VARIOUS TYPES OF COARSE AGGREGATES IN LEBANON
AND THEIR EFFECT
UPON THE STRENGTH OF CONCRETE

A Thesis

Submitted to the Faculty

of

Engineering and Architecture

The American University of Beirut

by

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In Partial Fulfillment of the

Requirements for the Degree

of

Master of Engineering

Major - Civil

June 1968

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ACKNOWLEDGEMENTS

The author wishes to express his gratitude to all those who helped him in the completion of this work. He is indebted in particular to his supervisor, Professor Y.M. Avedissian, for his continuous interest and guidance during the course of this investigation. Last, but not least, the author feels a sense of indebtedness to his father, Mr. Moustafa B. Banbouk, for his encouragement, moral and financial support which contributed greatly towards the accomplishment of the present study.

ABSTRACT

The aim of this investigation was to study the properties of various types of coarse aggregates taken from different locations in Lebanon and their effect upon the compressive strength of concrete. To nullify the effect of other factors, the mix design as well as the type and grading of the sand, and water cement ratio, were kept constant. The only variable being the type of the coarse aggregate used.

A general survey was made of the various districts in Lebanon with the purpose of procuring as representative sampling of coarse aggregate as possible. As a result, 22 samples from quarries in ledge rock and 2 natural gravel types from coastal regions of Trablos and Saida were selected for use as coarse aggregates in this study.

The selected aggregate samples, predominantly limestones, were crushed in the Material Testing Laboratories of the School of Engineering and Architecture, A.U.B., in order to obtain the proper gradation necessary for maximum strength. In addition, the bulk specific gravity, loose and rodded unit weights of the aggregate samples, their absorption capacity and Los Angeles Abrasion Losses were measured. None of the samples seemed to contain deleterious organic impurities.

Six sample mixes from each aggregate type were prepared according to an established method based upon the PCA design for Cement mixtures and poured into cylindrical molds, 12-in high and 6-in in diameter.

Three samples from each mix were tested for their compressive strength after 7 days, and the other three samples were tested after 28 days. The results were averaged in each case to obtain the respective strength values.

The results indicated that the Kafershima and Bdadoun aggregates, both dense, homogeneous limestones, possessed the highest and the second highest compressive strengths for the 28-days test.

The lowest strength values were recorded for the Aintora aggregate. However, this was not seemingly the worst type on the basis of its Los Angeles Abrasion loss, absorption, loose and rodded unit weights analysis. The low strength value was attributed to the poor bond. The next lowest strength was recorded for the Fawar Trablos Aggregate which was also characterized by having both the lowest loose and rodded unit weights. This, therefore, could mean that the mix obtained from the Fawar Trablos aggregate was not sufficiently dense to give it sufficient strength.

The absorption percentages ranged from a highest value of 3,55 % to 0,66 % the lowest. But the aggregates possessing these too extreme values had almost identical strength values indicating that absorption characteristics of aggregate does not have much influence upon the compressive strength of concrete.

On the basis of the test and assuming a compressive strength value of 3500 psi as an arbitrary minimum, only 3 samples out of the 24 tested were found to be unsatisfactory. All the rest were acceptable.

CHAPTER I

INTRODUCTION

1.1 General

Concrete is a composite mass which consists of fragments of a relatively inert mineral filler embedded in a binding medium usually a combination of Portland cement and water.

The most valuable property of concrete is its strength, although often some other property such as durability and impermeability are equally as important. But strength is usually taken as a measure of the quality of concrete.

Some of the important factors that control strength of concrete are water cement ratio and the degree of compaction.

It has been determined from measurements of the velocity of sound travelling through concrete that vertical cracking, in a concrete specimen subjected to direct compression, begins under a stress equal to 50-75 % of the ultimate stress. This crack forming stress largely depends upon the properties of the coarse aggregate. With smooth, rounded aggregates, cracking begins at lower stresses than with rough and angular crushed rock mainly due to the differences in the mechanical bond.

Furthermore, the relation between the flexural and compressive strengths depends upon the nature and type of the coarse aggregate used in the concrete. The shape and surface texture of coarse aggregate also influence the impact strength of concrete.

Concrete is used for many purposes and is subjected to various loading conditions and hence different types of stress develop in it. Whatever the purpose for which concrete is used, it must have strength, the ability to resist force. In general strong concrete will also possess impermeability and resistance to abrasion.

Aggregates make up approximately 75 % by volume of the concrete, hence their effect on strength is significant. By keeping all other factors constant, this thesis studied the effect of various aggregate types in Lebanon upon the strength of concrete.

1.2 Aggregate Definition

The inert mineral filler used with cement paste in concrete production is referred to as aggregate. For convenience sake, aggregates are classified into two groups according to their size, the basis of separation being the No. 3 or No. 4 sieve. Material having particles ranging in size from smallest to about 1/4 in. in diameter are called fine aggregate or sand. The portion consisting of particles between 1/4 to about 2 inches or more in diameter is called coarse aggregate. Coarse aggregate may consist of naturally occuring gravel, crushed rock fragments or slag.

1.3 Functions of the Coarse Aggregate

The specifications for coarse aggregate depend upon the functional service of the concrete. In highway construction, resistance to abrasion is the prime consideration, whereas in buildings and dams, shear and compressive strengths are the prime property.

The functions of the aggregate in a concrete mix are to prevent volume changes caused by the hardening or setting of the cement paste, to resist the action of abrasion, applied loads and weathering agents, and to provide relatively cheap concrete mass since coarse aggregate costs considerably less than cement.

1.4 Principal Qualifications of Coarse Aggregate

The quality and structure of the concrete mass produced depend to a great extent upon the characteristics of the aggregate used and therefore careful attention should be given to their selection. To be considered satisfactory, good aggregate must possess:

a) Mineral composition that will give the concrete sufficient strength and durability.

b) Surface characteristics of its fragment particles that would insure proper workability and bond strength within the hardened mass.

c) The grading characteristics that would give optimum workability, density and economy of the mix.

d) Freedom from deleterious material that would effect the quality of the concrete mass.

To give a durable concrete, an aggregate must be resistant to weathering action and be inert so that no unfavorable reaction may take place between it and the cement-paste.

A clean aggregate is free from excess silt, coated grains, and harmful minerals such as mica, pyrite and sulphur and must not contain injurious alkali and organic matter. In brief, the principal qualifications of coarse aggregates are that they be hard, tough, strong, durable, clean and of the proper gradation.

1.5 Classification of Aggregates

Concrete aggregates are classified according to their petrological characteristics into basaltic, granitic, sandstone, limestone, quartzite and other groups. They are further divided into heavy weight, normal and light weight aggregates on the basis of their densities. Another basis of classifications is the particle shape by which coarse aggregates could be classified as rounded, irregular, angular and flaky, and according to their surface texture into glassy, smooth, granular, crystalline, rough and porous.

Limestone, which is the common type of aggregate used in Lebanon, could be classified as naturally occuring normal weight aggregate, petrologically belonging to the carbonate (limestone) group having a granular surface texture and angular shape in its crushed form.

1.6 Aggregate Specifications

Certain tests are necessary to carry on aggregates in order to ascertain their quality before their use in concrete. Some of these tests are specific gravity, grading, absorption, loose and rodded unit weights, Los Angeles Abrasion test, organic and silt content. Sometimes, in addition, chemical tests are performed in order to check the possibility of chemical reaction between aggregate and cement paste.

Specific gravity of a substance is, in effect, the ratio of its unit weight to the unit weight of water. As applied to aggregates, specific gravity refers to density of the individual fragments. Specific gravity of aggregates is important, in that it helps to indicate quality of the aggregates. This quality can be used to separate good from bad material; for example, shale and coal and lignite which are harmful to concrete are easily recognized due to their low specific gravity. Therefore, these materials could be removed from the aggregates by a process of flotation based upon the differences in the specific gravities. The property of specific gravity also gives the engineer a means of calculating how much volume the aggregates will occupy in a designed mix.

Bulk specific gravity is defined as the ratio of the weight in air of a given volume of a material (including both the permeable and impermeable voids normal to the material) at the standard temperature to the weight in air of an equal volume of distilled water at the standard temperature.

Standard procedures for the determination of the bulk specific gravity of coarse aggregates are given in ASTM Specification C 127.

Unit Weight. Unit weight is usually the weight of 1 cu. ft. of the aggregate and methods of its determination are described in ASTM Specification C 29. Unit weight gives a measure of the voids in a unit volume of aggregate. Factors that influence unit weight are gradation, shape, moisture conditions, texture, and degree of compaction of the aggregate mass.

In mix computations, it is necessary to know whether the aggregate volume is measured under loss or compact, dry or damp conditions.

Moisture and Absorption. If the aggregate particles used in a concrete mix are not totally saturated, they will absorb some of the mixing water. On the other hand, if there is free moisture on the surface of the aggregate particles, it adds to the quantity of the mixing water. Hence in water cement ratio calculations, the saturated surface-dry (SSD) condition is used as the basis. Saturated surface-dry therefore, implies that there is no surface moisture on the particles and that all voids within the particles are filled with water.

Absorption capacity refers to the total internal moisture in an aggregate in the saturated surface-dry condition. The amount of water required to bring an aggregate from the air-dry to the saturated surface-dry condition is referred to as "effective absorption".

The absorption capacity is determined by finding the weight of a surface-dry sample after it has been soaked for 24 hours, and again finding the weight after the sample has been dried in an oven. The difference in the two weights, expressed as a percentage of the dry sample weight, is termed as the absorption capacity. The procedures for finding the absorption and moisture content of an aggregate type are described in ASTM Specifications C 127 and C 128.

<u>Gradation and Sieve Analysis</u>. In order to secure workability and economy in the use of cement, it is necessary that aggregate be combined in proper gradation. For mixes of given consistency and given amount of cement, a well-graded mixture with varied sizes of fragments of aggregates represented, produces a denser, and hence stronger concrete than a harsh or poorly graded one, since less water is required to give the necessary workability to the mix.

Optimum gradings, directed toward finding the combination to produce maximum density, could be achieved by calculating the percentage size distribution that would fill the voids with successively smaller sizes.

In general, it has been found that a continous grading is the most satisfactory method. The particle-size distributions are determined by sieve analysis. Sets of sieves give information on the grain sizes and their percentage in a sample. In the testing of concrete aggregates, the series of sieves employed have the relationship in which any sieve in the series has twice the clear opening of the next smaller size in the series.

CHAPTER II

THEORETICAL CONSIDERATIONS

Satisfactory designs of concrete structures are dependent to a considerable extent upon the familiarity of the engineer with the characteristics of the concrete. The properties of both freshly mixed and hardened concrete are governed largely by the relative proportions and nature of the ingredients. The essential problem for the engineer is to produce satisfactory concrete at a reasonable cost. A satisfactory concrete could be considered to be the one which possesses desired properties such as uniformity, workability, durability, impermeability and above all the necessary strength.

This research was aimed at studying various types of aggregates in Lebanon and their effect upon the strength of concrete. To this end, all the other variables effecting strength were kept constant and only the type of coarse aggregate used in the concrete mix was changed. As expected, the results showed that the type and nature of aggregate, its physical properties have considerable influence upon the compressive strength of concrete.

In as much as mineral aggregate constitutes about 3/4 of the concrete mix, the selection and gradation of the coarse aggregate therefore is of tremendous importance. Since the age of the rock from which the crushed fragments were obtained for the concrete mix effects a lot of the physical properties, an attempt was made to compare the compressive strengths obtained from concrete made from aggregates belonging to the same geological age.

Some of the important characteristics of the coarse aggregate used in production of concrete are:

a) The Abrasion Test. The results of this test are a measure of the aggregate's resistance to abrasion. A soft material will be characterized by a high percentage of loss of fines from the Los Angeles rattler. Since strength of concrete, among other factors, depends to a large extent upon the hardness of the aggregate, therefore such a test seems to be indicative of the expected compressive strength values from aggregates of different hardness, everything else kept constant. Furthermore, a soft rock, after crushing will give a lot more powder than a hard rock. The injurious effect of dust and powder upon the strength of concrete are obvious. The excess powder and fine dust attached to the rock fragments coming from the quarries will reduce the strength of the cement bond to the aggregate particles and hence drastically reduce the compressive strength of the concrete. On this basis, the Los Angeles Abrasion test gives an indirect indication of this very important property of aggregates. In this research, therefore, an attempt was made to correlate the compressive strength of concrete with the Los Angeles Abrasion test results.

b) Loose and Rodded Unit Weights. Everything else being constant, a dense and more compact concrete should be stronger and more impermeable than a less dense one. All the aggregate types in this research were tested for their loose and rodded unit weights, with an attempt to find the range of their theoretical compaction factor which among other things also will effect economy of a concrete mix design. The results of the 28-days strength values of the various concrete samples were correlated to their respective loose and rodded unit weights to find if there existed any relationship between the parameters. Units weights are influenced by specific gravity, shape and texture of the aggregate particles, gradation and degree of compaction of the mass.

c) Bulk Specific Gravity. Specific gravity of aggregates is of importance due to serveral reasons. First, sepcific gravity is an indication of the quality of the aggregate to be used in concrete. Soft, light aggregates are generally coal, shale and lignite types which are not desirable for use as concrete aggregates. Such aggregates will be characterized by having low specific gravities. Specific gravity is also a measure of the space the aggregate particles will occupy, therefore, on this basis, bulk specific gravity is most often used in mix proportions, since the pores of the aggregate particles are usually filled with water. Or in the case they are not filled with water the pores may not be large enough to be filled with cement paste.

