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Original Paper

Production of Low Permeability Concrete

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Abstract

This research aims to study the feasibility of producing low permeability concrete using bentonite. A comparison between concrete mixes with bentonite and the mixes with addicrate as a chemical addition for reducing the permeability was investigated. The impact resistance of this type of concrete was investigated. Two types of coarse aggregate (dolomite and gravel) were used. Bentonite with percent 0, 1, 2, 3, 4, 5, 10, 15 and 20 % as a replacement of cement weight was used. Addicrete DM2 with percent 0, 0.25, 0.5, 1 and 2 % of cement weight was used. The mechanical properties of the mixes (compressive, tensile and flexural strength) and the impact test were evaluated. Also, the permeability coefficient for the different mixes was calculated. The results clear that; 5 percent of bentonite was the optimum value to produce low permeability concrete. Also, the performance of the concrete was improved due to the use of bentonite. Out of this research, this type of concrete can be used in the marine structure which exposed to impact loads like dams and wears.

Keywords: Bentonite, Permeability, Mechanical properties, Impact.

1. Introduction

For many structures, reducing the permeability of concrete is considered the best suitable solution. Certainly, the permeability is an important property related to the durability of cementitious materials, [1]. There are several reasons which cause higher permeability such as Formation of cracks due to long-term drying shrinkage, Rupture of interface bond due to unequal thermal stresses, Existence of entrapped air due to insufficient compacting, Due to volume changes caused in the concrete because of various minor reasons and Cracks generated through structure`s stresses, [2]. Reducing permeability may be by adding waterproofing to the surface of concrete after hardening or using low permeability concrete. Low permeability concrete, plastic concrete, and impermeable concrete enable constructions to resist water, gases and fluids from penetrating concrete. Permeability can be useful in many fields such as hydrology, petroleum industry, environmental engineering, agriculture, soil mechanics, construction - civil engineering, drilling, environmental markets, medical applications, detergents, cat litter, paints, paper and ceramics, dyes and polishes, [3-6]. Low permeability concrete or plastic concrete consists of cement, coarse aggregates, fine aggregates, water, and some additives for reducing permeability such as silica fume, fly ash and bentonite. Plastic concrete is commonly used in the construction of diaphragm walls in earth dams to reduce seepage from their foundations. Improvement and modification of physical specifications of plastic concrete reduce cracks and increases the operating life of concrete. An important requirement for the plastic concrete in such applications is a low elastic modulus compatible with the foundation, [8, 9].

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Using bentonite slurry in plastic concrete results in higher formability and lower permeability [7]. In low permeability concrete, bentonite is used as a partial replacement of cement. Bentonite is a natural material. It has been found in most mountains of Red Sea in Egypt. Bentonite presents strong colloidal properties and its volume increases several times when coming into contact with water, creating a gelatinous and viscous fluid. The ionic surface of Bentonite has the useful property in making a sticky coating on sand grains, [10]. Some researchers studied the feasibility of using bentonite due to its properties in the manufacturing of concrete. The results showed that bentonite has an effect on the setting time of cement, [13-15].Poon et al. (2005) studied the effect of metakaolin clay and silica fume on the mechanical properties of the concrete. The effect of the supplementary materials on the durability of concrete also is discussed. The results indicate an improvement in both the strength and durability of concrete [16].Memon (2012) studied the behavior of mixes containing bentonite against acid attack. The aggressiveness of sulfuric acid on concrete was more pronounced than hydrochloric acid. Low-cost concrete can be produced by substituting bentonite as partial replacement of cement in concrete without compromising on strength parameters. The workability, density, and water absorption decreased with the introduction of bentonite as cement replacement [17-19].Pisheh and Hosseini (2012) concluded that an increase in the bentonite content results in a decrease of the compressive strength and elastic modulus of the material [20].Moayeri et al.(2017) studied on Investigating the Physical Characteristics of Non-Structural Lightweight Aggregate Blocks of Built with Region Materials [30].

2. Experimental Work

To achieve the object of this research, 28 mixes were prepared. Bentonite and addiecrete (DM2) as different types of materials for reducing the permeability were used. Two types of coarse aggregates (dolomite and gravel) were used. To evaluate the compressive strength, 168 cubes 150×150×150 mm were cast and tested. 84 Cylinder 10 × 20 mm were cast and testing for determine the splitting tensile strength. 84 Cylinder 10 × 10 mm were cast and testing for determining the permeability coefficient. 84 Prisms with 100×100×500 mm were cast to evaluate the flexural strength. For impact test; cylinder 84 × 10 × 10 mm were cast and tested.

