

**EFFECT OF FINELY DIVIDED MATERIALS ON  
SOME PROPERTIES OF CEMENT MORTAR**

A Thesis

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Fulfillment of the Requirements  
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of Science in Civil  
Engineering**

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*January ۲۰۰۴*

*Shawal ۱۴۲۴*

# بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَاللَّهُ أَخْرَجَكُمْ مِنْ بُطُونِ أُمَّهَاتِكُمْ لَا تَعْلَمُونَ شَيْئاً وَجَعَلَ لَكُمُ

السَّمْعَ وَالْأَبْصَارَ وَالْأَفْئِدَةَ لَعَلَّكُمْ تَشْكُرُونَ

صدق الله العظيم

سورة النحل، الآية ٧٨

# الإهداء

الى من زرعتني في الحياة بذرة  
وسقتني من دمها قطرة بعد قطرة  
إلى من ايمانها قبساً وصبرها عوناً  
الى اعز الناس

أمي

الى الشمعة التي احترقت لتتير الدرب لي  
الى شرفي العظيم ومثلي الأعلى

أبي

الى من زرع في نفوسنا حب العلم والتعليم  
إلى من علمنا حب الحرف والكلمة والحقيقة  
أساتذتنا الأفاضل

# *CERTIFICATION*

We certify that this thesis “**Effect of Finely Divided Materials on Some Properties of Cement Mortar**”, was prepared by “**Rawa Shakir Abdul-Rudha**”, under our supervision at Babylon University in partial fulfillment of the requirements for The degree of Master of Science in Civil Engineering.

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# CERTIFICATION

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**Rawa S. Abdul-Rudha**

٢٠٠٤

## *ABSTRACT*

Waterproofing of concrete structures is one of the most important problems facing Civil engineers. Most failures in water retaining structures are due to water seeping through their walls and floors, causing some troubles.

The most common method used in Iraq for waterproofing of walls and floors subjected to water flow is by covering (coating ) these walls and floors with bituminous materials. Some of these bituminous materials are mixed with sulfate resisting cement and fine sand before they are used for coating.

This method proved to be vulnerable with time as water starts seeping through walls and floors after certain period. This study was thus conducted to examine the feasibility of using some waterproofing agents as an admixture in mortar after mixing with sulfate resisting cement and fine sand and evaluate the effect of materials on the other properties of mortar.

Bentonite, Limestone dust, and silica fume are used in this study as a waterproofing agents .Therefore, this investigation focused on the evaluation of mortar by using the permeability, compressive strength, modulus of rupture, density and ultrasonic pulse velocity tests. The properties of the fresh mixes are investigated by measuring their flow values.

The results are indicated to noticeable reductions in the recorded flow values as the percent of the materials used in this study raised progressively. Depending on the recorded water permeabilities , it can be said that increasing the percentages of bentonite addition leads to decrease the quantity of penetrated water through mortar . Up to (1%) of bentonite addition, the quantity of penetrated water reaches about (91%) of the water permeation quantity of the control mix.

On the other hand , the results indicate that there is an optimum percentage of limestone dust for both series of mortar mixes , for lesser water permeability

accompanying, which is about (2.0%) of the weight of cement, the quantity of penetrated water through mortar at this level is about (18.2%) and (27.8%) of the water permeation quantity of the control mix of rich and lean mixes respectively. While for silica fume, shows trends similar to that observed for bentonite. At (2.0%) of silica fume addition, the quantity of penetrated water is about (20%) of the water permeation quantity of the control mix. The analysis of the test results also shows that the materials used in this study lead to slight increase in the density of mortar specimens. There is no specific correlation between the recorded values of water permeabilities and corresponding density of mortar samples .

Depending on the results of compressive strength investigation, it can be said that, the presence of bentonite increases the compressive strength, especially at early ages. The addition of (3%) of bentonite results in an improvement in compressive strength by about (20.2%). The results also indicate that the presence of limestone dust as an admixture in mortar increases the compressive strength of rich mixes , especially at later ages , while adversely affects the strength of relatively lean mixes . The addition of (2.0%) of limestone dust in rich mixes results in an improvement in compressive strength by about (01.8%). While for silica fume, it can be said that , increasing the percentages of silica fume addition in mortar leads to increase the compressive strength . At (2.0% ) of silica fume addition, the rate of increase in the strength of mortar at early ages(7days) is about (12.2%) .

Other mortar properties including modulus of rupture and ultrasonic pulse velocity, show trends similar to that observed in compressive strength for all materials used in this study.

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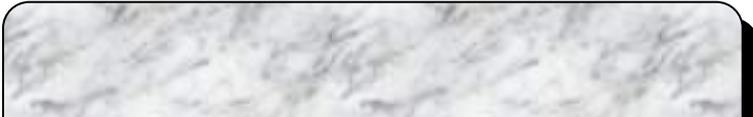
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# LIST OF NOTATIONS

<b>SYMBOL</b>	<b>DESCRIPTION</b>
<b>W/C</b>	Water to cement ratio.
HRWR	High- range water reducing.
W/b	Water to binder ratio.
OPC	Ordinary Portland cement.
RHPC	Rapid-hardening Portland cement.
L.O.I	Loss on ignition.
I.R.	Insoluble residue.
V	Ultrasonic pulse velocity.
T	Transit time.

Note :Other symbols are defined as they appear in the text.

*CHAPTER ONE*



# INTRODUCTION

## 1.1 *General*

One of the most important problems in the construction of underground structures such as basements and underground stores is the leakage of the underground water to the structure. The designer of such structures, therefore, must give this problem proper attention. He must inspect the soil investigation results of the site and examine the water table fluctuations. Furthermore, he must examine the quality of under-ground water, such as the chemical properties and the depth below natural ground level [1].

Some concrete dams, retaining walls, tanks and other structures show evidence of leakage, it is usually the result of faulty production and placement of concrete. When properly proportioned concrete mixtures are used and placed with high-quality workmanship under qualified inspection, the concrete in a structure should be virtually impermeable, although leakage may still occur through cracks [2]. From other point, cured concrete for a suitable period of time can be regarded as watertight because of cutting of the continuity of the capillary pores and difficulty in the passage of water and moisture through it. In spite of, present concrete structures often allow passage of water under different conditions not only through joints and discontinuous parts but also through concrete mass itself [3].

No concrete structure will be perfectly watertight. Some loss of water will occur at incidental defects, joints, and fittings. The amount of leakage depends upon the water pressure at these locations. The leakage will be reduced by the presence of a waterproofing coating or lining [4].

In the production of waterproof concrete two separate and distinct functions may be achieved. The concrete may be impervious to water pressure or it may merely resist the absorption of water. It is doubtful whether there is any really effective additive which will make concrete impervious to water under pressure under circumstances in which it would not otherwise be impervious. Concrete of proper mix design and low water cement ratio and good sound aggregate is impervious without additives and in general it is better to expend the extra cost involved by incorporating an additive, on increasing the richness of the mix and there by reducing the water / cement ratio. It is possible, however, by the use of additives , to improve the resistance of concrete to absorption of water [°].

Waterproofing is very important because it is used to protect the under-ground structures which are subjected to the under - ground water or to protect some buildings which are constructed above the ground such as water tanks.

Waterproofing underground structures is very important in Iraq especially in the middle and southern regions. Many leakage failures have happened in such buildings where water seeped into them. The problem is complicated because of the salty under-ground water in Iraq especially in the middle and southern regions. On the other hand, not enough attention is given to the problem during construction [ ʼ ].

## ***1.2 Aim of the Study***

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 be deteriorated as a result of its influence by external conditions like the movement of liquids and gases that carry the harmful agents which pass through its constituents.

The subject of waterproofing is an important subject in concrete technology.

Watertightness of concrete is desirable in order to increase the durability of concrete or is necessary in order that it may be used to hold water.

Concrete is often used when it is necessary to hold the water either inside as in reservoirs of water or outside the structure as in basements or shelters and similar structures, in which the flow of water through the concrete must be prevented.

In this research, fast and simple way was used for the laboratory assessment of cement mortar permeability and by using specimen of cement mortar as a cylinder with 100 mm diameter \* 50 mm height , and the specimen can be examined several times, and this is very important to determine how the cement mortar can be affected by external conditions and a sign of its durability. Also, in this research, the effect of bentonite , limestone dust, and silica fume on the permeability were studied by using various percentages of these materials as an additional ingredient by weight of sulfate-resisting Portland cement without altering the relative proportions of other ingredients. However, the effect of these materials on the other properties of cement mortar such as density, compressive strength, modulus of rupture and ultrasonic pulse velocity are also included in this research.

Furthermore , this research is distinguishable from others works were used and represent a new one in the site of using some finely divided materials such as bentonite,limestone dust , and silica fume as a permeability – reducing admixtures in the structures subjected to the flow of water through its .

### ***1.3 Research Layout***

The work presented in this thesis is given through five chapters. Chapter one represents the introduction. Chapter two is a review of durability, permeability and absorption, waterproofing admixtures and the previous works on the use of finely divided mineral admixtures in concrete; the properties and applications of bentonite, limestone dust , and silica fume are also included in this chapter. Chapter three includes the experimental program. The results of the experimental tests are presented and discussed in chapter four. Chapter five consists of the conclusions, which can be drawn from the results of this research and recommendations for future work.

## CHAPTER TWO

# REVIEW OF LITERATURE

### **2.1 Durability of Concrete**

The durability of concrete is one of its most important properties because it is essential that concrete should be capable of withstanding the conditions for which it has been designed throughout the life of a structure [1].

Lack of durability can be due either to external factors or to internal causes within the concrete itself. The various actions can be physical, chemical, or mechanical. Mechanical damage is caused by impact, abrasion, erosion or cavitation. Physical causes of deterioration include the effects of high temperature or of the differences in thermal expansion of aggregate and of the hardened cement paste. The chemical causes include the alkali - silica and alkali - carbonate reactions.

External chemical attack occurs mainly through the action of aggressive ions, such as chlorides, sulfates, or of carbon dioxide, as well as, many natural or industrial liquids and gases, which induce electro - chemical corrosion of steel reinforcement. Since this attack takes place within the concrete mass, the attacking agent must be able to penetrate throughout the concrete, which therefore has to be permeable. Permeability is, therefore, of critical interest. The attack is aided by the internal transport of agents by diffusion due to internal gradients of moisture and temperature and by osmosis [1,2,3].

## **2.2 Permeability and Absorption**

The permeability of a mortar or concrete is a measure of the rate at which a liquid will pass through it, while the absorption is a measure of the pore space in the material. The two are not necessarily related and the values obtained from them vary considerably with the conditions of measurement [9]. Low permeability is an important requirement for hydraulic structures and in some cases watertightness of concrete may be considered to be more significant than strength, although other conditions being equal, concrete of low permeability will also be strong and durable. A concrete which readily absorbs water is susceptible to deterioration [10]. Because of the existence of pores of different kinds, some of which contribute to permeability and some of which do not do so, it is important to distinguish between porosity and permeability. Porosity is a measure of the proportion of the total volume of concrete occupied by pores, and is usually expressed in percent. If the porosity is high and the pores are interconnected, they contribute to the transport of fluids through concrete so that its permeability is also high. On the other hand, if the pores are discontinuous or otherwise ineffective with respect to transport, then the permeability of the concrete is low, even if its porosity is high [11]. Although the porosity of the cement gel is 28 percent, its permeability is very low ( $1.5 \times 10^{-17}$ ) m/s because of the extremely fine texture of the gel and the very small size of the gel pores. The permeability of hydrated cement paste as a whole is greater because of the presence of larger capillary pores, and, in fact, its permeability is generally a function of capillary porosity. Since capillary porosity is governed by the water/cement ratio and by the degree of hydration, the permeability of cement paste is also mainly dependent on those parameters. The large influence of segmenting of capillaries on permeability illustrates the fact that permeability is not a simple function of porosity. In fact, only one large passage connecting capillary pores will result in a large permeability, while the porosity will remain virtually unchanged [12]. Concrete is inherently a porous material. This arises from the use of water in excess of that required for the purpose

of hydration in order to make the mix sufficiently workable and the difficulty of completely removing all the air from the concrete during compaction. Concrete of low permeability can be obtained by suitable selection of its constituent materials and their proportions followed by careful placing, compaction and curing. In general, for a fully compacted concrete, the permeability decreases with decreasing water - cement ratio. Permeability is affected by both the fineness and the chemical composition of cement. Coarse cements tend to produce pastes with relatively high porosity. Aggregates of low porosity are preferable when concrete with a low permeability is required. Segregation of the constituent materials during placing can adversely affect the impermeability of concrete [10].

### **2.2.1 Structure of Hydrated Cement**

Fresh cement paste is a plastic network of particles of cement in water, but once the paste has set, its apparent or gross volume remains approximately constant.

At any stage of hydration, the hardened paste consists of very poorly crystallized hydrates of the various compounds, referred to collectively as gel, crystals of  $\text{Ca}(\text{OH})_2$ , some minor components, unhydrated cement, and the residue of the water-filled spaces in the fresh paste. These voids are called capillary pores, but within the gel itself, there exist interstitial voids, called gel pores. The capillary pores represent that part of the gross volume which has not been filled by the products of hydration. Because these products occupy more than twice the volume of the original solid phase (i.e. cement) alone, the volume of the capillary system is reduced with the progress of hydration [11]. Capillary pores are much larger than gel pores, although, in fact, there is a whole range of pore sizes throughout the hardened cement paste. When only partly hydrated, the paste contains an interconnected system of capillary pores. The effect of this is a lower strength, and through increased permeability, a higher vulnerability to freezing and thawing and to chemical attack. This vulnerability depends also on the water/cement ratio. These problems are avoided if the degree of hydration is sufficiently high for the capillary

pore system to become segmented through partial blocking by newly developed cement gel .When this is the case ,the capillary pores are interconnected only by much smaller gel pores , which are impermeable [7] . The gel pores occupy about 10 percent of the total volume of gel , the material left after drying in a standard manner being considered as solids . The actual value is characteristic for a given cement but is largely independent of the water/cement ratio of the mix and of the progress of hydration . This would indicate that gel of similar properties is formed at all stages and that continued hydration does not affect the products already in existence. Thus, as the total volume of gel increases with the progress of hydration, the total volume of gel pores also increases while the volume of capillary pores decreases [8].

### ***2.2.2 Pore Structure of Concrete***

Concrete is inherently porous , as not all the space between the aggregate particles becomes filled with a solid cementing material .To obtain workable mixes it is necessary to use much more water in concrete than is required for hydration of the cement .Furthermore , the absolute volume of the cement and water gradually decreases as chemical combination proceeds , and this makes it impossible for a cement paste of any water-cement ratio to continue to occupy completely the space originally required by the fresh paste ; consequently ,the hardened paste develops some voids .In addition , during the mixing of concrete some air is always entrapped in the mass. As the water and air voids in concrete are generally interconnected , concrete is inherently pervious to water .This is evidenced by its absorption of water by capillary action and by the passage of water under pressure through it [9].

Aggregate can also contain pores , but these are usually discontinuous. Moreover , aggregate particles are enveloped by the cement paste so that the pores in aggregate do not contribute to the permeability of concrete . The same applies to discrete air voids , such as entrained-air bubbles .In addition , the concrete as a whole

contains voids caused by incomplete compaction or by trapped bleed water. These voids may occupy between a fraction of one percent and 10 percent of the volume of the concrete [1].

### **2.2.3 Significance of Permeability**

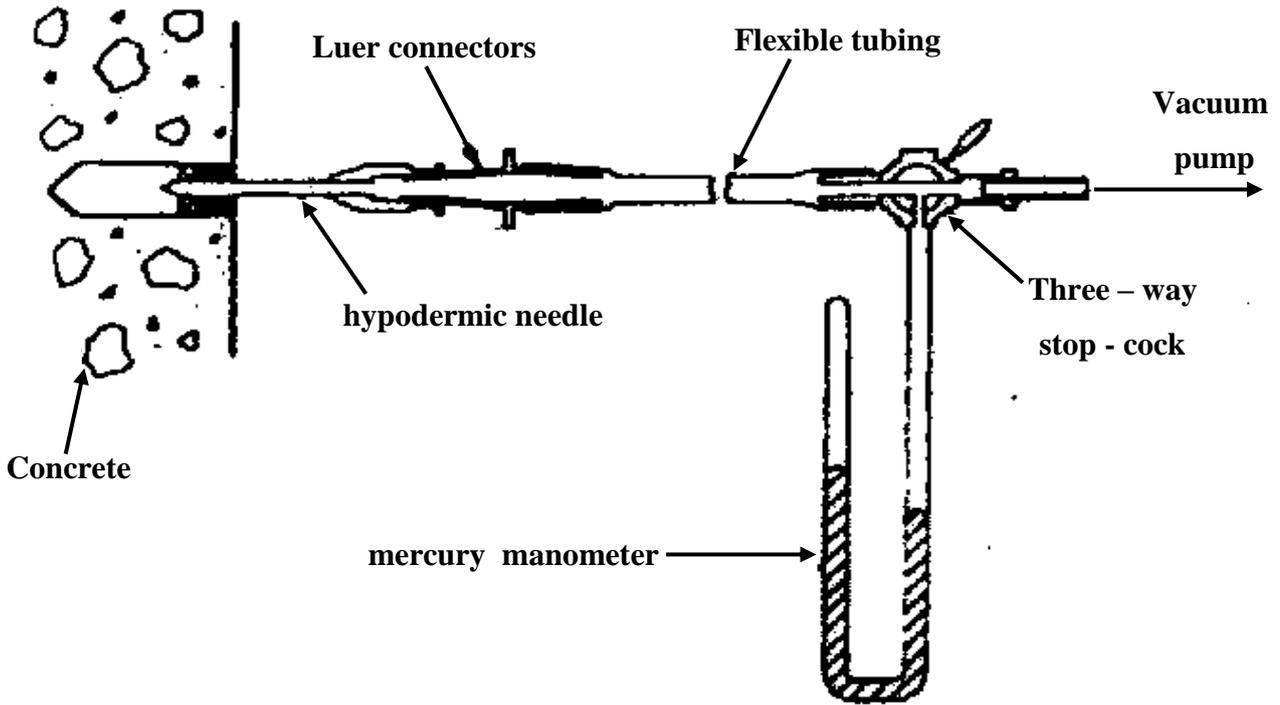
The use of concrete in many kinds of hydraulic structures as well as in other construction fields has impressed upon engineers that in some cases watertightness of concrete may be of greater importance than strength. In general, other conditions being the same, low permeability is associated with high strength and high resistance to weathering. Permeability tests of concrete are of value :- (1) to determine the rate of leakage through the walls of a structure such as concrete pipe, (2) to determine the effects of variations in the cement and aggregate or the effects of various operation in mixing, placing, and curing, (3) to estimate the relative durability and life of concrete as affected by the corrosive action of percolating waters, (4) to determine basic information on the internal pore structure of concrete, which is related directly to such items as absorption, capillarity, resistance to freezing and thawing, shrinkage, uplift, etc ... and (5) to compare the efficiencies of waterproofing materials [1].

### **2.2.4 Previous Researchers Works**

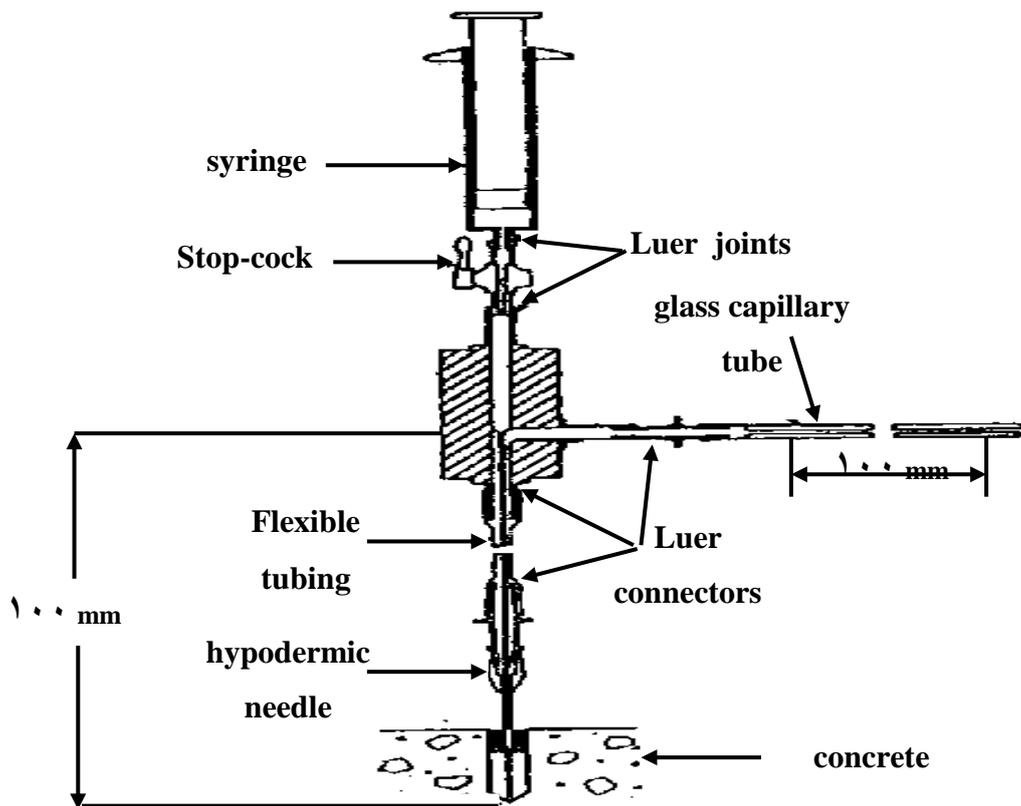
A large number of permeability tests and surface absorption tests have been developed, and there is a considerable amount of literature on laboratory investigations. These various tests require the application of high pressure, so that the necessary equipment is expensive and tests must be conducted by skilled technicians. The permeability of a mortar or concrete to the flow of water may be determined under a small or large head. 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 [9, 12, 13]. Tests of permeability at high pressures are most

commonly made on concrete cylinders of circular slabs in an apparatus in which permits of water under the pressure required being fed to the upper side of the specimen and the water percolating through being collected from the underside and measured . Alternatively , the rate of inflow of water may be measured . The specimens are usually sealed into metal containers with suitable watertight caps . The rate of flow is more rapid at the start , but decreases to a steady value after one or several days depending on the dimensions of the specimen and other factors . Tests may also be carried out under small pressures such as a 30-cm head of water or less . This form of test is often used in testing surface films of waterproofers which may be intended for use under conditions where a mortar or concrete will only be subject to small water pressures . It is also useful for testing thin concrete products ; the results in general run parallel with those obtained by a high-pressure test . A test of the permeability under a 30-cm head of water is included in the British standard for concrete roofing tiles ( BS 1881:1970 )<sup>(9)</sup> . 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 [9, 12].

Various studies are made to reach a simple and predictable way for measuring the permeability of concrete . Figg (1973) [12] measured the permeability of concrete for air and water using different concrete mixes .He made the investigation on prisms (100\*100\*500)mm by making a hole with a depth of 30 mm and 5.0 mm diameter at the end of each prism using masonry drill , after that the hole was cleaned and a piece of Polly ether with a diameter of 4.0 mm and 3mm thickness was put in the hole and was compressed inside by a rubber material at a distance 20 mm from the external face of specimen , after that a hypodermic needle was inserted , then the hole was filled with rubbery silicon and this needle attached to a rubbery tube, that this tube attached from other side by three way stop cock and the latter attached to vacuum pump and mercury manometer as in Fig. (2-1).



The apparatus that measures the permeability of concrete to air .



The apparatus that measures the permeability of concrete to water.

**Fig. (2-1):** The apparatus that was used by Figg [14] to investigate the permeability of concrete to air and water.

During evaluation in the laboratory, it was determined that a modified "Figg test" suffered several drawbacks, the most important of which were lack of control of moisture content and the uncertainty regarding the actual volume of concrete involved in the test (i.e., the extent to which water flows through the concrete under the conditions of the test). There are additional problems regarding the presence of air bubbles in the system, effective sealing, and the calculation of the coefficient of permeability. After trying various modifications, an entirely new approach was taken, as described by Ludirdja et al. (1989) [15]. The apparatus used to determine permeability is shown in Fig. (2-2). The specimen is contained between two polypropylene funnels 76 mm in diameter. The top funnel is joined to a 10 ml serological pipet. About 200 mm of vinyl tubing is connected to the side of the upper funnel using a 7 mm "poly flo" union connector. The other end of the vinyl tubing is connected through a one-way stopcock to a 10-ml syringe. The funnels specimen arrangement is clamped between two pieces of wood by means of four threaded bars. Specimens were cut from concrete cast as 102\*202 mm cylinders, 120 mm thick disks were cut from the center of the cylinders using a diamond saw with water as a coolant. Further development of this apparatus is shown in Fig. (2-3). The specimen is glued to a plexiglass ring 100 mm in diameter, 10 mm thick, and 200 mm long by means of fast-cured embedding resin. The ring is placed on a cell in-between plexiglass tubings 100 mm in diameter and 7 mm thick and clamped by four threaded bars. An appropriate size of serological pipet is glued to a 90 mm nylon

plug with a hole in the center . The pipet and nylon plug are connected to the center top of a 12.0 mm plexiglass plate .This apparatus has some advantages, such as:

- 1- Eliminating unnecessary drying that may cause cracking ;
- 2- Ability to change the pipet size at any time during an experiment; and
- 3- Eliminating absorption effects during the test .

The major problems that are generally encountered in performing laboratory permeability tests on concrete specimens include [ ١ ٢ ]:

- ١- The great amount of time required for each test;
- ٢- The possible leakage of water through the apparatus and/or the sides of the specimen; and
- ٣- The extremely low water-flow rate , which makes an accurate measurement difficult to obtain.