Based on this reasoning, an attempt was made to correlate the compressive strength of concrete with the bulk specific gravity of the aggregate used in the respective concrete mixes.

d) Moisture Content and Absorption. In concrete practice the saturated surface-dry moisture content is considered to be the basis of water-cement ratio calculations. In this case, all voids in the particle are filled, but no free surface water exists. This free moisture is found as an addition to the total mix water and, therefore, directly influences the water-cement ratio. Control of this free water addition to the mix water constitutes one of the more difficult problems in concrete design. Furthermore, it has been proven that a relationship exists between aggregate soundness and its absorption characteristics.

Naturally, when for purposes of reducing volume changes and improving impermeability a mix design is made with low total moisture, and when in such cases the absorption capacity of the aggregate is high, the aggregate therefore, may absorb a considerable amount of the free water from the mix and therefore reduce its workability. If the amount of the absorption is high enough such reduction of the mix water may also cause incomplete hydration of the cement and therefore reduce considerably the compressive strength of the concrete. In this research an attempt was made to correlate the physical property of absorption capacity of the aggregate types used in the concrete mixes with the respective strength values.

e) Other factors. There were other factors which seemed to influence the strength of the concrete mixes used in this research. Some of these factors were shape of particles and their surface texture. Since these two parameters are not easily determined, and also due to the fact that 22 out of the 24 samples used were angular in shape with only two natural gravels deposits from coastal areas with subrounded particle shapes, no attempt was made to correlate shape and surface texture of aggregate types with the compressive strength of the concrete. But that such factors do effect the strength of concrete was felt from the difference in strength results obtained from seemingly identical aggregate types. The particle shape may be expressed in terms of an angularity index. On the other hand, particles with smooth polished surfaces do not give high strength to the concrete due to the lower strength of the bond between cement paste and such aggregates.

CHAPTER III

GEOLOGICAL CONSIDERATIONS

3.1 General

The character and abundance of aggregate deposits of a region are the outcome of its geological history. The geomorphic processes shape the physical characteristics and reflect upon the agents that have been acting on the aggregate deposits, altering and transporting them. These processes influence the size, shape, uniformity, rounding and grading of the material. Thus a general knowledge of past geological happenings leads to a more intelligent search for aggregates.

3.2 Types of Aggregates in Lebanon

Since in the geologic past Lebanon had been submerged for long periods under water, the predominant rock types are sedimentary. The two major sources of coarse aggregates in Lebanon have been natural deposits of gravel, and crushed stones from quarries developed in ledge rock at many locations in the country.

3.3 Natural Gravel

The gravel, both from sea shores and river beds, in the form of rounded pebbles, cobbles and granules, have been exhausted in Lebanon or prohibited by government for purposes of preventing land erosion. Natural gravels, having undergone transportation and washing by streams and sea waters, consist of individual particles which are well-rounded, well-sorted and of relatively uniform hardness. Also, long periods of water transportation greatly reduces the less durable minerals by solution. Therefore, terrace deposits are often good sources of sand and coarse aggregates. Similarly, alluvial fans and talus debris which accumulate at the foot of cliffs, consist of rough coarse fragments and constitute good aggregate for concrete. Natural gravel, however, although characterized by hardness and cleanliness, have sometimes not given as high strength values to concrete as crushed rock aggregates due to poor bonding resulting from their rounded shapes and smooth surface texture.

3.4 Crushed Rock

At present, all coarse aggregates used in concrete in Lebanon come as crushed rock from quarries which process suitable bedrock. The crushed stones used as aggregates are exclusively limestone of different geological ages, ranging from the very dense, homogeneous types to slightly marly and sometimes interbedded with thin layers of argillaceous material. Crushed rocks are subject to the same careful discremination as naturally occurring deposits. A frequent defect of crushed rock is the presence of fractures imposed by the crushing action. In addition, there may be an undesirably high proportion of flats and fine material in the crushed rock which may lower the quality and strength of the concrete.

3.5 Location of Aggregate Samples

The crushed stones used as coarse aggregates in this study were taken from the following locations as shown in the accompanying map, (see Figure 1).

Sample 1. Fawar Antelias

Taken from the banks of the Antelias River, 2 Kilometers from the Casino of the same name. Consists of limestone with argillaceous seams of clay. Aptien in age.

Sample 2. Nahr Almout

Limestone of Albien age, dense and compact with thin veins of clay material.

Sample 3. Ain Saadet

On the road to Beit Merry. Massive, pure and homogeneous limestone of Bathonian age.

Sample 4. Gosta

From the mountainsides above Jounie. Slightly argillaceous limestone with seams of marly material. Aptien in age, very similar to sample No. 1 from the Fawar Antelias source.

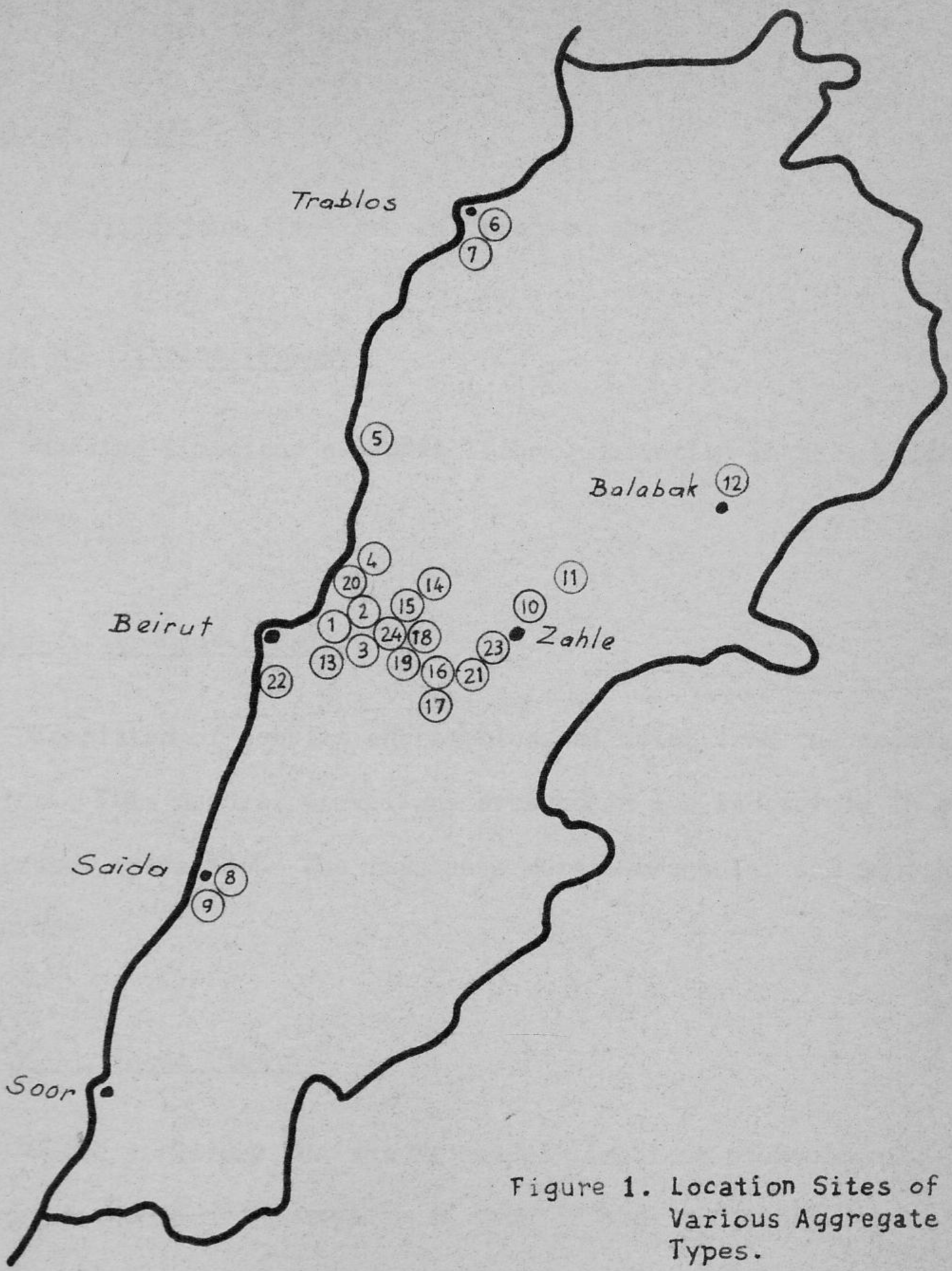

Figure 1. Location Sites of the Various Aggregate Types.

1. Fawar Antelias
2. Nahr-Almout
3. Ain-Saadet
4. Gosta
5. Jbail
6. Trablos (Fawar)
7. Trablos (Sea)
8. Saïda (Alman)
9. Saïda (Sea)
10. Zahle
11. Ferzol
12. Balabak
13. Dekwaneh
14. Aintora
15. Wadi-Shahrour
16. Shamlan
17. Dahr-Alwahesh
18. Kahalet
19. Jamhour
20. Lwaize
21. Bdadoun
22. Kafershima
23. Mdeirej
24. Faiadiet

Sample 5. Jbail

Fossiliferous limestone of Turonien age.

Sample 6. Trablos (Fawar)

Massive limestone of Jebel Tirbol, Helvetien in age, slightly fossiliferous.

Sample 7. Trablos (Sea)

Consisted of pebbles and cobbles collected from the coastal areas of Trablos. This natural gravel was crushed in the laboratory in order to get the proper gradation. The fragments were sub-angular and smooth surface textured.

Sample 8. Saida (Alman)

Close to Saida. Uniformly bedded limestone of Cenomanien-Turonien age, dense, pure and homogeneous, free of clay materials.

Sample 9. Saida (Sea)

Consisted of pebbles and cobbles collected from the coastal area near Saida. These sea-water washed gravels were crushed in the laboratory in order to obtain the proper gradation. They were sub-rounded fragments and had smooth surface textures.

Sample 10. Zahle

White, pure limestone, nummulitic fossils, belonging to Jebel ed Dahr limestone of the Lutetien age.

Sample 11. Ferzol

Taken from the main road between Zahle and Balabak.Marly limestone.

Sample 12. Balabak

Slightly marly limestone of Lutetien age.

Sample 13. Dekwane

East of Beirut, lightly marly conglomerate, characterized with a gritty touch.

Sample 14. Aintora

In the Kisrwan district and like the Gosta type is argillaceous limestone with clay seams. Aptien age.

Sample 15. Wadi Shahrour

A few miles above Kafershima. Uniformly bedded limestone of Cenomamien- Turonien age.

Sample 16. Shamlan

A few miles south of Souk el Gharb. Aptien limestone of alternating seams of argillaceous and sandy materials.

Sample 17. Dhahr-Alwahesh

Close to Aley. Aptien limestone, homogeneous and evenly bedded. Uniformly textured.

Sample 18. Kahalet

On the way to Aley. Marly, argillaceous limestone, Aptien age.

Sample 19. Jamhour

On the road to Aley. Soft limestone of Turonien age.

Sample 20. Lwaize

A few miles beyond Hazmiya, east of Beirut, evenly textured limestone of Turonien age.

Sample 21. Bdadoun

East of Aley. Uniformly bedded, dense and pure limestone, Cenomanien-Turonien age.

Sample 22. Kafershima

Uniformly bedded, dense and pure limestone, Cenomanien-Turonien age, similar to the Bdadoun type.

Sample 23. Mdeirej

Dense and uniform limestone, massive in structure.

Sample 24. Faiadiet

On the road to Aley, similar to the Jamhour aggregate type.

It was noted that there was quite a similarity between the aggregates collected from one particular district. This was so because they belonged to the same geologic age. However, in certain cases, noticeable differences in the textures and surface characteristics of the aggregates were observed even when there was little locality difference between them. This could be attributed to weathering effects and differences in the geomorphic agents acting upon the rocks in the past.

CHAPTER IV

TEST PROCEDURES AND EQUIPMENT

4.1 Sieve Analysis

In order to determine the particle size distribution of the aggregate, a sieve analysis of each sample was made by shaking the material through a series of sieves nested in order with the smallest on the bottom. The sieve analysis results were utilized in determining the proper established gradation for each of the aggregates.

4.2 Determination of the Shape of Rock Fragments

The study of the shape of the crushed rock particles was done by eyesight. The results are shown in Table 1.

4.3 Los Angeles Abrasion Test

In concrete practice, the method used for determining the hardness (resistance to abrasion) of aggregates is done by the Los Angeles Abrasion Test in which a sample of crushed rock and steel balls are rotated in a rattler and the amount of fine material produced in percentage of the original weight of the aggregate is taken as a measure of the hardness. A pictorial view of the equipment used is shown in Figure 2. The procedure involved is described in ASTM Specification C 131.

Table 1: Shape of Aggregate Grains

Sample No	Shape of grains	Sample No	Shape of grains
1	Angular	13	Angular
2	Angular	14	Angular
3	Angular	15	Angular
4	Angular	16	Angular
5	Angular	17	Angular
6	Angular	18	Angular
7	Rounded	19	Angular
8	Angular	20	Angular
9	Mostly Rounded	21	Angular
10	Angular	22	Angular
11	Angular	23	Angular
12	Angular	24	Angluar

Figure 2. Pictorial View of the Los Angeles

Abrasion Test Machine.

The abrasive charge used depends upon the desired grading of the test sample. Since Grading A was used in this study, the weight of the charge used was 5000 grams, and the number of the steel spheres was 12, each weighing 390 grams.

