Studying the effect of waterproofing admixtures on some properties of cement mortar

Rawa Shakir Muwashee¹, Hamid Ahab Al-Jameel²

¹² University of Kufa, Faculty of Engineering
Email: rawas.muwashee@uokufa.edu.iq

Abstract: This study mainly focused on testing the feasibility of using some finely divided materials (waterproofing) as a permeability-reducing admixture in mortar after mixing with sulphate resisting cement and fine sand and evaluating the effects of these materials on the other properties of mortar. Bentonite and limestone dust are used as a permeability –reducing admixture. Permeability, compressive strength, modulus of rupture, density and ultrasonic pulse velocity tests have been investigated in this study. At 1% of bentonite addition, the quantity of penetrated water reaches about 91% of the water permeation quantity of the control mix. The results indicate that the optimum percentage of limestone is 2.5% of the cement weight, the quantity of penetrated water through mortar at this level is about 18.2% and 47.8% of the water permeation quantity of the control mix of rich and lean mixes, respectively. The addition of 7.5% of limestone dust in rich mix results in an improvement in compressive strength by about 51.8%. Other mortar properties including modulus of rupture indicates trends similar to that observed in compressive strength for all materials used in this study.

Keywords
Waterproofing admixture, cement mortar, bentonite, compressive strength, limestone.

1. Introduction

Waterproofing underground structures is very important in Iraq, especially in the middle and southern regions. The problem is complicated because of the salty under-ground water (Muwashee, 2005).

The compressive strength of concrete is regarded as a principal indicator to determine the quality of concrete. But in other practical circumstances, other properties of concrete like durability and impermeability may be more important than strength. The concrete can get deteriorated as a result of the influence of external conditions like the movement of liquids and gases that carry the harmful agents which pass through its constituents (Muwashee, 2005).

The permeability of a mortar or concrete to the flow of water may be determined under a small or large head of water. In many cases a fairly high-water pressure, up to 1.38 MPa or more, is used, and the rate at which water passes through the specimen is determined (Meletlou et al., 1992, and Ludirdja et al., 1989). Tests of permeability at high pressures are most commonly made on concrete cylinders of circular slabs in an apparatus, which permits water under the required pressure is fed to the upper side of the specimen and the water percolating through is collected from the other side and measured. Alternatively, the rate of inflow of water may be measured. The specimens are usually sealed into metal containers with suitable watertight caps. A test of the permeability under a 20-cm head of water is included in the British standard for concrete roofing tiles (Muwashee, 2005). The British standards test methods measure the surface absorption and not the permeability of the concrete mass, and typically the
absorption of the outer surface layer is different from that of the bulk of the concrete (Meletlou et al., 1992).

Al–Khalidy (2001) evaluated the concrete permeability containing different percentages of sulphate using nitrogen gas. The evaluation process was carried out on the two different mixes of the gradient proportions of (1:1.5:3) and (1:2:4) containing various sulphate contents of the level (0.24, 0.5, 1.0, 1.5 and 2.0) % of the sand weight. One water cement ratio is used of the value (0.5). The properties of the fresh mixes are investigated by measuring their slump values. The results indicate noticeable reductions in the recorded slump values when the sulphate content is raised progressively.

2. Waterproofing admixtures

Waterproofing admixtures cannot be expected to be as reliable or effective as applying a moisture-barrier system to the concrete. Waterproofing may reduce the rate of penetration of aggressive chemicals found in water; however, it will not stop them. Waterproofing admixtures may also reduce the penetration of water into concrete, thus delaying the effects of damage caused by freezing and thawing by reducing the amount or rate of moisture entering the concrete (ACI, 1989). An admixture described as a damp proofer or as a water proofer may have a secondary effect on the properties of fresh concrete not directly indicated by the name. For example, it may promote entrainment of air; thus, it may more properly be considered an air-entraining admixture (ACI, 1989). The waterproofing admixture can be classified into three major groups (Muwashee, 2005): permeability-reducing admixtures, water-repellent admixtures and miscellaneous admixtures.

2.1 Permeability-reducing admixtures

Admixtures that fall within this group reduce both permeability and porosity of concrete and fill concrete pores. They also can be classified into two groups :-

i) Finely divided mineral admixtures

Finely divided mineral materials can be divided into three Types:

A - Relatively chemically inert materials: This class includes such materials as ground quartz, ground limestone, bentonite, clays, hydrated lime or the dust of normal-weight aggregates, chalk, and talc. These materials are called fillers (Neville and Brooks 1987 and Neville, 2011).

