the sample were cleaned. The above-mentioned procedure was repeated for each edge of concrete samples (total 88 cycles) by rotating the sample 90° in each period. The volume decrease was measured in $cm^3/50\ cm^2$ due to wear. Abrasive dust used in this test was corundum (crystalline Al_2O_3).

Results and Discussion

Along with physical properties of concrete was also studied hematite as a mineral. Figure 5a shows gradually increasing redness of the samples with increasing hematite concentration – an expected effect. This is because of those parts of hematite aggregates which degraded transferred to the matrix during the process of mixing. All mixtures have shown fairly wide distributions of aggregates - a consequence of the mixing process. The aggregates do not touch each other. Thus, load bearing relies on the matrix rather than on the aggregates.

The cross-section of concrete is shown in Fig. 5b as seen in a stereo microscope and thin section seen through a polarizing microscope is shown in Fig. 5a. Uniform distribution of the dispersed phase in the matrix can be seen from the results in Fig. 5. Thus, microscopy agrees with our inference from Fig. 5.

Figure 5b shows that hematite consists of two zones, oxide (H_o) and fresh (H_{fr}). Hematite aggregates have high porosity (Fig. 5c) – a consequence of voids which have appeared during formation of hematite. Difference between H_o and H_{fr} is that H_o parts subjected to oxidation or corrosion and a thin coating on the surface of hematite aggregate occurs as a result of this oxidation. This affects the adhesion of cement paste with aggregates.

As mentioned above, the workability is essential for strength and durability. However, workability is related to all operations such as mixing and transport to which the concrete is subjected. There is no single test to evaluate the workability. However, a widely used one is the so-called slump test that represents flow behavior of concrete under self-weight after standard compaction. The test is sensitive to small changes in water content. The results of the slump testing are shown in Fig. 6.

