# AIR ENTRAINMENT IN CONCRETE

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE
Bruce O. Wangen
1944

# Air Entrainment in Concrete

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

Bruce O. Mangen

Candidate for the Degree of

Bachelor of Science

March 1944

ACKNOWLEDGMENT

I wish to express my sincere appreciation to Mr. Edwin A. Finney and Mr. Roy Fulton of the Research Division of the Michigan State Highway Department for their helpful advice and for the use of equipment belonging to the department.

# INTRODUCTION

One of the most recent problems encountered in concrete work has been surface scaling. During the last few years much research has been done toward solving this problem, and a solution has been found in the form of entrained air in concrete. Recent results from numerous tests made during the past few years have shown that entrainment of air will enable the concrete to resist scaling without endangering its other characteristics to any great degree.

The Michigan State Highway Department has been and is doing much research in this subject of air entrainment, and their laboratory equipment and reference library were made available for my use. Since the study of air-entrainment in concrete is a very broad one, my studies were confined to one air entraining agent, Vinsol resin, which is the most widely used agent at present.

A library study of Vinsol resin itself was first made, and then the properties of Vinsol resin cement concrete (i. e., workability, strength, bond, mixing time, and proportioning) were investigated by using library references and literature furnished by the Michigan State Highway Department.

The next and primary objective was to develop a simple, accurate, and practical method of determining the air content of concrete. Although air-entraining materials are used by the Michigan State Highway Department in road construction, there had been no simple and accurate field method yet developed for determining the per cent of air entrained in the concrete, this per cent being required to be within a specified range. The process used by the Michigan State Highway Department at the present time to check the amount of air in concrete has been to find the unit weight of the freshly mixed concrete treated with air-entraining materials and compare it with the unit weight found in the laboratory using the mortar-voids method of proportioning. A loss in weight per cubic foot of about five pounds when using air-entraining materials was considered satisfactory, and corrections for the loss in weight were made by adding or subtracting sand from the mix. However, the results found in the laboratory using the mortar-voids method did not take into account a small percentage of voids which were present due to the use of Vinsol resin cement in the laboratory determinations, and thus the actual loss in weight may easily have varied from the theoretical loss. Results of this field method were and are not satisfactory, and consequently all of the laboratory work was directed toward finding a new field method to determine actual air content in concrete after a library analysis of the subject had been made. Results of the library and laboratory studies are contained on the following pages.

# Air-Entrainment in Concrete

One of the major problems encountered recently in highway work has been surface scaling of concrete pavements.

Surface scaling may be caused by severe frost action, direct application of calcium chloride or other salts to remove ice, or by consistent applications of granular materials impregnated with these salts.

Efforts to remove ice is the principle cause of scaling. Icy roads are a serious traffic hazard, expecially on bus stops, intersections, grades, and curves where good traction is required, and prompt removal of the ice is important. The method of ice removal most used is application of salts and, although this method accomplishes its purpose, it also subjects the pavement to the actions of the salts and to many more cycles of freezing and thawing than normally encountered. When treated so, the surface of the pavements usually come off in scales 1/16 to 1/4 inch in thickness, leaving a rough and unsightly surface. Progressive scale may then take place, being characterized by continued deterioration into the pavement after the mortar has worn off.

The severity and extent of scaling depend upon the amount of salts used, the frequency of application, and how early in the life of the concrete the salts are applied. Results from scaling are much worse if the salts are applied before the concrete is about four years old. After that time the concrete is effected considerably less by application of the ice removing materials.

One theory as to how salts affect the concrete is that the use of these salts on concrete pavements during winter weather tends to introduce solutions into the surface voids which, when subjected to freezing and thawing, produce crystals which have a progressive action in breaking down the surface structure. This has been accepted by many as a large and serious factor in pavement scaling. There are other causes, however, which have been advanced as of equal importance, but since there have been no definite results on the study at this time, further treatment of the subject seems unnecessary.

Studies of the scaling problem on a large scale were started in 1938 by the Dewey and Almy Chemical Company in connection with the application of a combined air-entraining and dispersing agent to portland cement concrete.

Cooperative studies made in the early thirties by Prof. C. H. Scholer showed that small amounts of air entrained in the concrete caused great improvement in the durability of the concrete. Although freezing and thawing benefits were recognized, the corresponding reductions in density and strength caused research on this problem to be suspended.