B - Cementitious materials: The cementitious materials include natural cement, hydraulic limes, slag cements (mixtures of blast-furnace slag and lime), and granulated iron blast-furnace slag (Muwashee, 2005).

C - Pozzolans: Pozzolan is defined in ASTM C219 (ASTM, 1989) as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (liberated by hydrating Portland cement) at ordinary temperatures to form compounds possessing cementitious properties". The pozzolanas can be divided into two groups, natural and artificial. The natural pozzolanic materials most commonly met with are: volcanic ash (the original pozzolana), pumicite, opline shales and cherts calcined diatomaceous earth, and burnt clay (Neville, 2011).

ii) Water-reducing and air - entraining admixtures

The purpose of using a water - reducing admixture in a concrete mix is to allow a reduction in the water/cement ratio while retaining the desired workability or, alternatively, to improve its workability at a given water/cement ratio (Neville, 2011). When the w/c ratio is reduced, the effect on the hardened concrete is increased compressive strength and reduced permeability (ACI, 1989).
2.2 Water - repellent admixtures
Such materials reduce the capillary forces by which water is drawn through a mortar or concrete and thus, the rate of absorption is under zero head. This action will also reduce capillary transmission of water, but not diffusion of water vapour, through concrete is in contact with the ground. This water-repellent action is not effective against water pressures in excess of a few centimetres (Muwashee, 2005).

2.3 Miscellaneous admixtures
There is a group of miscellaneous materials sometimes advertised as waterproofing agents. All of these are usually detrimental to concrete strength, and none are truly waterproofers. These include barium sulphate and calcium and magnesium silicates, finely divided silica and naphthalene, colloidal silica and fluosilicate, petroleum jelly and lime, cellulose materials and wax, silica and aluminium, coal tar cut with benzene, and sodium silicate (ACI, 1989).

3. Influence of finely divided mineral admixtures on properties of concrete

3.1 Effect of fillers on properties of concrete and specific uses
A filler is a very finely-ground material of about the same fineness as Portland cement, which, owing to its physical properties, has a beneficial effect on some properties of concrete, such as workability, density, permeability, capillarity, bleeding, or cracking tendency. Fillers are usually chemically inert but there is no disadvantage if they have some hydraulic properties or if they enter into harmless reactions with the products of reaction in the hydrated cement paste. Indeed, it has been found that CaCO₃, which is a common filler, reacts with C₃A and C₄AF to produce 3CaO.Al₂O₃.CaCO₃.11H₂O. Fillers can be naturally occurring materials or processed inorganic mineral materials. What is essential is that they have uniform properties, especially fineness. They must not increase the water demand when used in concrete, unless used with a water-reducing admixture, or adversely affect the resistance of concrete to weathering or the protection against corrosion, which concrete provides to the reinforcement. Clearly, they must not lead to a long-term retrogression of strength of concrete, but such a problem has not been encountered (Neville, 2011).

3.2 Bentonite
The physical and chemical properties of bentonites typically vary both within and between deposits due to differences in the degree of chemical substitution within the smectite structure and the nature of the exchangeable cations present, and also due to the type and amount of impurities present. No bentonite is universally acceptable for every application. In this context a distinction can be made between the grade and quality of the bentonites. The grade is defined as the smectite content of the bentonite, whilst its quality is related to the inherent physico-chemical properties of the clay, either in its natural or modified form, and is a measure of likely industrial performance. However, there is no recognised minimum grade or smectite content below which a clay is no longer considered to be a bentonite (Inglethorpe et al., 1993).

4. Material used
A sulphate-resisting Portland cement Type V was used, manufactured by AL-Muthanna factory, fine aggregate (Sand), which was brought from AL-Nawafith Co.LTD for sand and gravel filters in Najaf; yellowish-brown Bentonite was brought from General Company of Geological Survey and Mining in Baghdad (local materials from Al-sufra in western desert). These were mixed with tap water for a period of time ranging between (5-7) days for the absorption of the sufficient quantity of water and then added to the cement mortar mixture as a thick liquid.