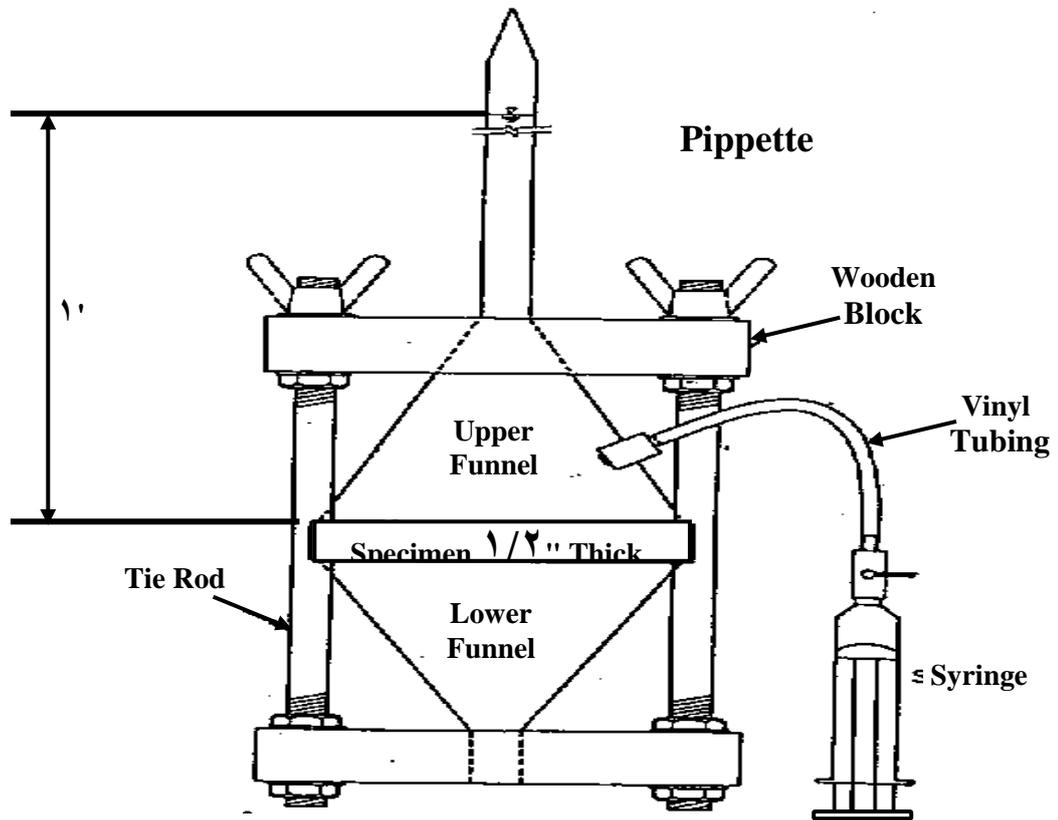


Fig. (2-2): Schematic view of Apparatus A [13].

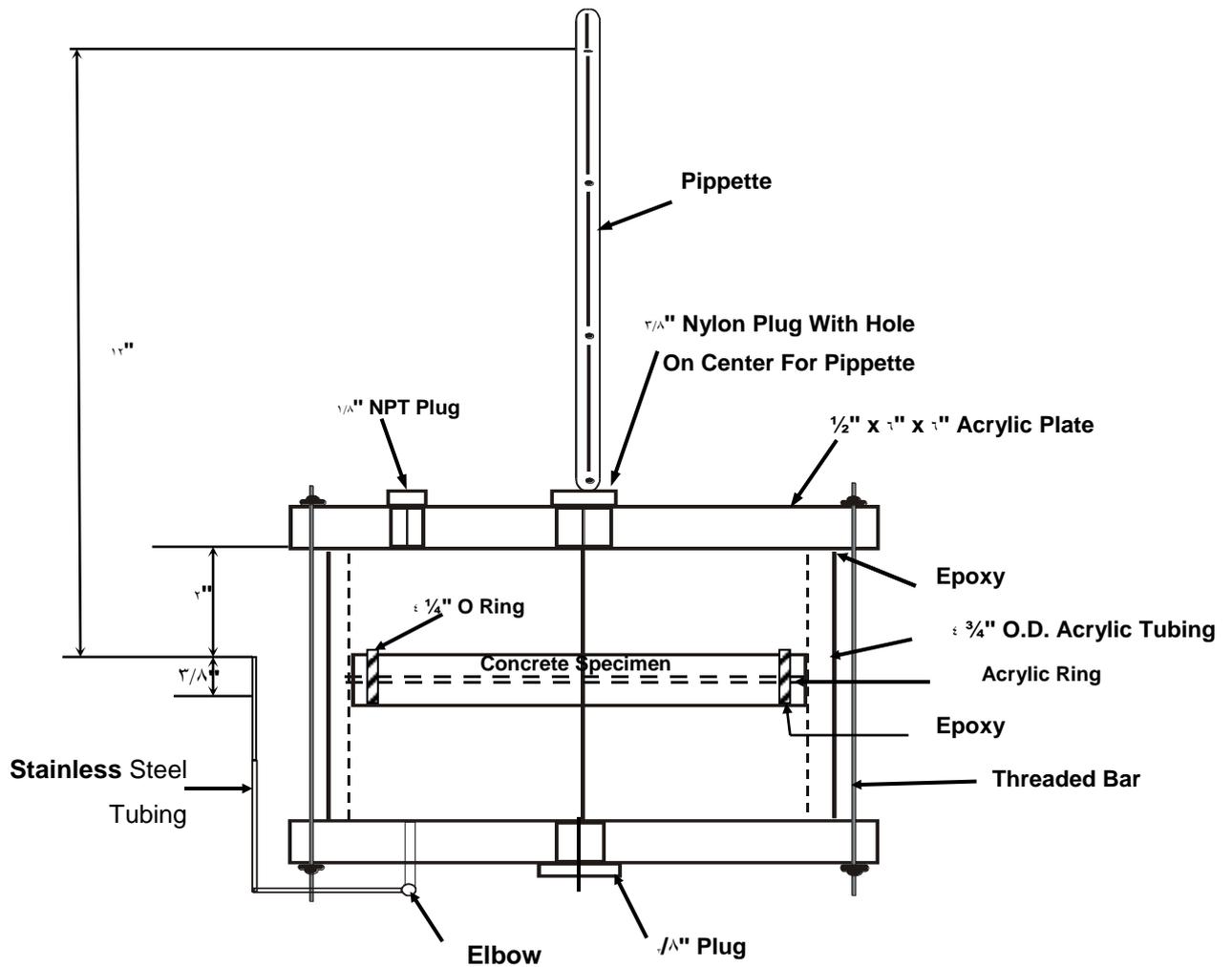


Fig. (2-3): Schematic view of Apparatus B [13].

Powers et al. (1904) [10] studied the effect of permeability on the fresh paste and hardened paste. They used in this study four types of Portland cement with different percentages of compounds and a specific surface of  $1800 \text{ cm}^2/\text{gm}$  (by method of Wagner) that the w/c ratio was 0.3-0.5. The researchers concluded the following :-

1- The coefficient of permeability in fresh paste is  $(0.1 \times 10^{-6} - 1.1 \times 10^{-6}) \text{ cm/sec}$  when w/c ratio is 0.3, the coefficient of permeability is  $(2.1 \times 10^{-6} - 3.1 \times 10^{-6}) \text{ cm/sec}$  when w/c ratio is 0.5 and for the same type of cement.

2- The cement paste made from coarse-ground-cements is not more permeable than the paste that is made from fine-ground-cements when the porosity is equal, the porosity for the coarse paste is more in case when w/c ratio is equal.

3- The coefficient of permeability in hardened cement paste is  $(0.1 \times 10^{-12} - 1.2 \times 10^{-12}) \text{ cm/sec}$  when the w/c ratio is 0.3 - 0.5 respectively.

4- Gradual drying increases permeability, that the drying in relative humidity 90% increases permeability about 4 times.

Abdul-Rehda (1977) [11] described an attempt to make the concrete itself as watertight material. Two main factors affecting the quality of concrete were considered in this work while keeping all other factors constant as much as possible. These two factors are w/c ratio and concrete mix proportions. Two types of concrete mix proportion were used 1:2:4 and 1:1 1/2:3 by weight. Five different w/c ratios were used 0.4, 0.45, 0.5, 0.55, 0.6. It was found that concrete mix proportion 1:1 1/2:3 and w/c ratio 0.4 were the best values making the concrete watertight. The quantity of penetrating water was found to be less with time. This is due to the impurities in the water which cause the constriction of the voids and passages within the concrete. Also, it was found that the age of the concrete is another factor

affecting the formation of the voids within the concrete . This is due to the continuity of the hydration process of the cement particles .

Harvey (1981) [16] studied the permeability of sea water to concrete and found that the permeability of concrete subjected to sea water has a different behavior if compared with concrete subjected to pure water , the rates of flow of the concrete subjected to sea water decreases with time and he explained this as micro-organisms in sea water close the voids, also , the chemical reaction between ions in sea water and products of cement hydration leads to a sedimentation of products and this leads to a reduction in permeability (i.e. closure of voids in concrete ).

Waston and Oyeka (1981) [17] studied the permeability of oil for hardened cement paste and concrete by using two types of cement (ordinary Portland cement and sulfate - resisting cement ); the cement contents of the concrete specimens (220 - 720 kg/m<sup>3</sup>), the results were as follows :-

1-The flow of fluid is correlated with the size of capillary pores more than that with total porosity , and as a result of that , it is impossible to find a correlation between porosity and permeability .

2-The coefficient of permeability for the concrete samples reduces with an increase in cement content up to 600 kg/m<sup>3</sup> ,and with cement content more than this level does not lead to a sensible change in coefficient of permeability ;i.e. when the w/c ratio is 0.6 the typical cement content 380 kg/m<sup>3</sup> and the aggregate /cement ratio (1.3 - 1.4) .

3-The coefficient of permeability is affected by fine aggregate /coarse aggregate ratio , and to decrease the coefficient of permeability the two researchers concluded that the typical percentage of the fine aggregate from the total aggregate should be (40 - 50)% when w/c ratio is 0.6 .

4-The coefficient of permeability increases with an increase in oil pressure applied to the specimen, and an increase in pressure from 0.286 N/mm<sup>2</sup> to 0.827

$N/mm^2$  increases the coefficient of permeability from 1.82 - 3.73 times and this depends on the porosity of concrete .

o-The coefficient of permeability reduces with time and this reduction is large during the first 24 hours , and this is usually constant after 120 hours; i.e. the reduction in the coefficient of permeability after 120 hours continues in the concrete that contains superplasticizer .

7-Ordinary Portland cement gives a non permeable concrete more than sulfate - resisting Portland cement . The addition of 4% of superplasticizer changes the permeability for the two types of cement .

8-The surface absorption of the sulfate - resisting cement paste is more than the surface absorption of the ordinary Portland cement paste by (16 - 23)% with the same w/c ratio ,but the concrete with sulfate - resisting cement had a surface absorption more than the concrete with ordinary Portland cement by (7-11)%.

9-The use of superplasticizer gives concrete a surface absorption less than the ordinary concrete.

Arnold and Littleton (1943) [18] studied the permeability of concrete to water and by using concrete mixtures of coarse aggregate with different absorption to water (0.6% - 8%), constant w/c ratio and similar workability .It is not important that the permeability increases with increase in absorption of aggregate when comparable with w/c ratio although this factor controls the permeability of concrete .

Brian and Malhotra(1948) [19] made different experimental investigations on the permeability of concrete to water and concluded that these investigations were not of constant results. The explanation is that as water passes through samples this leads to internal reaction of cement which decreases permeability during test in progress .

Nyame (1980) [20] made a study about the permeability to water through a normal mortar and a light weight mortar . He concluded the followings :-

1- Increase in aggregate volume concentration leads to an increase in permeability, while the absorption of water by the aggregate leads to a decrease in mortar permeability.

2-The permeability of mortar increases when porosity decreases in contrast to what happens in hardened cement pastes.

3-The permeability of light weight aggregate mortar is about twice that of natural sand mortar.

Lydon (1986) [21] concluded that light weight concrete is of lesser permeability than normal weight concrete and he explained that the use of light weight aggregate for concrete production gives a better correlation than normal aggregate and he added that the micro cracking will be less, and the aggregate distributed in concrete separately.

Theoretically, the intrinsic permeability coefficient of a given concrete should be the same regardless of whether a gas or a liquid is used in the tests. However, gases yield a higher value of the coefficient because of the phenomenon of gas slippage; this means that, at the flow boundary, the gas has a finite velocity. The difference between gas permeability and liquid permeability is larger at lower values of the intrinsic permeability coefficient, the ratio of the former to the latter ranging from about 1 to nearly 100. The air permeability of concrete is strongly affected by its moisture content; a change from near saturation to an oven-dried condition has been reported to increase the gas permeability coefficient by nearly 5 orders of magnitude [4].

Al - Khalidy (2001) [22] evaluated the permeability of concrete containing different percentages of sulfate by using nitrogen gas. The evaluation process was carried out on the two different mixes of the gradient proportions of (1:1.0:3) and (1:2:4) containing various sulfate contents of the level (0.2%, 0.5%, 1.0% 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 indicated to noticeable reductions in the recorded slump values when the sulfate content raised progressively. The gas permeability technique which was used in this investigation was adequate to be dependent on the evaluation procedure. Depending on the recorded gas permeabilities, it can be said that, there is an optimum sulfate content for lesser gas permeability accompanying, which is about (1.0%). Also, the increase in sulfate content to the level of about (2%) of the weight of the locally sand led to drastical increases in the recorded permeabilities, but the higher cement content of the concrete mixes may be beneficial to neutralize this previous destructive action, especially at later ages. The curing procedure variance from the moist curing to air curing, also played an important role in the recorded gas permeability values.

### **2.2.5 Factors Affecting Watertightness**

As shown in Fig. (2 - 4), the several factors affecting the permeability of concrete fall into three groups :-

- 1- The influence of the constituent materials
- 2- The effect of methods of preparing the concrete.
- 3- The influence of subsequent treatment of the concrete.

In general, any factor tending to improve the compressive strength of the concrete will have a beneficial effect upon the watertightness. Therefore, the better the quality of constituent materials, the less permeable the concrete [11].

**Factors affecting permeability of concrete**

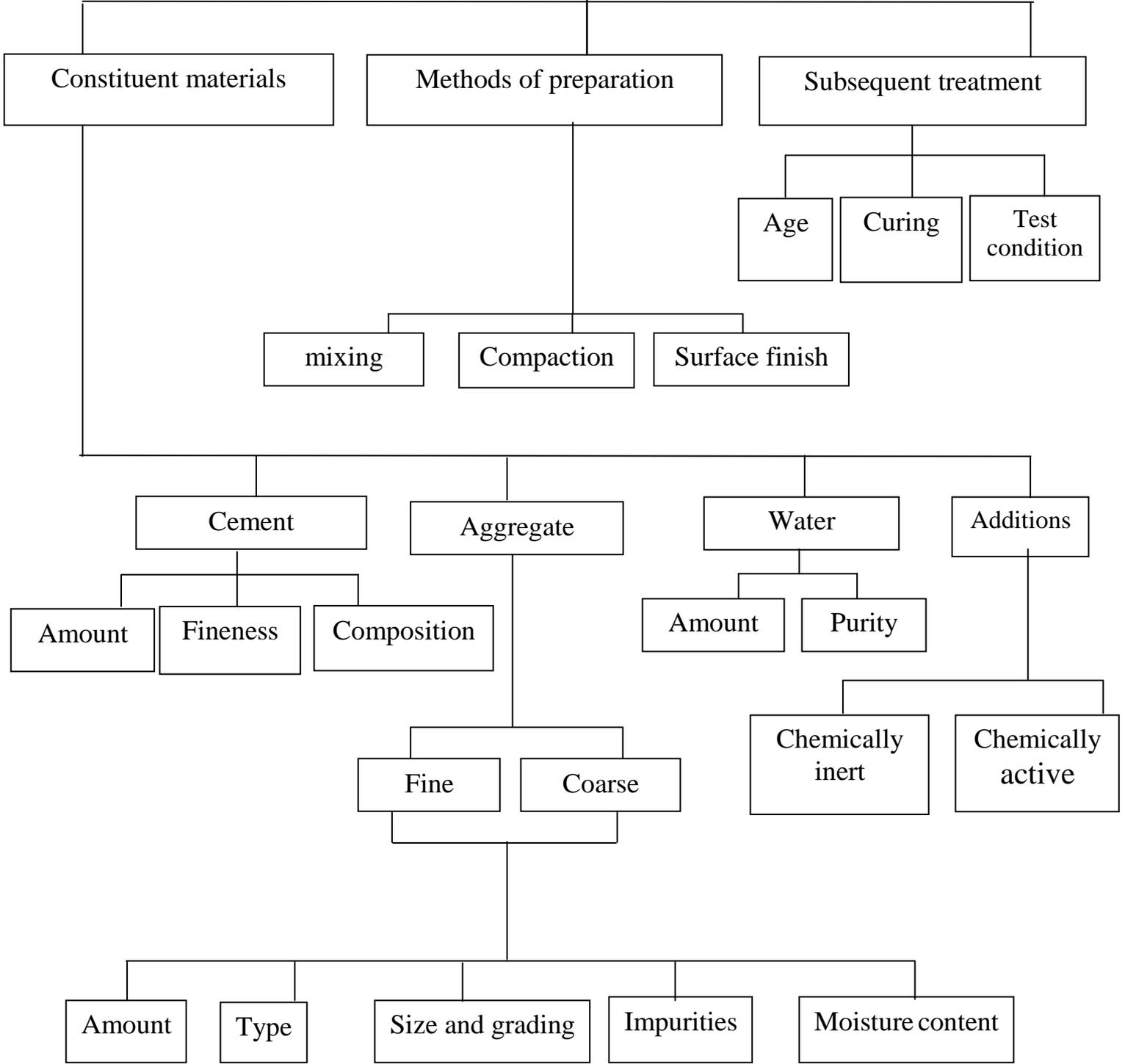


Fig. (٧ - ٤): Factors affecting permeability of concrete [١١].

## **2.3 Waterproofing Admixtures**

### **2.3.1 Introduction**

Concrete absorbs water because surface tension in capillary pores in the hydrated cement paste "pulls in" water by capillary suction . Water- proofing admixtures aim is to prevent this penetration of water into concrete . Their performance is very much dependent on whether the applied water pressure is low , as in the case of rain (other than driven by wind ) or capillary rise , or whether a hydrostatic pressure is applied , as in the case of water - retaining structures or structures such as basements in water logged ground . The term "waterproofing " is therefore of dubious validity [٧] .Many materials are sold ,usually under proprietary names , for incorporating in mortars and concretes with the object of making the concrete less permeable to water . They take the form of clear or cloudy liquids , thick liquids , pastes or dry powders and as a class are known as integral waterproofers .They are added either to the gauging water or direct to the concrete mix , or sometimes premixed with the cement [٩]. Waterproofing admixtures can not 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 also may 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 [٧] .An admixture described as a dampproofer or as a waterproofer 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 [ १ ] .

## **2.3.2 Classification of Waterproofing Admixtures**

Waterproofing admixtures can be classified into three major groups [3].

### **2.3.2.1 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 three groups :-

#### **1- 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 [4,5,6].

##### **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 [6].

##### **c-Pozzolans**

Pozzolan is defined in ASTM C 311 (7) 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 , opaline shales and cherts , calcined diatomaceous earth , and burnt clay .Fly ash , known also as pulverized - fuel ash , is the most common artificial pozzolana . There exists one

other material ,silica fume , which is formally an artificial pozzolana but its properties put it into a class of its own [٧,٩,٢٣] .

Many of the materials so used are powders as fine as or finer than Portland cement .They therefore serve to influence the physical properties of the fresh paste in the same manner as does cement and may be used to augment the cement in mixtures deficient in fine materials .Since the distinction between the fine material in the cement and that in the aggregates is more or less arbitrary ,such mineral admixtures may also serve as correctives for deficiencies in aggregate gradation (lacks sufficient fines).Many concrete mixtures , in order to have the necessary workability and plasticity , must contain a larger amount of Portland cement than would be required to develop adequate strength. A portion or all of this additional cement may be frequently left out when the mixture is proportioned with a suitable mineral admixture [١١,٢٣] .Finely divided materials which are either pozzolanic, or cementitious contribute to the strength development of the concrete , and mixtures in which they are used usually require considerably less cement to produce a given strength . The finely divided materials regardless of whether they are chemically inactive, pozzolanic, or cementitious , when used in concrete , are neither aggregate nor Portland cement , they are by definition admixtures when they are added to the concrete batch as separate ingredients , either before or during mixing .Such materials are , by definition , additions when interground or blended with Portland cement . There has, therefore, been a tendency to refer to these materials as "replacements" or "substitutes" for part of the Portland cement . Some concrete mixtures having characteristics deficient in some respects can be improved by adding a finely divided mineral admixture as an additional ingredient without altering the relative proportions of the other ingredients [٢٣] .

### **٢-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 [٧] .

When the w/c ratio is reduced, the effect on the hardened concrete is increased compressive strength and reduction in permeability[ ٧ ] .

The water- reducing admixtures are:-(a) lignosulfonic acids and their salts , and (b) hydroxylated carboxylic acids and their salts. These agents have no consistent effect on drying shrinkage but reduce permeability[ ٧, ٩].

The entrainment of air does not appear to have very much effect on the permeability or water absorption of concrete .The greater uniformity of concrete with entrained air due to its increased workability should reduce its permeability .The air bubbles are discontinuous and for that reason they would not be expected to make a concrete more permeable[ ٨ ] . Many materials , including natural wood resins , fats ,and oils may be used in preparing air -entraining admixtures[ ٧٣].

### **٣-Accelerators**

Accelerating admixtures such as calcium chloride increase the average rate of hydration and there by reduce the length of time required for a concrete mixture to attain a given fraction of its ultimate degree of impermeability .However, any advantage attained this way is likely to be temporary since , if condition is such that water is being transmitted through the concrete , they are also conducive to continued hydration of cement [ ٧ ] .

### ***2.3.2.2 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 [ ٩].

Water- repellent admixtures include soaps , butyl stearate , and certain petroleum products [ ٧ ] .

### **2.3.2.3 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 sulfate and calcium and magnesium silicates, finely divided silica and naphthalene, colloidal silica and fluosilicate, petroleum jelly and lime, cellulose materials and wax, silica and aluminum, coal tar cut with benzene, and sodium silicate [2].

## **2.4 Influence of Finely Divided Mineral Admixtures on Properties of Concrete**

### **2.4.1 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  $\text{CaCO}_3$  which is a common filler, reacts with  $\text{C}_3\text{A}$  and  $\text{C}_2\text{AF}$  to produce  $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaCO}_3 \cdot 11\text{H}_2\text{O}$ . Fillers can be naturally occurring materials or processed inorganic mineral materials. What is essential is that they have uniform properties, and 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 [15].

According to Lea (1970) [9], at the same fineness the dilution of cement by grinding sand with it leads to a reduction in strength in concrete of about 10, 20-30, and 40-50 percent for substitutions of 10, 20 and 30 percent respectively of sand for cement. When tests are made on mortars of dry consistence (i.g. w/c = 0.32) the results can be quite misleading, little or no reduction in strength is found for substitutions up to 20 percent. The effect of grinding limestone or marl with the cement clinker is more variable. With certain hard limestones and marls, combined with certain clinkers, at constant times of grinding, a substitution of 10 percent does not reduce the strength of concrete at constant slump. A small substitution, 2 percent, in certain cases may increase the strength probably owing to its acting as a grinding aid. With substitution of 20 percent the strength is reduced by about the same percentage. These effects appear to be very specific and the same hard marl has been found when substituted to the extent of 10 percent with one clinker to reduce the strength by 10-15 percent and with another to leave it more or less unchanged. This may be due in part to differential grinding actions.

Orchard (1973) [10] stated that the inert materials increase the workability by increasing the amount of paste in the concrete and hence the cohesiveness, but if they are used in large quantities, the amount of water has to be increased and there will be a consequent loss of strength.

According to the results of some studies on the effect of inert or filler materials on the properties of concrete, Soroka and Stern (1976) [11] studied the effect of two calcareous fillers (ground limestone and reagent quality  $\text{CaCO}_3$ ) on the compressive strength of Portland cement and compared with the corresponding effect of two pozzolanic fillers (ground scoria and Rhine trass) and on non - calcareous, non-hydraulic filler (reagent quality  $\text{CaF}_2$ ). In the first series of tests one non-hydraulic

calcareous filler (ground limestone) and two hydraulic ones (ground scoria and Rhine trass) were used to prepare blended cements. The parent cement was ordinary Portland of which 1%, 2%, 3% and 4% were substituted by each one of the three fillers. The amount of water was adjusted to give the mix a constant flow of  $110 \pm 5\%$ . Consequently, the water/blended cement ratio remained virtually constant (0.57-0.61) in all mixes. The compressive strength of the cements was determined at the age of 3, 7 and 28 days. It was concluded that all three fillers improved significantly the compressive strength of the parent cement. However, that this improvement is time-dependent being more pronounced at earlier rather than at later age. The fillers studied in the second series of tests were  $\text{CaCO}_3$  and  $\text{CaF}_2$ . The two fillers were added to a 1:2.70 ASTM mortar [0.45]. The amount added was 1%, 2%, 3%, and 4% of the cement weight replacing a corresponding volume of the Ottawa sand. Consequently, the cement content was kept constant in all mixes. As well as, the water/cement ratio was kept constant at 0.70.

In the second series, it was suggested essentially the same conclusions, namely,

1- The use of both fillers is associated with an improved compressive strength being more pronounced at earlier rather than at the later ages of 28 and 90 days.

2- The greater improvement in the strength of the  $\text{CaCO}_3$  containing mortars was evident only at the early ages of 3 and 7 days. At the later ages of 28 and 90 days, however, both fillers effect on strength was virtually the same irrespective of the difference in their chemical composition and fineness.