3. Materials

Portland cement (CEM I 42.5 N) was used according to the requirements of Egyptian standard specification, 4765-1/2012 [21]. 3.15 and 3989 cm^2/gm of the specific gravity and Blain fineness of ordinary Portland cement, respectively were measured. The cement has the fineness of 6% with initial setting time 1hr 20min and final setting time 5hrs 40 min. Gravel and dolomite were used as a coarse aggregate and comply the requirements of E.S.S. 1109/2008 and ASTM C33, respectively [22,23]. Well graded siliceous sand was used. The physical properties of the aggregate were shown in Table [1]. The physical and chemical properties of bentonite were shown in tables [2,3]. The bentonite used satisfies Egyptian standard specifications (5758/2006), [24-28].

Table 1. Physical properties of aggregate

	Sand	Crushed dolomite	Gravel
Specific gravity	2.6	2.74	2.60
Absorption %	0.78	2.5	1.0
Fineness modulus	2.55	7.1	6.8
Mximum nominal size	-	10	10
Fracture modules	-	16.5	15

Table 2. Physical properties of bentonite

Color	Light yellow
Size	Pass from sieve# 200
Free swell	60% by volume
Nature	pozzolanic

Table 3. Chemical properties of bentonite

Compound	Amount
SiO_2	49.634
Al_2O_3	21.118
Fe_2O_3	3.235
CaO	12.563
MgO	3.591
SO_3	0.163
K_2O	2.091
Na_2O	0.449
TiO_2	0.498
MnO	0.07
P_2O_5	0.119
Cr_2O_3	0.007

4. Casting and Testing Procedures

To cast the mixes, the coarse aggregate was added to mixes. The slurry (water, admixture and/or bentonite) was added and mixing continued for four minutes to ensure full mixing. After 24 hours of casting, the specimens were removed from the molds and submerged in water at 20°C until testing. A 2000 KN capacity compressive strength testing machine was used to determine the compressive strength considering the average value of three specimens as the representative value. The compressive strength test was performance in according to ASTM C579 test method B [11,12]. The concrete mix proportions were illustrated in Table (2). The test of permeability was carried out by a locally produced permeability apparatus as shown in figure 1. For preparing the specimens, the specimens were firstly isolated with silicon from all sides except the upper and lower faces to make only one direction for water to flow. After isolating the specimens, the specimens were placed in apparatus. Then the water is pumped into the apparatus and make sure there is no seepage between the specimens and the apparatus. The cover is placed and tied with screws. The water is poured from the top of the cover to fill the vacuum inside the cover. By pump, the water is pumped under pressure of 30 bars. The valves are then opened to distribute the pressure on the samples equally. The amount of water passed through the specimens is determined after 24 hours which indicates the permeability of specimens. To calculate the permeability coefficient in cm/sec (Darcy coefficient) we can use the following formula: $K == \frac{cc*h}{A*t*P})$ where, K is the permeability coefficient, cc is the permeated water in cm^3, h is the height of the specimen in cm, A is the surface area of the specimen in cm^2, t is the time to permeate in sec and P is the hydrostatic pressure in cm of water column

Figure 1. Permeability apparatus

Table 4. Concrete mix proportions (kg/m³)

Code mix	Cement	Sand	Gravel	Dolomite	Water	Bentointe	HRWR	Addicrete
Dc	350.0	597.1		1194.25	194	0		
D1	346.5	596.9		1193.9	194	3.5		
D2	343.0	596.7		1193.5	194	7		
D3	339.5	596.5		1193.1	194	10.5		
D4	336.0	596.4	-	1192.7	194	14		
D5	332.5	596.2		1192.3	194	17.5		
D10	315.0	595.2		1190.4	194	35		
D15	297.5	594.2		1188.4	194	52.5		
D20	280.0	593.3		1186.5	194	70		
Gc	350.0	613.5	1226.9			0	7	-
G1	346.5	613.3	1226.5			3.5		
G2	343.0	613.1	1226.1			7		
G3	339.5	612.9	1225.8			10.5		
G4	336.0	612.7	1225.4	-	174	14		
G5	332.5	612.5	1224.9			17.5		
G10	315.0	611.5	1222.9			35		
G15	297.5	610.5	1220.9			52.5		
G20	280.0	609.5	1218.9			70		
Tc		602.0		1204.0				0
T0.25		601.4		1202.7				0.875
T0.5		600.7	-	1201.4	194	-	-	1.75
T1		599.4		1198.8				3.5
T2		596.8		1193.5				7
Lc	350.0	618.5	1236.9					0
L0.25		617.8	1235.6					0.875
L0.5		617.1	1234.3	-	175	-	-	1.75
L1		615.8	1231.6					3.5
L2		613.1	1226.2					7