Then, the limestone dust used in the experimental work was supplied by Cement Plant of Kufa. Finally, the superplasticizer, which is a commercially marketed superplasticizer liquid Iraqi admixture
was used; chemically is a modified condensation product of melamine and formaldehyde (type F according to ASTM C494) (ASTM, 1986). The best known being Melment L10. It was added at the end of the mixing operation with 2-3 minutes additional mixing.

5. The experimental program

The experimental program of this study was conducted on specimens of cement mortar. Cement mortar specimens were prepared for permeability, density, compressive strength and modulus of rupture. Different percentages of bentonite, and limestone dust were used to investigate these properties.

The details of mixes can be summarized as: Firstly, the bentonite was used as an admixture to sulphate-resistant Portland cement mortar. Four percentages of bentonite were used: 1, 2, 3 and 4 percent by weight of cement. Secondly, limestone dust was used as an admixture to sulphate-resisting Portland cement mortar. Six percentages of this dust were used: 2.5, 5, 7.5, 10, 12.5 and 15 percent by weight of cement.

6. Testing procedures

6.1 The flow test

The flow table test of fresh cement mortar mixes was determined according to ASTM C1437 (ASTM, 2015). This test was carried out for giving a general indication about the effect of percentages of the materials used in this research on consistency.

6.2 The permeability test

It can be summarized into test specimens as:

a- Six test specimens are required for a single test. 3 test specimens of the 6 shall contain water penetration preventive agent, and other 3 specimens shall not contain any agent. It is required to obtain averaged value of the test results of each 3.

b- Cement/sand ratio of the mortar to be tested shall be 1:3. Immediately after mixing the cement, sand and adequate quantity of water to obtain the mortar to be tested, the mortar shall be filled into specimen moulds and shall be tamped with a tamping bar 80 times for each moulding. Concerning mortar, which contains the water penetration preventive agent, the mortar shall be prepared in the same way as mentioned above, but the agent shall be mixed together with other materials during mixing to prepare the test specimens in the same manner to the other kinds of specimens.

c- The mortar shall be left in the moulds for 48 hours, and shall be released from the moulds after that. The test specimens released from the moulds shall be cured in water for 19 days. After curing, the test specimens shall be washed well using clean water, and shall be brushed on both sides to remove the skin out from central area having more than 5 cm dia. They shall be dried to constant weights, and shall be kept at room temperature for 1 day before testing.

6.3 Density test

This test was carried out in order to get information about the variation of void contents due to the difference in percentages of the materials used in this research. It was carried out on the same specimens, which are used in the permeability test. The specimens were weighted to the nearest (0.05 gm) and the average of the three specimens was taken as mentioned in details in Muwashee (2005).

6.4 Compressive strength test

Compressive strength of cement mortar specimens was conducted on (50mm) cubes according to the ASTM C109/C 109M (ASTM, 2008) using 200KN capacity testing machine. The compressive strength of the mortar specimens was tested at the ages 7, 28 and 90 days. The average of three specimens in
each age was taken.

6.5 Modulus of rupture test

The center point loading method was used in making flexure tests on the prism specimens. This test was performed according to ASTM C348 (ASTM, 1989) using (40*40*160 mm) prism specimens with a span of 100 mm. The average of three prism specimens was adopted and the specimens were tested at the ages of 7, 28 and 90 days.

7. Discussion of the results

7.1 Workability results

The flow table test was adopted for measuring the workability of the cement mortar mixes containing various percentages of bentonite, and limestone dust. The flow and W/C ratio for all bentonite mixes are indicated in table 1.

| Mix no. | Bentonite by weight of cement % | W/C ratio | Flow % |
|---------|---------------------------------|-----------|--------|
| M1B     | 0                               | 0.49      | 110    |
| M2B     | 1                               | 0.49      | 95     |
| M3B     | 2                               | 0.49      | 85     |
| M4B     | 3                               | 0.49      | 80     |
| M5B     | 4                               | 0.49      | 70     |

Workability results of Limestone dust mixes prepared by two groups of limestone dust mixes were tried. The W/C ratio was kept constant in the first group. In the second group, the W/C ratios were changed to maintain a flow of (100 ± 10) percent. The flow and W/C ratios for all mixes are shown in tables 2 and 3.