About 5000 grams of the test sample, dried in an oven at 110°C, were placed in the rattler, together with the abrasive steel balls, and the machine was rotated for 500 revolutions (about 17 minutes) at a speed of 33 rpm. After that the material was taken from the machine and was sieved on a No. 12 sieve. The portion retained was washed, and oven-dried. The difference between the original weight (5000 grams) and the amount retained on the No. 12 sieve was expressed as percentage of the original weight and taken as an indication of the amount of wear or loss. Table 2 shows the grading of Los Angeles test samples:

Table 2: Grading of Los Angeles Test Samples

Passing	Retained	Grading A	Grading B	Grading C	Grading D
$1\frac{1}{2}$"	1"	1250			
1"	3/4"	1250			
3/4"	1/2"	1250	2500		
1/2"	3/8"	1250	2500		
3/8"	No 3			2500	
No 3	No 4			2500	
No 4	No 8				2500

The results of the Los Angeles Abrasion Test for the various aggregate types used in this research are listed in Table 3.

Table 3: Results of Los Angeles Abrasion Test

Sample No	Initial Weight GRS	Final Weight GRS	Weight of Lost GRS	Percentage of lost
1	5000	3095	1905	38.10
2	5000	3575	1425	28.50
3	5000	3255	1745	34.90
4	5000	3235	1765	35.30
5	5000	3450	1550	31.00
6	5000	3620	1380	27.60
7	5000	3815	1185	23.70
8	5000	4135	865	17.30
9	5000	3730	1270	25.40
10	5000	3685	1315	26.30
11	5000	3295	1705	34.10
12	5000	3310	1690	33.80
13	5000	2220	2780	55.60
14	5000	3715	1285	25.70
15	5000	3285	1715	34.30
16	5000	3235	1765	35.30
17	5000	3515	1485	29.70
18	5000	3440	1560	31.20
19	5000	3050	1950	39.00
20	5000	3825	1175	23.50
21	5000	3750	1250	25.00
22	5000	3340	1660	33.20
23	5000	3540	1460	29.20
24	5000	3280	1720	34.40

4.4 Absorption

The percentage of absorption was calculated from the following formula:

$$\text{Absorption} (\%) = \frac{B - A}{A} (100)$$

In which A is the dry weight of the specimen.

B is its weight after being soaked in water.

The results of the absorption tests of the various aggregate samples are shown in Table 4.

4.5 Loose Unit Weight

The loose unit weight is the unrodded weight of a sample filling a measure having the dimensions 20 x 20 x 19.1cm. The contents of a measure full of the sample were weighed and the Loose unit weight in grams/cubic centimeter calculated. The results are listed in Table 5.

4.6 Rodded Unit Weight

After filling 1/3 of the measure with the test sample, the contents were rodded with 25 strokes evenly distributed over the surface, by a tamping rod made of steel 5/8 inch. The measure was then filled 2/3 full and again rodded with 25 strokes. Lastly the measure was filled to overflowing and rodded 25 times and the surplus aggregate struck off.

Table 4: Results of the Absorption Test

Sample No	Weight in air gr	Weight in oven gr	Weight in air-Weight in oven gr	Absorption %
1	3500	3380	120	3.55
2	3500	3472	28	0.81
3	3500	3448	52	1.49
4	3500	3477	23	0.66
5	3500	3450	50	1.45
6	3500	3452	48	1.39
7	3500	3470	30	0.86
8	3500	3475	25	0.72
9	3500	3432	68	2.04
10	3500	3465	35	1.01
11	3500	3465	35	1.01
12	3500	3465	35	1.01
13	3500	3403	97	2.84
14	3500	3455	45	1.30
15	3500	3440	60	1.74
16	3500	3465	35	1.01
17	3500	3470	30	0.86
18	3500	3470	30	0.86
19	3500	3445	55	1.64
20	3500	3470	30	0.86
21	3500	3467	33	0.95
22	3500	3455	45	1.30
23	3500	3460	40	1.15
24	3500	3440	60	1.74

Table 5: Loose Unit Weights

Sample No	Loose Unit Weight gr/cm^3	Sample No	Loose Unit Weight gr/cm^3
1	1.458	13	1.400
2	1.500	14	1.458
3	1.498	15	1.453
4	1.501	16	1.510
5	1.450	17	1.550
6	1.400	18	1.548
7	1.618	19	1.558
8	1.545	20	1.525
9	1.456	21	1.512
10	1.480	22	1.510
11	1.508	23	1.475
12	1.510	24	

The contents were weighed and the rodded unit weight in grams cubic centimeter was calculated for each sample. The results are indicated in Table 6.

4.7 Bulk Specific Gravity

The bulk specific gravity of the various aggregate types was calculated according to the formula:

$$\text{Bulk Specific Gravity} = \frac{B}{B - C}$$

in which B is the weight in grams of saturated surface-dry sample, in air,

C is the weight in grams of the saturated sample in water.

The results of the bulk specific gravity of the various sample aggregates are listed in Table 7.

4.8 Tests On Sand

The fine-aggregate (sand) grading requirements of ASTM C 33 permit a wide range in grading. The most desirable grading depends on the type of work, richness of mix, and maximum size of coarse aggregate with which the sand is to be mixed for the production of the desired concrete.

The amounts of fine aggregate (sand) passing the Nos. 50 and 100

Table 6: Rodded Unit Weights

Sample No	Rodded Unit Weight gr/cm^3	Sample No	Rodded Unit Weight gr/cm^3
1	1.602	13	1.650
2	1.680	14	1.630
3	1.670	15	1.605
4	1.645	16	1.668
5	1.572	17	1.663
6	1.565	18	1.730
7	1.730	19	1.730
8	1.710	20	1.710
9	1.620	21	1.680
10	1.637	22	1.655
11	1.670	23	1.650
12	1.672	24	1.640

Table 7: Bulk Specific Gravities

Sample No	Weight in air gr	Weight in water gr	Weight in air gr	Bulk Specific Gravity
1	3500	2125	1375	2.544
2	3500	2197	1303	2.685
3	3500	2177	1323	2.642
4	3500	2200	1300	2.694
5	3500	2144	1356	2.580
6	3500	2170	1330	2.630
7	3500	2175	1325	2.640
8	3500	2235	1265	2.765
9	3500	2158	1342	2.605
10	3500	2187	1313	2.660
11	3500	2192	1308	2.680
12	3500	2184	1316	2.665
13	3500	2152	1348	2.600
14	3500	2208	1292	2.708
15	3500	2179	1321	2.645
16	3500	2195	1305	2.685
17	3500	2218	1282	2.725
18	3500	2202	1298	2.695
19	3500	2175	1325	2.640
20	3500	2198	1302	2.690
21	3500	2202	1298	2.695
22	3500	2182	1318	2.655
23	3500	2175	1325	2.640
24	3500	2180	1320	2.650

sieves effect workability of the mix, its surface texture, and bleeding characteristics. Most specifications allow 10-30 % to pass the 50 sieve. The presence of sufficient quantities of fines is more important in the wetter mixes than in the stiffer mixes, and in leaner mixes than in richer ones.

The sand used in the concrete mixes for this study was taken from Khalde region. The following are the results of the tests performed on this sand, (see Table 8).

Table 8: Results of Tests on Khalde Sand

Loose Unit weight	1.435 gr/cu.cm.
Rodded Unit weight	1.605 gr/cu.cm.
Absorption	1.0 %

Sieve Analysis (1 Kg of sand)

Sieve Size	Retained (grs)	% Retained
No 30	130	13.0
No 50	273	27.3
No 100	495	49.5
No 200	74	7.4
Pan	28	2.8
		100.00

4.9 Bulk Specific Gravity of Sand

The bulk specific gravity of the Khalde sand, used in the concrete mixes, was calculated using the formula:

$$\text{Bulk Specific Gravity} = \frac{A}{V - W}$$

in which A is the weight in grams of oven-dry sample, in air

V is volume in milliliters of flask (=500 cc) pycnometer

W is weight in grams or volume in milliliters of water added to flask.

Weight of pycnometer empty = 133.0 grams

Weight of pycnometer + sand = 431.8 grams

$$A = 431.8 - 133.0 = 298.8 \text{ grams}$$

Weight of pycnometer + sand + water to the signal = 816.7 grams

Weight of pycnometer + water to the signal = 630.3 grams

$$W = 816.7 - 431.8 = 384.9 \text{ grams}$$

$$V = 500 \text{ cc}$$

$$\text{Therefore, bulk specific gravity} = \frac{298.8}{500 - 384.9} = \underline{2.59}$$

4.10 Tests on Cement

The properties of the cement used influences to a great extent the compressive strength of the concrete obtained. The fineness of a cement has an important effect on its properties, such as the rate of hydration and the rate of heat evolution, and hence, control shrinkage and cracking characteristics of the concrete. The fineness of the cement particles also affects the workability of the concrete mix.

Normal Consistency Test

Involves calculating the proper amount of water to make a cement paste of normal consistency. The cement paste is considered of normal consistency when the Vicat needle penetrates 10 mm in 30 seconds.

After the cement paste was formed, it was molded into a ball and tossed six times from one hand to the other, held about 6 inches apart. The ball was then pressed into the larger end of the conical ring and the excess paste removed. The top was smoothed with a trowel. The paste in the ring was centered under the needle, the plunger was then brought in contact with it. The rod was released about 30 seconds after the completion of the mixing. The paste was considered, normal when, after several trials with different water content, the needle penetrated 10 mm into it.

From the trials of the normal consistency tests, it was found that for normal consistency, 124 grams of water, were required for 500 grams of cement.

4.11 Compression of Mortar

This test is aimed at finding the strength properties of the cement used in the concrete mix. Accordingly, a mortar formed from cement, sand and water is used. The sand used in this mortar was Ottawa sand, well graded, pure and of standard qualifications.

The mortar samples were tested for their 7-days and also their 28-days strength in compression. A total of three samples for each test were examined. The following are the results of the loading tests of the mortar:

7-days Strength P.S.I.		28-days Strength P.S.I.	
1.	1975	1.	3575
2.	2100	2.	3475
3.	2750	3.	3450
Average:	2050 PSI	Average:	3500 PSI

Hence, both the 7-days and the 28-days compressive strength values were found to be satisfactory, according to ASTM specification which specify a minimum value of 1600 PSI for the 7-days compressive strength of mortar and 2500 PSI for the 28-days compressive strength.

4.12 Aggregate Grading and Mix Design

The shape of the aggregate particles determines the proportioning of a particular concrete mix. Very sharp and rough aggregate particles or flat and elongated particles require more fine material to produce concrete which is workable than aggregate which is largely composed of rounded or cubical shaped fragments.

The gradation or particle-size distribution of aggregates is determined by a sieve-analysis. The grading and maximum size of the aggregate is also important because of their effect on relative economy, workability, porosity and shrinkage characteristics of the hardened concrete.

With given materials, the four variables to be considered in specifying a concrete mix are:

a) Water-cement ratio.

b) Cement-aggregate ratio.

c) Consistency of the fresh concrete.

d) Gradation of the aggregate.

Water-cement ratio expresses the dilution of paste. The cement aggregate ratio varies with the amount of paste of given water content for the practical proportioning of a given set of materials, the gradation of aggregate is controlled by varying the amounts of the given fine (sand) and coarse aggregates.

There are many methods used for the gradation of concrete aggregates: Trial methods[5], Fuller-Thompson method[5] for maximum density, Abram's method[5]. The grading of the aggregate sizes for the mixes used in this study was done according to the PCA method (see Figure 3), and Table 9.

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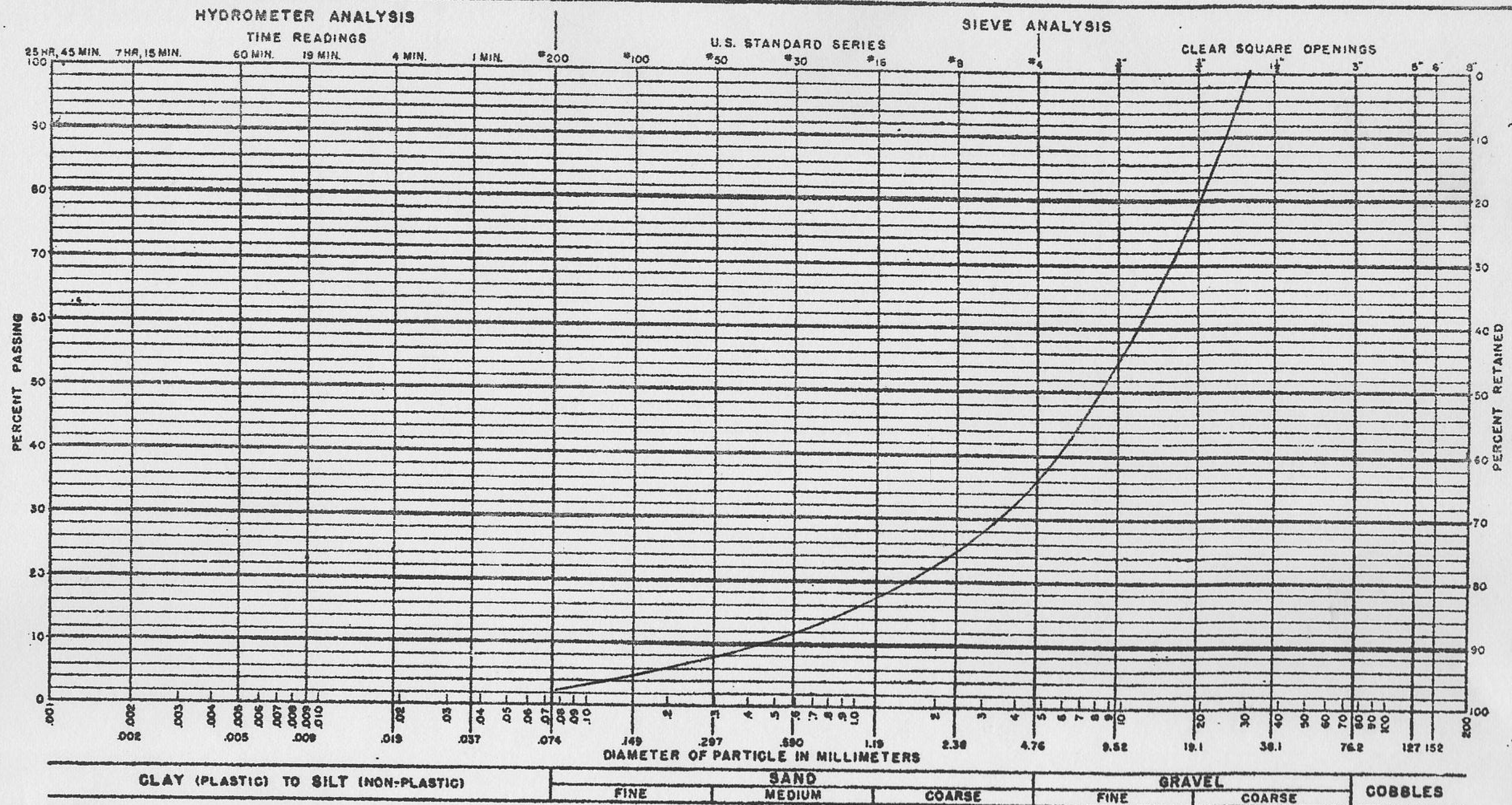

NOTES:

Figure 3. The Gradation Curve Used for the Concrete Mixes.