Fig. 4 – Abrasion test apparatus as specified in TS 699

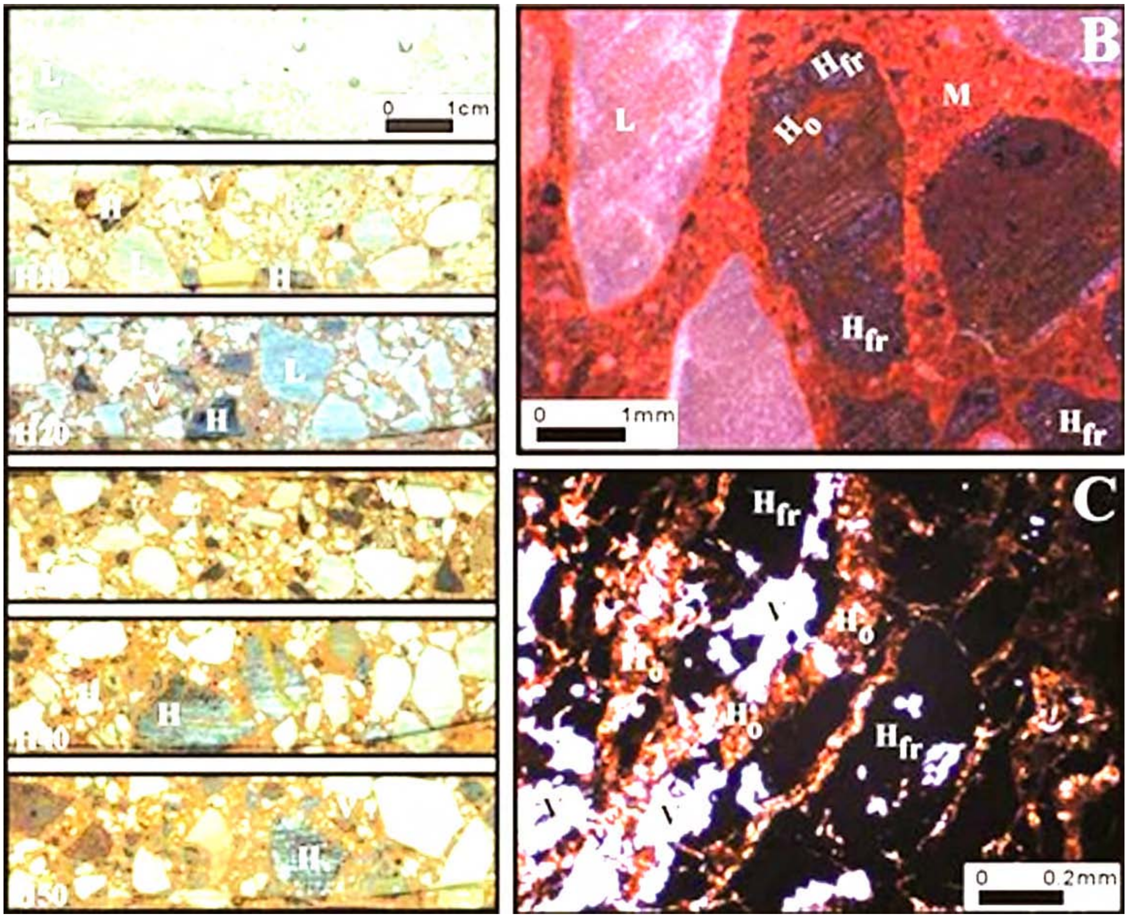

Fig. 5 – Cross-section views of concretes

Figure 6 shows us that all materials studied including the plain concrete (PC) without hematite fulfill the condition of minimum 50 mm. It is also noted that the effect of hematite addition is periodic and not very strong.

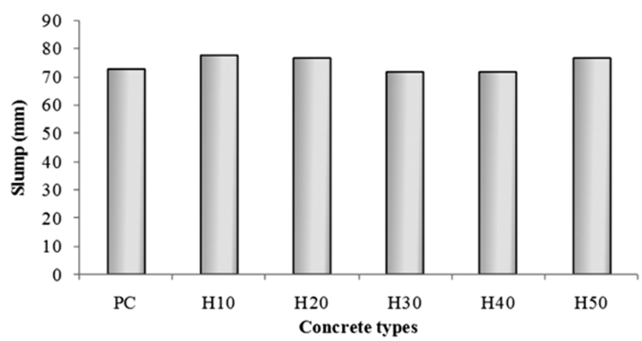

Fig. 6 – Comparison of slump values of concretes

Compressive strength

The compressive strength was determined on 150 mm cubic samples according to ASTM C 39-86. It was expected that addition of hematite – a material with higher density and higher hardness than ordinary aggregate – will increase the compressive strength. The results are presented in Fig. 7. As shown in Fig. 7, hematite increases gradually the compressive strength of plain concrete depending on increasing hematite content in the concrete.

Oluokun and Malak[23] reported that incorporation of ilmenite and hematite coarse aggregates into concrete mixes appeared to significantly increase the compressive strength, enhance the stress-strain behavior, and result in the production of tougher and more ductile concrete with a compressive strength of about 36 MPa. The present results are found in good agreement with the reported results[23].

Flexural strength

Flexural strengths of concretes are presented in Fig. 8. As seen from Fig. 8, the flexural strength increases with hematite content increasing. It was observed that flexural strength is increased up to 50% for 50% replacement ratio when compared to PC. The reason behind it, great bond between hematite aggregate and paste can be.

Colak[24] and Atis[25] reported that the wear loss is very much dependent on the flexural strength of concrete. The wear resistance of concrete increases with increase in the flexural strength of concrete. So, it can be expected that increment on hematite content increases flexural strength, and consequently resulting in decrease of wear loss of concrete.

Wear resistance

Relation between mass loss and unit weight on samples is presented in Fig. 9. As seen from Fig. 9, the highest mass loss has been observed on the PC. The reason is that the PC does not have a component protecting itself from negative effects of abrasive particles wearing away concrete.

Figures 10 and 11 show relation between compressive strengths and wear losses of concretes tested. As seen clearly from these figures, compressive strength increases by depending on hematite content increasing in the concrete. And parallel to increase in the compressive strength, resistance of concrete to abrasive wear increases significantly. Even in case of 10% addition of hematite to the PC, a significant decrease (about 50%) on the mass loss was obtained. This can be primarily attributed to Fe_2O_3 in hematite which is harder. One of effective factor contributing to wear resistance in concrete has been hardness of materials[13].

The surface of the abraded material comes into contact with abrasive particles under a normal load applied on the abrasion test. As abrasive particles achieve relative motion, shear forces are formed on the surface of the abraded material along with a normal load. While normal load helps abrasive particles penetrate into the specimen's surface, shear force helps the formation of grooves and scratches on the specimen's surface. A combination of a normal load and shear forces allows material transfer from the surface of the specimen[26].