It was concluded that fillers affect strength through their accelerating effect on the cement hydration. This effect was found to be essentially the same for all the fillers studied irrespective of their specific chemical composition. It was also concluded that the formation of calcium carboaluminate, if it took place when

calcareous fillers were involved , did not necessarily affect the cement compressive strength .

Soroka and Setter(1977) [26] stated that fillers effect on strength is primarily accelerating on the cement hydration . This improvement in strength can also be attributed to the increase in the density of the mix due to increasing filler content in the mix .

Dhir and Jackson(1983) [10] reported that the inert materials may result in some reduction in concrete strength , although they improve workability, stability and impermeability of concrete . Neville and Brooks (1987) [6] stated that the inert materials clearly did not contribute to the strength of concrete and are generally used as workability aids for grouts and masonry mortar .

Chan and Wu (2000) [27] stated that the durable concrete could be made with 20 percent of cement replaced with inert materials such as silts and clays .Up to this level , the compressive strength was slightly lower than that of the control mix . They also indicated that the inert materials could give more micro - filler effect and nucleation sites for cement hydration.

## **2.4.2 Effect of Pozzolanic Materials on Various Properties of Concrete**

Pozzolanas were originally used in Portland cement mortars and concretes on account of their property of combining with lime and so removing the calcium hydroxide liberated during the setting of the Portland cement . The calcium hydroxide, which is readily subject to chemical attack , is thus removed and in its place a lime -pozzolana compound is formed . The substitution of pozzolana for Portland cement reduces the strength obtained at the earlier ages though the ultimate strength attained may be increased . The permeability of concretes at early ages is not much influenced by the substitution of pozzolana for Portland cement , but at longer ages under conditions of wet curing it becomes progressively Lower [9].

The use of pozzolanas such as pulverised fuel ash and blast furnace slag as a cement replacement material was discussed by several authors. Some researchers [28, 29] observed that the fly ash concretes may have better strength performance when they are replaced at lower water to binder (w/b) ratios. It can be concluded that the advances of concrete admixtures technology allow concrete mixtures to be prepared with lower w/b ratios. It is therefore believed that high strength concrete can be obtained with large volumes addition of fly ash. However, the optimum cement replacement to satisfy the strength and durability requirements of fly ash concretes is about 30 percent by weight of cement [30, 31, 32].

Wilbert et al. (1989) [33] investigated the use of low cement content and high volumes of ASTM Class F fly ash in concrete. The results showed that the optimum percentage of fly ash may be in the range of 00 to 60 percent of the total cementitious content. However, a very significant strength gain from 7 to 28 days and again from 28 to 90 days for the mixtures containing high volumes of the fly ash. Further moist curing of the fly ash concrete from the ages of 90 days to 360 days resulted in additional strength increases ranging from about 20 to 30 percent. All fly ash concrete show substantial increases in both flexural and splitting-tensile strengths from the ages of 28 to 360 days. As a result, the fly ash concretes exhibit superior flexural and splitting-tensile strengths at the age of 1 year. Ravindra and Ewan(1993) [34] stated that the use of fly ash as a partial replacement for up to 30 percent for OPC, or up to 50 percent for RHPC, reduces the permeability of concrete when mixtures are designed for equal 28 day strength. The extent of this influence is dependent upon design strength, age, curing environment, and fly ash content. Poon et al. (1997) [35] observed that the fly ash concrete is more sensitive to the curing condition and requires a longer curing time because its hydration rate is slower than that of plain concrete. Also, the benefits of using fly ash in concretes may be diminished due to inadequate curing.

Many studies were carried out to investigate the effect of blast furnace slag on the properties of concrete. This material is widely being used as a cementitious of concrete and a valuable cement replacement material that imparts some specific qualities to the concrete [36]. If a part of the Portland cement of concrete is substituted by slag, the strength gain is changed so that early strength decreases and later strength is either the same as, or higher than that of Portland cement concrete [37,38].

According to Neville(1990)[9], there are several possible beneficial effects of incorporating ground granulated blast furnace slag in the mix. These are: the fresh concrete has an improved workability; the heat development is slower so that the peak temperature is lower; a denser microstructure of hydrated cement paste is achieved and this improves long-term strength and, especially, durability; and the risk of alkali-silica reaction can be eliminated, regardless of the alkali content of the Portland cement or the reactivity of the aggregate.

## **2.5 Bentonite**

Bentonite, which consists essentially of clay minerals of the smectite group, has a wide range of industrial uses. Depending on the dominant exchangeable present cations, the clay may be referred to as either calcium bentonite or sodium bentonite, the two varieties exhibiting markedly different properties and uses. The terms non swelling bentonite and swelling bentonite are synonymous with calcium bentonite and sodium bentonite respectively. When mixed with water, swelling bentonites exhibit a greater degree of dispersion and better plastic and rheological properties than non swelling bentonites [39]. 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

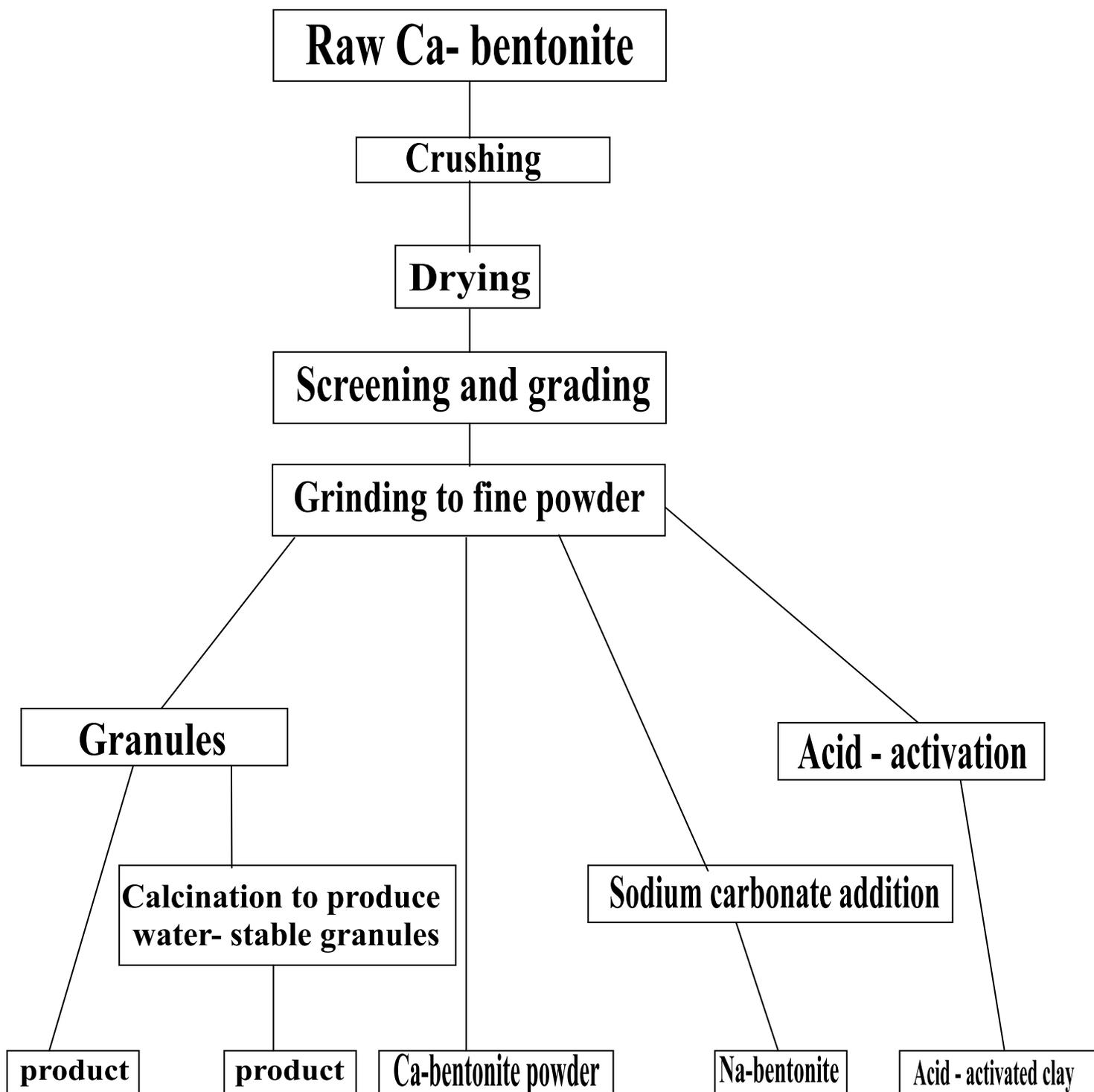
defined as the smectite content of the bentonite, whilst its quality is related to the inherent physico-chemical properties of the clay, either in its natural or modified form, and is a measure of likely industrial performance. However, there is no recognised minimum grade or smectite content below which a clay is no longer considered to be a bentonite. Commercial bentonites rarely contain less than 60% smectite and usually more than 80%, associated minerals typically being quartz, cristobalite, feldspars, zeolites, calcite, volcanic glass, and other clay minerals such as kaolinite. Amounts and types of associated minerals are related to the origin of the bentonite [39].

## 2.5.1 Processing

Bentonite is rarely used in the raw form but undergoes processing essentially to modify its properties for specific industrial applications rather than to increase its smectite content. The major product groups are listed below [39]:-

- 1- Ca-bentonite (fine powders and granules).
- 2- Na- bentonite and Na-exchanged bentonite.
- 3- Acid-activated clays.
- 4- Speciality clays (white bentonite and organoclays).

A simplified flow diagram for the processing of Ca-bentonite is given in Fig.(2-5)<sup>(39)</sup>.



**Fig.(۲-۵):** Typical processing routes for Ca-bentonite [۳۹].

## 2.5.2 Field Characteristics of Bentonite

Bentonites range in colour from black through to white but most frequently are bluish-green when fresh, weathering to a yellowish-brown at or near outcrop due to the oxidation of ferrous iron. Material from near outcrop often exhibits enhanced swelling properties. Despite their often on characteristic appearance at outcrop, where they tend to exhibit a ‘frothy’ or ‘popcorn’ texture due to successive wetting and drying, deposits may be easily overlooked during field mapping, particularly in tropical areas where this feature may be obscured [39].

## 2.5.3 Industrial Applications

Bentonites have a wide range of industrial applications. Relationships between the physico-chemical properties of bentonite and commercial applications are summarised in Table (2-1).

**Table(2-1):** Commercial applications of bentonite in relation to physico-chemical properties [39].

<b>Rheological properties</b>	
A: Viscosity and suspending powers	Drilling fluids
Paints (oil and water-based)	
Fertilizer sprays	
Bitumen emulsions	
Formulation of ceramic glazes	
B: Thixotropy	Wall support for boreholes
Civil engineering (diaphragm wall construction)	
Non-drip paints	
Impermeability, coating properties	Civil engineering
(grouting, impermeable membrane)	
Drilling in permeable strata	
Bonding properties	Bonding foundry moulding sands
Pelletising iron ore concentrates	
Pelletising animal feedstuffs	
Plasticity	Formulation of mortars, putties,
adhesives, some ceramic bodies	

## **2.6 Silica Fume as a Waterproof Agent**

In recent years, significant attention has been given to the use of the pozzolan, silica fume, as a partial replacement for Portland cement, when available at almost the same price as cement, or as an additive when special properties are desired, such as ease of placement, high strength, low permeability, high durability, etc. It is also available in some blended cements. Silica fume has also been referred to as silica dust, condensed silica fume, microsilica, and fumed silica. The most appropriate term is silica fume. Initial interest in the use of silica fume was mainly caused by the strict enforcement of air-pollution control measures in various countries to stop release of the material into the atmosphere. Furthermore, the availability of high-range water-reducing admixtures (superplasticizers) has opened up new possibilities for the use of silica fume as part of the cementing material in concrete to produce very high strength, very high durability, or both [ ٤٠, ٤١, ٤٢ ].

Silica fume is a by-product of the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. Silica fume, which condenses from the gases escaping from the furnaces, has a very high content of amorphous silicon dioxide and consists of very fine spherical particles [ ٤٠, ٤٢ ].

### **2.6.1 Physical Properties and Chemical**

#### **Composition of Silica Fume**

##### **2.6.1.1 Color**

Silica fume varies from light to dark gray in color [ ٤٠ ].

##### **2.6.1.2 Specific Gravity**

The specific gravity of a typical silica fume is about ٢.٢ as compared to ٣.١ for

normal Portland cement however, in some cases it can be as high as ۲.۵ [۴۰].

### 2.6.1.3 Bulk Loose Density

The bulk density of silica fume is of the order of 200 to 300 kg/m<sup>3</sup> as compared with about 1200 kg/m<sup>3</sup> for normal Portland cement [20].

### 2.6.1.4 Fineness

Silica fume consists of very fine vitreous particles with a surface area on the order of 20,000 m<sup>2</sup>/kg when measured by nitrogen adsorption techniques [20]. The extreme fineness of silica fume is best illustrated by the following comparison with other fine materials [20]:

Silica fume	≈ 20,000 m <sup>2</sup> /kg (as measured by nitrogen adsorption method)
Fly ash	ξ00 to 400 m <sup>2</sup> /kg (ξ000 to 4000 cm <sup>2</sup> /g) Blaine
Ground granulated blast-furnace slag	300 to 600 m <sup>2</sup> /kg (3000 to 6000 cm <sup>2</sup> /g) Blaine
Normal Portland cement	300 to 400 m <sup>2</sup> /kg (3000 to 4000 cm <sup>2</sup> /g) Blaine

The particle-size distribution of a typical silica fume shows most particles to be smaller than one micrometer (1 Mm) with an average diameter of about 0.1 Mm, which is approximately 10 times smaller than the average cement particle [20, 21].

### 2.6.1.5 Chemical Composition

The chemical analysis of silica fume is shown in Table (2-2) as reported by some previous studies [23, 24, 25, 26, 27].

Table (۲-۲): Chemical composition of silica fume.

Oxide %	Hooton (43)	Detwiler (44)	Cong (45)	Bayasi (46)	Ozyildirim (47)
SiO <sub>۲</sub>	۹۳.۸۹	۹۶.۰	۹۵.۰	۹۶.۵	۹۳.۲
Fe <sub>۲</sub> O <sub>۳</sub>	۰.۳۲	۰.۶	۰.۴	۰.۱۵	۰.۳
Al <sub>۲</sub> O <sub>۳</sub>	۰.۱۹	۰.۱	۰.۱۳	۰.۱۵	۰.۱
CaO	۰.۳	۰.۱	۰.۳۹	۱.۴	۱.۰
MgO	۰.۷۱	۰.۲	۰.۲۱	۰.۲	۰.۲
SO <sub>۳</sub>	۰.۲۸	-	-	-	۰.۱
Na <sub>۲</sub> O	۰.۷۴	۰.۱	۰.۱۵	۰.۲	۰.۱۸
K <sub>۲</sub> O	۰.۹۳	۰.۴	۰.۱۱	۰.۰۴	۰.۱۸
L.O.I	۲.۷۲	۱.۷	۲.۴۶	-	۱.۸

## 2.6.2 Applications of Silica Fume

The ACI Committee ۲۳۴ [۴۲] described the use of silica fume, primarily in concrete. Other applications in grout or mortar are also mentioned. Many different types of projects that have been accomplished since silica fume has been commercially available are included. Among the applications are abrasion resistance, alkali - silica reaction mitigation, chemical attack resistance, corrosion resistance, high-early strength concrete, high-strength concrete, offshore and marine placements, overlays and pavements, and shotcrete.

Cong et al. (۱۹۹۲) [۴۵] explained the contradictory evidence and established the role played by silica fume in controlling the strength of concrete and its constituent materials. These goals were accomplished using cement pastes, mortars, and concretes with water-cementitious material ratios ranging from ۰.۳ to ۰.۳۹. Mixes incorporate ۱) no admixtures, ۲) a superplasticizer only, or ۳) silica fume and a superplasticizer. This research demonstrated that replacement of cement by

silica fume and the addition of a superplasticizer increase the strength of cement paste. It also demonstrated that cement paste specimens, with or without silica fume, can exhibit reduced strength compared to other specimens with the same water-cementitious material ratio if the material segregates during fabrication. The segregation of cement paste is caused by high superplasticizer dosages that do not cause segregation of concrete with the same water-cementitious material ratio. Concrete containing silica fume as a partial replacement for cement exhibited an increased compressive strength in large part because of the improved strength of its cement paste constituent.

Bayasi and Zhou (1993) [26] studied the various properties of silica fume concrete. These properties, including slump, air-content, compressive strength, flexural strength, permeability and permeable void volume, were investigated, and the effect of the silica fume replacement ratio of cement was described.

The results showed that increasing the silica fume content of concrete decreases permeability dramatically, improves compressive strength significantly, and decreases air content slightly. Decreasing aggregate content will increase the permeability of silica fume concrete significantly. Superplasticizer may cause an increase of silica fume concrete permeability. However, this effect of superplasticizer seems to diminish with a high silica fume content.

Ozyildirim and Halstead (1994) [27] tested the Portland cement concretes and concretes with various combinations of cement (type II,III), fly ash (class F), and silica fume for strength and chloride permeability. The effects of different curing temperatures and different durations of moist-curing were also determined. In general, the results showed that in the temperature range of 23 to 38°C, concretes at a water-cement ratio of 0.4 to 0.5 with satisfactory 28 day strengths and good resistance to chloride-ion penetration at 28 days can be obtained with either type of cement and various combinations of fly ash and silica fume. Similar specimens cured at 7°C generally did not develop an adequate early strength, and the chloride permeability was high. Combinations of the pozzolans with type III cement yielded a higher strength and lower chloride permeability than did similar combinations with

type II cement.

## CHAPTER THREE

### EXPERIMENTAL WORK

### 3.1 Introduction

In this chapter, the details of the experimental program of the study are presented. These include the materials used, specimens preparation and the tests carried out.

### 3.2 Materials

#### 3.2.1 Cement

Sulfate-resisting Portland cement type V manufactured by AL-Muthanna factory was used throughout this study conforming to Iraqi specification (IOS ٥:١٩٨٤)<sup>(٤٨)</sup>. To avoid any differences between different batches, the whole quantity of cement was brought to the laboratory and stored in a dry place. The physical and chemical properties of this cement are give in Tables (A-١) and (A-٢).

#### 3.2.2 Fine Aggregate (Sand)

The graded standard sand used in this study was brought from AL-Nawafith Co.LTD for sand and gravel filters in Najaf. Table (A-٣) shows the grading of this sand. The table also includes the limits specified by ASTM C ٧٧٨<sup>(٤٩)</sup>.

#### 3.2.3 Bentonite

Bentonite used throughout the research was brought from General Company of

Geological Survey and Mining in Baghdad (local materials from el-sufra in western desert) . This bentonite is yellowish-brown in colour . It was mixed with gauging water for a period of time ranging between (٥-٧) days for the absorption of the sufficient quantity of water and then added to the cement mortar mixture as a thick liquid. The physical and chemical analysis of bentonite are shown in Table (A-٤).

### **3.2.4 Limestone Dust**

Limestone dust used in the experimental work was supplied by Cement Plant of Kufa. The dust was stored in a dry place and added to the cement mortar mixture as a dry powder. The physical and chemical analysis of this dust are given in Table (A-٥).

### **3.2.5 Silica Fume**

Silica fume used throughout the research was brought from the commercial market. The fume was stored in a dry place and added to the cement mortar mixture as a dry powder. The chemical analysis of this fume is given in Table (A-٦).

### **3.2.6 Water**

Ordinary drinking water was used throughout this work for both making and curing the specimens.

### **3.2.7 Superplasticizer**

A commercially marketed superplasticizer liquid Iraqi admixture was used; chemically is a modified condensation product of melamine and formaldehyde (type F according to ASTM C ٤٩٤)<sup>(٥٠)</sup>. The best known being Melment L<sup>١٠</sup> . It was added at the end of the mixing operation with ٢-٣ minutes additional mixing. Table (A-٧)<sup>(٥١)</sup> shows its technical description.

## **3.3 Outline of 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, modulus of rupture and ultrasonic pulse velocity. Different percentages of bentonite, limestone dust, and silica fume were used to investigate these properties.

## ***3.4 Details of Mixes***

### **3.4.1 Bentonite Mixes**

Bentonite was used as an admixture to sulfate-resisting Portland cement mortar. Four percentages of bentonite were used: 1, 2, 3 and 4 percent by weight of cement.

### **3.4.2 Limestone Dust Mixes**

Limestone dust was used as an admixture to sulfate-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.

### **3.4.3 Silica Fume Mixes**

Silica fume was used as an additional ingredient to sulfate-resisting Portland cement mortar. Five percentages of silica fume were used: 2.5, 5, 6, 7 and 8 percent by weight of cement.

## ***3.5 Specimens Preparation***

### **3.5.1 Mixing**

The materials were mixed by using an electrically driven mechanical batch mixer. The interior surface of the mixer was cleaned and moistened before it was used.

Bentonite was added in the following order, the sand and cement were first mixed dry for 60 sec., then the thick liquid of bentonite was added and mixed

between 3 and 5 min. to get homogeneous fresh mortar mixes.

Limestone dust or silica fume was mixed dry with sand and cement for 60 sec., then the water was added and mixed between 3 to 5 min. to achieve adequate dispersion of limestone dust or silica fume in mortar mixes. In the silica fume mixes, the dosage of superplasticizer was then added. After that, mixing was continued for 3 minutes to guarantee uniform distribution within the mixture.

### **3.5.2 Casting and Compaction**

After mixing, the cement mortar was poured into the moulds and compacted by using a tamper. The excess mortar was cut and removed with a trowel from the top of the specimens.

### **3.5.3 Curing**

The moulds of cement mortar specimens were covered with nylon bags to prevent water from evaporation, and left in the laboratory for 24 hours. The specimens were then demoulded carefully and stored in water tanks until testing. The water in the tank was changed every two or three weeks.

## ***3.6 Testing procedures***

### **3.6.1 Flow Table Test**

The flow table test of fresh cement mortar mixes was determined according to ASTM C230 (02).

This test was carried out for giving a general indication about the effect of percentages of the materials used in this research on consistency.

### **3.6.2 Permeability Test**

This test was carried out to obtain a clear idea about the formation of voids within the cement mortar containing various percentages of the materials used in this research. This apparatus is designed for water permeability test of mortar, using air pressure generated by electric driven air compressor as pressure source. Ratio and quantity of water permeated through mortar test specimens are measured by this apparatus. The test was carried out according to MIC-330-3H [03].

**Note : See Figs. (3-1) , (3-2) , (3-3) , (3-4) , (3-5) and (3-6)**

▪

### **3.6.2.1 Permeability Test Method**

#### **1- Test specimens.**

a- Six test specimens are required for a single test. 3 test specimens of the 1 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 10 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 24 hours, and shall be released from the moulds after that. The test specimens released from the moulds shall be cured in water for 14 days. After curing, the test specimens shall be washed well using clean water, and shall be brushed on both sides to remove skin out from central area having more than 10 cm dia. They shall be dried to constant weights, and shall be kept at room temperature for 1 day before testing.

#### **2- Setting test specimens in water permeation containers.**

a- Unscrew to loosen setting shaft of the container, and fold frame of the containers to rear side. Remove lid of the container to set the test specimen inside.

b- place a sheet of rubber packing on base of the container, and place the test specimen on the rubber packing. Place another rubber packing on the test specimen.

Both rubber packings have holes of 2 cm diameter in the centre.

c- place lid of the container on the rubber packing, and screw down the setting shaft to fix everything assembled. Care shall be taken to make everything meets each other centre to centre.

**3 - Air driving out from pipings.**

Air shall be driven a way out from pipings before setting test specimens in the water permeation containers.

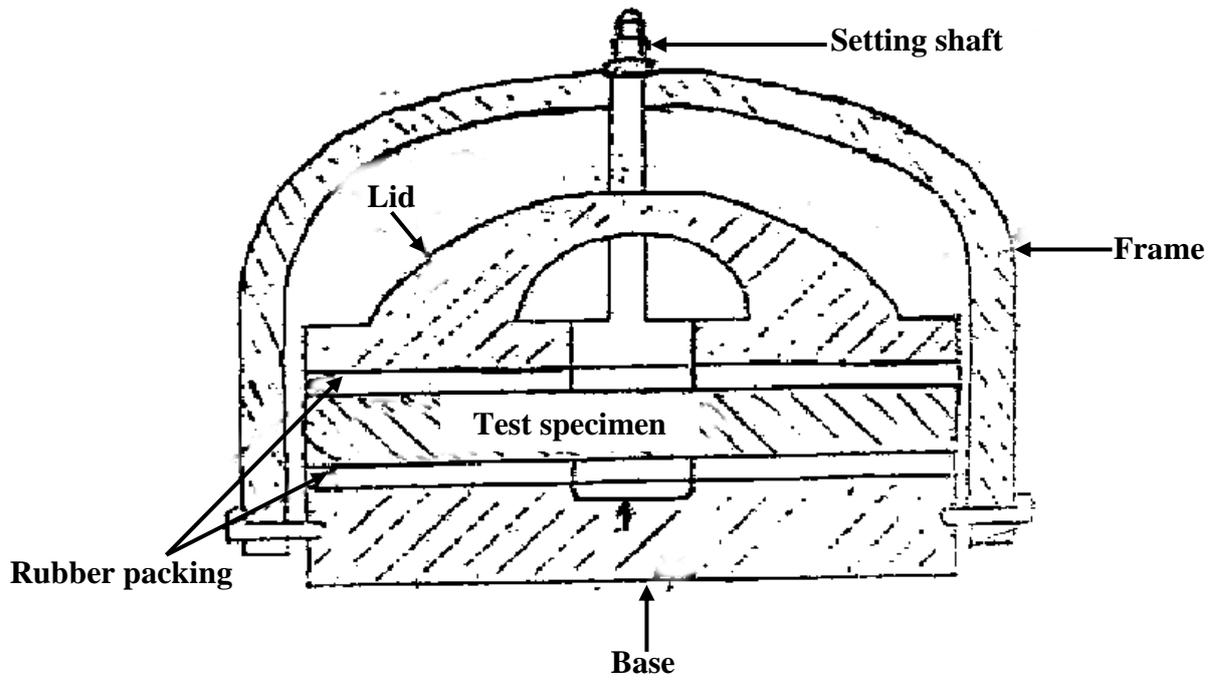


Fig. (۳-۱): Water permeation container [۰۳].