Materials Testing Laboratory
GRADATION TEST

DRAWN CHECKED DATE

Table 9: The Gradation Used for the Concrete Mixes

Sieve No	Opening Dia. mm.	Percent Passing	Percent Retained on each Sieve	Amounts Required for 1 cylinder Kg
1	25.40	100.00	0	
3/4"	19.10	83.00	17.00	2.040
1/2"	12.70	61.00	22.00	2.640
3/8"	9.52	55.00	6.00	0.720
4	4.76	37.00	18.00	2.160
8	2.38	25.00	12.00	1.440
16	1.19	17.50	7.50	0.900
30	0.59	12.00	5.50	0.660
50	0.297	7.50	4.50	0.540
100	0.149	4.50	3.00	0.360
200	0.074	2.50	2.00	0.240
Pan			2.50	0.300
				12.000 Kg

Six bags of cement = 300 Kg. per m^3 of concrete were used and a water/cement ratio = 0.6. Thus the amounts required for 6 cylinders are 12.700 Kg of cement and 7.600 Kg of water, and one notices that this amount of water equals about 10 % of the total weight of aggregate and sand = 72.000Kg.

A useful method of showing the grading of individual and combined aggregate is by grading charts, in which the abscisses are the sieve openings and the ordinates show the total percentage coarser (or passing) 0 to 100 from bottom to top. If an ideal grading curve has been plotted, the curve for the aggregate to be used in combination can be varried so as to approach the established ideal curve by trial percentage of the individual gradings. The grading curve used for the test mixes for this study is shown in Figure 3.

The curve was established from the sieve analysis shown in Table 9.

The mix quantities were calculated so that six cylinders, 6 inches in diameter and 12-inches in height, were obtained from each sample type. The necessary tests for consistency of the mix were performed. A slump of between 2-6 inches was considered to be satisfactory. The mix was poured into the cylindrical molds. At 1/3 full, the mix was rodded 25 times with a 5/8 inch steel tamping rod. Similarly, at 2/3 and again at overflowing, the mix was rodded with 25 strokes distributed evenly over the surface.

After 24 hours, the samples were taken from the molds and placed in the wet room for curing.

4.13 Curing

Concrete sets and hardens as a result of the chemical reactions which take place between the compounds of the cement and the mixing Water. The process of hardening, which is due to the hydration of the cement, proceeds indefinitely but at a diminishing rate, as long as there is water present to facilitate the reaction. The process of furnishing this hydration water to the concrete is referred to as curing. Curing of the concrete is important so as to prevent rapid loss of mixing water which will cause stresses to set up in the concrete due to shrinkage. This shrinkage will cause cracks to develop in the concrete since it is not yet strong enough to resist the stresses. Hence it is very important to prevent loss of mixing water by curing the concrete for at least 5 days or a week.

4.14 Capping

After 7 or 28 days from the time of pouring, the concrete cylinders, prior to their loading for the unconfined compressive test, were capped with a special sulphur compound to ensure flat and parallel surfaces in order to ensure even loading on the test sample. The sulphur compound is supposed to have a compressive strength well above that of the concrete and it has the very convenient property of setting in less than a minute.

Figure 4 shows a pictorial view of the Soiltest apparatus used for capping the samples.

4.15 Compressive Strength Test

The capped concrete cylinders were loaded to failure in unconfined

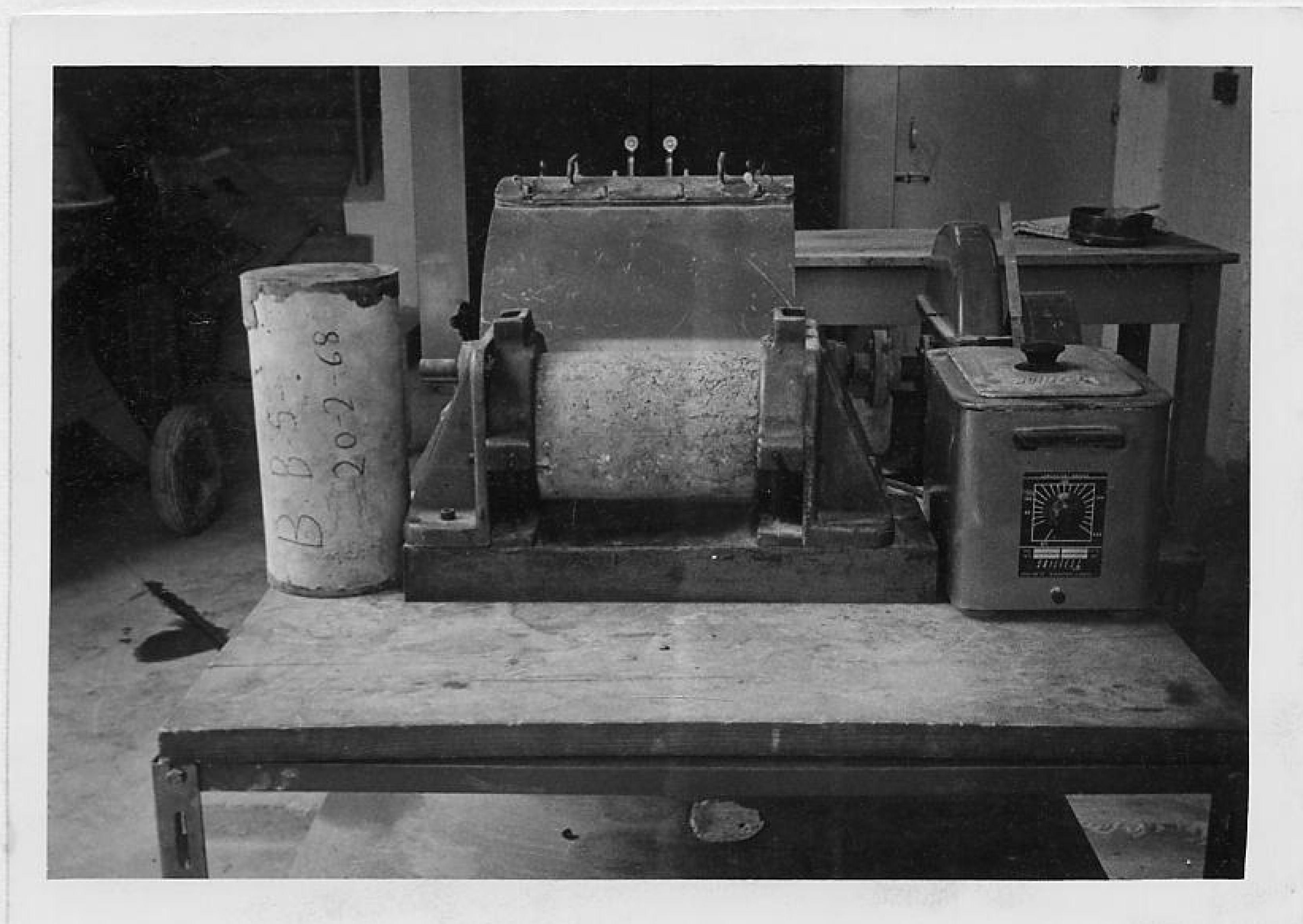

Figure 4. Soiltest Apparatus Used for Capping Cylindrical Concrete Samples.

compressive strength test with a W.H. Emery 400,000-lb Hydraulic Testing Machine, Figure 5. The total load at failure was divided by the cross sectional area in order to find the compressive strength. The values of the three samples from each mix, tested for both the 7 and 28 days, strength were averaged. The results are shown in Table 10.

Figure 6 shows a pictorial view of a test specimen that has failed under the unconfined compressive load imposed upon it.

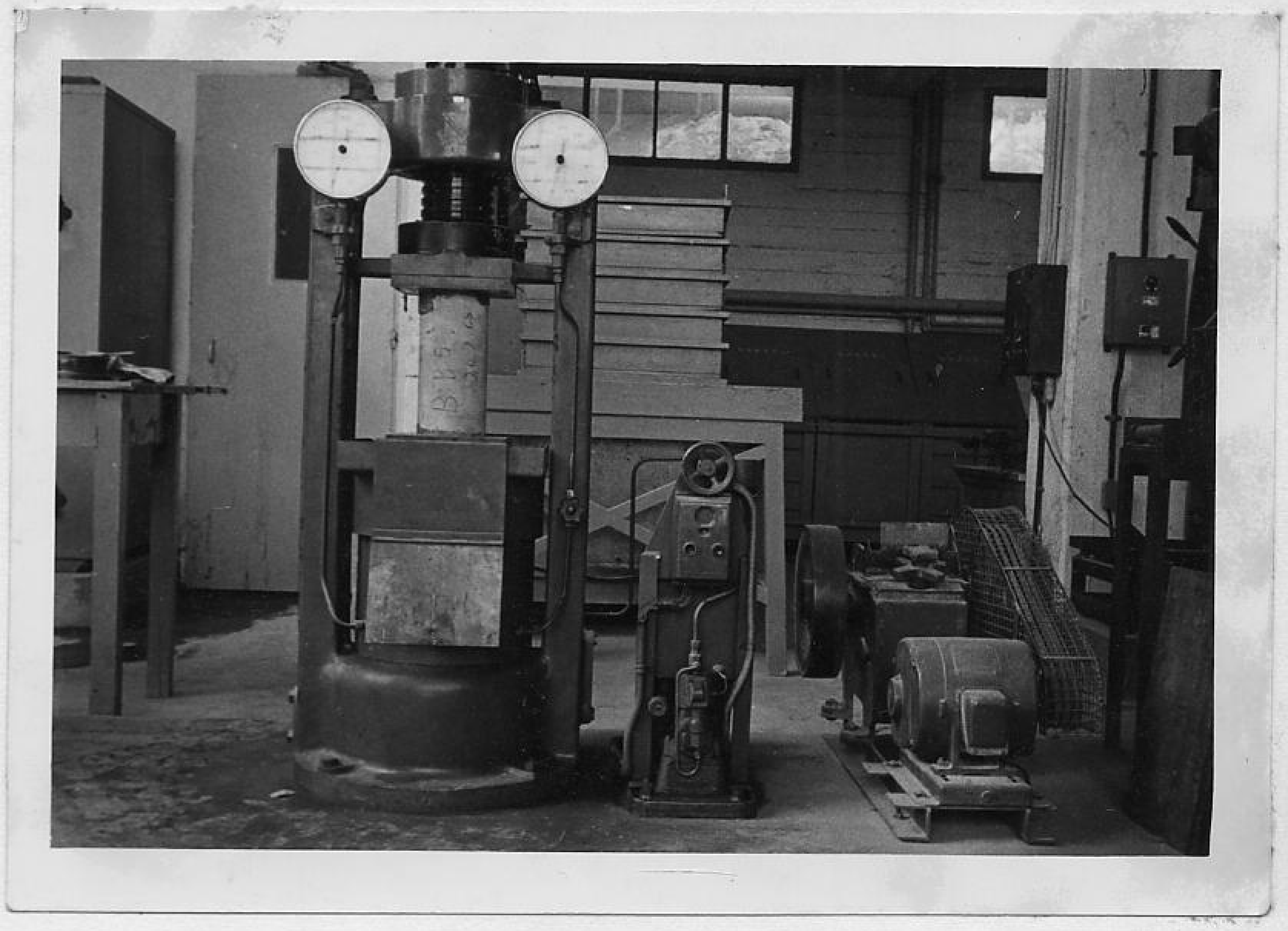

Figure 5. The 400,000 lb. W.H. Emery Compressive Strength Hydraulic Machine With a Concrete Sample Set Ready for Testing.