*HRWR: high rang water reducer

5. Results and Discussions

5.1 Effect of type of Permeability Reduction Materials on Slump

Figures (1) and (2) illustrate the effect of type of permeability reduction materials on the slump of the fresh concrete with dolomite or gravel as a coarse aggregate. Figure (2) indicates the effect of percent of bentointe as a replacement of cement weight on the slump. It is clear that; as the percent of bentointe increases as the value of slump decreases. This is because bentointe absorbs lots of water which decreases the water content in concrete mix. The slump of gravel was higher than the slump of crushed dolomite. Because the crushed dolomite absorbs water more than gravel and because of the softness of the gravel surface which raises concrete workability. The slump value for the mixes of gravel and dolomite as a coarse aggregate ranged from (1.7 to 8 cm) and (0.3 to 6.7 cm), respectively. It is noticed that, the slump for the mixes with gravel increases than that for the mixes with dolomite by an average 16.3 %. Figure (3) shows the relation between the percent of addicrete by cement weight on the slump value of concrete. The figure illustrates that the slump value for the concrete mixes increase as increasing the percent of addicrete. Where, it works on the ease of sliding granules on each other. The slump value for the mixes of gravel and dolomite as a coarse aggregate ranged from (2.9 to 7.5 cm) and (2 to 6.3 cm), respectively. It is noticed that, the slump for the mixes with gravel increases than that for the mixes with dolomite by an average 13.3 %. From the two figures it is an opposite effect on the slump of concrete for bentointe and addicrete.

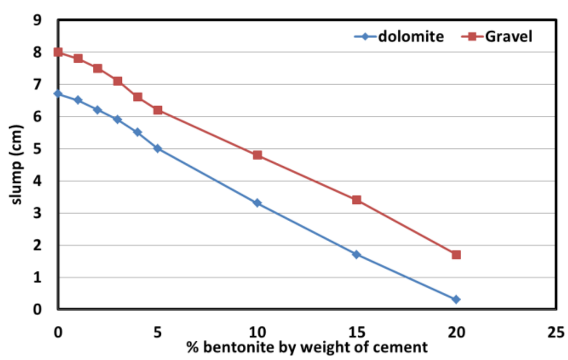


Figure (2) Relationship between slump and percent of bentonie as a replacement of cement

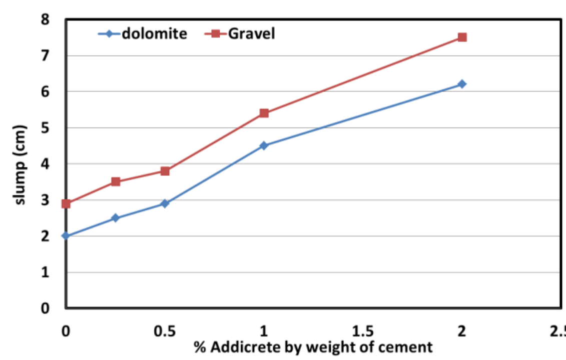


Figure (3) Relationship between slump and percent of addicrete as a percent of cement weight

5.2 Effect of type of permeability reduction materials on the mechanical properties

5.2.1 The Compressive Strength

Figures (4) to (7) describe the effect of type of permeability reduction materials on the compressive strength of the concrete mixes with dolomite or gravel as a coarse aggregate. In the figure (4) the effect of bentonite percentage as a replacement of cement weight on the compressive strength of the mixes with dolomite or gravel was discussed. Generally, as increases the percent of bentonite as increases in the compressive strength of both dolomite and gravel up to 5 % of bentonite as a replacement of cement content. In addition to a reduction in the compressive strength was recorded after 5% up to 20% of bentonite as a replacement of cement content. Also, the compressive strength of the mixes with dolomite more than that with gravel. For example, the maximum compressive strength at 28 days was calculated at 5% bentonite as a replacement of cement content and the compressive strength was 207.6 and 168.7 kg/cm^2 for mixes with dolomite and gravel, respectively. However, these results reduced to 167.7 and 160.4 kg/cm^2, respectively by the end of the testes at 20% of bentonite as a replacement of cement content. The same trends were observed for the mixes with dolomite or gravel at 7 days. The reason for these results yields to filling the voids and pores at 5 % of bentonite, however, more than this percent the weakening the cohesion strength between aggregates grains and the paste leads reduces the compressive strength. These results were supported by Chandrakanth et al., (2016) [29]. Figure (5) illustrates the effect of addicrete percentage as a percent of cement weight on the compressive strength of the mixes with dolomite or gravel. Generally, as increases the percent of addicrete as increases in the compressive strength of both dolomite and gravel up to 1 % of addicrete by cement weight. In addition to a reduction in the compressive strength was recorded after 1% up to 2% of addicrete by cement weight. For example, the maximum compressive strength at 28 days was calculated at 1% addicrete as a percent of cement content and the compressive strength was 350 and 328.5 kg/cm² for mixes with dolomite and gravel, respectively. However, these results reduced to 253.7 and 231.1 kg/cm², respectively by the end of the testes at 2% of addicrete as a percentage of cement content. The same trends were observed for the mixes with dolomite or gravel at 7 days. Figures (6) and (7) illustrates that the compressive strength of the mixes with addicrete higher than that of bentonite for both mixes with dolomite or gravel as a coarse aggregate. Where 40.6 % increases in the maximum compressive strength for the mixes with dolomite or gravel.