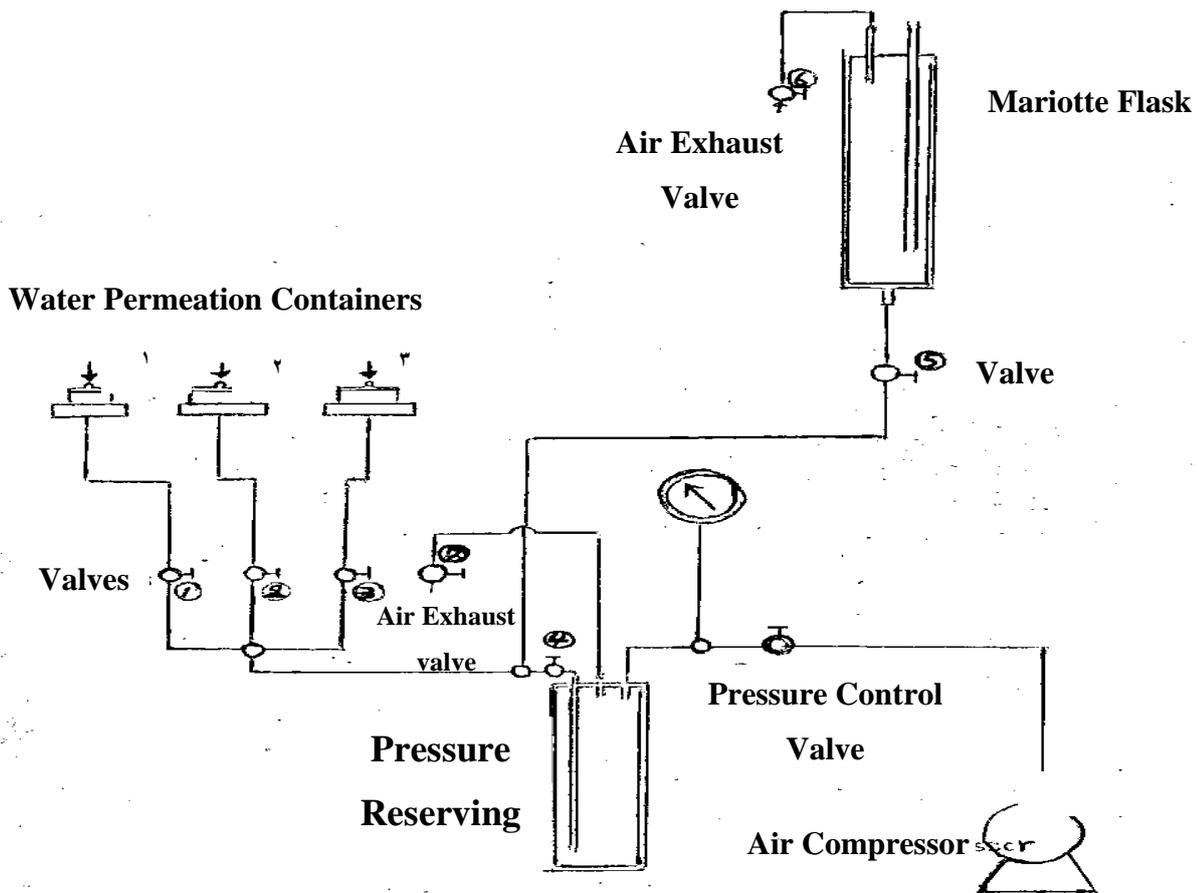


Fig. (۳-۲): Permeability apparatus [۰۳].

Methods to be employed for low pressure system ( $1 \cdot 1 \text{ g/cm}^2$ ) which is equipped to test mortar and for high pressure system ( $3 \text{ kg/cm}^2$ ) which is equipped to test concrete are different from each other.

a- For low-pressure system.

Remove lid of Mariotte flask, and supply water in the flask. There is another method to supply water into the Mariotte flask, i.e. after filling water into pressure reserving water tank first, open valves ( $\xi$ ), ( $\rho$ ) and ( $\nu$ ), and apply approx.  $1.0 \text{ kg/cm}^2$  pressure air to the pressure reserving water tank. Either method can be employed. After filling water to the Mariotte flask (it is enough to fill about  $3/5$  part of the capacity of the flask), start to supply water to the water permeation containers through valves ( $\rho$ ), ( $\lambda$ ), ( $\nu$ ) and ( $\nu$ ). If there remains air in plastic tube underneath the the Mariotte flask, the water does not flow. In such a case, repeat pinching/releasing actions by fingers to the plastic tube to make the tube be filled with water. This pinching/releasing shall be continued until no bubble remains in the water. According to water flow, water comes out from centres of the water permeation containers. Confirming water flow out from the water permeation containers, close the valve ( $\rho$ ).

b- For high-pressure system.

Open water supply inlet of pressure reserving water tank, and supply water there in to fill the tank up to about  $4/5$  of its capacity. Close the water supply inlet and all valves as well. To close pressure control valve, turn it counter-clockwise to make it loosen. Then start to drive air compressor. Open valve of compressor through which pressured air is supplied to the apparatus via rubber hose. After opening valves ( $\lambda$ ), ( $\nu$ ), ( $\nu$ ) and ( $\xi$ ), open the pressure control valve a little just to make slow water flow to the water permeation containers. Do not open the pressure control valve too much, otherwise the water will flash out from the water permeation containers. After the water is observed coming out from the water permeation containers, close the valve ( $\xi$ ).

#### **4. Pressure giving.**

a- For low pressure system.

The apparatus is designed to make the height of the Mariotte flask from the bottom of test specimens be 1 meter so that 100 g/cm<sup>3</sup> pressure may be applied to the test specimens. For the test, valves (1),(2),(3) and (4) shall be opened for 1 hour (applying the pressure).

b- For high-pressure system.

Confirm the valve (4) is closed for the first. And then, open valves (1),(2),(3) and (5). Open the pressure control valve turning it clockwise carefully up to specified pressure which is indicated in the gauge. If the pressure is raised more than that specified, loosen air exhaust valve (6) and close the pressure control valve turning it counter - clock - wise. Specified pressure shall be applied to the test specimens for 1 hour.

#### **5. Pressure releasing**

a- For low-pressure system.

Close the valve (4), and open the valve (5). Disassemble the water permeation container, and the water comes back to pressure reserving water tank. (In case when the tank is full of water already, remove the excess water by some adequate means).

b- For high-pressure system.

Close the pressure control valve, and open the air exhausting valve (6). Disassemble the water permeation containers, and the water comes back to the pressure reserving water tank.

### **3.6.3 Density Test**

This test was carried out in order to get informations 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 (0.001 gm) and the average of the three specimens was taken.

### **3.6.4 Compressive Strength Test**

Compressive strength of cement mortar specimens was conducted on (50 mm) cubes according to the ASTM C109 (04) by using 200 kN 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.

### **3.6.5 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 (02) using (40x40x160 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.

### **3.6.6 Ultrasonic Pulse Velocity Test**

The velocity of the ultrasonic pulse of the cement mortar specimens was determined before finding the crushing compressive strength. This test was carried out according to ASTM C597 (07). Portable ultrasonic concrete tester known as (PUNDIT) was used for this purpose.

Calibration of the concrete tester was done before testing to check the accuracy of the transit time measurements. This was achieved by a calibration bar or reference bar. A thin layer of grease was applied to act as a couplant and to increase the transmitted energy. The pulse travelling path length was measured accurately and the time of its travelling was recorded to the order of 0.1 Msec. The cement mortar cubes at each age were tested immediately after removing them from curing water.

The pulse velocity was determined as follows:

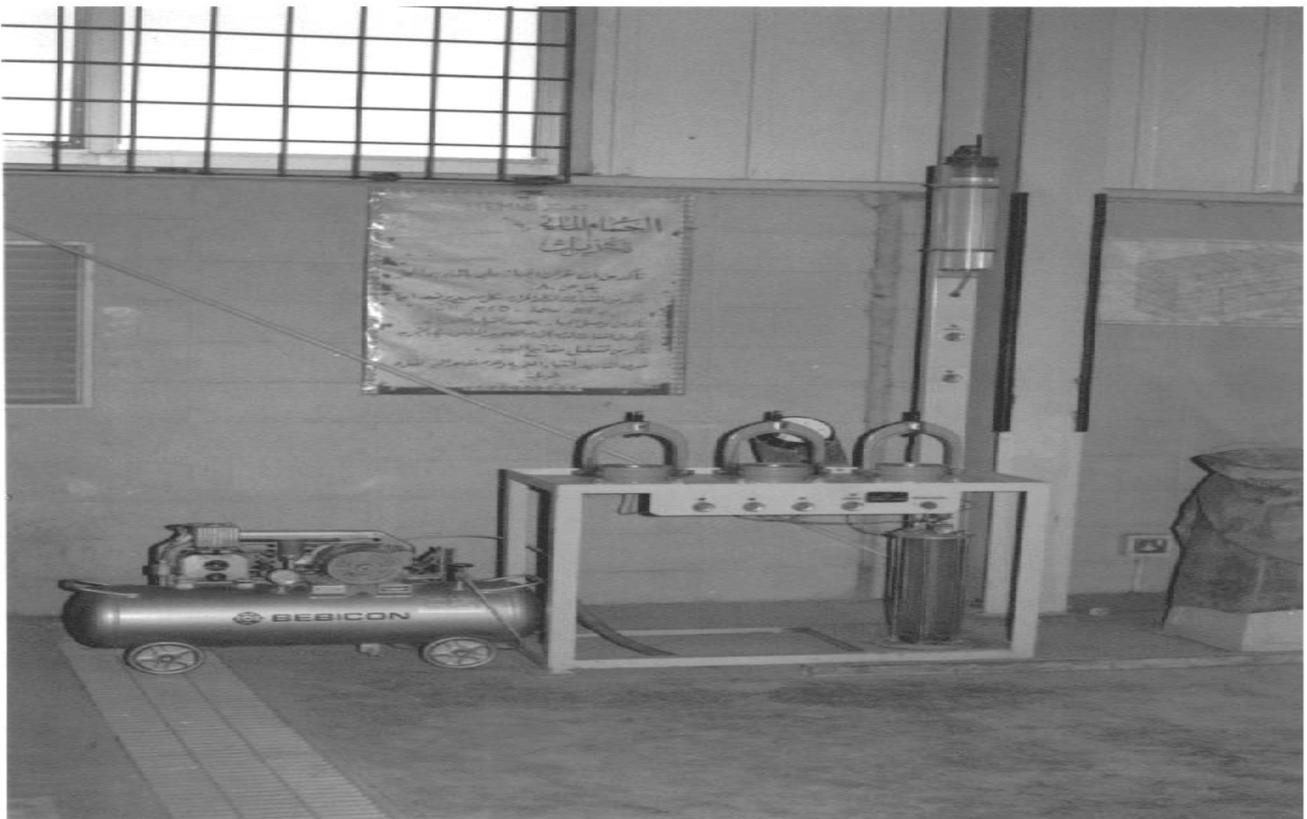
$$V = L/T \dots\dots\dots(3-1)$$

Where:

V= ultrasonic pulse velocity, Km/sec.

L= path length, Km.

T= transit time, Sec.

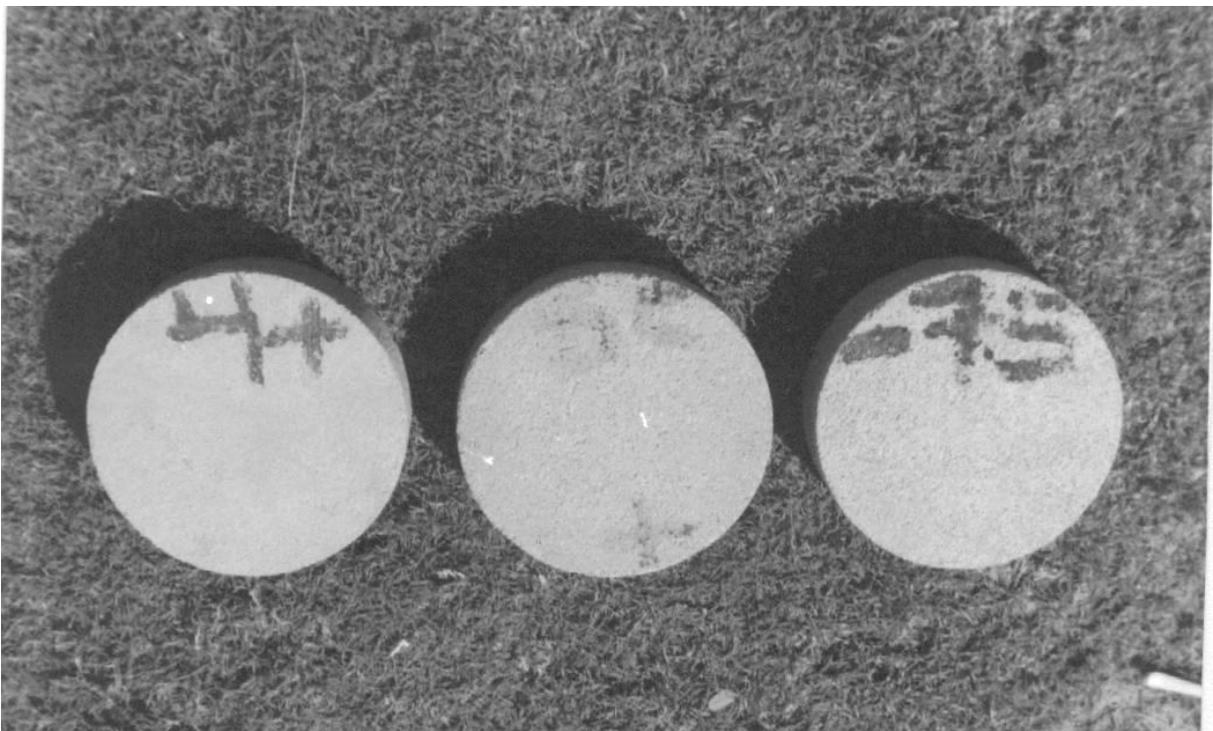


**Fig. (3-3) :** Permeability apparatus (unloaded).





Fig .(۳-۵): Mould for casting mortar permeability specimens.



## CHAPTER FOUR

# RESULTS AND DISCUSSION

### 4.1 Introduction

In this chapter, the results of the tests described in chapter three are presented and discussed. Tests were carried out under laboratory conditions. To condense the data, only the average values are provided in the tables and figures.

### 4.2 Workability Test Results

The flow table test was adopted for measuring the workability of the cement mortar mixes containing various percentages of bentonite, limestone dust, and silica fume.

#### 4.2.1 Workability Test Results of Bentonite Mixes

The flow and W/C ratio for all bentonite mixes are shown in Table (4-1).

Table (4-1): Flow test results of bentonite mixes.

Mix no.	Bentonite by weight of cement %	W/C ratio	Flow %
M <sub>1</sub>	0	0.480	110

M <sup>2</sup>	1	•.ελσ	90
M <sup>3</sup>	2	•.ελσ	80
M <sup>ε</sup>	3	•.ελσ	80
M <sup>ο</sup>	ε	•.ελσ	70

## 4.2.2 Workability Test Results of Limestone Dust Mixes

Two series of limestone dust mixes were tried. The W/C ratio was kept constant in the first series. In the second series, the W/C ratios were adjusted to maintain a flow of  $(100 \pm 10)$  percent. The flow and W/C ratios for all mixes are shown in Tables (4-2) and (4-3).

Table (4-2): Flow Test results of limestone dust mixes.

Mix no.	Limestone dust by weight of cement %	W/C ratio	Flow %
M <sup>1</sup>	0	0.480	110
M <sup>2</sup>	2.0	0.480	90
M <sup>3</sup>	0	0.480	90
M <sup>4</sup>	7.0	0.480	80
M <sup>5</sup>	10	0.480	80
M <sup>6</sup>	12.0	0.480	70
M <sup>7</sup>	10	0.480	70

Table (4-3): Variations in the W/C ratios of limestone dust mixes.

Mix no.	Limestone dust by weight of cement %	W/C ratio	Flow %
M <sup>1</sup>	0	0.480	110
M <sup>2</sup>	2.0	0.5	100
M <sup>3</sup>	0	0.51	100
M <sup>4</sup>	7.0	0.52	90
M <sup>5</sup>	10	0.54	90

M <sup>7</sup>	12.0	0.07	9.
M <sup>v</sup>	10	0.09	90

### 4.2.3 Workability Test Results of Silica Fume Mixes

The flow, W/C ratio and superplasticizer percent for all silica fume mixes are shown in Table (ξ-ξ).

Table (ξ-ξ): Flow test results of silica fume mixes.

Mix no.	Silica fume by weight of cement %	W/C ratio	Superplasticizer by weight of cement %	Flow %
M <sup>1</sup>	0	0.480	0	110
M <sup>2</sup>	2.0	0.480	3	90
M <sup>3</sup>	0	0.480	3	80
M <sup>ξ</sup>	6	0.480	3	70
M <sup>ο</sup>	7	0.480	3	70
M <sup>7</sup>	8	0.480	3	60

From Tables (ξ-1) , and (ξ-2) it can be seen that the workability of mortar mixes containing bentonite, limestone dust is slightly affected when these materials are used as an admixture to cement mortar. Generally, this reduction in the workability for a given water content is due to the higher specific surface of these admixtures.

From Table (ξ-3), the results indicate also that when limestone dust is used as an admixture to the mortar, the water demand to produce the same workability is a function of the percentage of limestone dust used and increases with the increase in limestone dust content. This increase could be due to the increase in the proportion of the fine particles in the modified mixes. However, excessive quantities of fine dust cause an increase in the surface area of the particles that will result in an increase in

the amount of water required to wet the particles [7].

From Table (4-2), it can be noticed that the workability of mortar mixes is greatly affected when silica fume is used as an additional ingredient to cement mortar. The results show that the water demand of mortars incorporating silica fume increases with increasing amounts of silica fume. This increase in water demand is due to the very large surface area of the particles of silica fume, which have to be wetted. Therefore, the use of superplasticizer assists in this respect. Silica fume should always be used together with water-reducing or high-range water-reducing admixtures (HRWR, or superplasticizer) to maintain the required workability with no change in the water-to-cement ratio. The dosage of the HRWR will depend upon the percentage of silica fume and the type of HRWR used [8].

### 4.3 Permeability Test Results

The water permeation quantity and water permeation ratio of cement mortar containing different percentages of bentonite, limestone dust, and silica fume are discussed in the following sections.

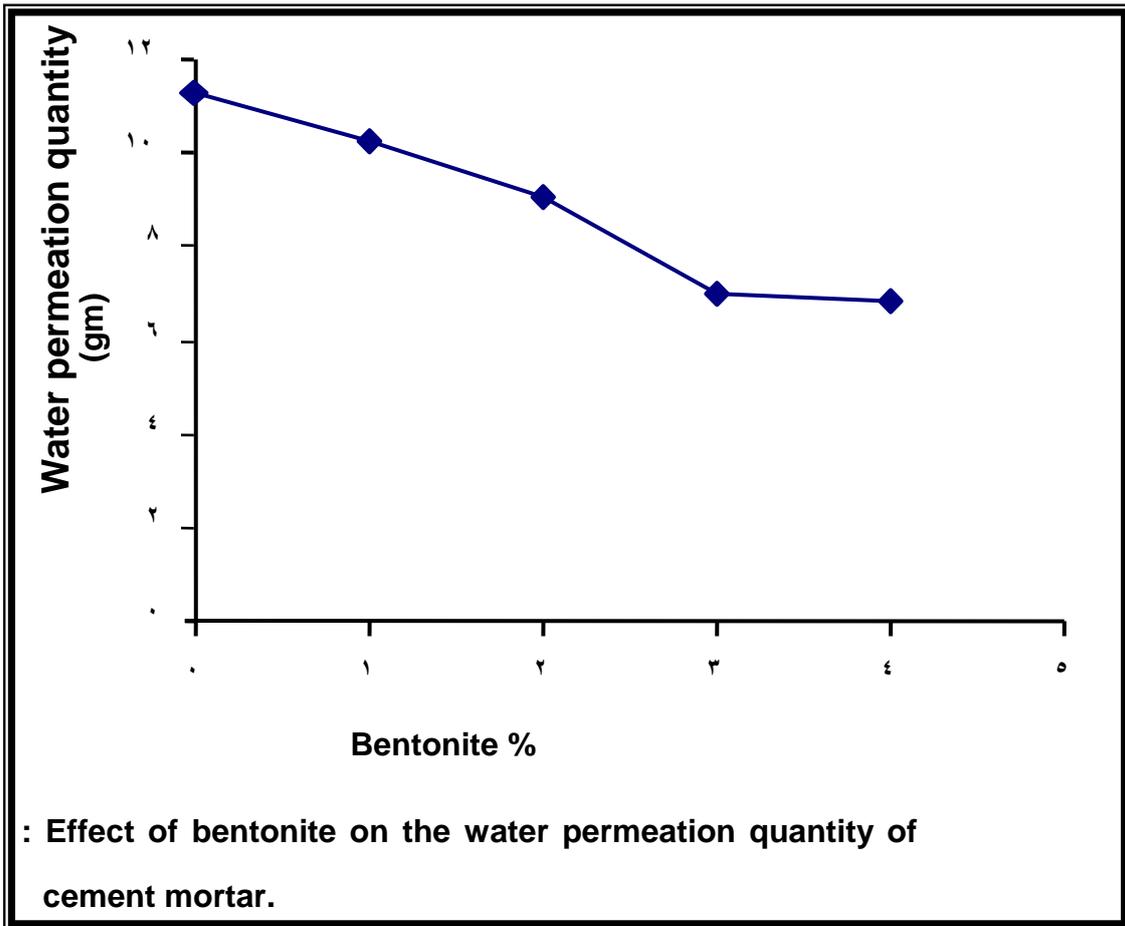
#### 4.3.1 Effect of Bentonite on the Permeability of Cement Mortar

Table (4-3) and Fig.(4-1) show 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 1.9 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.

**Table (٤-٥):** Permeability test results of bentonite containing mortar

<b>Bentonite by weight of cement%</b>	<b>Water permeation quantity (gm)</b>	<b>Water permeation ratio</b>
٠	١١.٢٥	١.٠٠
١	١٠.٢٥	٠.٩١١
٢	٩.٠٣	٠.٨٠٢
٣	٧.٠٢	٠.٦٢٤
٤	٦.٨٧	٠.٦١١

**Note :** Method of calculation of permeability test results is shown in appendix B .

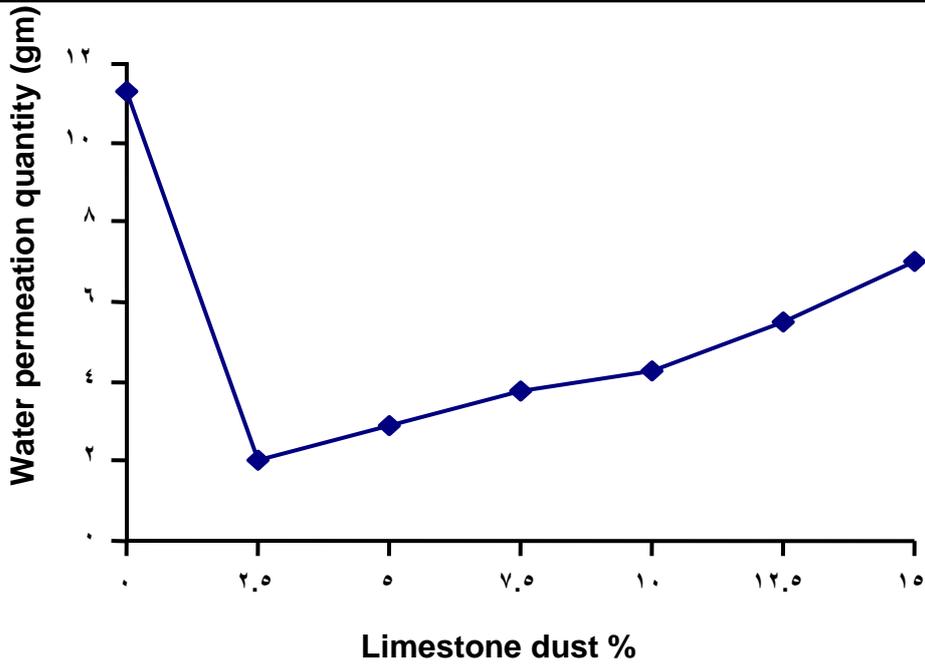


### 4.3.2 Effect of Limestone Dust on the Permeability of Cement Mortar

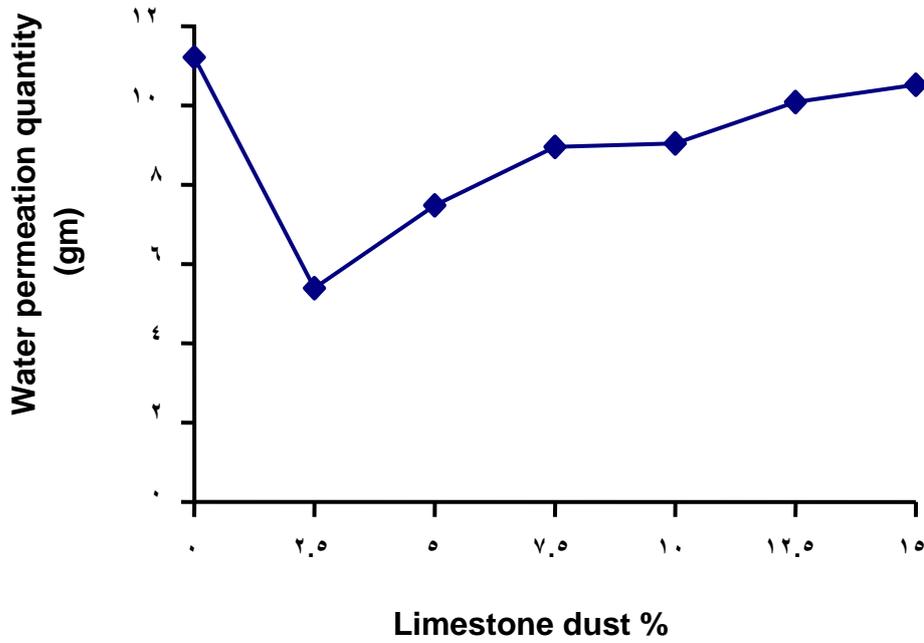
The influence of limestone dust as an admixture to cement on the water permeation quantity of cement mortar has been studied using two series of mixes. Details of the results are shown in Table (٤-٦), Figs. (٤-٢) and (٤-٣).