Table 10: Results of the 7-days and 28-days Compressive Strength Tests and Their Ratio

Sample No	7-days Strength (PSI)	28-days Strength (PSI)	$\frac{f'_c\ 28}{f'_c\ 7}$ days
1. Fawar Antelias	2480	3580	1.44
2. Naher-Almout	2620	3945	1.50
3. Ain Saadet	2870	4620	1.67
4. Gosta	2300	3580	1.55
5. Jbail	2620	4540	1.73
6. Trablos (Fawar)	1735	3360	1.93
7. Trablos (Sea)	2800	4070	1.45
8. Saida (Alman)	3080	4700	1.53
9. Saida (Sea)	3010	4000	1.33
10. Zahle	2690	4245	1.58
11. Ferzol	2535	3780	1.49
12. Balabak	2550	4210	1.65
13. Dekwane	2760	4650	1.68
14. Aintora	1275	2460	1.93
15. Wadi Shahrour	2980	4070	1.37
16. Shamlan	2620	4110	1.57
17. Daher Alwahesh	2800	4215	1.50
18. Kahalet	1808	3440	1.90
19. Jamhour	2940	3820	1.30
20. Lwaize	2725	4000	1.46
21. Bdadoun	3190	4885	1.53
22. Kafershima	3640	5530	1.52
23. Mdeirej	2940	4390	1.49
24. Faiadiet	2960	4000	1.35

Figure 6. View of the Vertical Cracks Developed in a Concrete Cylinder Subjected to Unconfined Compressive Test.

CHAPTER V

ANALYSIS OF TEST RESULTS

5.1 Introduction

The purpose of this investigation was to study the properties of various aggregate types from different localities in Lebanon and their effect upon the compressive strength of concrete. Prior to their use in the concrete mix, each aggregate type was carefully examined for the presence of deleterious substances in them. Also their fragment shape was determined by visual study. Other properties determined for each sample aggregate included loose and rodded unit weights, absorption, bulk specific gravity, and Los Angeles Abrasion test. The grading adopted for the mix design was based upon PCA method. Three samples of each mix were tested for their unconfined compressive strength after 7 days, and the other three were tested for their 28-days strength. The results of all the tests are listed in various tables included in this thesis.

5.2 Los Angeles Abrasion Test Results

In the Los Angeles Abrasion test, sample 13 taken from Dekwane gritty conglomerate type, gave the highest percentage of loss with 55.60 %, while sample 8 the Alman Saida aggregate showed the lowest abrasion value with 17.90 %, loss. The results of the Los Angeles Abrasion test are shown in Table 4.

An attempt was made to correlate Los Angeles Abrasion test results with the 28-days compressive strength values, see Figure 7. The plotting of the two values on traditional cartesian coordinates did not show any definite trend, the values seemed to lump together and not spread out, and hence no conclusion could be made relating the compressive strength to Los Angeles Abrasion (hardness) property of the aggregates. At first, it is expected that hardness, a property measured from the percentage Loss of fines from the abrasion test, should have an inverse linear relationship with strength, that is the harder the aggregate, the lower its percentage loss and therefore the higher its compressive strength. But this relationship could not be established from plotting of the test results. Example: although sample 13 Dekwane Conglomerate had the highest percentage loss (55.6 %), and hence, was the softest material, it showed considerably higher strength than a great majority of the aggregate used in this research. With a compressive strength value for the 28-days test of 4650 psi, it rated fourth among the 24 aggregate. There were other similar cases (like the Aintora Aggregate, Sample 14), of inconsistent results obtained from comparison between the compressive strength and the Los Angeles Abrasion test results. This discrepancy could possibly be attributed to the fact that there are many other factors that influence the strength of concrete and therefore it is difficult to be able to correlate any two such properties when there is no practical means of investigating each of these factors individually and separately.

5.3 Results of the Loose Unit Weight

Table 6 shows the results of the loose unit weights of the various

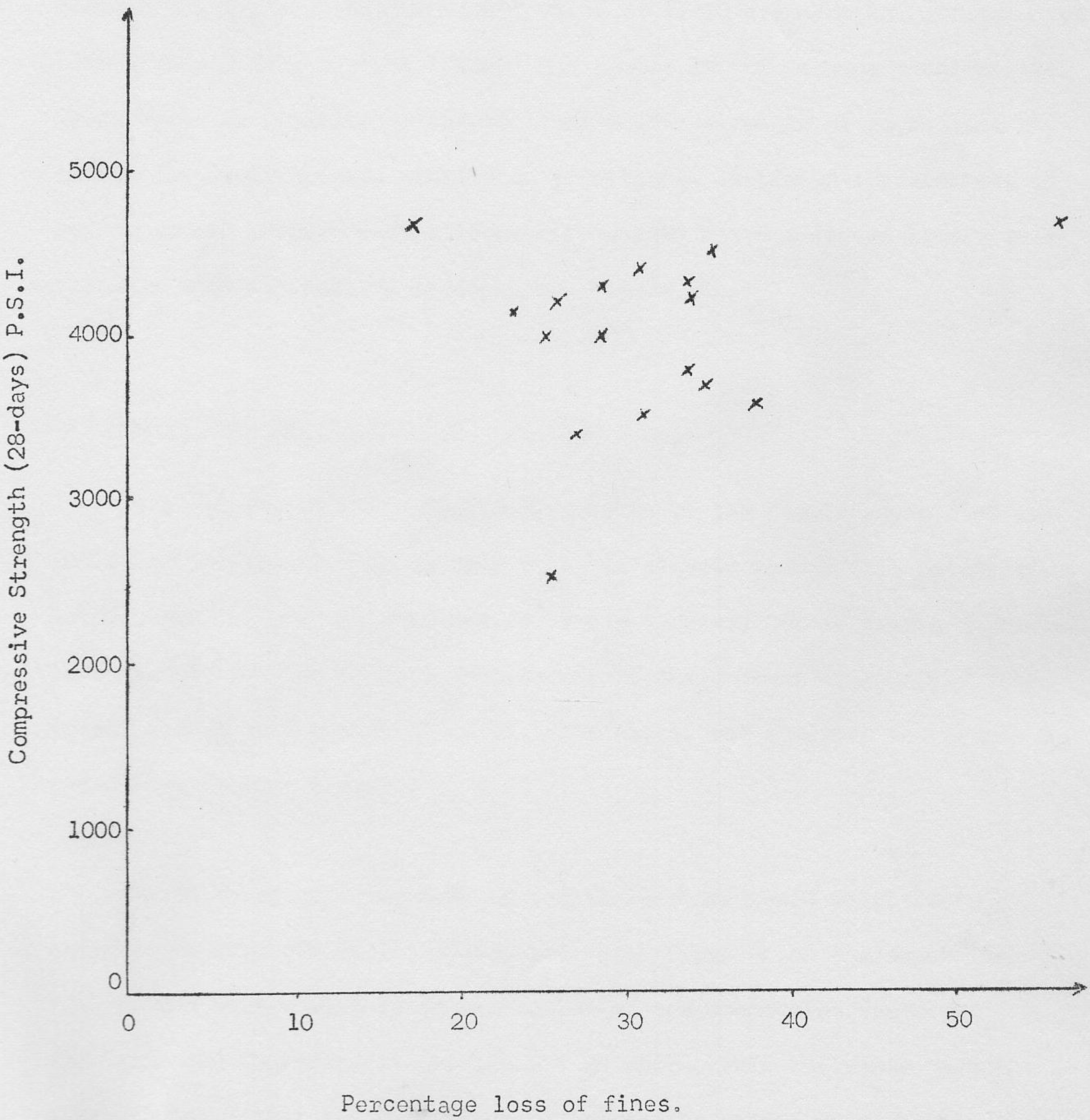

Figure 7. Compressive Strength (28-days) Versus Percentage Loss of Fines From Los Angeles Abrasion Test.

aggregate types. It will be noted that the highest value (1.618 grams/ cu.cm.) of loose unit weight was recorded for sample 7 taken from Trablos (Sea) coastal area, and the lowest value of 1.400 grams/cu.cm. recorded for both sample 6 from Trablos (Fawar) and sample 13 the Dekwane conglomerate. Trend could be established between compressive strength of aggregates and their loose unit weights plotted on traditional cartesian coordinates, it was concluded therefore that loose unit weight bears a direct linear relationship with compressive strength, see Figure 8.

5.4 Rodded Unit Weight Results

The results of the rodded unit weights of the sample aggregates are indicated in Table 7. It is seen that the highest rodded unit weight of 1.730 grams/cu. cm. was obtained for three samples, namely sample 7 Trablos (Sea) sample 18 from Kahalet, and sample 19 the Jamhour aggregates. The lowest rodded unit weight of 1.565 grams/cu.cm. was obtained for sample 6 taken from Trablos (Fawar).

Again an attempt was made to correlate rodded unit weight with compressive strength of the aggregates, see figure 9, on the asuumption that rodded unit weight is an indication of the compaction factor of the aggregate and therefore it should have an appreciable influence upon the strength. The higher the compaction factor or the rodded unit weight, therefore the higher the compressive strength. As expected the results of plotting these two values on traditional cartesian coordinates did indicate a trend of linear relationship. It was concluded, therefore, that

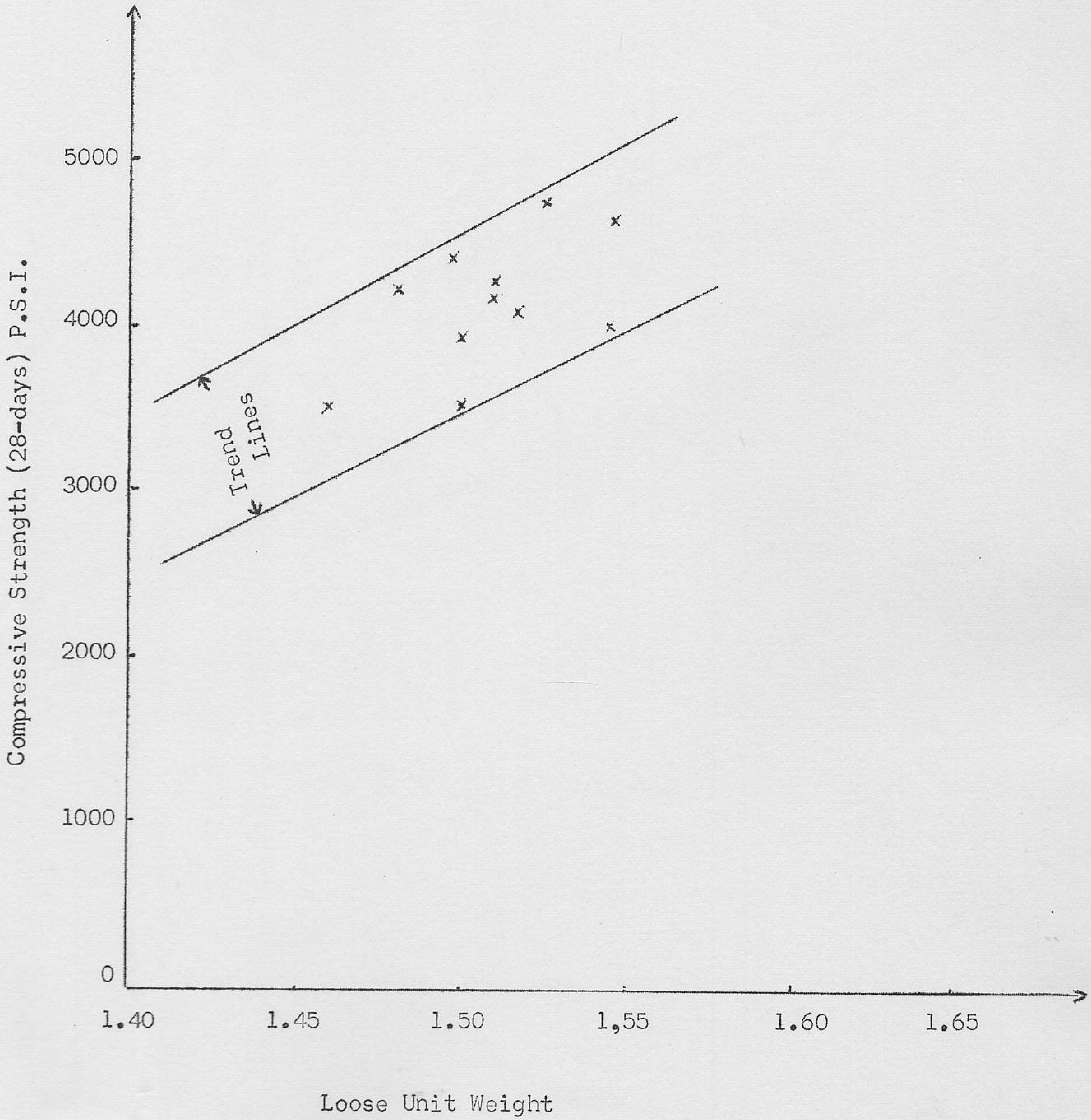

Figure 8. Relationship Between Compressive Strength (28-days) and Loose Unit Weight.