| Mix no. | Limestone dust by weight of cement % | W/C ratio | Flow % |
|---------|--------------------------------------|-----------|--------|
| M1L     | 0                                    | 0.49      | 110    |
| M2L     | 2.5                                  | 0.49      | 95     |
| M3L     | 5                                     | 0.49      | 90     |
| M4L     | 7.5                                   | 0.49      | 85     |
| M5L     | 10                                    | 0.49      | 80     |
| M6L     | 12.5                                  | 0.49      | 75     |
| M7L     | 15                                    | 0.49      | 70     |

Table 3. Variations in the W/C ratios of limestone dust mixes.

| Mix no. | Limestone dust by weight of cement % | W/C ratio | Flow % |
|---------|--------------------------------------|-----------|--------|
| M1L1    | 0                                    | 0.49      | 110    |
| M2L1    | 2.5                                  | 0.5       | 105    |
| M3L3    | 5                                     | 0.51      | 100    |
| M4L4    | 7.5                                   | 0.52      | 95     |
| M5L5    | 10                                    | 0.54      | 95     |
| M6L6    | 12.5                                  | 0.56      | 90     |
| M7L7    | 15                                    | 0.59      | 95     |

7.2 Permeability results

The water permeation quantity and water permeation ratio of cement mortar containing different percentages of bentonite and, limestone dust as discussed below.

Table 4 demonstrates the effect of bentonite on the water permeation quantity of cement mortar. The
results show that the presence of bentonite as an admixture in cement mortar leads to a reduction in the quantity of penetrated water and this reduction increases with the increase of bentonite percentage. At 1% of bentonite as an admixture, the decrease in the water permeation ratio is about 8.9 percent as compared with control mix. This reduction could be attributed to an increase in the quantities of fine materials because of the addition of a mineral powder of bentonite, which may fill the pores of the hardened mortar.

The influence of limestone dust as an admixture to cement on the water permeation quantity of cement mortar has been studied using two groups of mixes. Details of the results are indicated in table 5.

**Table 4.** Permeability test results of bentonite containing mortar

| Bentonite by weight of cement% | Water permeation quantity (gm) | Water permeation ratio |
|-------------------------------|--------------------------------|-----------------------|
| 0                             | 11.25                          | 1.00                  |
| 1                             | 10.25                          | 0.91                  |
| 2                             | 9.03                           | 0.80                  |
| 3                             | 7.02                           | 0.62                  |
| 4                             | 6.87                           | 0.61                  |

The water permeation quantity of the first group is indicated in table 5. The results have demonstrated that the presence of limestone dust in the cement mortar leads to a reduction in the quantity of penetrated water. Generally, beyond 2.5% of limestone dust, the quantity of penetrated water started to increase. However, the minimum water permeation quantity has been achieved at 2.5% of limestone dust. At this level, the reduction in the water permeation ratio is 81.8% less than that of the control mix.

For the second group, similarly as in the first group, the minimum water permeation quantity has been achieved at 2.5% of limestone dust and the decrease in the water permeation ratio is 52.2 percent less than that of the control mix.

**Table 5.** Influence of limestone dust on the cement mortar permeability.

| Mix groups | Limestone dust by weight of cement % | Water permeation quantity (gm) | Water permeation ratio |
|------------|--------------------------------------|--------------------------------|-----------------------|
| First group| 0                                    | 11.25                          | 1.00                  |
|            | 2.5                                  | 2.05                           | 0.18                  |
|            | 5                                     | 2.88                           | 0.26                  |
|            | 7.5                                   | 3.75                           | 0.33                  |
|            | 10                                    | 4.23                           | 0.38                  |
|            | 12.5                                  | 5.53                           | 0.49                  |
|            | 15                                    | 7.03                           | 0.63                  |
| Second group| 0                                    | 11.25                          | 1.00                  |
|            | 2.5                                  | 5.38                           | 0.48                  |
|            | 5                                     | 7.52                           | 0.67                  |
|            | 7.5                                   | 8.92                           | 0.79                  |
|            | 10                                    | 9.03                           | 0.80                  |
|            | 12.5                                  | 10.12                          | 0.89                  |
|            | 15                                    | 10.5                           | 0.93                  |

For the first group having the same W/C ratio and decreasing workability tends to impair the compaction of the mix beyond 2.5% resulting in an increase in voids. While in the second group the water content in the mix was increased to maintain the workability and that requires excessive water to cover the surface area of the stone resulting in additional voids after drying.
7.3 Compressive strength test results

The results of the compressive strength up to an age of 90 days for bentonite containing mortar are presented in figure 1. The best strength has been achieved at 7 days for 3% of bentonite. The compressive strength at this level is 25.2% more than that of the control mix. At 28 and 90 days less enhancement in strength is observed. The increase in compressive strength is probably due to the filling effect of fine materials in bentonite.