**Table (٤-٦):** Influence of limestone dust on the cement mortar permeability.

Mix Series	Limestone dust by weight of cement %	Water permeation quantity (gm)	Water permeation ratio
First Series	٠	١١.٢٥	١.٠٠
	٢.٥	٢.٠٥	٠.١٨٢
	٥	٢.٨٨	٠.٢٥٦
	٧.٥	٣.٧٥	٠.٣٣٣
	١٠	٤.٢٣	٠.٣٧٦
	١٢.٥	٥.٥٣	٠.٤٩١
	١٥	٧.٠٣	٠.٦٢٥
Second Series	٠	١١.٢٥	١.٠٠
	٢.٥	٥.٣٨	٠.٤٧٨
	٥	٧.٥٢	٠.٦٦٨
	٧.٥	٨.٩٢	٠.٧٩٣
	١٠	٩.٠٣	٠.٨٠٣
	١٢.٥	١٠.١٢	٠.٨٩٩
	١٥	١٠.٥	٠.٩٣٣



**Fig.(٤-٢):Influence of limestone dust on the water permeation quantity of cement mortar (First series).**



**Fig (٤-٣) : Influence of limestone dust on the water permeation quantity of cement mortar (Second series).**

The water permeation quantity of the first series is shown in Fig.(ξ-ϒ). The results have shown that the presence of limestone dust in the cement mortar leads to a reduction in the quantity of penetrated water. Generally, beyond ϒ.๐% of limestone dust, the quantity of penetrated water started to increase. However, the minimum water permeation quantity has been achieved at ϒ.๐% of limestone dust. At this level, the reduction in the water permeation ratio is ๗๑.๗% less than that of the control mix.

For the second series, Fig. (ξ-ϓ) shows that the presence of limestone dust in the cement mortar has shown a reduction in the quantity of penetrated water, especially at low values of addition. Generally, beyond ϒ.๐% of limestone dust, the quantity of penetrated water started to increase. The minimum water permeation quantity has been achieved at ϒ.๐% of limestone dust. At this level, the decrease in the water permeation ratio is ๐ϒ.ϒ percent less than that of the control mix.

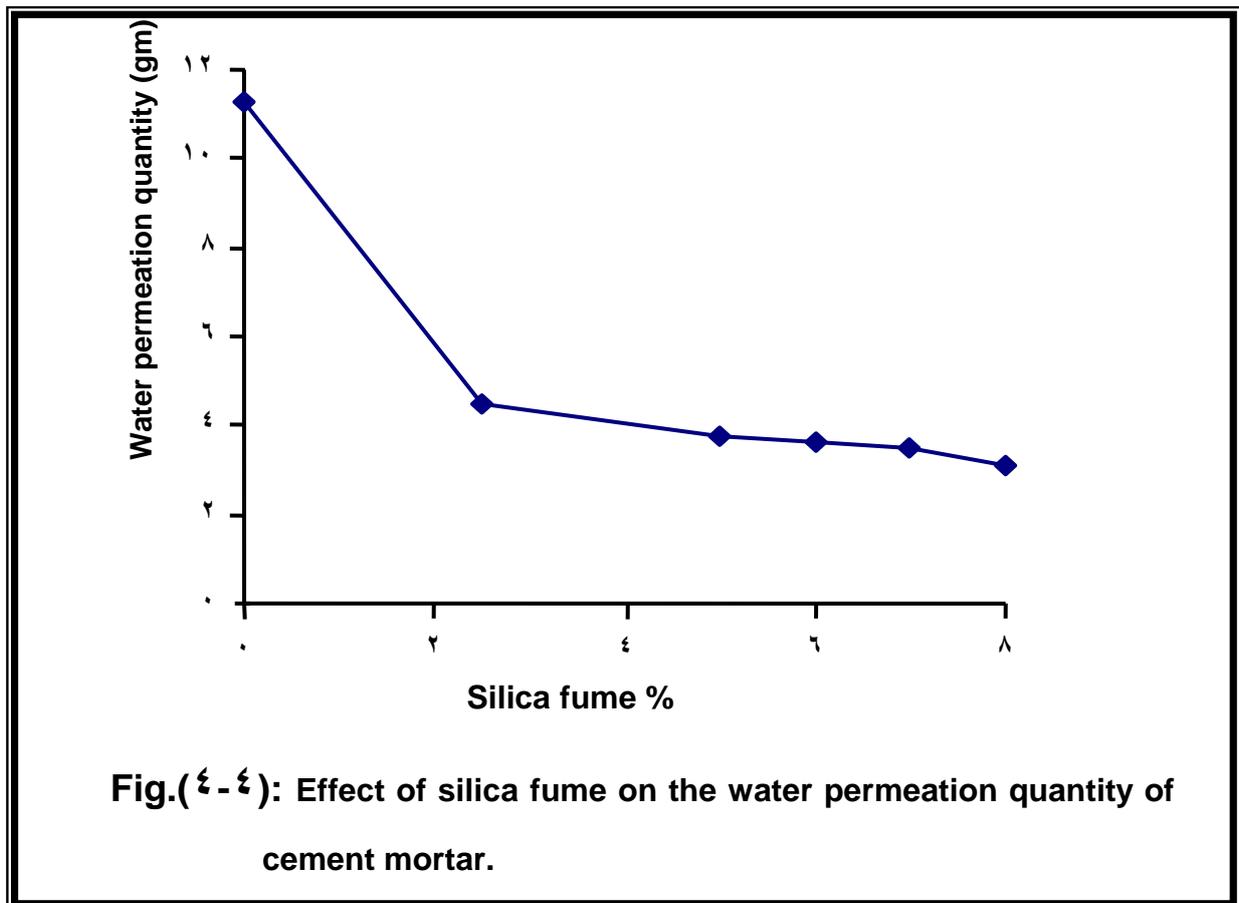
For the first series having the same W/C ratio and decreasing workability tends to impair the compaction of the mix beyond ϒ.๐% resulting in an increase in voids . While in the second series the water content in the mix was increased to maintain the workability and that requires excessive water to cover the surface area of the stone resulting in an additional voids after drying .

### **4.3.3 Effect of Silica Fume and Superplasticizer on the Permeability of Cement Mortar**

The influence of addition of silica fume on the permeability of cement mortar is presented in Table (ξ-ν) and plotted in Fig. (ξ-ξ). It can be noticed that the addition of silica fume and superplasticizer to cement mortar reduces the quantity of penetrated water and this reduction increases with the increase of silica fume content. At ๐% of silica fume as an admixture to cement mortar, the decrease in the water permeation ratio is about ๖๖.ξ percent less than that of the control mix. Beyond ๐% the decrease in water permeation is very small .

Table (٤-٧): Influence of silica fume on the cement mortar permeability.

Silica fume by weight of cement %	Water permeation quantity (gm)	Water permeation ratio
٠	١١.٢٥	١.٠٠
٢.٥	٤.٥	٠.٤
٥	٣.٧٨	٠.٣٣٦
٦	٣.٦	٠.٣٢
٧	٣.٤٨	٠.٣٠٩
٨	٣.١٢	٠.٢٧٧



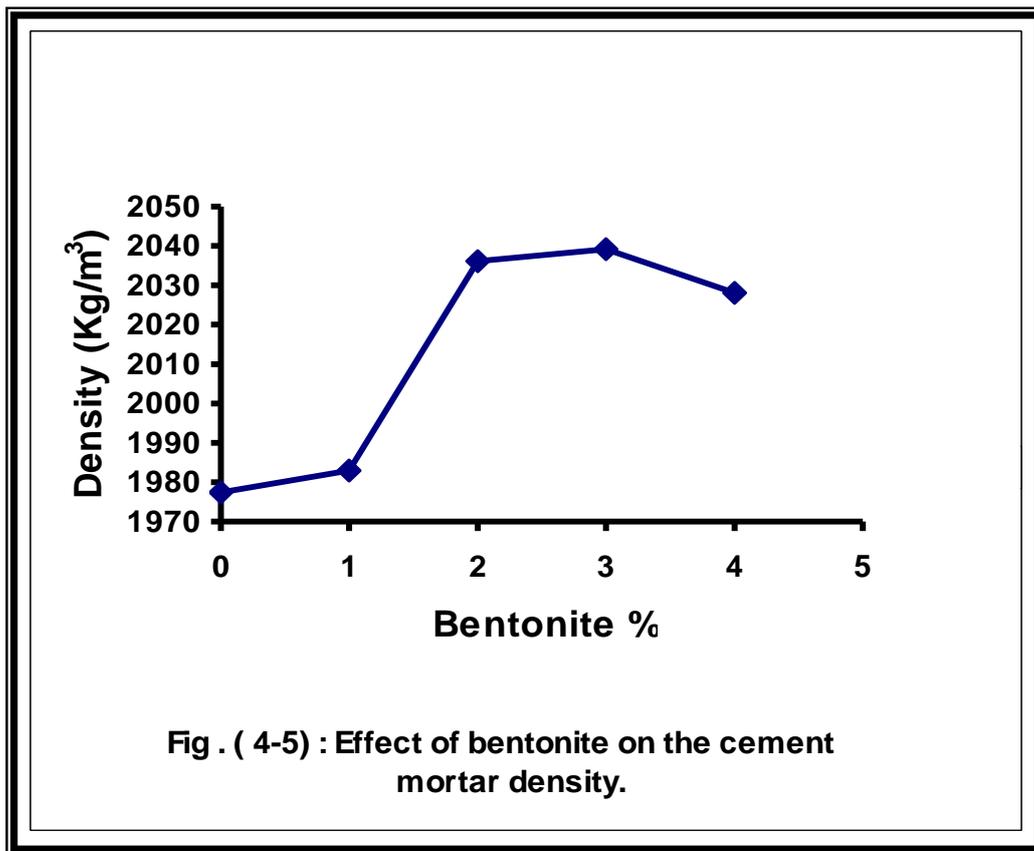
Lower permeability of silica fume concrete compared to plain cement concrete is attributed to the increase in the denseness of such concrete from addition of silica fume, resulting in the transformation of large pores into fine pores and thereby causing pore refinement. Pore refinement occurs due to the conversion of  $\text{Ca}(\text{OH})_2$  by pozzolanic silica into a secondary calcium silicate hydrate (C-S-H) gel, which effectively fills up large voids in hydrated silica fume-Portland cement concretes. The calcium silicate hydrate that is formed by the reaction of silica fume may be slightly different from that formed by hydration of the calcium silicate phases in Portland cement. The density of the hydrate is somewhat lower than that of the hydrate normally formed with hydration of Portland cement; in spite of the lower density the new hydrate has very low permeability [20, 21]. Some investigators suggest that the decrease in permeability of pozzolanic cement concretes is due to the effect of these pozzolans on the transition zone between the cement paste and aggregate. In plain cement concrete, the transition zone is generally less dense than the bulk paste, and contains a large amount of plate-like crystals of  $\text{Ca}(\text{OH})_2$ . The thickness of the transition zone, which is about 2 to 3  $\mu\text{m}$  in plain cement concrete, is decreased with the addition of such pozzolanic materials [22].

## **4.4 Density Test Results**

The influence of bentonite, limestone dust, and silica fume on the density of cement mortar mixes is presented in the following sections.

### **4.4.1 Influence of Bentonite on the Density of Cement Mortar**

Fig.(2-5) shows that the presence of bentonite as an admixture in cement mortar has shown slight increase in the density. Except for 2 percent of bentonite, the results show that the density of mixes increases with the increase in the percentage of bentonite.



**Note :** Method of calculation of the density is shown in appendix B .

#### 4.4.2 Influence of Limestone Dust on the Density of Cement Mortar

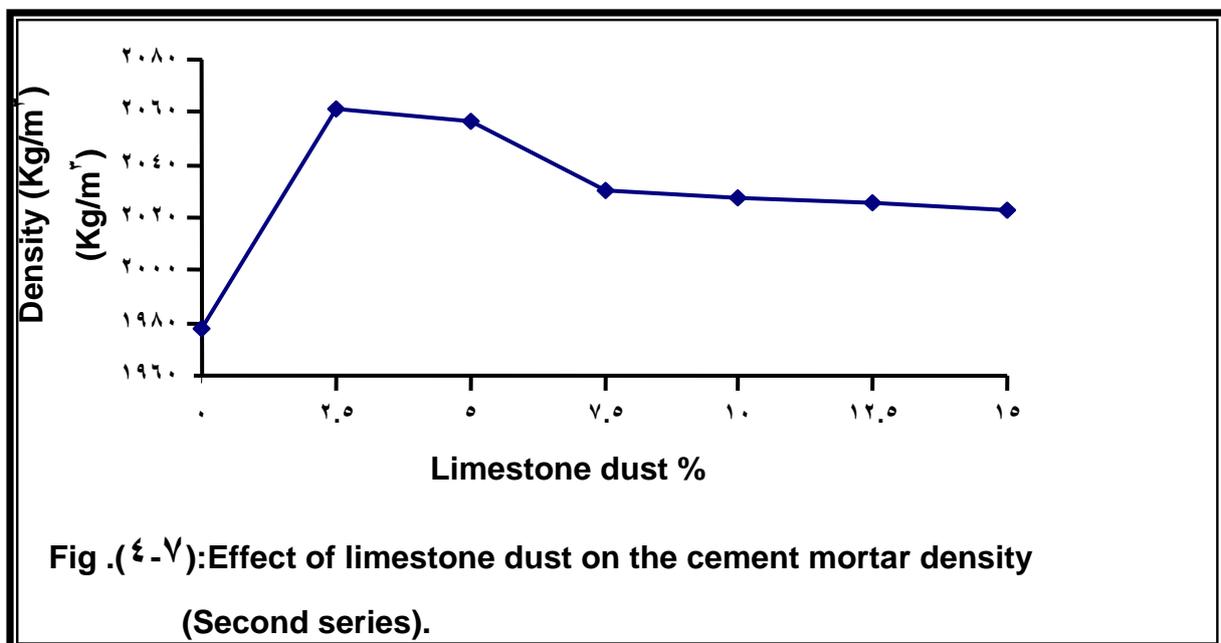
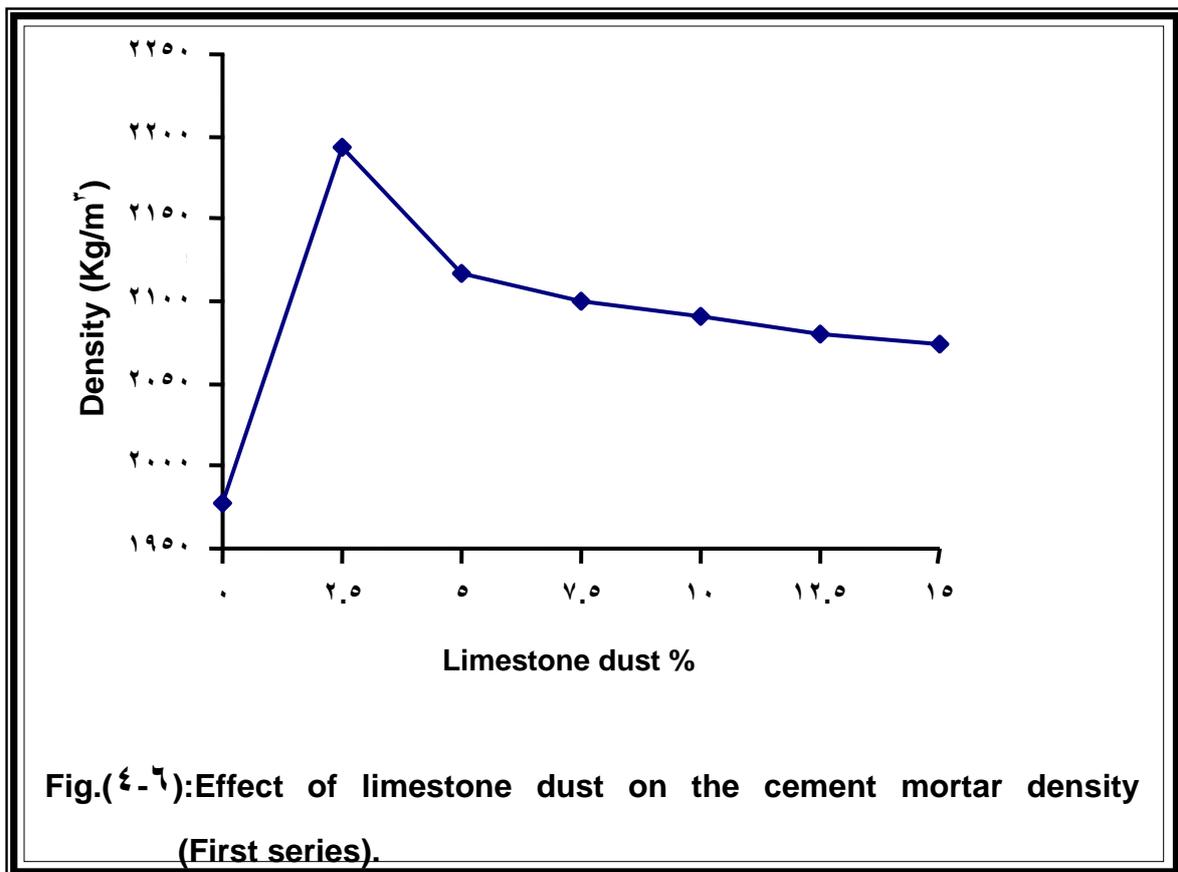
The effect of limestone dust as an admixture to cement mortar on the density for both series of mixes is plotted in Figs.(ξ-٦) and (ξ-٧).

In the first series of mixes, Fig.(ξ-٦) shows that the presence of limestone dust as an admixture in mortar mixes leads to an increase in the density. In general, beyond ٢.٥% of limestone dust, the rate of increase in the density of cement mortar mixes started to decrease. The maximum density has been achieved at ٢.٥% of limestone dust. At this level, the increase in the density is about ١١ percent more than that of the control mix.

For the second series, the results have shown that the presence of limestone dust as an admixture in mortar mixes gives an increase in the density, see Fig. (ξ-٧) .

However, beyond 2.0% of limestone dust, the rate of increase in the density of cement mortar mixes started to decrease. The maximum density has been achieved at 2.0% of limestone dust. At this level, the increase in the density is about 4.3 percent.

For the first series having the same W/C ratio, decreasing workability tends to impair the compaction of the mix beyond 2.0% resulting in an increase in voids. While in the second series 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 an additional voids after drying.

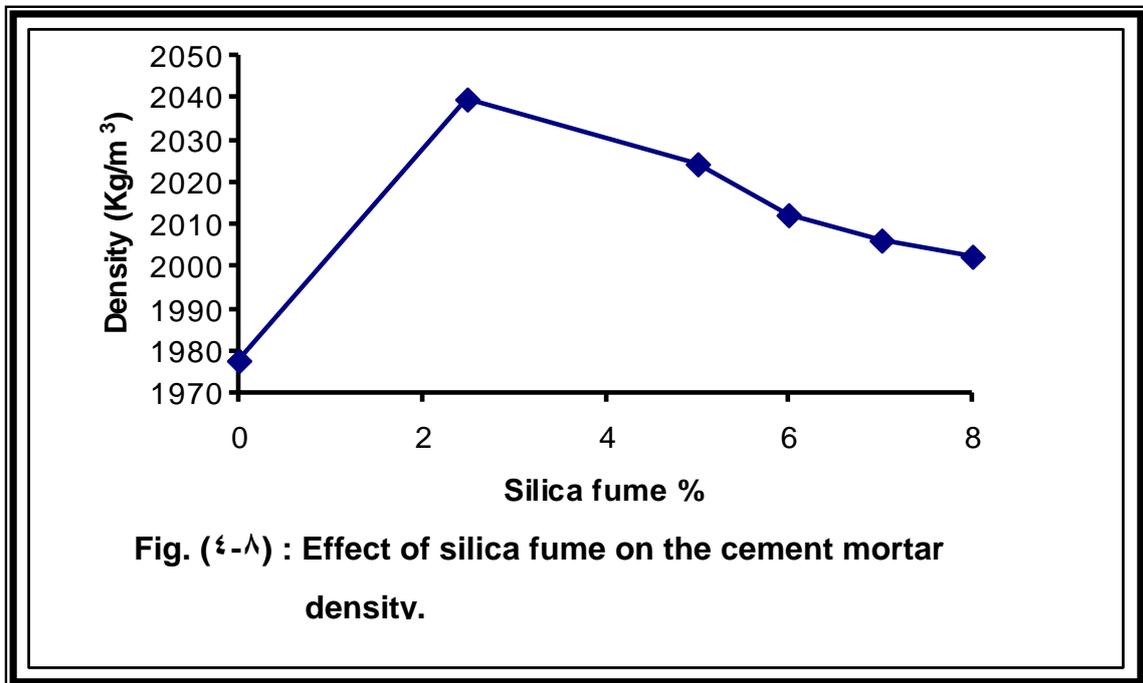


### 4.4.3 Influence of Silica Fume on the Density of Cement

#### Mortar

Fig.(4-1) shows that the presence of silica fume as an admixture in cement mortar has shown slight increase in the density. The results show that the rate of increase in the density of mixes decreases with the increase in the percentage of silica fume over 2.5%. The maximum density has been achieved at 2.5% of silica fume. The density at this level is 3.2 percent more than that of the control mix.

The slight reduction in the density of mixes above 2.5% of silica fume is due to that the density of the calcium silicate hydrate that is formed by the reaction of silica fume with  $\text{Ca(OH)}_2$  is somewhat lower than that of the hydrates normally formed with hydration of Portland cement [40].



## 4.5 Compressive Strength Test Results

The compressive strength of cement mortar containing various percentages of bentonite, limestone dust, and silica fume as an admixture to cement mortar is discussed in the following sections.

### 4.5.1. Influence of Bentonite on the Compressive Strength of Cement Mortar

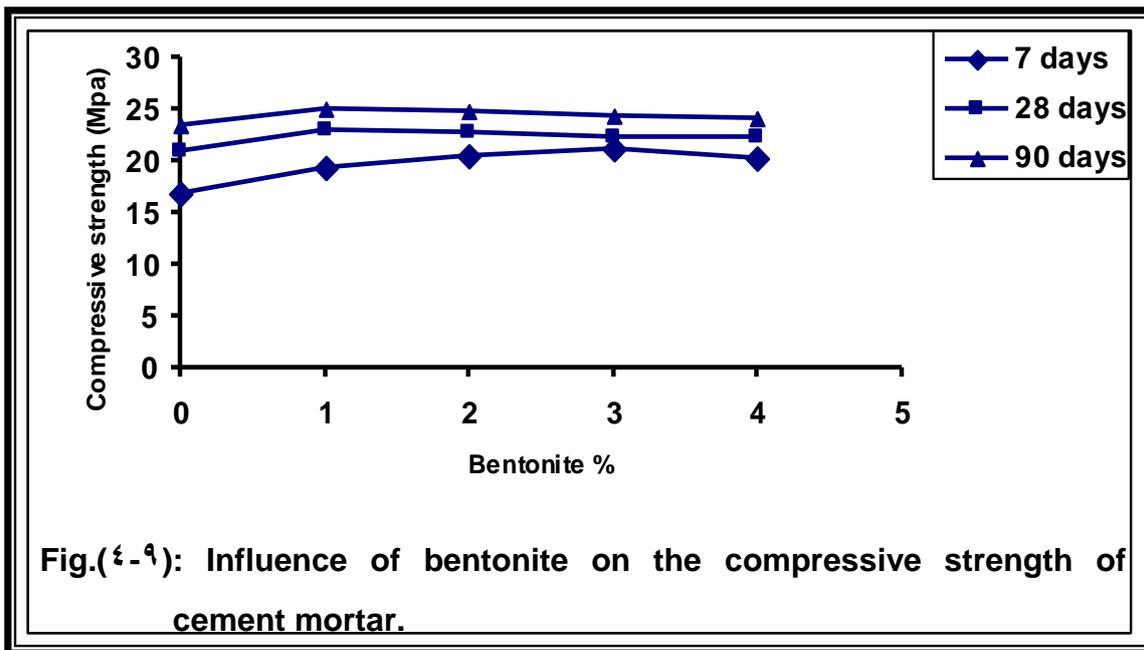
The results of the compressive strength up to an age of 90 days for bentonite containing mortar are presented in Table (٤-٨) and Fig.(٤-٩).

Table (٤-٨): Effect of bentonite on the cement mortar compressive strength.