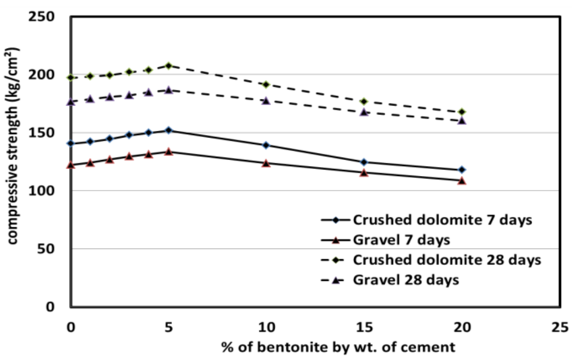


Figure 4. Relationship between compressive strength and percent of bentointe as a replacement of cement weight at different ages

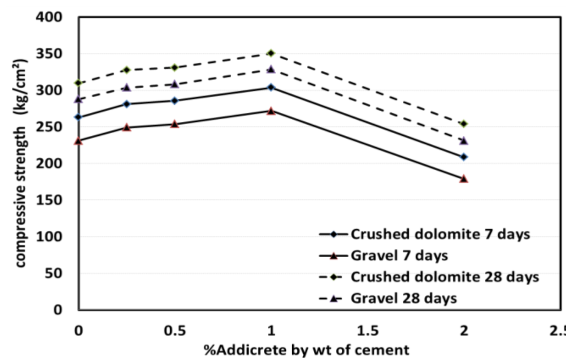


Figure 5. Relationship between compressive strength and percent addicrete as a percent of cement weight at different ages

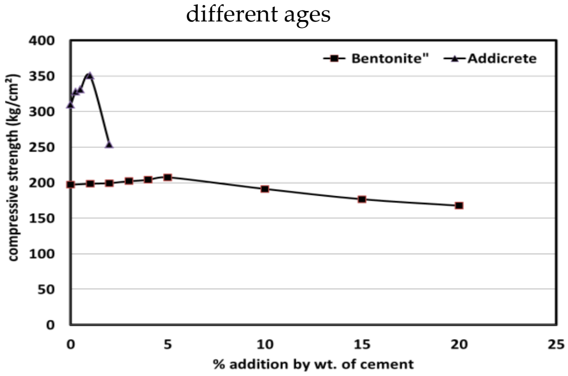


Figure 6. Relationship between compressive strength and percent of type of permeability reduction materials for the mixes with dolomite as a coarse aggregate

Figure 7. Relationship between compressive strength and percent of type of permeability reduction materials for the mixes with gravel as a coarse aggregate