The influence of curing time on the compressive strength up to 90 days is shown in Figure 1. It can be stated that the compressive strength develops with curing time for all hardened samples. This development may be due to the presence of some cementitious compounds in bentonite, which leads to the formation and accumulation of hydration products with age.

The effect of limestone dust as an admixture to cement mortar on the compressive strength has been studied using two groups of mixes. Details of the results are shown in figures 2 and 3.

In the first group, figure 2 demonstrates that the presence of limestone dust as an admixture in cement mortar leads to an increase in the compressive strength, especially at the ages of 28 and 90 days. Generally, beyond 7.5% of limestone dust, the rate of increase in the compressive strength at all ages starts to decrease. However, the best strength has been achieved at 7.5% of limestone dust. At this level, the increase in the compressive strength is 38.4 and 51.8 percent for 28 and 90 days, respectively. At earlier ages (7 days) less enhancement in strength is observed. The contribution to the strength increase can be attributed to the increase in the quantities of fine particles because of the addition of a mineral powder of limestone dust, which may fill the pores of the mortar mixes.

![Figure 1. Influence of bentonite on the compressive strength of cement mortar.](image-url)
Figure 2. Influence of limestone dust on the compressive strength of cement mortar (First group).

Figure 3. Influence of limestone dust on the compressive strength of cement mortar (Second group).

For the second group, figure 3 illustrates that the compressive strength decreases with the increase in limestone dust content. In general, the strength started decreasing rapidly above the level of 7.5% of limestone dust. The reduction in compressive strength is due to the presence of the fine material of limestone dust, which causes a consequent increase in the water demand. Also, the increase in the total water content results in a decrease in the density, and finally a decrease in strength. When limestone dust is used as an admixture to cement mortar, the water demand to maintain the same workability has increased rapidly. However, fine dust should not be presented in excessive quantities because, owing to their fineness and therefore, large surface area, fine dust increases the amount of water necessary to wet all the particles in the mix, and then a reduction in strength will result (Neville, 2011).

It is clear from these figures that the compressive strength develops with curing time for all specimens. This development may be due to the presence of cementitious materials in limestone dust composition, which leads to the formation and accumulation of hydration products with age.

7.4 Modulus of rupture test results

Figure 6 indicates the influence of bentonite on the modulus of rupture of cement mortar. The influence of bentonite on the modulus of rupture is found to be somewhat similar to that of compressive strength. The table shows that the presence of bentonite as an admixture in cement mortar has shown an increase in the modulus of rupture up to a certain percentage, and then the modulus of rupture reduces as bentonite percentage increases. The best modulus of rupture has been achieved at 7 days for 3% of bentonite. The modulus of rupture at this level is 38.7 more than that of the control mix. At 28 and 90 days less
enhancement in the modulus of rupture is observed.

The effect of limestone dust on the modulus of rupture of cement mortar for both groups of mixes is shown in table 5 and plotted in figures 4 and 5.

![Graph showing the effect of bentonite on the modulus of rupture of cement mortar.](image)

**Figure 4.** Effect of bentonite on the modulus of rupture of cement mortar.

![Graph showing the effect of limestone dust on the modulus of rupture of cement mortar (First group).](image)

**Figure 5.** Effect of limestone dust on the modulus of rupture of cement mortar (First group).

For the first group, figure 4 shows that the presence of limestone dust as an admixture in cement mortar has shown an increase in the modulus of rupture except for 12.5 and 15 percent at the age of 7 days. In general, beyond 2.5% of limestone dust, the rate of increase in the modulus of rupture at all ages started to decrease. However, the best modulus of rupture has been achieved at 28 and 90 days for 2.5% of limestone dust. The modulus of rupture at this level is about 69.7 and 61.3 percent more than that of the control mix. At 7 days less enhancement in strength is observed. This reduction in the rate of increase in the modulus of rupture beyond 2.5% of limestone dust may be due to the use of a constant W/C ratio for all levels of addition which results in a decrease in density and strength.

In the second group, the effect of limestone dust is found to be somewhat similar to that of first group, see Figure 6.
Figure 6. Effect of limestone dust on the modulus of rupture of cement mortar (Second group).