Bentonite by weight of cement %	Compressive strength (MPa)		
	7 days	28 days	90 days
٠	١٦.٩٣	٢١	٢٣.٣٣
١	١٩.٤	٢٣	٢٥
٢	٢٠.٤	٢٢.٨	٢٤.٧٥
٣	٢١.٢	٢٢.٢٧	٢٤.٢٢
٤	٢٠.٢	٢٢.٢	٢٤.٠٢

Fig. (٤-٩) shows that the presence of bentonite as an admixture in cement mortar leads to an increase in compressive strength. The best strength has been

achieved at 7 days for 3% of bentonite. The compressive strength at this level is 20.2% 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 Fig.(4-9). 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.

#### 4.5.2 Influence of Limestone Dust on the Compressive Strength of Cement Mortar

The effect of limestone dust as an admixture to cement mortar on the compressive strength has been studied using two series of mixes. Details of the results are shown in Table (4-9) and plotted in Figs. (4-10) and (4-11).

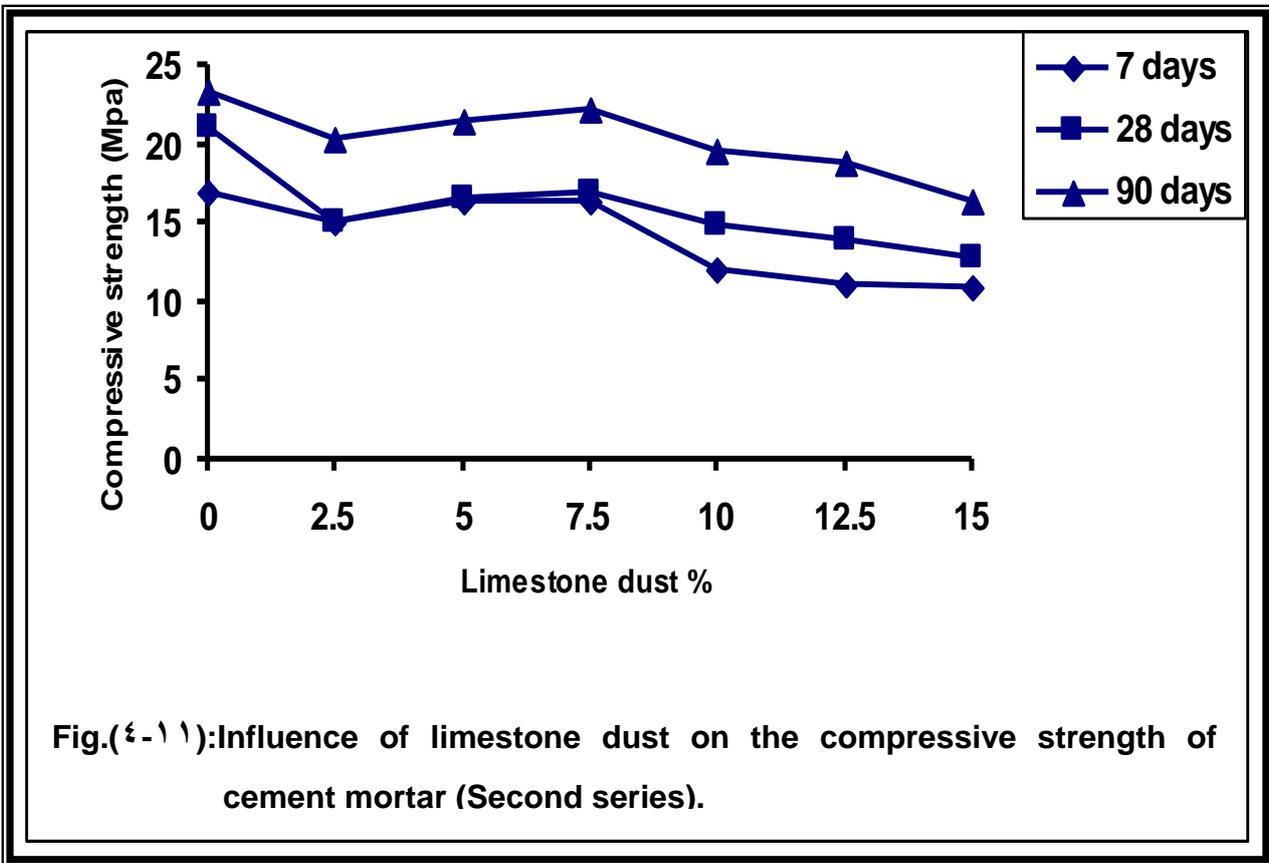
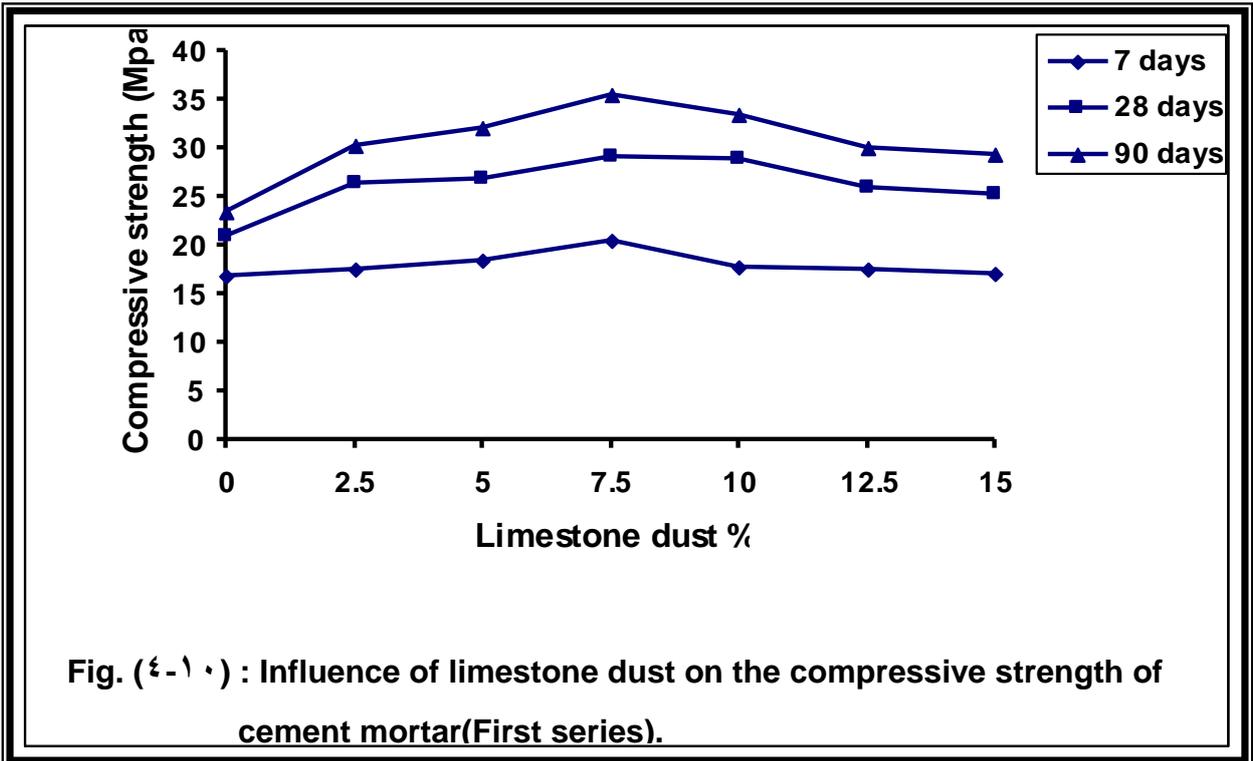
**Table (٤-٩):** Compressive strength test results of limestone dust containing mortar.

Mix Series	Limestone dust by weight of cement %	Compressive strength (MPa)		
		7 days	28 days	90 days
First Series	٠	١٦.٩٣	٢١	٢٣.٣٣
	٢.٥	١٧.٥٦	٢٦.٤٧	٣٠.٢٣
	٥	١٨.٣	٢٦.٧٣	٣٢.١٥
	٧.٥	٢٠.٥٣	٢٩.٠٧	٣٥.٤٣
	١٠	١٧.٧	٢٨.٨٧	٣٣.٤١
	١٢.٥	١٧.٥٣	٢٦	٢٩.٩٦
	١٥	١٧.١٣	٢٥.٢	٢٩.٢٧
Second Series	٠	١٦.٩٣	٢١	٢٣.٣٣
	٢.٥	١٥.٠٧	١٥.١	٢٠.٢٣
	٥	١٦.٢٧	١٦.٥	٢١.٤٢
	٧.٥	١٦.٤	١٧	٢٢.١٣
	١٠	١٢.٠٧	١٤.٩٣	١٩.٥٥
	١٢.٥	١١.٠٧	١٤	١٨.٧٣
	١٥	١٠.٠٩	١٢.٨	١٦.٤٤

In the first series, Fig. (ξ-10) shows 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 5.0% of limestone dust, the rate of increase in the compressive strength at all ages started to decrease. However, the best strength has been achieved at 5.0% of limestone dust. At this level, the increase in the compressive strength is 38.5 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.

For the second series, Fig. (ξ-11) shows that the compressive strength decreases with the increase in limestone dust content. In general, the strength started decreasing rapidly above the level of 5.0% 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. From Table (ξ-3), 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 [7].

The influence of curing time on the compressive strength for both series of limestone dust is shown in Figs. (ξ-10) and (ξ-11). 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.



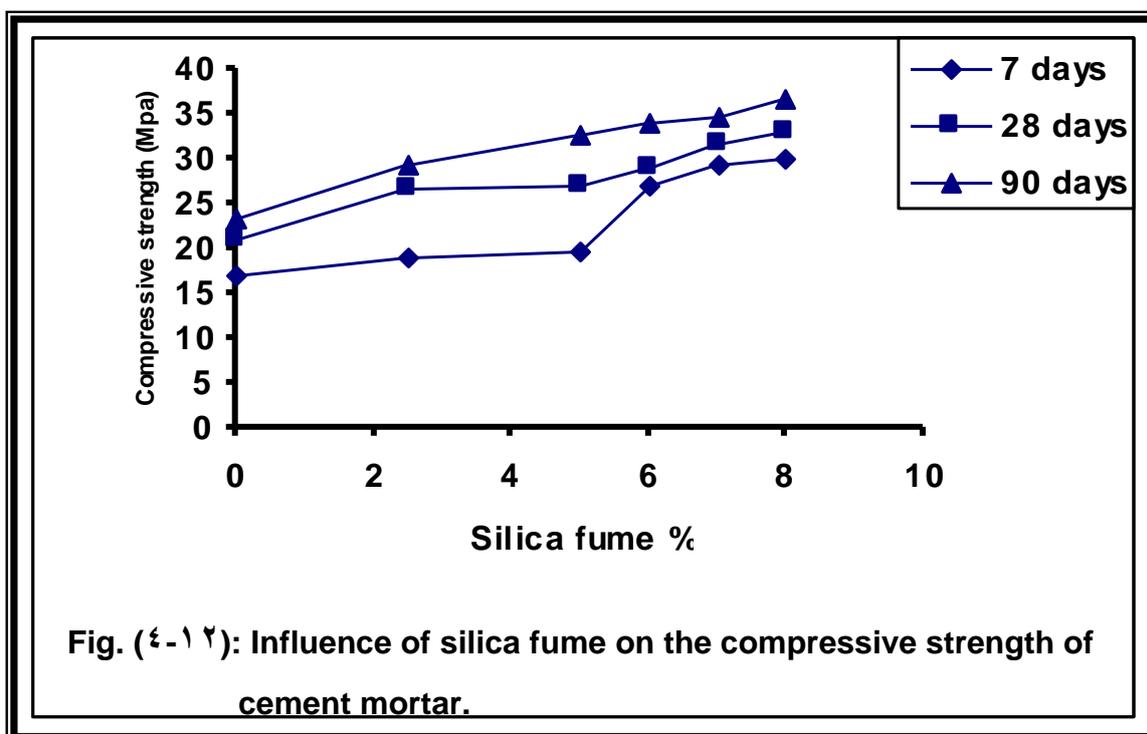
### 4.5.3. Influence of Silica Fume and Superplasticizer

#### on the Compressive Strength of Cement Mortar

Table (٤-١٠) and Fig.(٤-١٢) show the effect of silica fume on the compressive strength of cement mortar. The results show that the compressive strength of the mixes increases with the increase in the percentage of silica fume. At ٢.٥% of silica fume as an admixture to cement mortar, the increase in the compressive strength is ١٢.٢ and ٢٧.٦ percent for ٧ and ٢٨ days respectively.

**Table (٤-١٠):** Compressive strength test results of silica fume containing mortar.

Silica fume by weight of cement %	Compressive strength (MPa)		
	7 days	28 days	90 days
٠	١٦.٩٣	٢١	٢٣.٣٣
٢.٥	١٩	٢٦.٨	٢٩.٤٧
٥	١٩.٧	٢٧.٠٧	٣٢.٨
٦	٢٧.١	٢٩.٠٣	٣٣.٩٣
٧	٢٩.٣٣	٣١.٥٢	٣٤.٥٢
٨	٣٠.١٥	٣٢.٨٧	٣٦.٧٧



This increase in compressive strength can be attributed to the pozzolanic effect of silica fume. However, in the presence of hydrating Portland cement, silica fume will react as any finely divided amorphous silica rich constituent in the presence of calcium hydroxide- the calcium ion combines with the silica to form a calcium silicate hydrate through the pozzolanic reaction [ 42 ].

The influence of curing time on the compressive strength up to 90 days is shown in Fig. ( 4-12 ). It can be observed that the compressive strength develops with curing time for all hardened samples. This is due to the pozzolanic properties of silica fume. The pozzolanic reaction is slower than normal cement hydration, but continues over time. As more calcium hydroxide is converted to calcium silicate hydrate, the strength of the material will continue to increase [ 40 ].

## **4.6 Modulus of Rupture Test Results**

The modulus of rupture of cement mortar containing various percentages of bentonite, limestone dust, and silica fume as an admixture to cement mortar was determined after 7, 28 and 90 days of moist curing and discussed in the following sections.

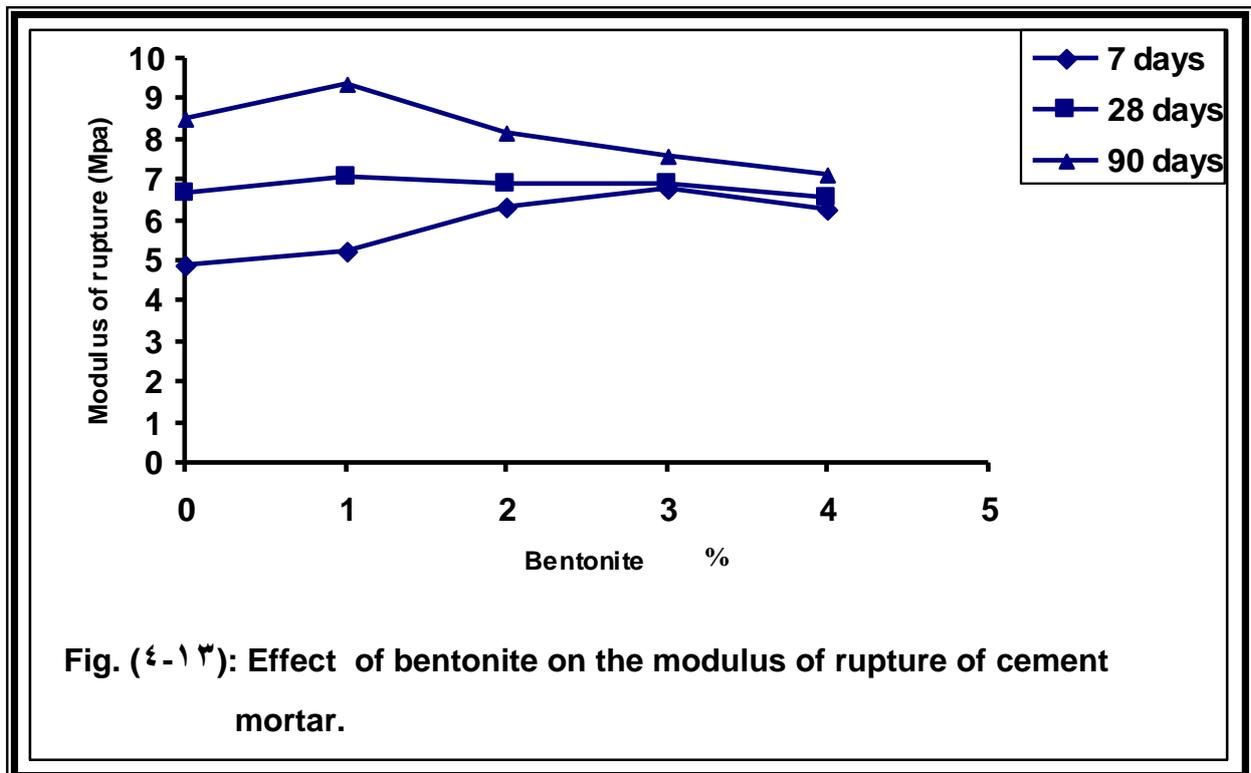
### **4.6.1 Effect of Bentonite on the Modulus of Rupture of Cement Mortar**

Table ( 4-11 ) and Fig. ( 4-13 ) show 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. Fig.( 4-13 ) 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.

Table (٤-١١): Modulus of rupture of cement mortar when bentonite is used as an admixture to cement mortar.

Bentonite by weight of cement %	Modulus of rupture (MPa)		
	7 days	28 days	90 days
٠	٤.٨٨	٦.٥٦	٨.٥٣
١	٥.٢٢	٧.٠٦	٩.٣٨
٢	٦.٣٤	٦.٨٩	٨.١٤
٣	٦.٧٧	٦.٨٧	٧.٥٨
٤	٦.٢٥	٦.٥٤	٧.١١



## 4.6.2 Effect of Limestone Dust on the Modulus of

### Rupture of Cement Mortar

The effect of limestone dust on the modulus of rupture of cement mortar for both series of mixes is shown in Table (ξ-12) and plotted in Figs. (ξ-13) and (ξ-14).

For the first series, Fig. (ξ-13) shows that the presence of limestone dust as an admixture in cement mortar has shown an increase in the modulus of rupture except for 12.0 and 10 percent at the age of 7 days. In general, beyond 2.0% 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 2.0% 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 2.0% 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 series, the effect of limestone dust is found to be somewhat similar to that of first series, see Fig.(ξ-14).

**Table (٤-١٢):** Influence of limestone dust on the modulus of rupture of cement mortar.

Mix Series	Limestone dust by weight of cement %	Modulus of rupture (MPa)		
		7 days	28 days	90 days
First Series	٠	٤.٨٨	٦.٥٦	٨.٥٣
	٢.٥	٧.٢٢	١١.١٣	١٣.٧٦
	٥	٦.١٥	١٠.٤٢	١٢.٣٣
	٧.٥	٥.٣٧	٩.٠٢	١١.٩٧
	١٠	٤.٩٢	٨.٧٧	١١.١٢
	١٢.٥	٤.٧٨	٧.٦٩	١٠.٧٥
	١٥	٤.٦٤	٧.٠٣	٩.٦٦
Second Series	٠	٤.٨٨	٦.٥٦	٨.٥٣
	٢.٥	٦.٦٨	٨.١٢	١١.٥٥
	٥	٥.٢١	٧.٦٢	٩.٧٨
	٧.٥	٤.٩٦	٧.٢٩	٩.٢٧
	١٠	٤.٧٧	٦.٩١	٨.٧٨
	١٢.٥	٤.٦٢	٦.٧٤	٨.٦٦
	١٥	٤.٥	٦.٢١	٨.٠٥

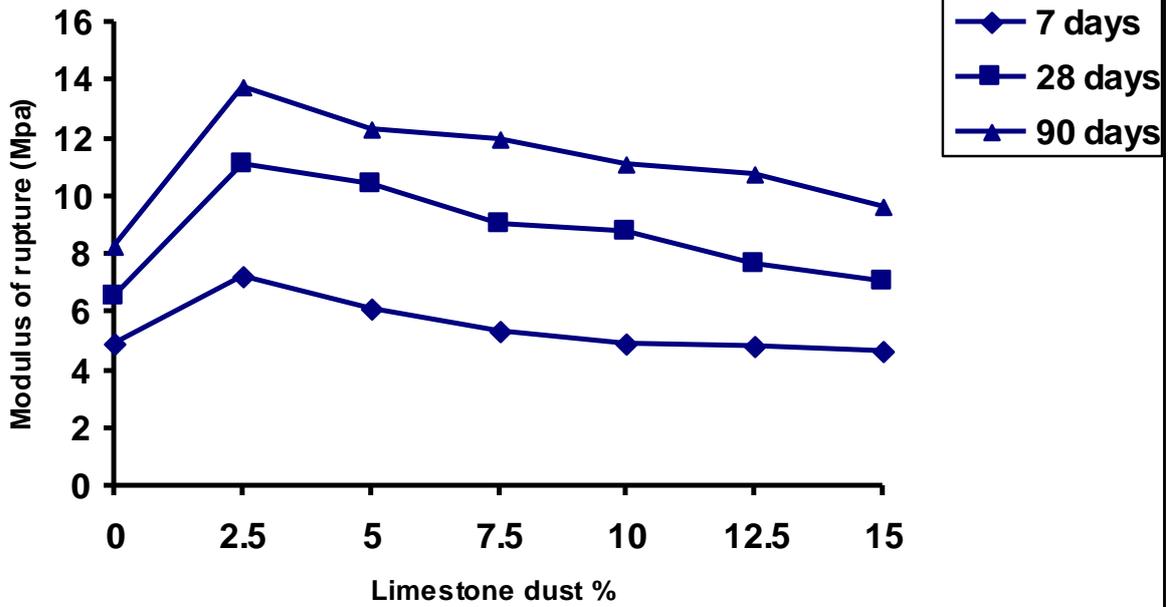


Fig. (٤-١٤) : Effect of limestone dust on the modulus of rupture of cement mortar (First series).

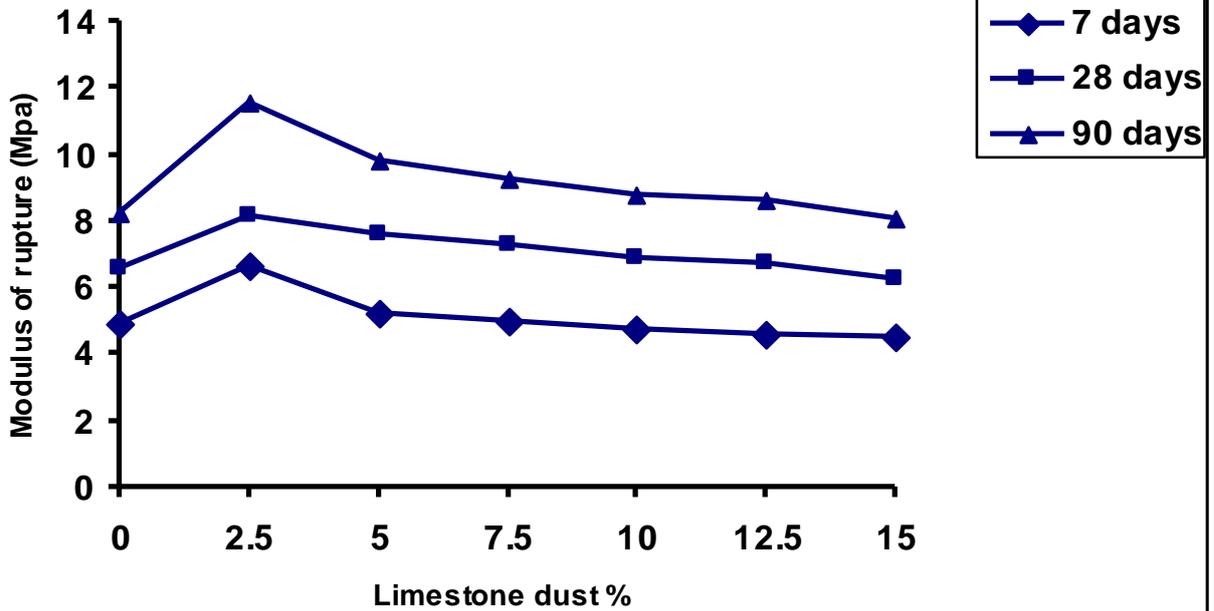


Fig. (٤-١٥) : Effect of limestone dust on the modulus of rupture of cement mortar (Second series).

### 4.6.3 Effect of Silica Fume and Superplasticizer on the Modulus of Rupture of Cement Mortar

Table (٤-١٣) and Fig.(٤-١٦) show the influence of silica fume on the modulus of rupture of cement mortar. The influence of silica fume and superplasticizer on the modulus of rupture is similar to that of compressive strength.

Fig.(٤-١٦) shows an improvement in the modulus of rupture as the silica fume percentage is increased. At ٢.٥% of silica fume as an admixture to cement mortar, the increase in the modulus of rupture is about ٣٠ and ٣٨ percent for ٧ and ٢٨ days respectively.