However, due to hardness of hematite added to the PC, primarily hematite particles prevent abrasive particles from penetrating into the concrete, secondly act as a barrier against abrasive particles causing shear force, thus hematite particles absorb energy of abrasive particles and consequently the negative effects of shear forces on concrete surface decrease significantly. But, it must not be forgotten that

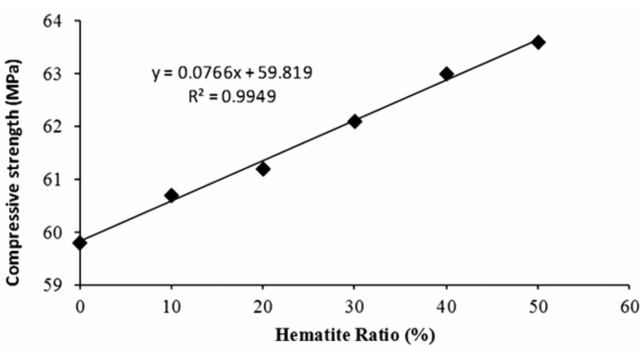

Fig. 7 – Compressive strengths of concretes depending on hematite content

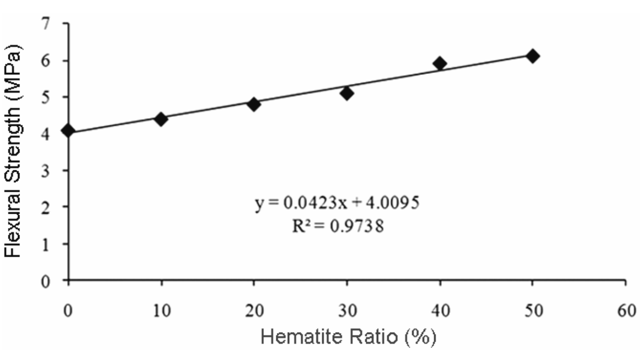

Fig. 8 – Flexural strengths of concrete

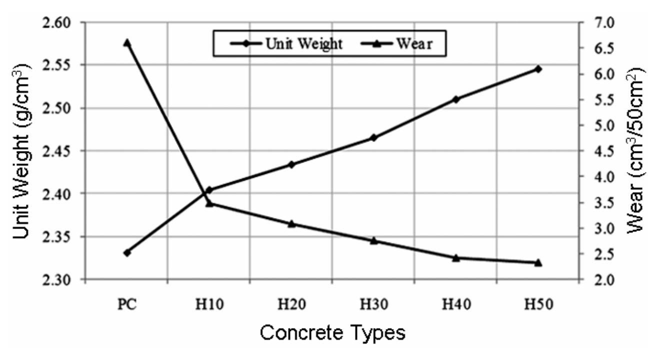

Fig. 9 – Relation between unit weight and mass loss of concretes

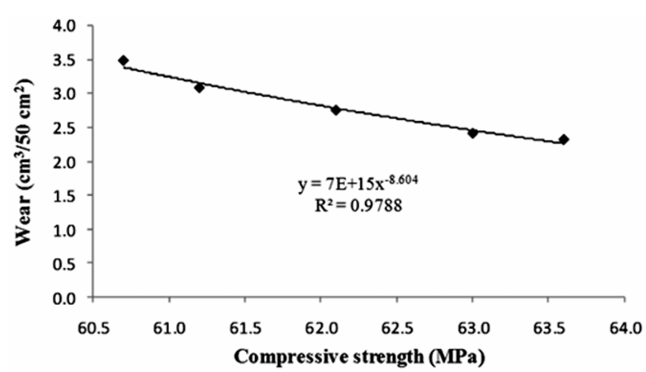

Fig. 10 – Relation between compressive strength and wear of only concrete with hematite

although there are many factors that influence wear resistance of concrete, it is evident that two major attributes of wear resistance are hardness and aggregate/paste bond.

Hardness is the single most important characteristic that controls aggregate wear. The hard aggregate protects the softer paste, providing that for a given aggregate the strength of the paste is such that there is an adequate aggregate/paste bond, strong enough to hold the aggregate securely in the face of the attacking abrasion load[13].