8. Conclusions and recommendations

Based on the results of the experimental work of this study, the following conclusions can be drawn.

1- The addition of limestone dust to cement mortar has resulted in decreasing the quantity of penetrated water for both groups of mixes. It was found that the minimum water permeation quantity for both groups of mortar mixes has been achieved at 2.5% of limestone dust. At this level, the reduction in the water permeation ratio is 81.8 and 52.2 percent for the first and second groups of mixes, respectively.

2- The addition of limestone dust to cement mortar leads to an increase in the density of mortar mixes for both groups of mixes. It was found that the maximum density for both groups of mortar mixes has been achieved with 2.5% of limestone dust. At this level, the increase in the density is about 11 and 4.3 percent for first and second groups of mixes, respectively.

3- The presence of bentonite as an admixture in cement mortar showed an increase in the compressive strength. The best strength has been achieved at 7 days for 3% of bentonite. The compressive strength at this level is 25.2% more than that of the control mix.

4- The addition of limestone dust to the cement mortar in the first group of mortar mixes leads to an increase in the compressive strength, especially at the ages of 28 and 90 days. It was found that the best strength has been achieved with 7.5% of limestone dust. The increase in the compressive strength at this level is about 38.4 and 51.8 percent for 28 and 90 days, respectively. In the second group of mortar mixes, the addition of limestone dust to the cement mortar has shown a reduction in the compressive strength. Above the level of 7.5% of limestone dust, the strength started to decrease rapidly.

5- The presence of bentonite as an admixture in cement mortar leads to an increase in tensile strength up to a certain percentage, and then the strength reduces as bentonite percentage increases. The best tensile strength has been achieved at 7 days for 3% of bentonite. At this level, the increase in strength is 38.7 percent.

6- The addition of limestone dust to the cement mortar in both groups of mortar mixes has resulted in increasing the tensile strength of mortar. The best tensile strength for both groups of mortar mixes has been achieved at 2.5% of limestone dust. At 28 days, the increase in the tensile strength at this level is about 69.7 and 23.7 percent for first and second group of mortar mixes.

References
[1] ACI Committee 212. 1989 Chemical admixtures for concrete ACI Materials Journal, Vol 86, No.3, pp 322-323
[2] Al-Abdaly N 2012 Evaluation the effect of cement kiln dust addition on absorption and some mechanical properties of the concrete. *The Iraqi Journal for Mechanical And Material Engineering*, Vol.12, No.4

[3] Al-Khalidy S 2001 Permeability Evaluation of Concrete Containing Different Percentages of Sulfate Using Nitrogen Gas. M.Sc. Thesis, The University of Al-Mustansiriya

[4] American Society for Testing and Materials ASTM C219-89 1989 Standard Terminology Relating to Hydraulic Cement. Annual Book of ASTM Standards, Vol.04.01 pp 167-168

[5] American Society for Testing Materials and Standards (ASTM) 1986 Concrete and Mineral Aggregates. Part 14

[6] American Society for Testing and Materials, (ASTM) C109/C 109M 2008 Standard Test Method for Compressive Strength of Hydraulic Cement Mortar (Using 2-in. or 50-mm Cube Specimens

[7] American Society for Testing and Materials, (ASTM) C348-86, 1989 Standard Test Method for Flexural Strength of Hydraulic Cement Mortars (Using Simple Beam with Center- Point Loading)

[8] American Society for Testing and Materials, ASTM C1437 2015 Standard Test Method for Flow of Hydraulic Cement Mortar

[9] Inglethorpe S, Morgan D, Highly D and Bloodworth A 1993 “Bentonite”, *British Geological Survey*, United Kingdom

[10] Ludirdja D, Berger R and Young J 1989 “Simple Method for Measuring Water Permeability of Concrete”, *ACI Materials Journal*, Vol.86, No.5, pp 433-439

[11] Meletlou A, Tia M and Bloomquist D 1992 Development of a Field Permeability Test Apparatus and Method for Concrete *ACI Materials Journal*, Vol.89, No.1, pp 83-89

[12] Muwashee R 2005 Effect of Finely Divided Materials on Some Properties of Cement Mortar. MSc Thesis, The University of Babylon

[13] Neville, A 2011 *Properties of Concrete* 5th Ed., Pitman Publishing London