**Table (٤-١٣):** Influence of silica fume on the modulus of rupture of cement mortar.

Silica fume by weight of cement %	Modulus of rupture (MPa)		
	7 days	28 days	90 days
٠	٤.٨٨	٦.٥٦	٨.٥٣
٢.٥	٦.٣٤	٩.٠٦	١١.٣٦
٥	٧.٢٣	١٠.٢٣	١٢.٢٢
٦	٩.٤٢	١٠.٨٧	١٣.٠٦
٧	٩.٧٧	١٢.٠٥	١٤.٠٢
٨	١٠.٠٢	١٢.٨٨	١٥.١٥

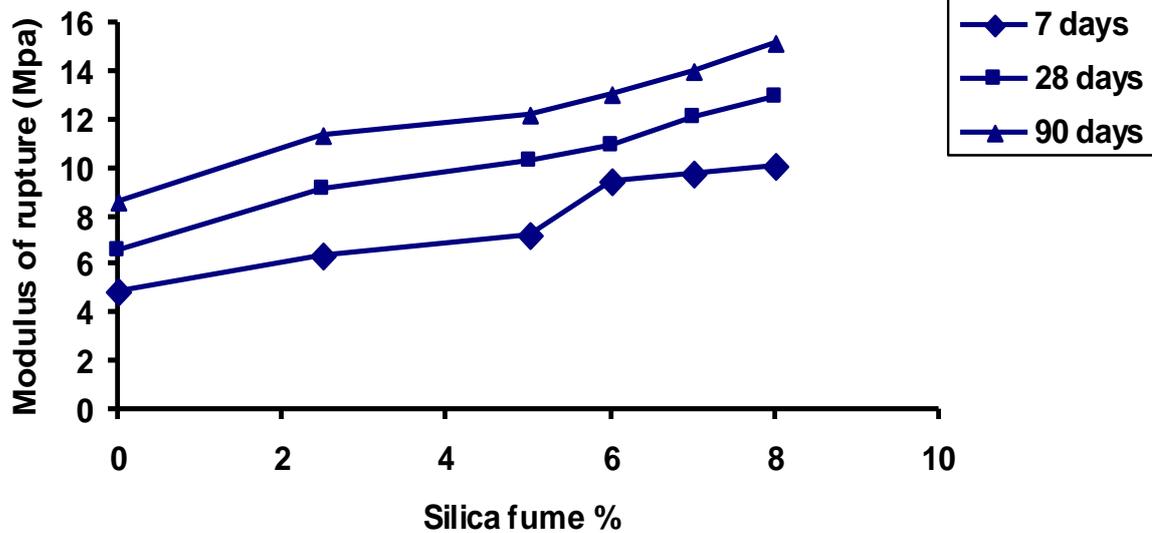


Fig. (4-16) : Effect of silica fume on the modulus of rupture of cement mortar.

## 4.7 Ultrasonic Pulse Velocity Test Results

The ultrasonic pulse velocity of cement mortar specimens was determined before finding the compressive strength by the destructive method. This technique is now widely used for assessing the quality of concrete in structures [10]. The measured pulse velocity of cement mortar can be affected by many factors, including smoothness of contact surface, temperature of specimen, moisture conditions, age of the specimen and presence of reinforcing steel [11]. Generally, high pulse velocity readings are indications of good quality concrete. The ranges of pulse velocity of different concrete qualities are shown in Table (4-17).

**Table (٤-١٤):** Pulse velocity ranges of concrete [٦٠].

<b>Pulse velocity (Km/sec.)</b>	<b>Concrete quality</b>
Above ٤.٥٨	Excellent
٣.٦٦-٤.٥٨	Good
٣.٠٥-٣.٦٦	Questionable
٢.١٤-٣.٠٥	Poor
Below ٢.١٤	Very poor

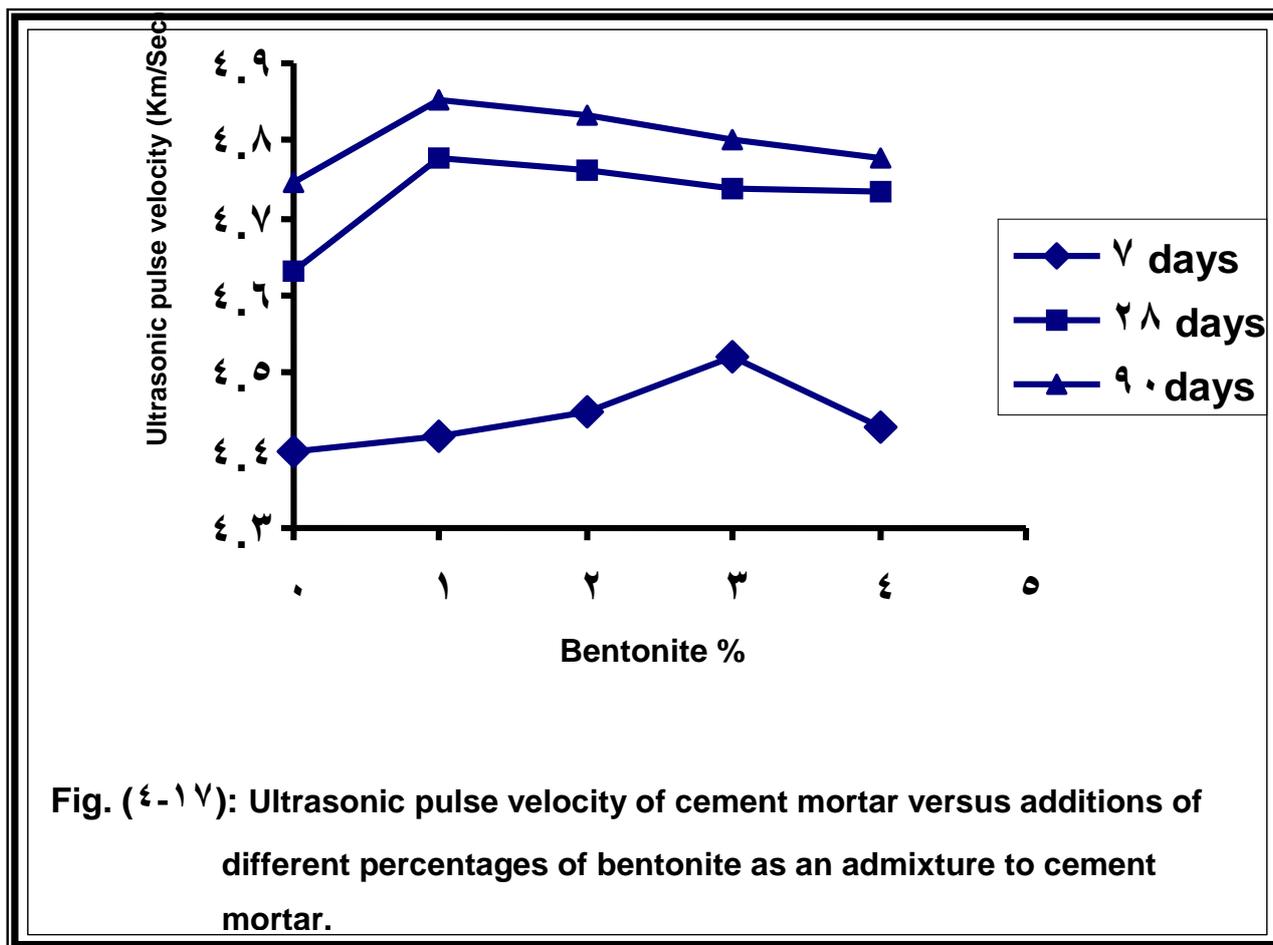
#### **4.7.1 Influence of Bentonite on the Ultrasonic Pulse**

##### **Velocity of Cement Mortar**

Table (٤-١٥) and Fig.(٤-١٧) show the Influence of bentonite on the ultrasonic pulse velocity of cement mortar. It is found that the presence of bentonite as an admixture in cement mortar mixes shows an increase in pulse velocity, see Fig. (٤-١٧). This increase in pulse velocity reflects the increase in compressive strength and tensile strength of mortar mixes.

**Table (٤-١٥):** Ultrasonic pulse velocity of bentonite containing mortar.

<b>Bentonite by weight of cement %</b>	<b>Ultrasonic pulse velocity (Km/sec.)</b>		
	<b>7 days</b>	<b>28 days</b>	<b>90 days</b>
٠	٤.٣٩٩	٤.٦٣١	٤.٧٤٥
١	٤.٤١٨	٤.٧٧٦	٤.٨٥٤
٢	٤.٤٥١	٤.٧٦٢	٤.٨٣١
٣	٤.٥٢١	٤.٧٤	٤.٨٠٢
٤	٤.٤٣٢	٤.٧٣٣	٤.٧٧٨



#### 4.7.2 Influence of limestone Dust on the Ultrasonic Pulse Velocity of Cement Mortar

The effect of limestone dust on the pulse velocity of cement mortar for two series of mixes is shown in Table (4-16).

In the first series, it is noticed that the presence of limestone dust in mixes leads to an increase in pulse velocity, see Fig.(4-18). This increase in pulse velocity reflects the increase in compressive strength and tensile strength of the mixes.

In the second series, Fig. (4-19) shows that the presence of limestone dust in cement mortar mixes leads to a decrease in pulse velocity. The decrease in pulse velocity reflects the reduction in compressive strength of the mixes.

Table (4-16): Ultrasonic pulse velocity of limestone dust containing mortar.

Mix Series	Limestone dust by weight of cement %	Ultrasonic pulse velocity (Km/sec)		
		7 days	28 days	90 days
First Series	0	4.399	4.731	4.740
	2.5	4.421	4.78	4.786
	5	4.513	4.700	4.801
	7.5	4.724	4.767	4.804
	10	4.482	4.730	4.82
	12.5	4.401	4.740	4.768
	15	4.401	4.093	4.770
Second Series	0	4.399	4.731	4.740
	2.5	3.937	4.399	4.701
	5	3.908	4.478	4.700
	7.5	3.979	4.087	4.723
	10	3.927	4.348	4.086
	12.5	3.886	4.330	4.433
	15	3.846	4.220	4.370

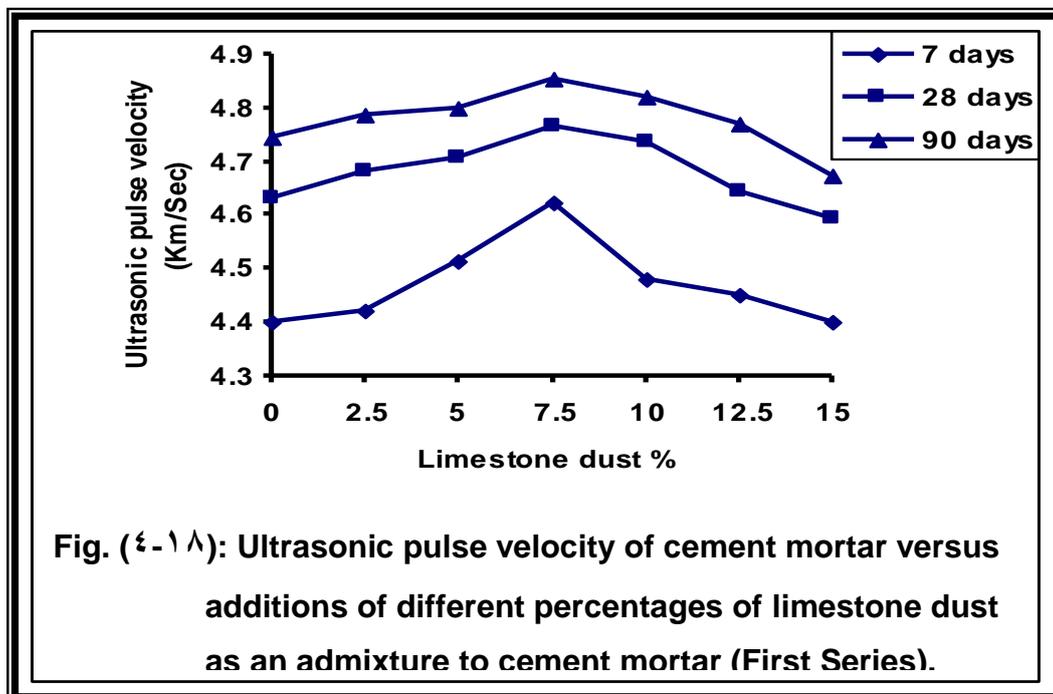
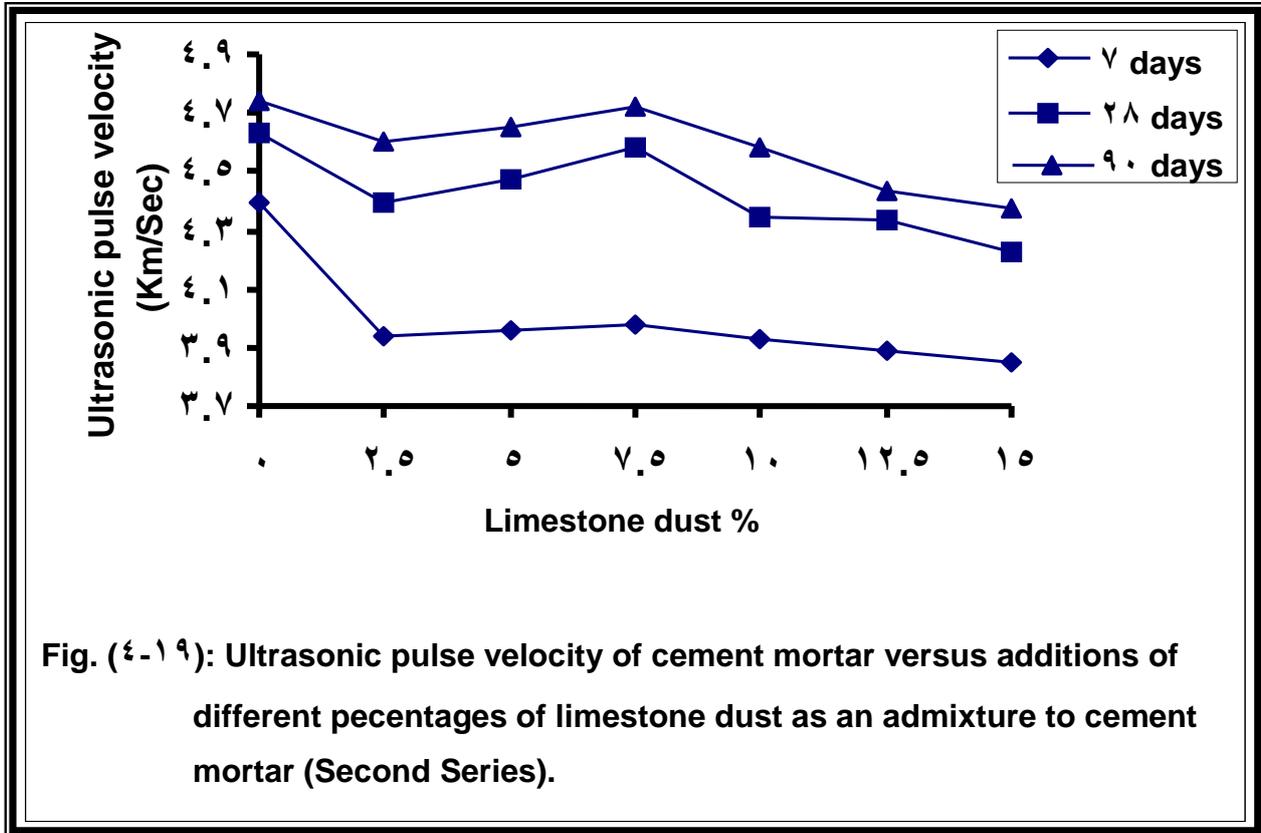


Fig. (4-17): Ultrasonic pulse velocity of cement mortar versus additions of different percentages of limestone dust as an admixture to cement mortar (First Series).



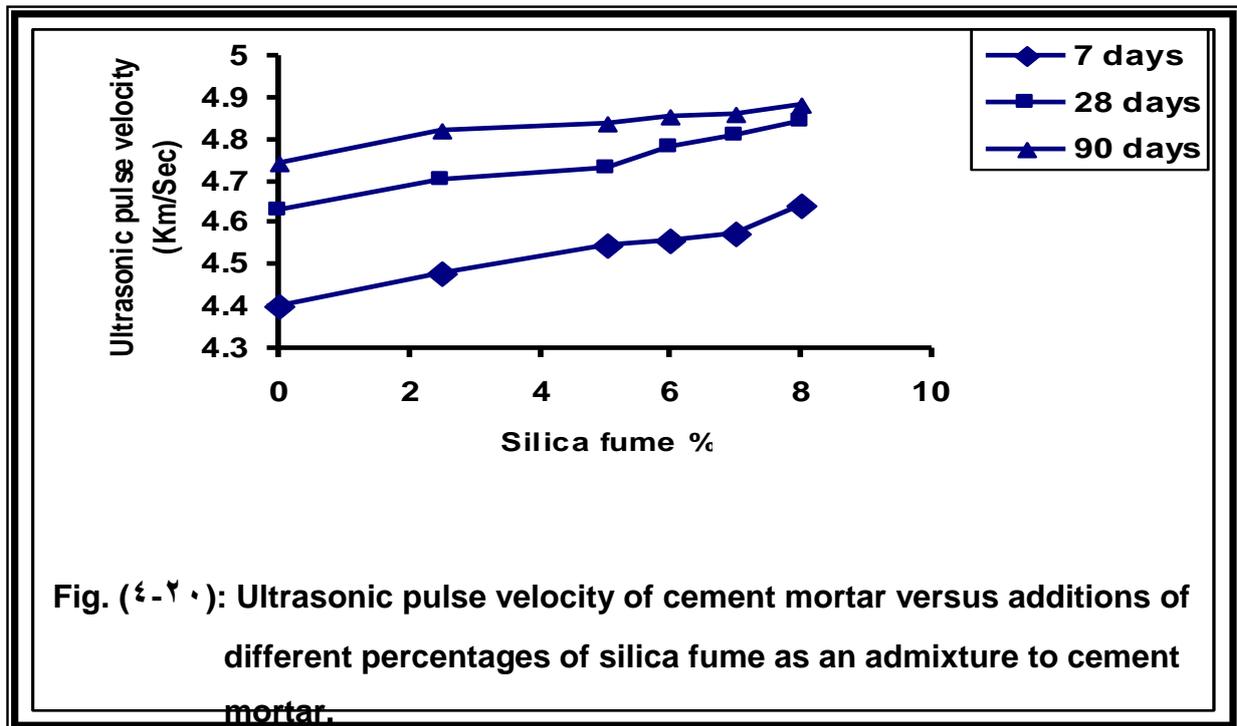
### 4.7.3 Influence of Silica Fume on the Ultrasonic

#### Pulse Velocity of Cement Mortar

The effect of silica fume on the pulse velocity of cement mortar is shown in Table (4-17) and plotted in Fig. (4-20). This figure shows an improvement in pulse velocity and this improvement increases with the increase in the silica fume percentage. This increase in pulse velocity reflects the increase in compressive strength and tensile strength for all mixes.

Table (٤-١٧): Ultrasonic pulse velocity of silica fume containing mortar.

Silica fume by weight of cement %	Ultrasonic pulse velocity (Km/sec.)		
	7 days	28 days	90 days
٠	٤.٣٩٩	٤.٦٣١	٤.٧٤٥
٢.٥	٤.٤٨٢	٤.٧٠٢	٤.٨٢٣
٥	٤.٥٤٥	٤.٧٣٤	٤.٨٣٨
٦	٤.٥٥٩	٤.٧٨٢	٤.٨٥٤
٧	٤.٥٧٣	٤.٨١١	٤.٨٦٢
٨	٤.٦٤٣	٤.٨٤٢	٤.٨٨٥



## 4.7.4 Relationship between the Ultrasonic Pulse

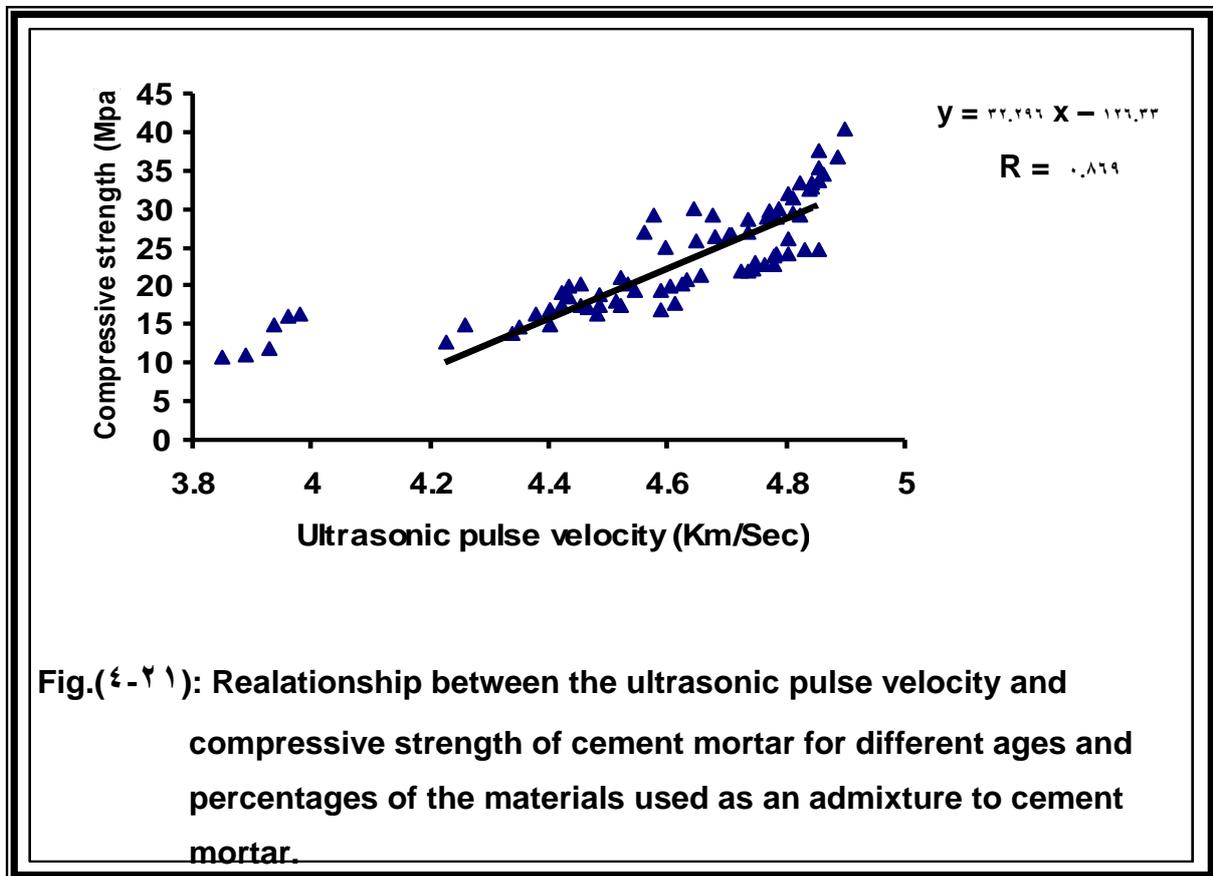
### Velocity and the Compressive Strength

Fig.(٤-٢١) shows the relationship between compressive strength of cement mortar and pulse velocity for ages from ٧ to ٩٠ days for all materials used in this research. However, an empirical formula can be suggested for this work:

$$Y = ٣٢.٢٩٦X - ١٢٦.٣٣$$

Y= compressive strength of ١٠٠ mm mortar cube, Mpa.

X= ultrasonic pulse velocity of mortar, Km/Sec.



## CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

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

#### 5.1.1 Workability

- ١- The workability of mortar mixes containing bentonite, and limestone dust is slightly affected when these materials are used as an admixture to cement mortar.
- ٢- For the limestone dust as an admixture to cement mortar, the water demand to produce the same workability increases with the increase in limestone dust content.
- ٣- The workability of mortar mixes containing silica fume is greatly affected when silica fume is used as an additional ingredient to cement mortar. However, silica fume should always be used together with a water-reducing or high-range water-reducing (HRWR, or superplasticizer) to maintain the required workability with no change in the water- to-cement ratio.

#### 5.1.2 Permeability

- ١- The presence of bentonite as an admixture in cement mortar leads to a reduction in the quantity of penetrated water through mortar and this reduction is more

pronounced when the amount of addition is increased . It was found that the minimum water permeation quantity has been achieved at 3% of bentonite . At this level , the reduction in the water permeation ratio is about 37.6 percent .

2- The addition of limestone dust to cement mortar has resulted in decreasing the quantity of penetrated water for both series of mixes. It was found that the minimum water permeation quantity for both series 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 series of mixes respectively.

3 -The addition of silica fume to cement mortar reduces the quantity of penetrated water of mortar and this reduction increases with the increase in the percentage of silica fume. The reduction in water permeation ratio is about 60 percent when 2.5% of silica fume is used as an admixture to cement mortar.

### **5.1.3 Density**

1- The density of mortar mixes containing bentonite as an admixture to cement mortar is slightly increased with the increase in the percentage of bentonite. The maximum density has been achieved at 3% of bentonite . The density at this level is about 3% more than that of the control mix .

2- The addition of limestone dust to cement mortar leads to an increase in the density of mortar mixes for both series of mixes. It was found that the maximum density for both series 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 series of mixes respectively.

3- The presence of silica fume as an admixture in cement mortar has shown slight increase in the density. The maximum density has been achieved at 2.5% of silica fume. At this level, the density at this level is 3.2% more than that of the control

mix.

### 5.1.4 Compressive Strength

- 1 - 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 20.2% more than that of the control mix.
- 2 - The addition of limestone dust to the cement mortar in the first series 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 4.5% of limestone dust. The increase in the compressive strength at this level is about 38.8 and 51.8 percent for 28 and 90 days respectively. In the second series of mortar mixes, the addition of limestone dust to the cement mortar has shown a reduction in the compressive strength. Above the level of 4.5% of limestone dust, the strength started to decrease rapidly.
- 3 - The addition of silica fume to the cement mortar has resulted in increasing the compressive strength of the mortar. At 2.5% of silica fume as an admixture, the magnitude of strength increase at 7 and 28 days is about 12.2 and 27.6 percent respectively.

### 5.1.5 Tensile Strength

- 1 - 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.
- 2 - The addition of limestone dust to the cement mortar in both series of mortar mixes has resulted in increasing the tensile strength of mortar. The best tensile strength

for both series 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 series of mortar mixes.

3- The tensile strength of mortar is higher than that of the control mix when silica fume is used as an admixture in cement mortar. At 2.5% of silica fume, the increase in the strength is about 30 and 38 percent for 7 and 28 days respectively.