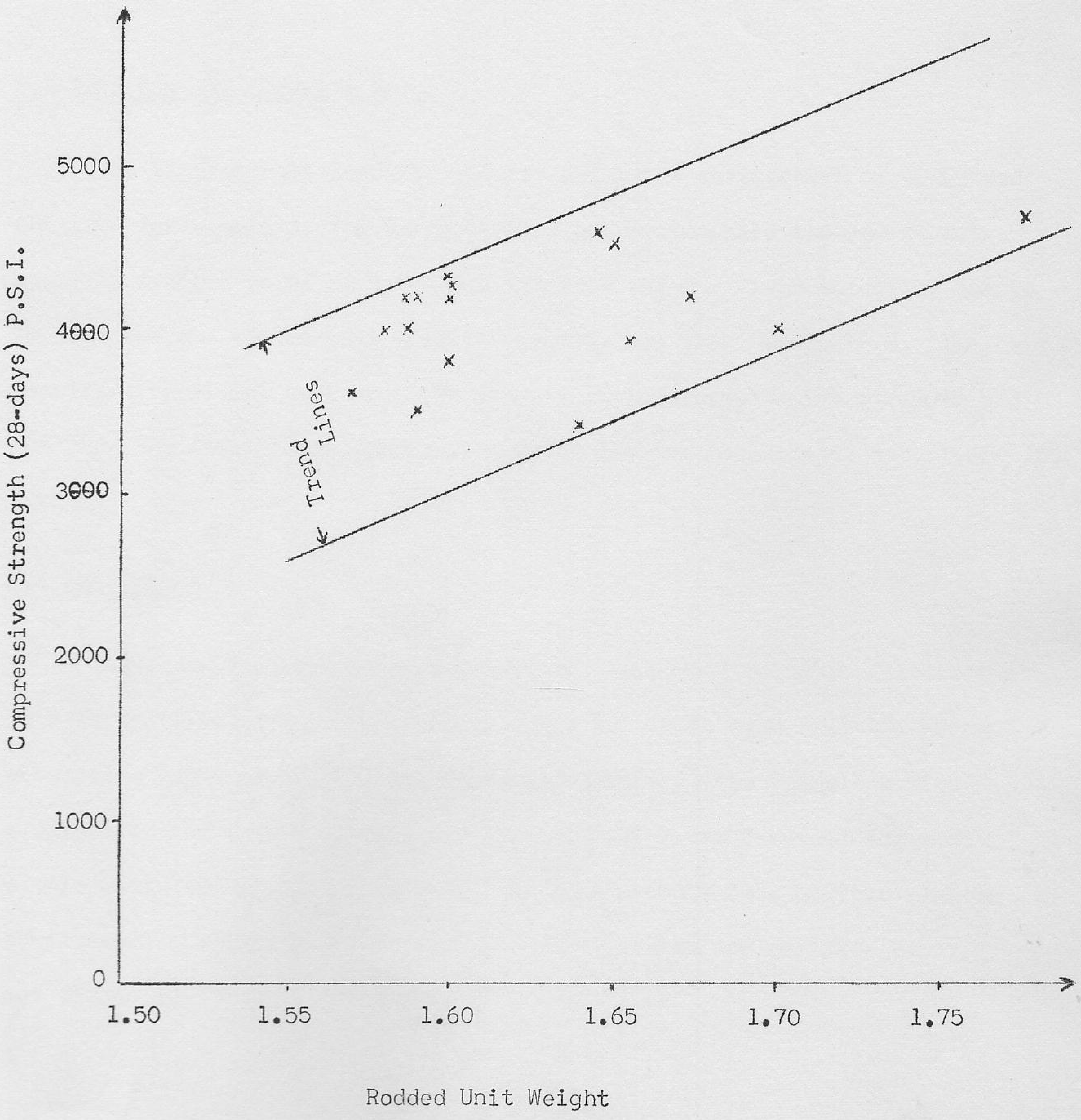

Figure 9. Relationship Between Compressive Strength (28-days) and Rodded Unit Weight.

rodded unit weight bears a direct linear relationship with compressive strength.

5.5 Bulk Specific Gravity Results

The highest bulk specific gravity saturated surface-dry of 2.765 was obtained for sample 8, the Saida (Alman) aggregate while the lowest bulk specific gravity value of 2.544 was recorded for the Fawar Antelias, sample 1. The results of the bulk specific gravity are shown in Table 8. The results of plotting bulk specific gravity against compressive strength did not show any definite relationship between the two parameters, see figure 10.

5.6 Absorption

The absorption values of the various aggregates calculated according to ASTM specifications, are shown in Table 5. It is seen that the highest absorption value of 3.55 %, was found for sample 1, the Fawar Antelias aggregate. The lowest absorption value of 0.66 % was recorded for sample 4, the Gosta aggregate. Similarly, the absorption values plotted against compressive strength at (28-days) did not establish any definite trend, see figure 11.

5.7 Compressive Strength Test Results

The detailed results of the unconfined compressive strength tests are shown in Appendix A. The averaged 7-days and 28-days strength values

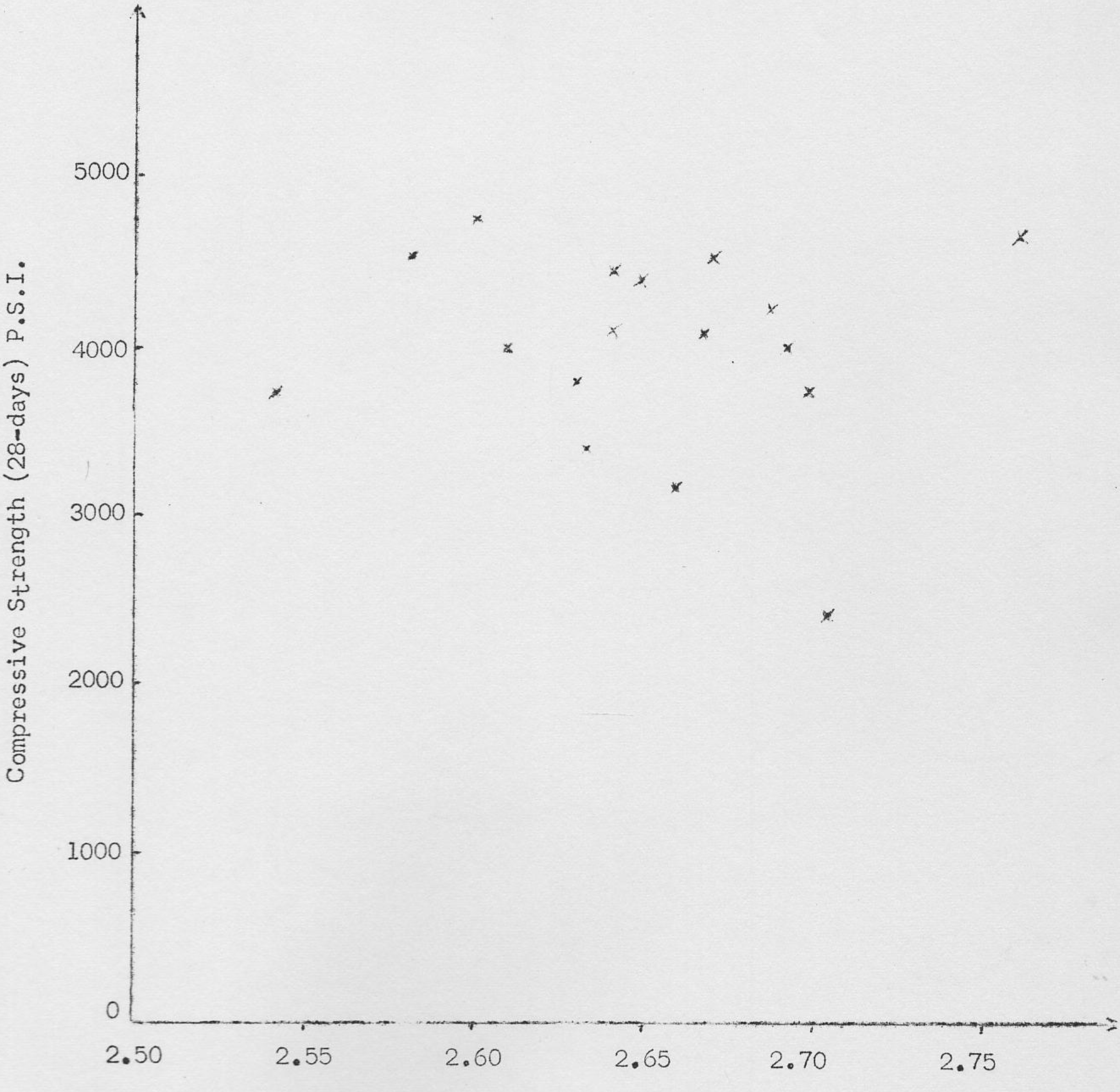

Figure 10. Relationship Between Compressive Strength (28-days) and Bulk Specific Gravity.

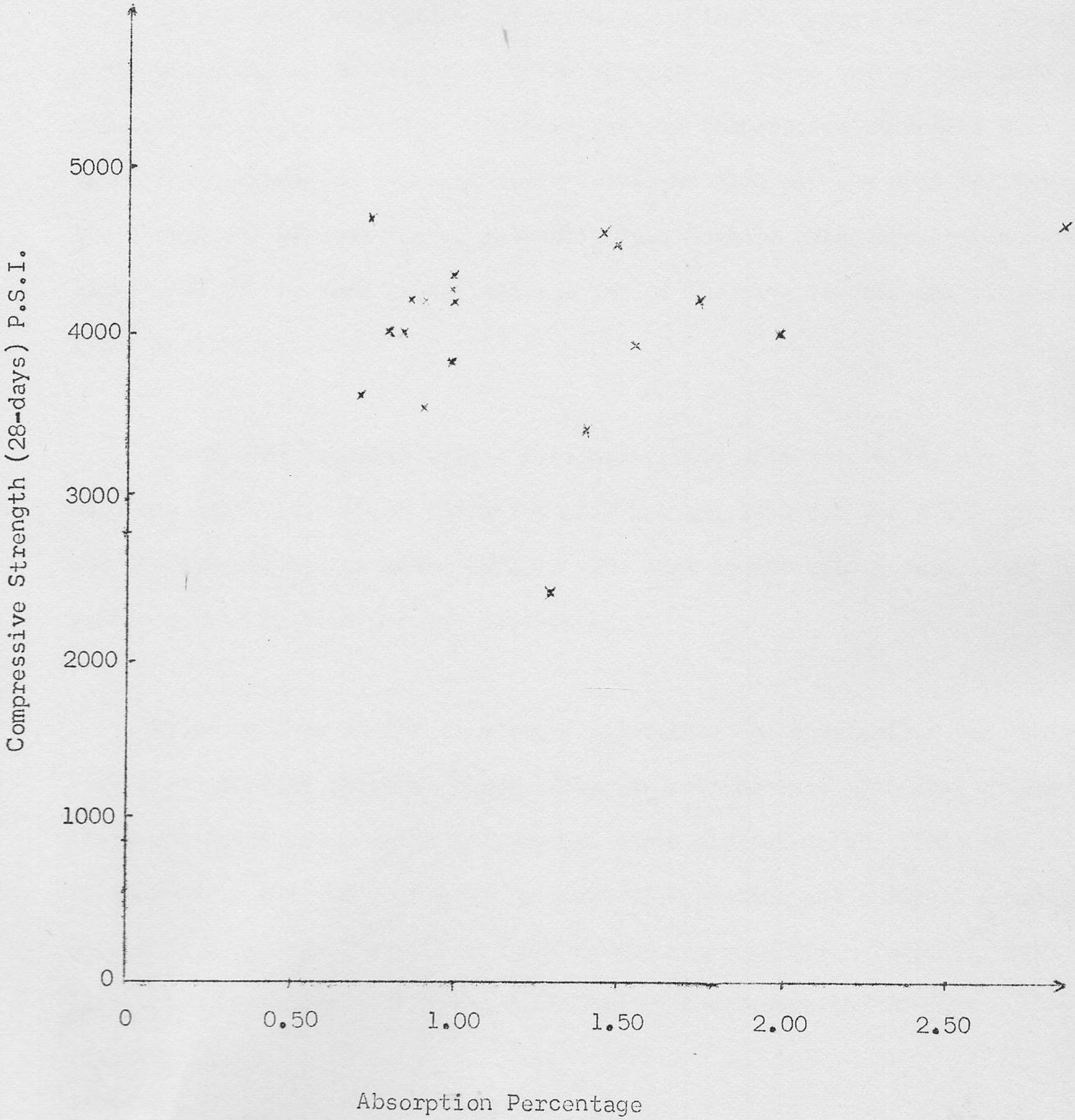

Figure 11. Relationship Between Compressive Strength (28-days) and Absorption Capacity.

are shown in Table 10.

The highest compressive strengths for both the 7-days and the 28-days tests was obtained for the Kafershima aggregate. These values were 3640 psi and 5530 psi, respectively. The next highest compressive strengths were found for the Bdadoun aggregate with values of 3190 psi and 4885 psi for the 7-days and 28-days tests, respectively. Both of these aggregates were limestones of the same geological age and of the same texture and structural characteristics.

The lowest strength values were associated with sample 14, the Ain tora aggregate, which indicated 1275 psi and 2460 psi for the 7-days and 28-days strengths, respectively. The next lowest values were found for sample 6, the Trablos (Fawar) aggregate.

Although some of the aggregates maintained the same rating for their 7-days and 28-days strength tests, this was not the case with many of them. There were many whose ranks for the two tests did not match. This is attributed to the difference in the rate of hydration and chemical reactions between the various ingredients used in the concrete mix. Table 11 shows the various aggregates with their ratings of the 7-days and 28-days strength values.