If the issue of mass loss and cycle on concrete samples is taken into account, it is observed that mass losses have decreased by depending on hematite content in concrete. This can be explained with distribution and distance of hematite with each other at unit area of concrete. Concrete consists of a graded mix of aggregate particles in a cement paste matrix. All mixtures have shown a wide homogeneous distribution of aggregates. This is due to great gradation of aggregates and mixing process. When looked at the views in Fig. 5a, a reasonably uniform distribution of the dispersed phase in the matrix can be seen. Because great dispersed hematite aggregates (closer to each other) in the matrix prevent abrasive particles from penetrating more to concrete, this

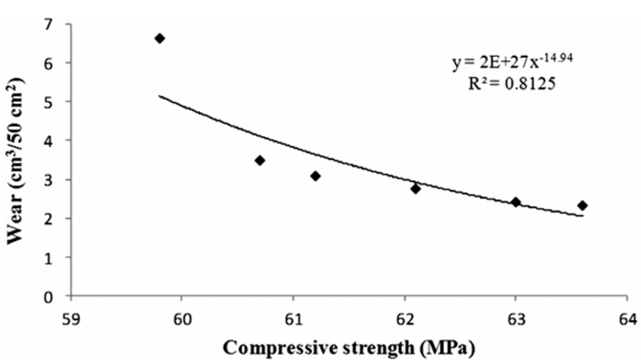

Fig. 11 – Relation between compressive strength and wear of all concretes

grading plays an important role in point of decreasing mass losses.

Studies of the effect of compressive strength on the wear characteristics of Portland cement concrete have shown that the wear decreases with increasing compressive strength several researchers[12,27,28,] have found an essentially relationship between these variables.

Principal factors affecting the abrasion resistance of concrete can be the environmental conditions and dosage of aggregate, the concrete strength, the mixture proportioning, use of special cements, use of supplementary cementitious materials such as fly ash, and addition of fibers. Two other important factors are: surface finish and curing conditions[29]. However, Cavdar and Yetkin reported[30] that a compact cement matrix is more effective against both sulfate and abrasive effects than cementitious mineral additives.

Statistical evaluation of test results

A multiple regression analysis was applied to obtain the following relationship among compressive strength, hematite content and loss on wear value:

$$W_{wear} = 72.037 - 1.117\, f_c + 0.014\, V_H \qquad \ldots(1)$$

where W_{wear} is the 28-day wear loss value of concrete ($cm^3/50\ cm^2$); f_c the 28-day compressive strength of concrete (MPa); and V_H is the hematite content in the concrete (%). The measured and estimated losses on wear values are given in Table 6.

The comparison of experimental and estimated mass loss values obtained from Eq. (1) is shown in Fig. 12. The estimated values are in a good agreement with the experimental values obtained in this study, and the differences between calculated and experimentally obtained values are within the range of ±1.16. On the other hand, here is the point that when we evaluated the all concretes together, the coefficient of correlation between estimated and experimental values is R^2 = 0.759 as seen from Fig. 12a. However,

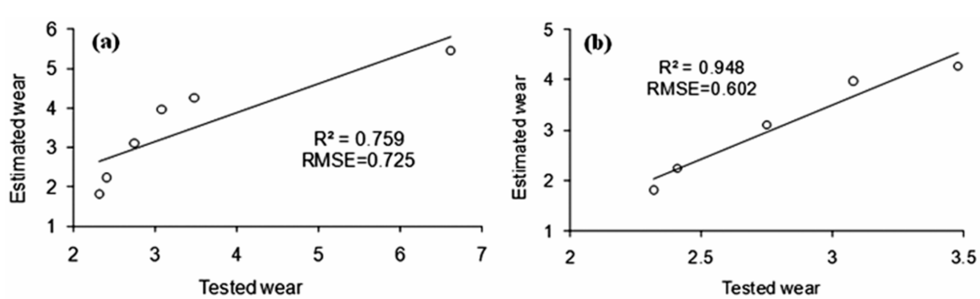

Fig. 12 – Comparison of experimental and calculated loss on wear values

when only concretes containing hematite were considered, R^2 was 0.948 as seen from Fig. 12b.

The root mean square error (RMSE) statistic is also used in this work. The RMSE statistics is defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(W_{Tested,j} - W_{Estimated,j})^2} \qquad \ldots(2)$$

The RMSE and R^2 statistics obtained by using coefficients in Eq. (1) were shown in Fig. 12.

Besides, the absolute relative errors (ARE) of estimated wear was used as the accuracy of the proposed equation. The ARE is defined as;

$$ARE\ (\%) = \left|\frac{W_{Tested} - W_{Estimated}}{W_{Tested}}\right| x100 \qquad \ldots(3)$$

The absolute relative errors (ARE) for tested and estimated values are given in Table 6.