### **5.1.6 Ultrasonic Pulse Velocity**

1- The presence of bentonite as an admixture in cement mortar has resulted in increasing the ultrasonic pulse velocity of the mortar samples, reflecting the increase in compressive strength and tensile strength of the specimens.

2- The presence of limestone dust in the first series of mortar mixes shows an increase in the pulse velocity for mortar samples. Generally, beyond 4.5% of limestone dust, the pulse velocity started to decrease. In the second series of mortar mixes, the addition of limestone dust to the cement mortar has shown a reduction in the pulse velocity. Above the level of 4.5% of limestone dust, the ultrasonic pulse velocity started to decrease rapidly. This reduction in pulse velocity reflects the decrease in compressive strength of the mixes.

3- The addition of silica fume to the cement mortar leads to an increase in the pulse velocity, reflecting the increase in compressive strength and tensile strength of the mortar specimens.

## **5.2 Recommendations for Future Works**

As there are limited data available for usage of bentonite, limestone dust, and silica fume in mortar, further investigations in the following fields are suggested.

- ١- The effect of these materials on the permeability of concrete mixes.
- ٢- The effect of these materials on the other properties of concrete mixes such as compressive , flexural , and splitting tensile strengths , ... etc.
- ٣- The effect of partial replacement of these materials by weight of cement.
- ٤- The effect of these materials on the properties of concrete and mortar mixes using different curing conditions.
- ٥- Studying the cost of production of concrete with these materials.
- ٦- Studying the possibility of using of superplasticizers as a waterproof agent.
- ٧- Investigating the properties of concrete containing these materials with and without superplasticizer .
- ٨- Further studies are needed to evaluate the effect of fineness of bentonite , and limestone dust on the properties of concrete and mortar mixes .
- ٩- The effect of using different dosages of superplasticizer and different aggregate content on the properties of concrete containing these

materials .

)-Data are needed to investigate the same problem using superplasticizers when bentonite, and limestone dust is used as an admixture in cement mortar.

## REFERENCES

- [١] – Abdul-Rehada, Salman Hussain, “**Effect of Quality of Concrete on Waterproofing**”, M.SC. Thesis, The University of Baghdad, ١٩٧٧.
- [٢] – ACI Committee ٢١٢, “**Chemical Admixtures for Concrete**”, ACI Materials Journal, Vol. ٨٦, No. ٣, May-June, ١٩٨٩, pp. ٣٢٢-٣٢٣.
- [٣] – الخلف ، مؤيد نوي ، ويوسف ، هناء عبد ، “مضافات الخرسانة”، وزارة التعليم العالي والبحث العلمي ، الجامعة التكنولوجية ، مطبعة جامعة الموصل ، بغداد ، ص ٢٨٧-٢٩٣ .
- [٤] – ACI Committee ٣٥٠, “**Testing Reinforced Concrete Structures for Watertightness**”, ACI Structural Journal , Vol. ٩٠ , No. ٣ , May-June, ١٩٩٣, pp. ٣٢٤-٣٢٨.
- [٥] – Orchard, D.F., “**Concrete Technology**”, Vol. ١, ٣<sup>rd</sup> Ed., Applied Science Publisher Ltd., London, ١٩٧٣.
- [٦] – Neville, A.M., and Brooks, J.J., “**Concrete Technology**”, New York, ١٩٨٧.
- [٧] – Neville, A.M., “**Properties of Concrete**”, ٤<sup>th</sup> Ed., Pitman Publishing London, ١٩٩٥.
- [٨] – “**Concrete Durability**” , Canadian Strategic Highway Research Program, Internet Explorer, June, ١٩٩٥.
- [٩] – Lea, F.M., “**The Chemistry of Cement and Concrete**”, ٣<sup>rd</sup> Ed., ١٩٧٠.
- [١٠] – Dhir, R.K., and Jackson, N., “**Civil Engineering Materials**”, ٣<sup>rd</sup> Ed., Hong Kong, ١٩٨٣, pp. ١٠٧.
- [١١] – Troxell, G.E., and Others, “ **Composition and Properties of Concrete**”, ٢<sup>nd</sup> Ed., New York, ١٩٦٨.

- [١٢] – Meletlou, A.C., Tia, M., and Bloomquist, D., “**Development of a Field Permeability Test Apparatus and Method for Concrete**”, ACI Materials Journal, Vol.٨٩, No.١, January- February, ١٩٩٢,pp.٨٣-٨٩.
- [١٣] – Ludirdja, D., Berger, R.L., and Young, J.F., “**Simple Method for Measuring Water Permeability of Concrete**”, ACI Materials Journal, Vol.٨٦, No.٥, September- October, ١٩٨٩,pp.٤٣٣-٤٣٩.
- [١٤] – Figg, J.W., “ **Method of Measuring the Air and Water Permeability of Concrete**”, Magazine of Concrete Research, Vol.٢٥, No.٨٥, December, ١٩٧٣,pp.٢١٣-٢١٩.
- [١٥] – Powers, T.C., Copeland, L.E., Hayes, J.C., and Mann, H.M., “**Permeability of Portland Cement Paste**”, Journal of American Concrete Proc., Vol.٢٦, November, ١٩٥٤,pp.٢٨٥-٢٩٨.
- [١٦] – Harvy, H.H., “**Permeability of Concrete in Sea Water**”, ACI International Conference on Performance of Concrete in Marine Environment, Canada, August, ١٩٨٠.
- [١٧] – Waston, A.J., and Oyeka, C.C., “ **Oil Permeability of Hardened Cement Paste and Concrete**”, Magazine of Concrete Research, Vol.٣٣, No.١١٥, June, ١٩٨١,pp.٨٥-٩٥.
- [١٨] – Arnold,S.R. and Littleton, I., “**Investigation into the Relationship between Aggregate Absorption and the Permeability of Concrete**” Royal Military College of Science, Shrivenham, Department of Civil Engineering, Technical Note Materials and Structure/١٢, May, ١٩٨٣,pp.١-١٨.
- [١٩] – Brian, B.H., and Malhotra, V.M., “**The Measurment of Concrete Permeability**”, Canadian Journal of Civil Engineering , Vol.١١, ١٩٨٤, pp.٢٨٢-٢٩٢.
- [٢٠] – Nayme, B.K., “**Permeability of Normal and Light Weight Mortar**”,

Magazine of Concrete Research, Vol. 37, No. 13, March, 1980.

[21] – Lydon, F.D., “ **Concrete Materials an Update**”, The Institute of Concrete Technology, 14<sup>th</sup> Annual Convention 23-25, April, 1986, pp. 1-21.

[22] – Al-Khalidy, Safi Mehdi, “**Permeability Evaluation of Concrete Containing Different Percentages of Sulfate Using Nitrogen Gas**”, M.SC. Thesis, The University of Al-Mustansiriya, 2001.

[23] – ACI Committee 212, “**Admixtures for Concrete**”, ACI Materials Journal, November, 1963.

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

[25] – Soroka, I., and Stern, N., “**Calcareous Fillers and Compressive Strength of Portland Cement**”, Cement and Concrete Research, Vol. 6, No. 3, March, 1976, pp. 367-376.

[26] – Soroka, I., and Setter, N., “**The Effect of Fillers on Strength of Cement Mortars**”, Cement and Concrete Research, Vol. 7, No. 4, April, 1977, pp. 449-456.

[27] – Chan, W.W.J, and Wu, C.M.L., “**Durability of Concrete with High Cement Replacement**”, Cement and Concrete Research, Vol. 30, No. 6, June, 2000, pp. 860-879.

[28] – Feng, N., Yang, H., And Zu, L., “**The Strength Effect of Mineral Admixture of Cement Concrete**”, Cement and Concrete Research, Vol. 18, No. 3, March, 1988, pp. 464-472.

[29] – Poon, C.S., Lam, L., and Wong, Y.L., “**A Study on High Strength Concrete Prepared with Large Volumes of Low Calcium Fly Ash**”, Cement and Concrete Research, Vol. 30, No. 3, March, 2000, pp. 447-450.

[୩୦] – Owens ,P.L., “**Fly Ash and its Usage in Concrete**”, Concrete,Vol. ୧୩, No.୮, July, ୧୯୮୧,pp.୩୩-୩୮.

[୩୧] – Cook,J.E., “**Fly Ash in Concrete-Technical Considerations**”, Concrete International: Design and Construction, Vol. ୦, No.୧, Sept., ୧୯୮୩, pp.୦୧-୦୬.

[୩୨] – Swamy, R.N., “**Utilization of Fly Ash: A Challenge to Concrete Technology-୧**”, Indian Concrete Journal, Vol. ୦୧, No.୦, May, ୧୯୮୦,pp.୧୧-୧୮.

[୩୩] – Wilbert,S.L., Carette,G.G., and Malhotra, V.M., “**Structural Concrete Incorporating High Volumes of ASTM Class F Fly Ash**”, ACI Materials Journal, Vol. ୮୬, No. ୦, September-October, ୧୯୮୧, pp. ୦୮୮-୦୯୫.

[୩୪] – Ravindra, K.D. , and Ewan, A.B., “**Pulverized Fuel-Ash Concrete: Intrinsic Permeability**”, ACI Materials Journal, Vol. ୧୦ ,No. ୬, November-December, ୧୯୯୩, pp. ୦୮୧-୦୮୮.

[୩୫] – Poon, C.S., Wong, Y.L., and Lam,L., “**The Influence of Different Curing Conditions on The Pore Structure and Related Properties of Fly Ash Cement Pastes and Mortars**”, Construction and Building Materials, Vol. ୧୧, No.୮, July, ୧୯୯୮, pp.୩୮୩-୩୯୩.

[୩୬] – Swamy, R.N., and Bouikni, A., “**Some Engineering Properties of Slag Concrete as Influenced by Mix Proportioning and Curing**”, ACI Materials Journal, Vol. ୮୮ ,No. ୩, May – June, ୧୯୯୦, pp. ୨୧୦-୨୧୮.

[୩୭] – Kaitila, H., “**Particle Recommendations for the Use of Industrial By-Products in Concrete with the Focus on the Durability of Concrete Structures**”, International Seminar on “ Aspects of Admixture and Industrial By- Products” Sydney, ୧୯୮୬, pp.୨୬୧-୩୦୧.

[୩୮] – Olorunsogo, F.T., and Wainwright, P.J., “**Effect of Ground**

**Granulated Blast Furnace Slag Particle- Size Distribution on Mortar Compressive Strength**” Journal of Materials in Civil Engineering, Vol. 10, No. 3, Aug., 1998, pp. 180-187.

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

[40] – ACI Committee 226, **“Silica Fume in Concrete”**, ACI Materials Journal, March- April, 1987.

[41] – Larrard, F., and Aitcin, P. C., **“Apparent Strength Retrogressing of Silica-Fume Concrete”** , ACI Materials Journal, Vol. 90, No. 6, November-December, 1993.

[42] - ACI Committee 238, **“Guide for the Use of Silica Fume in Concrete”**, ACI Materials Journal, Vol. 92, No. 8, July- August, 1990.

[43] – Hooton, R.D., **“ Influence of Silica Fume Replecment of Cement on Physical Properties and Resistance to Sulfate Attack, Freezing and Thawing, and Alkali- Silica Reactivity”**, ACI Materials Journal, Vol. 90, No. 2, March- April, 1993.

[44] – Detwiler ,R.J., and Mehta, P.K., **“Chemical and Physical Effects of Silica Fume on the Mechanical Behavior of Concrete”**, ACI Materials Journal, Vol. 86, No. 6, November – December, 1989.

[45] – Cong, X.,Gong,S., Darwin , D., and Cabe, S.L., **“Role of Silica Fume in Compressive Strength of Cement Paste, Mortar, and Concrete”**, ACI Materials Journal, Vol. 89, No. 8, July- August, 1992.

[46] – Bayasi,Z., and Zhou, J. , **“Properties of Silica Fume Concrete and Mortar”**, ACI Materials Journal, Vol. 90, No. 8 July- August, 1993.

[47] – Ozyildirim, C., and Halstead , W.J., **“Improved Concrete Quality with Combinations of Fly Ash and Silica Fume”**,ACI Materials Journal,

Vol. ٩١ ,No.٦, November- December, ١٩٩٤.

[٤٨] – Iraqi Organization of Standards, IOS ٥:١٩٨٤, for Portland Cement.

[٤٩] – American Society for Testing and Materials, C٧٧٨-٨٧, “**Standard Specification for Standard Sand**”, Annual Book of ASTM Standards, Vol. ٠٤.٠١, ١٩٨٩, pp.٣٣٣-٣٣٤.

[٥٠] – ASTM Standards, “ **Concrete and Mineral Aggregates**”, Part ١٤, ١٩٨٦.

[٥١] – “**Melment**” , Applications in Concrete, Sheet Information, QAD Products, May, ١٩٧٨.

[٥٢] – American Society for Testing and Materials, C٢٣٠-٨٣, “ **Standard Specification for Flow Table for Use in Tests of Hydraulic Cement**”, Annual Book of ASTM Standards, Vol. ٠٤.٠١, ١٩٨٩, pp.١٧٣-١٧٧.

[٥٣] – MARUI and CO.LTD., "**Operation Manual for MIC – ٣٣٥ – ٣H Permeability Apparatus**" .

[٥٤] American Society for Testing and Materials, C١٠٩-٨٨, “**Standard Test Method for Compressive Strength of Hydraulic Cement Mortar (Using ٢-in. or ٥٠-mm Cube Specimens**” , Annual Book of ASTM Standards, Vol. ٠٤.٠١, ١٩٨٩, pp.٥٧-٦١).

[٥٥] - American Society for Testing and Materials , C٣٤٨-٨٦, “**Standard Test Method for Flexural Strength of Hydraulic Cement Mortars (Using Simple Beam with Center- Point Loading)**” , Annual Book of ASTM Standards, Vol. ٠٤.٠١, ١٩٨٩, pp.٢٠٤-٢٠٩.

[٥٦] - American Society for Testing and Materials, C٥٩٧-٧١, “**Standard Method for Pulse Velocity Through Concrete**” , Annual Book of ASTM Standards, ١٩٧٧, pp.٣٤١-٣٤٤.

[٥٧] – Saricimen , H., Maslehuddin , M., Al- Tayyib , A.J., and Al-Mana,

A.I., "Permeability and Durability of Plain Blended Cement Concretes Cured in Field and Laboratory Conditions", ACI Materials Journal, Vol. ٩٢, No. ٢ March- April, ١٩٩٥, pp. ١١١-١١٦.

[٥٨] – Tomsett, H.N., "The Practical Use of Ultrasonic Pulse Velocity Measurements in the Assessment of Concrete Quality", Magazine of Concrete Research, Vol. ٣٢, No. ١١٠, March, ١٩٨٠, pp. ٧-١٦.

[٥٩] – Malhotra , V.M., "Testing Hardened Concrete : Nondestructive Methods", American Concrete Institutes Monograph, No. ٩, Michigham, ١٩٧٦.

[٦٠] – السامرآني، مفيد، وروؤف، زين العابدين، "الفحوصات غير الإتلافية للخرسانة"، جامعة الشارقة، الإمارات العربية المتحدة، مطبعة اكسبريس ، اكتوبر ، ١٩٩٩ .

## APPENDIX A

Table (A-١): Physical properties of the cement

Physical Properties	Test Results	IOS ٥:١٩٨٤(٤٨) Limits
Fineness, Blaine, $\text{cm}^2/\text{gm}$	٣٣٣٤	$\geq ٢٥٠٠$

Setting time, Vicat's method		
Initial hrs:min.	۳:۱۰	$\geq ۰۰:۴۵$
Final hrs:min.	۴:۳۰	$\leq ۱۰:۰۰$
Compressive strength of ۷۰.۷mm cube, MPa		
۳ days	۲۰.۸	$\geq ۱۵$
۷ days	۳۰.۱	$\geq ۲۳$

A-۱

**Table (A-۲):** Chemical composition of the cements

<b>Oxide</b>	<b>(%)</b>	<b>IOS 5:1984<sup>(48)</sup> Limits</b>
SiO <sub>۲</sub>	۲۲.۲۲	
Al <sub>۲</sub> O <sub>۳</sub>	۴.۵۲	
Fe <sub>۲</sub> O <sub>۳</sub>	۵.۱۲	
CaO	۶۳.۴۱	≤ ۵.۰
MgO	۱.۴۸	≤ ۲.۵
SO <sub>۳</sub>	۱.۸۶	
Free lime	۰.۸۷	≤ ۴.۰
L.O.I	۰.۶۹	≤ ۴.۰
I.R.	۰.۴۴	≤ ۱.۵
<b>Compound composition</b>	<b>(%)</b>	<b>IOS 5:1984<sup>(48)</sup> Limits</b>
C <sub>۳</sub> S	۴۲.۷۴	
C <sub>۲</sub> S	۳۱.۴۶	
C <sub>۳</sub> A	۳.۳۱	≤ ۳.۵
C <sub>۴</sub> AF	۱۵.۵۸	
L.S.F	۰.۸۸	۰.۶۶-۱.۰۲

**Table (A-۳):** Grading of the standard sand

<b>Sieve</b>	<b>Percent retained</b>	<b>ASTM C778-1987<sup>(49)</sup></b> <b>Limits</b>
No. ۱۶ (۱.۱۸mm)	None	None
No. ۳۰ (۶۰۰Mm)	۲	۲ ± ۲
No. ۴۰ (۴۲۵ Mm)	۲۷	۳۰ ± ۵
No. ۵۰ (۳۰۰Mm)	۷۵	۷۵ ± ۵
No. ۱۰۰ (۱۵۰Mm)	۹۷	۹۸ ± ۲

**Table (A-۴):** Chemical and physical properties of bentonite

<b>Chemical compound</b>	<b>Percent of total weight</b>
SiO <sub>۲</sub>	۳۹.۸۸
Al <sub>۲</sub> O <sub>۳</sub>	۱۲.۲۹
Fe <sub>۲</sub> O <sub>۳</sub>	۶.۶۷
CaO	۱۵.۱۶
MgO	۶.۰۵
SO <sub>۲</sub>	۱.۲۴
L.O.I	۱۸.۶۶
Physical properties	
Fineness , Blaine, cm <sup>۳</sup> /gm	۳۷۹۲

**Table (A-5):** Chemical and physical properties of limestone dust

Chemical compound	Percent of total weight
SiO <sub>2</sub>	3.5
Al <sub>2</sub> O <sub>3</sub>	0.34
Fe <sub>2</sub> O <sub>3</sub>	0.20
CaO	52.21
MgO	1.25
SO <sub>2</sub>	0.86
L.O.I	41.03
Physical properties	
Fineness , Blaine, cm <sup>2</sup> /gm	37.6

**Table (A-6):** Chemical analysis of silica fume

Chemical compound	Percent of total weight
SiO <sub>2</sub>	98.76
Al <sub>2</sub> O <sub>3</sub>	0.12
Fe <sub>2</sub> O <sub>3</sub>	0.20
CaO	0.20
MgO	0.15
SO <sub>2</sub>	-
K <sub>2</sub> O	0.03
Na <sub>2</sub> O	0.10



**Table (A-V):** Technical description of superplasticizer (Melment L<sup>1</sup>)

Main action	Concrete super-plasticizer
Subsidiary effect	Hardening accelerator
Appearance	Clear to slightly milky
Solids in aqueous solution	Approx. 20%
Density	1.1 g/cm <sup>3</sup>
Chloride content	less than 0.005%
Sugar content	None
Handling	No special precautions
PH value	7-9
Frost resistance	
Storage life	Melment L <sup>1</sup> withstands any number of frost cycles. It should be thoroughly thawed before use. At least two years. It should not, however, be exposed to excessive heating

## APPENDIX B

### **Methods of Calculations**

#### 1- **Permeability**

The permeability of cement mortar was calculated from the following formulas

$$\text{Water permeation quantity (g)} = W_2 - W_1$$

Where:

$W_1$  = weight (g) after drying followed by 1 hour keeping in room air.

$W_2$  = weight (g) immediately after applying water pressure of 100 g/cm<sup>2</sup> for 1 hour.

$$\text{Water permeation ratio} = \frac{\text{Water permeation quantity of A(g)}}{\text{Water permeation quantity of B(g)}}$$

A= test specimen containing water penetration preventive agent.

B= test specimen not containing any agent.

#### 2- **Density**

The density of cement mortar was calculated from the following formula

$$D = W/V$$

Where:

D = hardened mortar density, (Kg/m<sup>3</sup>).

W = oven dry weight of the specimen, Kg.

V = volume of the specimen, m<sup>3</sup>.

B-1

## الخلاصة

تعتبر عملية حماية المنشآت الخرسانية من نفوذ الماء من خلال ارضياتها وجدرانها من اهم المشاكل الصعبة التي تواجه المهندسين المدنيين. ان معظم الفشل في المنشآت الحافظة للماء يعود الى تسربي الماء من خلال جدرانها وأرضياتها مسبباً بعض المشاكل .

ان الطريقة الشائعة الاستخدام في العراق لحماية المنشآت الخرسانية المعرضة للمياه من مشكلة النضوح هي طريقة استخدام المواد القيرية في تغليف جدرانها وارضياتها. ولقد استخدمت بعض المواد مثل السمنت المقاوم للأملاح والرمل الناعم بعد خلطها مع القير لهذا الغرض.

وقد ثبت بمرور الوقت بان هذه الطريقة لا يُعول عليها حيث ان هذه المواد القيرية تفقد مقاومتها لمنع تسرب الماء بمرور الزمن مؤدية الى تسرب الماء من خلال الجدران والارضيات الخرسانية. لذا تهدف هذه

الدراسة الى تحري امكانية استخدام بعض المواد الدقيقة التجزئة ( **Finely Divided Materials** ) كمضاف في اعمال المونة بعد خلطها مع السمنت المقاوم للأملاح والرمل الناعم وتقييم مدى تأثيرها على خواص المونة الاخرى.

تم في هذا البحث استخدام البنتونايت، غبار حجر الكلس، وبخار السليكا كمضافات مقللة للنفاذية. وقد تم تقييم المونة بإجراء فحص النفاذية، فحص مقاومة الانضغاط، معايير التصدع، فحص منضدة الانسياب، الكثافة وسرعة الموجات فوق الصوتية . ان خواص الخلطات الطرية تم دراستها بقياس قيم الانسياب لها. أظهرت النتائج ان زيادة نسبة المواد المستعملة في هذا البحث تؤدي الى انخفاض في قيم الانسياب للمونة ، من حيث تقييم نتائج فحص النفاذية لخلطات المونة الحاوية على نسب مختلفة من المواد المستعملة في هذا البحث، تبين ان هذه المواد تؤدي الى نقصان كمية الماء النافذ من خلال المونة. فقد لوحظ ان زيادة نسب اضافة البنتونايت يؤدي إلى نقصان في كمية الماء النافذ من خلال المونة حيث بلغت كمية الماء النافذ حوالي ( ٩١%) من كمية الماء النافذ من خلال الخلطة المرجعية عند نسبة اضافة ( ١%) من البنتونايت . من ناحية اخرى ، فقد اظهرت النتائج ان النسبة المثلى لغبار حجر الكلس لكلا المجموعتين ( الخلطات الغنية والضعيفة ) من خلطات المونة هي ( ٢.٥%) من وزن السمنت، حيث بلغت كمية الماء النافذ عند هذا المستوى حوالي ( ١٨.٢%) و ( ٤٧.٨%) من كمية الماء النافذ من خلال الخلطة المرجعية للخلطات الغنية والضعيفة على التوالي . اما بالنسبة لبخار السليكا فقد ابدت سلوكاً مشابهاً لمادة البنتونايت حيث بلغت كمية الماء النافذ حوالي ( ٤٠%) من كمية الماء النافذ من خلال الخلطة المرجعية عند نسبة اضافة ( ٢.٥%) من

بخار السليكا . كما أظهرت النتائج أيضاً أن المواد المستعملة في هذا البحث تؤدي إلى زيادة بسيطة في الكثافة لنماذج المونة، كما لا توجد علاقة محددة بين النفاذية والكثافة.

وبالاعتماد على نتائج فحص مقاومة الانضغاط، تبين أن استخدام البنتونايت له تأثير ملحوظ على زيادة مقاومة الانضغاط ، خصوصاً عند الأعمار المبكرة . إن إضافة (٣%) من البنتونايت يؤدي إلى تحسن مقاومة الانضغاط بالنسبة تقدر بحوالي (٢٥.٢%) من قوة تحمل الخلطة المرجعية . كما أظهرت النتائج أيضاً أن استخدام غبار حجر الكلس كمضاف في المونة له تأثير ملحوظ على زيادة مقاومة الانضغاط للخلطات الغنية ، خصوصاً عند الأعمار المتأخرة ، بينما يكون له تأثير معاكس على مقاومة الانضغاط للخلطات الضعيفة نسبياً . إن إضافة (٧.٥%) من الغبار في الخلطات الغنية يؤدي إلى تحسن مقاومة الانضغاط بنسبة تقدر بحوالي (٥١.٨%) . أما بالنسبة لبخار السليكا فقد لوحظ أن زيادة نسب إضافة السليكا في المونة يؤدي إلى زيادة مقاومة الانضغاط، حيث بلغت الزيادة في مقاومة المونة عند الأعمار المبكرة (١٧ أيام) حوالي (١٢.٢%) عند نسبة إضافة (٢.٥%) من بخار السليكا .

أما الخواص الأخرى للمونة والتي تتضمن معايير التصدع وسرعة الموجات فوق الصوتية، فقد أبدت سلوكاً مشابهاً لمقاومة الانضغاط ولجميع المواد المستعملة في هذه الدراسة.

# تأثير المواد الدقيقة التجزئة على بعض خواص مونة السمنت

رسالة

مقدمة الى كلية الهندسة في جامعة بابل  
كجزء من متطلبات نيل درجة الماجستير  
في علوم الهندسة المدنية

من قبل

رواء شاكر عبد الرضا

اشراف

أ.م.د. ماهر بهنام السمعاني  
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