Table 11: The Ratings for the 7-days and 28-days Compressive Strength Test for all the Samples

Sample No	Compressive Strength P.S.I. 7-days	Rating 7-days	Compressive Strength P.S.I. 28-days	Rating 28-days
1. Fawar Antelias	2480	20	3580	20
2. Nahr-Almout	2620	17	3945	17
3. Ain Saadet	2870	9	4620	5
4. Gosta	2300	21	3580	21
5. Jbail	2620	16	4540	6
6. Trablos(Fawar)	1735	23	3360	23
7. Trablos(Sea)	2800	11	4070	13
8. Saida(Alman)	3080	3	4700	3
9. Saida (Sea)	3010	4	4000	16
10. Zahle	2690	14	4245	8
11. Ferzol	2535	19	3780	19
12. Balabak	2550	18	4210	10
13. Dekwane	2760	12	4650	4
14. Aintora	1275	24	2460	24
15. Wadi Shahrour	2980	5	4070	12
16. Shamlan	2620	15	4110	11
17. Daher Alwahesh	2800	10	4215	9
18. Kahalet	1808	22	3440	22
19. Jamhour	2940	8	3820	18
20. Lwaize	2725	13	4000	15
21. Bdadoun	3190	2	4885	2
22. Kafershima	3640	1	5530	1
23. Mdeirej	2940	7	4390	7
24. Faiadiet	2960	6	4000	14

CHAPTER VI

SPECIFIC COMMENTS FOR EACH AGGREGATE TYPE

A total of 24 different aggregate types taken from various districts in Lebanon were used in this study in order to study their effect upon the strength of concrete. The following are the specific comments and results pertinent to each one of them:

Sample 1. Fawar Antelias

This argillacesous limestone aggregate had an absorption value of 3.55 %, loose unit weight of 1.458 grams/cu.cm., rodded unit weight of 1.602 grams/cu.cm. bulk specific gravity of 2.544 and Los Angeles Abrasion Loss of 38.1 %. It had a 7-days compressive strength of 2480 psi and the 28-days strength was 3580 rating 20/24 of all the aggregates.

Sample 2. Nahr Almout

Limestone of Albien age. Absorption 0.81 %, loose unit weight 1.500 grams/cu.cm. rodded unit weight, 1.680 grams/cu.cm., bulk specific gravity 2.685. Its percentage loss from the Los Angeles Abrasion test was 28.50 %. Its 7-days compressive strength was 2620 psi and with a 28-day compressive strength of 3945 psi, it rated 17 out of the 24 aggregate types tested.

Sample 3. Ain Saadet

This massive, homogeneous limestone showed an absorption of 1.49 %, loose unit weight of 1.498 grams/cu.cm., rodded unit weight of 1.670 grams/cu.cm., bulk specific gravity of 2.642. The loss from the Los Angeles Abrasion Test was rather high with a value of 34.90, yet, contrary to this, its strength was also rather high with a value of 2870 psi for the 7-days test and 4620 psi for the 28-days strength. It rated the 5th place among the 24 aggregates.

Sample 4. Gosta

This argillaceous limestone, belonging to the same geological age as Sample 1, the Fawar Antelias type, had the lowest absorption value of 0.66 %, loose unit weight of 1.501 grams/cu.cm., rodded unit weight of 1.645 grams/cu.cm., bulk specific gravity of 2.694. The loss from the Los Angeles Abrasion Test was 35.30 %, slightly less than Sample 1, and hence showed better results for its compressive strength tests. The 7-days strength value of 2300 psi was lower, but the 28-days strength was higher with a value of 3580 psi, rating it 21 out of the 24 aggregate types.

Sample 5. Jbail

Fossiliferous limestone of Turonien age. Absorption value of 1.45 %, loose unit weight of 1.450 grams/cu.cm., rodded unit weight of 1.572 grams/cu.cm., bulk specific gravity of 2.580. The loss of fines in the Los Angeles Abrasion test amounted to 31.00 %. Its 7-days compressive strength was found to be 2620 psi and the 28-days strength 4540 psi which gave it a rating of 6/24.

Sample 6. Trablos (Fawar)

Massive limestone of Jebel Tirbol, Helvetien age. Absorption of 1.39%, loose unit weight of 1.400 grams/cu.cm., rodded unit weight of 1.565 grams/cu.cm., bulk specific gravity of 2.630. This aggregate type gave rather inconsistent results. It showed rather low loss of fines in the Los Angeles Abrasion test of 27.60 %, but had very low compressive strength, 1735 psi for the 7-days test, and 3360 psi for the 28-days test which rated it 23/24. This low strength value could be attributed to the weak bonding between the aggregate and the cement paste. This aggregate, in addition, was characterized by having the lowest loose unit weight, and the lowest rodded unit weight, this latter could partly explain the low strength values.

Sample 7. Trablos (Sea)

Consisted of pebbles and cobbles, further crushed in the laboratory to obtain the proper grading. The fragments were subrounded in their shape, smooth in their surface texture. Absorption of 0.86 %, loose unit weight of 1.618 grams/cu.cm., rodded unit weight of 1.730 grams/cu.cm., bulk specific gravity of 2.640. The loss from the Los Angeles Abrasion test was 23.70 %. Its 7-days compressive strength was 2800 psi and the 28-days st strength was 4070 psi. Rating 13/24.

Sample 8. Saida (Alman)

Uniformly bedded limestone of Cenomanien-Turonien age; dense, pure and homogeneous. Low absorption value of 0.72 %, loose unit weight of

1.545 grams/cu.cm., high rodded unit weight of 1.710 grams/cu.cm., bulk specific gravity value of 2.765. It had rather low loss (17.30 %), from the Los Angeles Abrasion test. This sample seemed to conform to the expected results. Its low loss of fines and high rodded unit weight could partly explain its high strength. The 7-days compressive strength value was found to be 3080 psi and its 28-days strength value of 4700 psi gave the aggregate a rather high rating of 3/24.

Sample 9. Saida (Sea)

Consisted of pebbles and cobbles of natural gravel from the coastal areas, which were further crushed in the laboratory for the purpose of obtaining the proper gradation. Fragment shapes sub-rounded, surface texture smooth.

Absorption 2.04 %, loose unit weight of 1.456 grams/cu.cm., rodded unit weight of 1.620 grams/cu.cm., bulk specific gravity of 2.605. Its Los Angeles Abrasion loss of 25.40 % was slightly higher than the other natural gravel type aggregate used in this study, namely the Trablos (Sea) (Sample 7) which had a loss of 23,70 %. Accordingly, this aggregate type showed to possess slightly less strength for the 28-days test (4000 psi). But its 7-days strength was higher than its prototype, 3010 psi versus 2800 for sample 7. Its 28-days strength value of 4000 psi gave it a rating of 16/24.

Sample 10. Zahle

White, pure limestone belonging to the Jebel ed Dahr formation of Lutetien age. Absorption 1.01 %, loose unit weight of 1.480 grams/cu.cm., rodded unit weight of 1.637 grams/cu.cm., 26.30 % loss from the Los Angeles Abrasion test. Compressive strength test results 2690 psi for the 7-days test, 4245 psi for the 28-days test for which it was rated 8/24.

Sample 11. Ferzol

This aggregate was marly limestone. Its absorption value was 1.01 %. Loose unit weight 1.508 grams/cu.cm., rodded unit weight of 1.670 grams/cu.cm., loss from the Los Angeles Abrasion test was rather high with a value of 34.10 %, and this high percentage of loss could partly explain its rather low strength values which were 2535 psi for the 7-days test and 3780 psi for the 28-days test, giving it a rating of 19/24.

Sample 12. Balabak

Slightly marly limestone of lutetien age. Absorption of 1.01 %, loose unit weight of 1.510 grams/cu.cm., rodded unit weight of 1.672 grams/cu.cm., bulk specific gravity of 2.665. Loss from the Los Angeles Abrasion test was 33.80 %. Compressive strength values were 2550 psi for the 7-days test and 4210 psi for the 28-days test which gave it a rating of 10/24.

Sample 13. Dekwane

Slightly marly and sandy conglomerate. Rather high absorption value of 2.84 %. This aggregate was characterized as having the lowest loose unit weight of 1.400 grams/cu.cm., its rodded unit weight value was calculated at 1.650 grams/cu.cm., its bulk specific gravity was 2.600. It was further characterized as having the highest loss of fines from the Los Angeles Abrasion test calculated at 55.60 %. Despite its seemingly poor physical characteristics, highest percentage loss from the Los Angeles Abrasion, and lowest loose unit weight. It had rather high compressive strength values, 2760 psi for the 7-days test, and 4650 psi for the 28-days test, rating it 4/24.

Sample 14. Aintora

Slightly argillaceous similar to the Gosta aggregate, both belonging to the Kisrwan district, Aptien age. Its absorption was established at 1.30 %, rather low loose unit weight of 1.458 grams/cu.cm., rodded unit weight of 1.630 grams/cu.cm., bulk specific gravity of 2.705. Despite the fact that the physical properties of this aggregate was superior to many of the aggregate types examined; it resulted with the lowest strength of all. Its percentage of loss of fines from the Los Angeles Abrasion test was 25.70 %, a satisfactory average value. But its strength was the lowest with 1275 psi for the 7-days test, and 2460 psi for the 28-days test. It rated 24/24. The low strength colld be attributed to the poor bonding between the aggregate and the cement paste.

Sample 15. Wadi Shahrour

Uniformly bedded limestone of Cenomenien-Turonien age. Absorption less that 2%, loose unit weight 1.453 grams/cu.cm., rodded unit weight 1.605 grams/cu.cm., bulk specific gravity of 2.645. Rather high loss of fines from the Los Angeles Abrasion Test of 36.30 %. Its compressive strength values were 2980 psi for the 7-days test, and 4070 psi for the 28-days test by which it had a rating of 12/24.

Sample 16. Shamlan

Aptien limestone showing argillaceous thin seams, alternating with sandy material. Absorption value of 1.01 %, loose unit weight of 1.515 grams/cu.cm., rodded unit weight of 1.668 grams/cu.cm., bulk specific gravity of 2.685. Rather high loss (35.30 %) of fines from the Los Angeles Abrasion test. Compressive strength results, 2620 psi for the 7-days test, 4110 psi for the 28-days test. Rating 11/24.

Sample 17. Dhahr-Alwahesh

Aptien Limestone, homogeneous and uniformly textured. Absorption 0.86 %, loose unit weight, 1.510 grams/cu.cm., rodded unit weight 1.663 grams/cu.cm., bulk specific gravity 2.725. Loss percentage of fines from Los Angeles Abrasion test 29.70 %. Compressive Strength for 7-days 2800 psi and 4215 psi for 28-days. It had rating 9/24.

Sample 18. Kahalet

Marly argillaceous limestone of Aptien age. Absorption 0.86 %. Loose unit weight 1.550 grams/cu.cm., rodded unit weight of 1.730 grams/cu.cm., was the highest value recorded among all the 24 aggregate used in this research. Bulk specific gravity of 2.695. About average loss (31.20 %), from the Los Angeles Abrasion Test. The 7-days compressive strength value was 1808 psi and the 28-days strength was 3440 psi, giving it a rather low rating of 22/24. Again, it is seen the very apparent inconsistency of an aggregate possessing the highest rodded unit weight, a measure of the high compaction factor possible to be achieved, yet its strength value turned out to be very low in comparison to the other aggregate types.

Sample 19. Jamhour

Limestone of the Turonien age. Absorption value of 1.64 %, loose unit weight of 1.548 grams/cu.cm., highest value of rodded unit weight of 1.730 grams/cu.cm., bulk specific gravity of 2.640. Rather high loss (39.00 %), of fines from the Los Angeles Abrasion test. This sample aggregate also one of those inconsistent in its results. Although it had a high value of rodded unit weight (1.730 grams/cu.cm., one of the highest recorded) it showed very low compressive strength value of 3820 psi for the 28-days test. However, on the other hand, this result was quite consistent and acceptable on the basis of its rather high loss of fines of 39.00 %. A 28-days compressive strength value of 3820 psi gave the aggregate a rating of 18/24.

Sample 20. Lwaize

Evenly textural limestone of Turonien age. Absorption 0.86 %. Loose unit weight 1.558 grams/cu.cm., rodded unit weight 1.710 grams/cu.cm., bulk specific gravity 2.690, percentage loss of fines from Los Angeles Abrasion test 23.50 %. Compressive strength 7-days 2725 psi, 28-days 4000 psi. It had Rating 15/24.

Sample 21. Bdadoun

Uniformly bedded, dense and pure limestone, Cenomanien-Turonien age. Absorption less than 1 %, loose unit weight of 1.525 grams/cu.cm., 2.695. Rather low percentage (25.00 %), loss of fines from the Los Angeles Abrasion test. Second highest compressive strength value of 4885 psi for the 28-days test. This value seems to be conformable with its high rodded unit weight and low loss percentage of fines. Rating 2/24. Strength values very satisfactory and results consistent with its physical properties.

Sample 22. Kafershima

Uniformly bedded, dense and pure limestone, Cenomanien-Turonien age. In many ways resembling very much the Bdadoun aggregate, Sample 21. Absorption 1.30 %, loose unit weight 1.512 grams/cu.cm., rodded unit weight 1.655 grams/cu.cm., bulk specific gravity 2.655. Higher loss of fines (33.20 %) than the Bdadoun aggregate, but still higher strength values. Its compressive strength values: 3640 psi for the 7-days test; 5530 psi (the highest of all the aggregates) for the 28-days test. Its rating 1/24. Besides its generally acceptable physical properties examined for this research, the Kafershima aggregate must have given the highest and compressive strength due to its strong bond between cement paste and aggregate.

Sample 23. Mdeirej

Dense and uniform limestone. Absorption 1.15 %, loose unit weight 1.510 grams/cu.cm., rodded unit weight rather high with a value of 1.650 grams/cu.cm., bulk specific gravity 2.640. Average percentage loss from the Loss Angeles Abrasion test of 29.20 %. Strength test results; 2940 psi for the 7-days test, 4390 psi for the 28-days test, Rating 7/24.