5.2.2 The Splitting Tensile Strength

Figures (8) to (11) describe the effect of type of permeability reduction materials on the splitting tensile strength of the concrete mixes with dolomite or gravel as a coarse aggregate. In the figure (8) the effect of bentonite percentage as a replacement of cement weight on the splitting tensile strength for the mixes with dolomite or gravel was discussed. Generally, as increases the percent of bentonite as increases in the splitting tensile strength for both dolomite and gravel up to 5 % of bentonite as a replacement of cement content. In addition to a reduction in the splitting tensile strength was recorded after 5% up to 20% of bentonite as a replacement of cement content. Also, the splitting tensile strength for the mixes with dolomite more than that with gravel. For example, the splitting tensile strength at 28 days was calculated at 5% bentonite as a replacement of cement content and the splitting tensile strength was 22.7 and 19.5 kg/cm^2 for mixes with dolomite and gravel, respectively. However, these results reduced to 11.4 and 8.1 kg/cm^2, respectively by the end of the testes at 20% of bentonite as a replacement of cement content. These results were supported by Chandrakanth et al., (2016) [29]. Figure (9) illustrates the effect of addicrete percentage as a percent of cement weight on the splitting tensile strength for the mixes with dolomite or gravel. Generally, as increases the percent of addicrete as increases in the splitting tensile strength for both dolomite and gravel up to 1 % of addicrete by cement weight. In addition to a reduction in the splitting tensile strength was recorded after 1% up to 2% of addicrete by cement weight. For example, the maximum splitting tensile strength at 28 days was calculated at 1% addicrete as a percent of cement content and the splitting tensile strength was 30.8 and 27.6 kg/cm^2 for mixes with dolomite and gravel, respectively. However, these results reduced to 17.9 and 14.6 kg/cm^2, respectively by the end of the testes at 2% of addicrete as a percentage of cement content. Figures (10) and (11) illustrates that the splitting tensile strength for the mixes with addicrete higher than that of bentonite for both mixes with dolomite or gravel as a coarse aggregate. Where 26.3 and 29.3 % increases in the maximum splitting tensile strength for the mixes with dolomite and gravel, respectively.

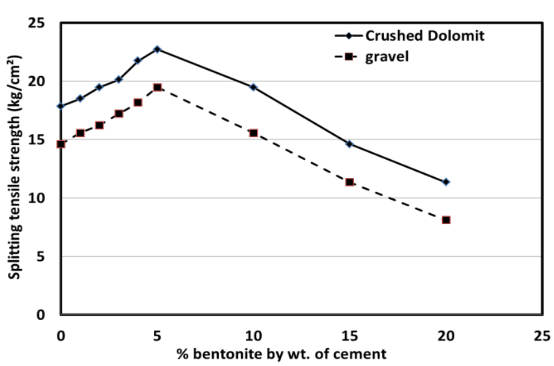


Figure 8. Relationship between splitting tensile strength and percent of bentointe as a replacement of cement weight

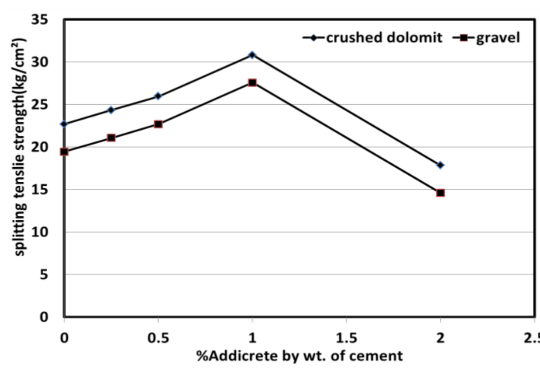
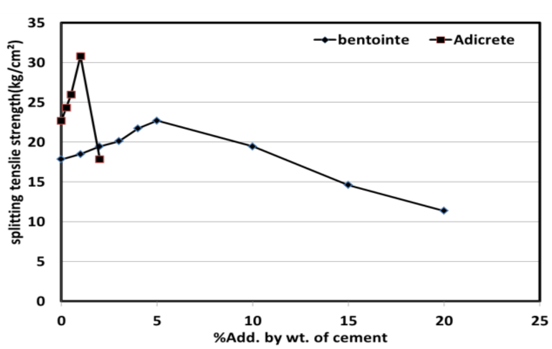


Figure 9. Relationship between splitting tensile strength and percent addicrete as a percent of cement weight



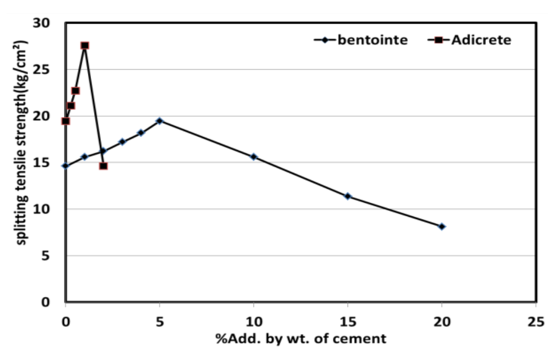


Figure 10. Relationship between splitting tensile strength and percent of type of permeability reduction materials for the mixes with dolomite as a coarse aggregate

Figure 11. Relationship between splitting tensile strength and percent of type of permeability reduction materials for the mixes with gravel as a coarse aggregate