Conclusions

The wear resistance of concrete structures is very important for their service life. In this study, abrasion resistance behavior of concretes containing different hematite proportions is investigated. According to experimental studies, hematite replacement has increased gradually the compressive and flexural strength due to a good bond between hematite aggregates and paste. Abrasion resistance has increased in all samples containing hematite. Besides, there is a relationship between compressive strength and abrasion resistance that since compressive strength increases, abrasion resistance also increases as parallel to the compressive strength.

The increase in wear resistance of concretes containing hematite when compared to the PC can be explained by excess surface hardness coming from the iron oxide (Fe_2O_3) content of hematite aggregates. However, it must be kept in front of eye that rising rates with use of hematite, a reduction in wear resistance can occur due to the increase in oxide space (H_o) that is inferred from thin section image and cross-section image of concrete. Compressive strength is the same for this change. Finally, wear damage of concrete can be estimated from compressive strength and hematite content. The proposed equation has a sufficient reliability.

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References

1 Hinislioglu S, Bayrak O U, *Indian J Eng Mater Sci*, 12 (2005) 111-116.
2 Sebok T & Stranel O, *Cem Concr Res*, 34 (2004) 1853-1858.
3 Alexander M G, *Mater Struct*, 18 (4) (1985) 297-307.
4 Brostow W & Hagg Lobland H E, *Polym Eng & Sci*, 48 (2008) 1982-1985.
5 *ACI Guide to durable concrete*, ACI 201.2R-92. USA: American Concrete Institute, 1992.
6 Erdogan T Y, *Materials of construction* (Middle East Technical University press, Ankara), 2005.
7 Gyurova L A, Justel P M & Schlarb A K, *Wear*, 268 (2010) 708-714.
8 Mindess S & Young J F, *Concrete* (Prentice-Hall International, USA), 1985.
9 Naik T R, Singh S S & Ramme B W, *J Mater Civil Eng*, 14 (5) (2002) 417-426.
10 Bechyne S, *Technology of concrete*, vol 3, (State Publishing (SNTL), Prague), 1959.
11 Pul S, *Indian J Eng Mater Sci*, 15 (2008) 467-472.
12 Naik T R, Singh S S, Hossain M M, *ACI Mater J*, 92 (6) (1995) 649-659.
13 Papenfus N, *Applying concrete technology to abrasion resistance*, 7th Int Conf Concrete Block Paving, Sun City, South Africa, 2003.
14 Yazıcı S & Inan G, *Wear*, 260 (2006) 615-618.
15 Kaplan M F, *Concrete radiation shielding* (Wiley press, New York), 1989
16 *ASTM C 127, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*, Annual Book of ASTM Standards, USA, 2001, p 5.
17 *ASTM C 128, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate*, Annual Book of ASTM Standards, USA, 1997, p 5.
18 *ASTM C 29, Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate*, Annual Book of ASTM Standards, USA, 1997, p 4.
19 Sebok T & Stranel O, *Cem Concr Res*, 34 (2004) 1853-1858.
20 *ACI 304-3R, Heavyweight Concrete: Measuring, Mixing, Transporting and Placing*, American Concrete Institute, USA, 1989, p 8.
21 Arslan M, *Constr Build Mater*, 15 (2001) 149-156.
22 Oymael S, Yeginobali M A, *The effect of bituminous schist on abrasion resistance of concrete*, 4th Nat Concrete Conf on Mineral and Chemical Admixtures in Concrete Technology, Istanbul, 1996, 359-367.
23 Oluokun A F & Malak S A J, *ACI Mater J*, 96 (1999) 320-330.
24 Colak A, *Constr Build Mater*, 22 (2008) 2276-2280.
25 Atis C D & Celik O N, *Mater Struct*, 35(5) (2002) 257-260.
26 Modi O P, Mondal D P, Prasad B K, Singh M & Khaira H K, *Mater Sci Eng A*, 343 (2003) 235-242.
27 Ghafoori N, Sukandar B M, *ACI Mater J*, 92(1) (1995) 25-35.
28 Atis C D, *J Mater Civil Eng*, 14 (2002) 274-277.
29 Horszczaruk E, *Wear*, 259 (2005) 62-69.
30 Cavdar A & Yetgin S, *Constr Build Mater*, 24 (2010) 461-470.