Sample 24. Faiadiet

Limestone of the Turonien age, very similar to the Jamhour aggregate. Absorption of 1.74 %, loose unit weight of 1.475 grams/cu.cm., rodded unit weight of 1.640 grams/cu.cm., bulk specific gravity 2.650 rather high loss (34.44 %) of fines from the Los Angeles Abrasion test. Compressive strength results; 2960 psi for the 7-days test, psi 4000 for the 28-days test. Rating 14/24.

The results of the properties of each aggregate type are shown in Table 12.

Table 12: Properties of Various Types of Coarse Aggregates

Sample No.	Compressive Strength at 7-days	Rating at 7-days	Compressive Strength at 28-days	Rating at 28-days	Percent-age of lost	Bulk Specific Gravity	Absorp-tion %	Loose Unit Weight gr/cm3	Rodded Unit Weight gr/cm3
1. Fawar Antelias	2480	20	3580	20	38.10	2.544	3.55	1.458	1.602
2. Nahr-Almout	2620	17	3945	17	28.50	2.685	0.81	1.500	1.680
3. Ain Saadet	2870	9	4620	5	34.90	2.642	1.49	1.498	1.670
4. Gosta	2300	21	3580	21	35.30	2.694	0.66	1.501	1.645
5. Jbail	2620	16	4540	6	31.00	2.580	0.66	1.450	1.572
6. Trablos (Fawar)	1735	23	3360	23	27.60	2.630	1.39	1.400	1.565
7. Trablos (Sea)	2300	11	4070	13	23.70	2.640	0.86	1.618	1.730
8. Saida (Alman)	3080	3	4700	3	17.30	2.765	0.72	1.545	1.710
9. Saida (Sea)	3010	4	4000	16	25.40	2.605	2.04	1.456	1.620
10. Zahle	2690	14	4245	8	26.30	2.660	1.01	1.480	1.637
11. Ferzol	2535	19	3780	19	34.10	2.680	1.01	1.508	1.670
12. Balabak	2550	18	4210	10	33.80	2.665	1.01	1.510	1.672

Table 12: **Properties of Various Types of Coarse Aggregates (Cont.)**

Sample No.	Compressive Strength at 7-days	Rating at 7-days	Compressive Strength at 28-days	Rating at 28-days	Percentage of lost	Bulk Specific Gravity	Absorption %	Loose Unit Weight gr/cm3	Rodded Unit Weight gr/cm3
13. Dekwane	2760	12	4650	4	55.60	2.600	2.84	1.400	1.650
14. Aintora	1275	24	2460	24	25.70	2.705	1.30	1.458	1.630
15. Wadi Shahrour	2980	5	4070	12	34.30	2.645	1.74	1.453	1.605
16. Shamlan	2620	15	4110	11	35.30	2.685	1.01	1.515	1.668
17. Daner-Alwahesh	2800	10	4215	9	29.70	2.725	0.86	1.510	1.663
18. Kahalet	1808	22	3440	22	31.20	2.695	0.86	1.550	1.730
19. Jamhour	2940	8	3820	18	39.00	2.640	1.64	1.548	1.730
20. Lwaize	2725	13	4000	15	23.50	2.690	0.86	1.558	1.710
21. Bdadoun	3190	2	4885	2	25.00	2.695	0.95	1.525	1.680
22. Kafershima	3640	1	5530	1	33.20	2.655	1.30	1.512	1.655
23. Mdeirej	2940	7	4390	7	29.20	2.640	1.15	1.510	1.650
24. Faiadiet	2960	6	4000	14	34.40	2.650	1.74	1.475	1.640

CHAPTER VII

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The art and science of successfully using concrete can be gained only by detailed experience with the basic ingredients that compose it. A civil engineering materials laboratory is the proper medium for sponsoring limited research projects. Good laboratory work and technique is an art in itself and should be adopted with the purpose of the project in mind.

In the discussion of results and conclusions, the experimental work is examined in the light of experience and the findings of other workers. Such discussion should lead logically into the conclusions. The conclusions must be supported by the experimental work. Very often the conclusions can be made within the context of the existing specification and the recommendations will follow from such conclusions in a logical sequence. Generally, recommendations are drawn from the conclusions or the engineering background or judgment of the investigator.

Some of the important conclusions that could be drawn from the present investigation are:

a) The highest compressive strength value for the 28-days test was recorded for the Kafershima aggregate, dense, homogeneous limestone. However, this aggregate had a rather high loss from the Los Angeles Abrasion test and also much higher absorption percentage than most of the other aggregate types examined in this study. Yet the Kafershima aggregate seemed to possess the highest compressive strength. This could be attributed to better bond between the cement paste and the aggregate than the other types, a factor which may depend to a great extent upon the surface texture of the aggregate.

b) The lowest 28-days strength value was found for the Aintora aggregate. On the basis of its physical properties, this aggregate did not seem to be the worst of the aggregates tested, yet it gave the lowest compressive strength value for its 28-days test. This again is an indication that other factors, like surface texture, powder which influences bond control the strength of concrete.

c) The hardest aggregates were the two coastal natural gravels taken from the Saida and Trablos littoral. These two aggregates also were the only two whose fragments were not angular but subrounded. Due to their hardness values, it was expected that they may possess the highest strength values, yet these natural aggregates gave concrete that rated the 13th and 14th out of the 24 aggregates types tested. Likewise, the reason for this inconsistent result could be attributed to the poor bond between the cement paste and the aggregate particles.

d) On the basis of the three extreme cases mentioned above, it could be concluded that in addition to hardness, rodded unit weight, bulk specific gravity, shape of fragments, other factors such as surface texture of the aggregate particles which influence greatly the bond strength control the ultimate compressive strength of the concrete.

e) The lowest percentage loss of fines was recorded for the Saida (Alman) aggregate. Consistent with this physical property this sample's compressive strength for the 28-days was high, with a rating of 3/24.

f) The highest percentage loss of fines was found for the Dekwane conglomerate. Inconsistent with this physical property this aggregate was found to possess high strength which gave it the 4th place among the 24 samples tested.

g) The highest rodded unit weights were recorded equally for three different samples, the Jamhour, the Kahalet and the Trablos (Sea) natural gravel. But inconsistent with theory, the compressive strength values of these aggregates rated as 18.22, and 13 out of the 24 sample types.

h) The lowest loose and the lowest rodded unit weights were found for the Trablos (Fawar) aggregates which also happened to have a very low compressive strength (3360 psi), rated 23/24. This was one of the few cases where the appraised physical properties and the compressive strength values conformed to accepted theory.

i) The highest absorption value (3.55 %) was calculated for the Fawar Antelias aggregate and the lowest value of absorption (0.66 %) for the Gosta aggregate. The former was rated the 20th while the latter 21st in their compressive strengths. It could therefore, be concluded that percentage of absorption does not have any influence upon the strength of concrete if there is sufficient water in the original mix so that the cement used can have complete hydration.

j) Although some of the aggregate seemed to maintain the same ratings for both the 7-days and the 28-days strength, there were many cases where the ratings of these two strengths for the same aggregate did not match and varied very widely. It could be concluded that some characteristics of the aggregate controls the rate of hydration of the cement paste thus causing such a discrepancy between the two strengths.

k) It is recommended that a study of statistical methods be applied to materials research for an investigation such as the present research.

l) Such a study must be supplemented by further study of the poor aggregate types, those with the low strength values, with the hope of improving their results. This could be achieved by an investigation of the effects of changing the concrete mixture proportions, changing the maximum size of the aggregate at constant slump and water/cement ratio.

m) The poor aggregate types could be improved by the addition of proper admixtures. It is therefore recommended that further work be carried out to find what admixture will possibly improve the performance of the low-strength aggregate types.

n) It is also recommended that further investigation be carried on to study the possibility of improving the low-strength aggregates by changing the sand percentage for a constant slump and constant water/cement ratio mixture.

COMPRESSIVE STRENGTH OF CONCRETE USING

VARIOUS AGGREGATE SAMPLES

Sample No. 1		Source: Fawar Antelias	
Crushing load lbs		7 days	28 days
	1.	70000	98000
	2.	68000	102000
	3.	72000	103000
	Average	70000	101000
Compressive Strength - PSI		2480	3580

Sample No. 2		Source: Naher Almout	
Crushing load lbs	1.	7 days	28 days
	1.	71000	110000
	2.	75000	111500
	3.	76000	113000
	Average	74000	111500
Compressive Strength - PSI		2620	3945

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 3	Source: Ain Saadet		
Crushing load lbs		7 days	28 days
	1.	79500	129000
	2.	81000	133000
	3.	82500	130000
	Average	81000	131000
Compressive Strength - PSI		2870	4620

Sample No. 4	Source: Gosta		
Crushing load lbs		7 days	28 days
	1.	68000	101000
	2.	64000	99000
	3.	63000	103000
	Average	65000	101000
Compressive Strength - PSI		2300	3580

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 5	Source: Jbail		
Crushing load lbs		7 days	28 days
	1.	76000	130000
	2.	73500	126000
	3.	72500	129000
	Average	74000	128333
Compressive Strength - PSI		2620	4340

Sample No. 6	Source: Trablos (Fawar)		
Crushing load lbs		7 days	28 days
	1.	47000	92500
	2.	48000	93000
	3.	52000	87500
	Average	49000	91000
Compressive Strength - PSI		1735	3360

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 7	Source: Trablos (Sea)		
Crushing load lbs		7 days	28 days
	1.	80000	114000
	2.	75000	112000
	3.	82000	116000
	Average	79000	114000
Compressive Strength - PSI		2800	4070

Sample No. 8	Source: Saida (Alman)		
Crushing load lbs		7 days	28 days
	1.	86500	129000
	2.	88000	134000
	3.	86500	136000
	Average	87000	133000
Compressive Strength - PSI		3080	4700

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 9	Source: Saida (Sea)		
Crushing load lbs		7 days	28 days
	1.	87000	114500
	2.	83000	110500
	3.	85000	114000
	Average	85000	113000
Compressive Strength - PSI		3010	4000

Sample No. 10	Source: Zahle		
Crushing load lbs		7 days	28 days
	1.	77500	118000
	2.	75500	119000
	3.	75000	123000
	Average	76000	120000
Compressive Strength - PSI		2690	4245

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 11	Source: Ferzol		
Crushing load lbs		7 days	28 days
	1.	69000	109000
	2.	73500	108000
	3.	72000	104000
	Average	71500	107000
Compressive Strength - PSI		2535	3780

Sample No. 12	Source: Balabak		
Crushing load lbs		7 days	28 days
	1.	74000	115500
	2.	71000	121000
	3.	71000	120500
	Average	72000	119000
Compressive Strength - PSI		2550	4210

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 13	Source: Dekwane		
Crushing load lbs		7 days	28 days
	1.	76000	131000
	2.	77000	129000
	3.	81000	134000
	Average	78000	131333
Compressive Strength - PSI		2760	4650

Sample No. 14	Source: Aintora		
Crushing load lbs		7 days	28 days
	1.	34500	69000
	2.	37000	68000
	3.	37500	71500
	Average	36000	69500
Compressive Strength - PSI		1275	2460

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 15		Source: Wadi Shahrour	
Crushing load lbs		7 days	28 days
	1.	88000	116000
	2.	83000	116000
	3.	81000	113000
	Average	84000	115000
Compressive Strength - PSI		2980	4070

Sample No. 16		Source: Shamlan	
Crushing load lbs		7 days	28 days
	1.	73000	113000
	2.	73000	117000
	3.	76000	118000
	Average	74000	116000
Compressive Strength - PSI		2620	4110

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 17	Source: Dahr-Alwahesh		
Crushing load lbs		7 days	28 days
	1.	76000	119000
	2.	81000	118500
	3.	80000	120000
	Average	79000	119167
Compressive Strength - PSI		2800	4215

Sample No. 18	Source: Kahalet		
Crushing load lbs		7 days	28 days
	1.	50000	94000
	2.	53000	95000
	3.	50000	103000
	Average	51000	97333
Compressive Strength - PSI		1808	3440

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 19	Source: Jamhour		
Crushing load lbs		7 days	28 days
	1.	84000	105000
	2.	84000	107000
	3.	81000	112000
	Average	83000	108000
Compressive Strength - PSI		2940	3820

Sample No. 20	Source: Lwaize		
Crushing load lbs		7 days	28 days
	1.	74000	112000
	2.	79000	111000
	3.	78000	116000
	Average	77000	113000
Compressive Strength - PSI		2725	4000

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 21	Source: Bdadoun		
Crushing load lbs		7 days	28 days
	1.	85000	135000
	2.	92000	139000
	3.	93000	140000
	Average	90000	138000
Compressive Strength - PSI		3190	4885

Sample No. 22	Source: Kafershima		
Crushing load lbs		7 days	28 days
	1.	100000	153000
	2.	104000	155000
	3.	105000	160000
	Average	103000	156000
Compressive Strength - PSI		3640	5530

COMPRESSIVE STRENGTH OF CONCRETE USING VARIOUS AGGREGATE SAMPLES

Sample No. 23	Source: Mdeirej		
Crushing load lbs		7 days	28 days
	1.	81000	126000
	2.	80000	121000
	3.	85000	121000
	Average	83000	124000
Compressive Strength - PSI		2940	4390

Sample No. 24	Source: Faiadiet		
Crushing load lbs		7 days	28 days
	1.	85000	112000
	2.	83500	113000
	3.	82000	114000
	Average	83500	113000
Compressive Strength - PSI		2960	4000

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