5.2.3 The Flexural Strength

Figures (12) to (15) describe the effect of type of permeability reduction materials on the flexural strength of the concrete mixes with dolomite or gravel as a coarse aggregate. In the figure (12) the effect of bentonite percentage as a replacement of cement weight on the flexural strength of the mixes with dolomite or gravel was discussed. Generally, as increases the percent of bentonite as increases in the flexural strength of both dolomite and gravel up to 5 % of bentonite as a replacement of cement content. In addition to a reduction in the flexural strength was recorded after 5% up to 20% of bentonite as a replacement of cement content. Also, the flexural strength of the mixes with dolomite more than that with gravel. For example; the flexural strength at 28 days was calculated at 5% bentonite as a replacement of cement content and the flexural strength was 75 and 71.3 kg/cm^2 for mixes with dolomite and gravel, respectively. However, these results reduced to 51.8 and 48.4 kg/cm^2, respectively by the end of the testes at 20% of bentonite as a replacement of cement content. These results were supported by Chandrakanth et al., (2016) [29]. Figure (13) illustrates the effect of addicrete percentage as a percent of cement weight on the flexural strength of the mixes with dolomite or gravel. Generally, as increases the percent of addicrete as increases in the flexural strength of both dolomite and gravel up to 1 % of addicrete by cement weight. In addition to a reduction in the flexural strength was recorded after 1% up to 2% of addicrete by cement weight. For example; the maximum flexural strength at 28 days was calculated at 1% addicrete as a percent of cement content and the flexural strength was 85.2 and 83.3 kg/cm^2 for mixes with dolomite and gravel, respectively. However, these results reduced to 56.3 and 54.4 kg/cm^2, respectively by the end of the testes at 2% of addicrete as a percentage of cement content. Figures (14) and (15) illustrates that the flexural strength of the mixes with addicrete higher than that of bentonite for both mixes with dolomite or gravel as a coarse aggregate. Where 12.3 and 14.4 % increases in the maximum flexural strength for the mixes with dolomite and gravel, respectively.

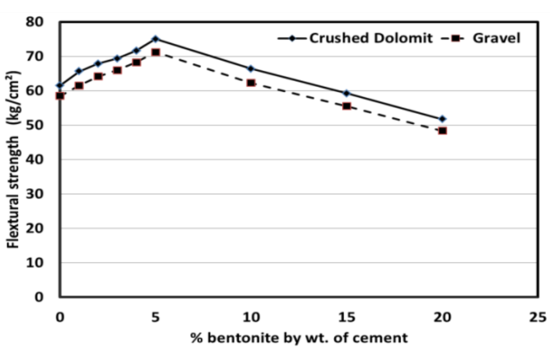


Figure 12. Relationship between flexural strength and percent of bentointe as a replacement of cement weight

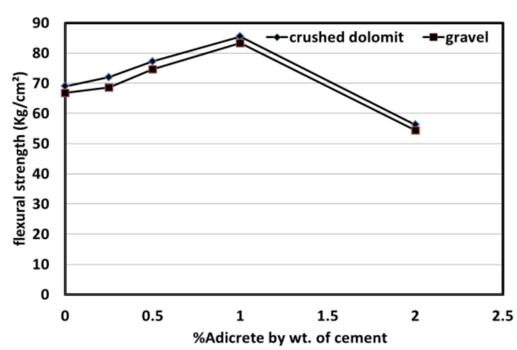


Figure 13. Relationship between flexural strength and percent addicrete as a percent of cement weight

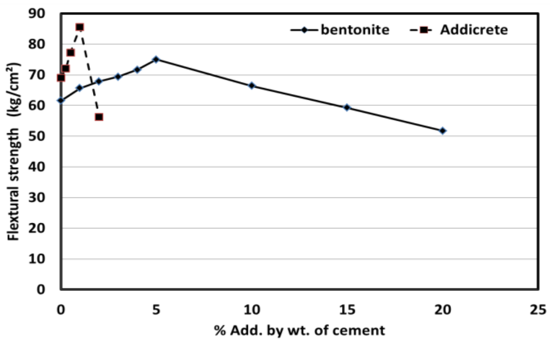


Figure 14. Relationship between flexural strength and percent of the type of permeability reduction materials for the mixes with dolomite as a coarse aggregate

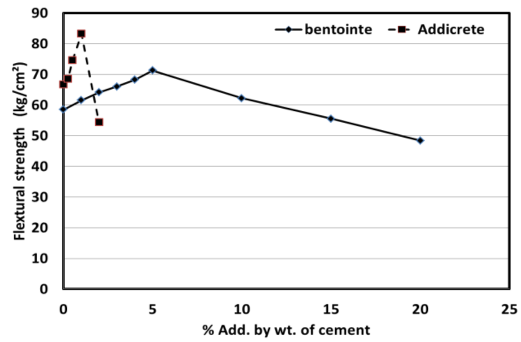


Figure 15. Relationship between flexural strength and percent of the type of permeability reduction materials for the mixes with gravel as a coarse aggregate

5.3 Effect of type of Permeability Reduction Materials on the Permeability Coefficient of Concrete

Figures (16) to (19) describe the effect of type of permeability reduction materials on the permeability coefficient of the concrete mixes with dolomite or gravel as a coarse aggregate. In the figure (16) the effect of bentonite percentage as a replacement of cement weight on the permeability coefficient for the mixes with dolomite or gravel was discussed. Generally, as increases the percent of bentonite as decreasing in the permeability coefficient for both dolomite and gravel up to 5 % of bentonite as a replacement of cement content. In addition to an increase in the permeability coefficient was recorded after 5% up to 20% of bentonite as a replacement of cement content. Also, the permeability coefficient for the mixes with dolomite more than that with gravel. For example; the permeability coefficient was calculated at 5% bentonite as a replacement of cement content and the permeability coefficient was 0.0000021 and 0.0000016 cm/sec for mixes with dolomite and gravel, respectively. However, these results were increasing to 0.0000032 and 0.0000028 cm/sec, respectively by the end of the testes at 20% of bentonite as a replacement of cement content. Figure (17) illustrates the effect of addicrete percentage as a percent of cement weight on the permeability coefficient for the mixes with dolomite or gravel. Generally, as increases the percent of addicrete as decreasing in the permeability coefficient for both dolomite and gravel. For example; the permeability coefficient was calculated at 2% addicrete as a percent of cement content was 0.0000008 and 0.0000006 cm/sec for mixes with dolomite and gravel, respectively. Figures (18) and (19) illustrates that the permeability coefficient for the mixes with bentonite is higher than that of addicrete for both mixes with dolomite or gravel as a coarse aggregate. Where the average increase in the permeability coefficient was 61.9 and 62.5 % for the mixes with dolomite and gravel, respectively. These results yield to the difference in the microstructure of the mixes.

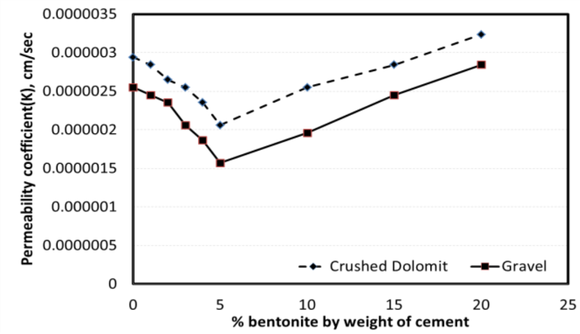


Figure 16. Relationship between permeability coefficient and percent of bentonite as a replacement of cement weight

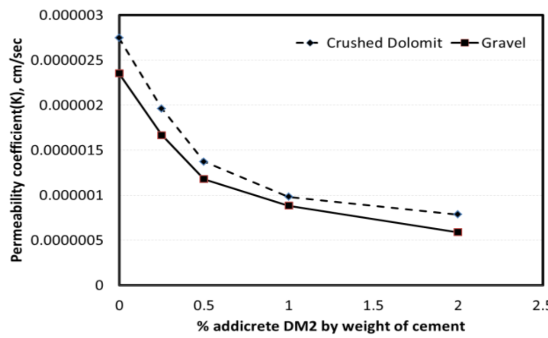


Figure 17. Relationship between permeability coefficient and percent addicrete as a percent of cement weight

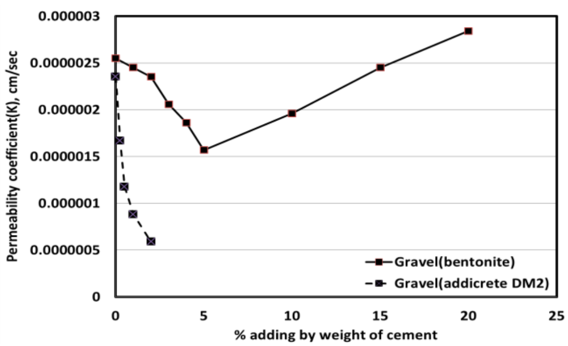


Figure 18. Relationship between permeability coefficient and percent of the type of permeability reduction materials for the mixes with gravel as a coarse aggregate

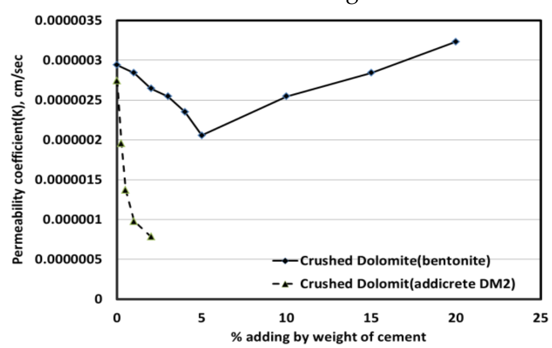


Figure 19. Relationship between permeability coefficient and percent of the type of permeability reduction materials for the mixes with dolomite as a coarse aggregate

5.4 Impact Resistance

The response of a structural element to impact depends on the interaction between the impacting body and the structure described by a number of factors as relative masses, velocities, the stiffness of contact zone, the frequency of loading, the accuracy of impact, and the area of local energy absorbed. In this study, a drop-weight was used to apply the impact loading to mixes from a certain drop height. Impact test was carried out by using a hammer of 7740 gm falling from 700 mm height on the specimens and the number of blows for first crack (N1) and for failure (N2) is calculated. The relationship between the number of drops and percentage of addition of permeability reduction materials with dolomite as a coarse aggregate is shown in figure (20). It can be noticed as increases the percent of bentonite as increasing in the number of drops needed for the first cracks and failure for the mixes with dolomite up to 10 % of bentonite as a replacement of cement content. In addition to a reduction in the number of drops was recorded after10% up to 20% of bentonite as a replacement of cement content. This yield to the bentonite increases the elasticity of concrete so that the number of drops increases so the impact energy increases. For example, the maximum number of drops was recorded at 10 % bentonite as a replacement of cement content was 13 and 18 for first crack and failure, respectively. However, these results reduced to 7 and 10, respectively by the end of the testes at 20% of bentonite as a replacement of cement content. The figure shows also the as increases the percent of addicrete as decreasing the number of drops needed for the first cracks and failure for the mixes with dolomite. The maximum number of drops was 11 and 14 for first crack and failure, respectively. The results show that the number of drops for the mixes with bentonite was higher than that for the mixes with addicrete. For the example, at 2 % of addition, the number of drops for the failure was 15 and 7 for the mixes with bentonite and addicrete, respectively.

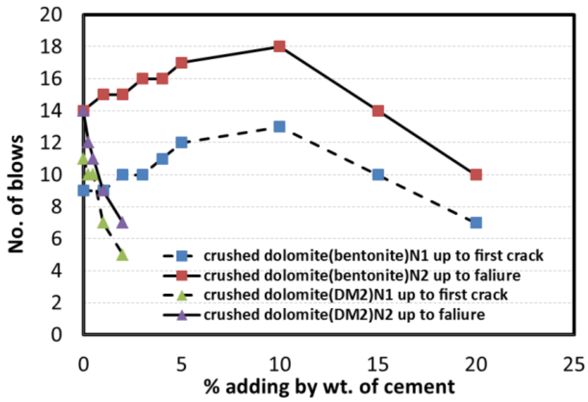


Figure 20. Relationship between the number of blows and the different percentage of permeability reduction materials

6. Conclusions

The results summarize that the following conclusions

1. For the mixes with bentonite and addicrete, the slump value for the mixes with gravel increases than that the mixes with dolomite by an average 16.3 and 13.3%, respectively.
2. It is an opposite effect on the slump of concrete for bentonite and addicrete mixes.
3. 5% was the optimum values of bentonite as a replacement of cement content.
4. 1 % was the optimum value of addicrete as a percentage of cement content.
5. The mechanical properties of the mixes with addicrete higher than that of bentonite for both mixes with dolomite or gravel as a coarse aggregate. Where 40.6 % increases in the maximum compressive strength for the mixes with dolomite or gravel. 26.3 and 29.3 % increases in the maximum splitting tensile strength for the mixes with dolomite and gravel, respectively. 12.3 and 14.4 % increases in the maximum flexural strength for the mixes with dolomite and gravel, respectively.
6. The permeability coefficient for the mixes with bentonite is higher than that of addicrete for both mixes with dolomite or gravel as a coarse aggregate. The average increase the permeability coefficient was 61.9 and 62.5 % for the mixes with dolomite and gravel, respectively.
7. The number of drops for the mixes with bentonite was higher than that for the mixes with addicrete.

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