The New York State Highway Division built thirteen experimental sections of concrete highway in 1939 in an effort to find an answer to the surface scaling problem. Tests both inside and outside the laboratory gave results in which concrete made with a mixture of a certain natural cement and other portland cements showed greater resistance to scaling than concrete in which was used either portland cement or other natural cements alone. Later studies led to the conclusion that the presence of small amounts of grease or fat was the cause of the resistance of the resistance of the concrete to freezing and thawing action.

In studies made during the winter of 1937-38 at the research laboratory of the Universal Atlas Cement Company, the portland-natural cement blend was again found to resist surface scaling when used in concrete and another cement in which a small amount of fish-oil stearate made from cod oil, gave even better results.

In the last few years, agencies all over the country have carried out comprehensive studies to find solutions to the scaling problem. These agencies include Federal departments, State Highway departments, cities, portland cement manufacturers, and the technical and research departments of the Portland Cement Association.

Air-entraining agents which were and are used in tests are fish-oil stearate, beef tallow, orvus and other wetting agents, and from a commercial product named Vinsol resin. Vinsol resin has been found to give as good results if not better than the other agents and has the added advantage that it is incorporated into the cement during the manufacturing process and consequently does not have to be added to the mix in the field.

The remainder of this study of air-entrainment will be made considering Vinsol resin as th air entraining agent.

Vinsol resin is a product extracted from pine wood and is believed to exist as such in wood at the time of extraction. It was developed by the Hercules Powder Company which has assigned it to the public. It may be defined as the petroleum-hydrocarbon insoluble fraction of a coal-tar hydrocarbon extract of wood. The name Vinsol resin is a contraction of the phrase "very insoluble in oil", this property being the first unique property noted as compared to other pine resins and rosins.

The reaction of Vinsol resin with constituents of portland cement and water are as follows (general statements will be used since the nature of the tests is complex):

1. It is highly saponifiable in a solution of sodium hydroxide.
2. It is present in a quantity readily soluble in the water-soluble alkali ($Na_2O \neq K_2O$) normally present in cement.
3. It is relatively insoluble in calcium hydroxide and the saponifiable reaction with cement and water cannot be attributed to a simple reaction between it and the lime dissolved by the addition of water to cement.
4. There is a possibility that the relationship of water soluble alkali in a cement may have a bearing on the effectiveness of Vinsol resin treatment of that cement.

Other chemical properties of Vinsol resin are:*

*Cement Durability Program, First Interim Report, U. S. Army Engineers, June 1942.

1. Contains approximately 5% of rosin.

2. Contains coloring matter which can be only partially separated and removed.

3. Is resistant to oxygen.

4. Contains hydroxyl groups which are readily acetylated.

5. Can be saponified by means of sodium, potassium, or ammonium hydroxide to yield water soluble soaps.

6. Can be converted to calcium, magnesium, lead, and zinc salts which are water insoluble.

7. Will react with aldehydes or their ammonia reaction products to form infusible and insoluble resins.

8. Contains about 5.5% of methoxyl group which does not vary appreciable from sample to sample.

9. Its melting point (drop) varies from 110° to 115° C.

10. Approximate molecular weight is 450.

11. Approximate formula is $C_{27}H_{30}O_5$.

A microscopic study, outlined in the First Interim Report, U. S. Army Engineers, June 1942, gave the following results. A large number of powder sections of two unhydrated cements were made to determine the form in which Vinsol resin existed in a dry cement as shipped from the mill. Studies were then made on the assumption that Vinsol resin either coated the cement particles with a thin resinous film, or it occurred as minute individual particles scattered throughout the cement. "No evidence could be observed which supported the resinous film hypothesis, and only two flakes of Vinsol resin were observed in all of the unhydrated cement powder sections examined. The fact that even two unaltered Vinsol resin particles were present in a dry, unhydrated cement indicated the probability that Vinsol resin exists as unaltered particles disseminated throughout the cement. The amount of Vinsol resin in these cements is very small, and the particles are so widely scattered that it is reasonable that they should occur only occasionally in the small specimens used for microscopic examinations. No other evidence of its presence was detected under the microscope with magnifications as high as 2400X."*

The effect of air-entrainment in concrete is as follows:

Workability -- Workability of concrete made with air-entraining materials is excellent when compared to a corresponding mix using standard portland cement. The fresh concrete is cohesive, somewhat sticky, and has a fatty appearance, but may be handled, screeded, and finished easily with some slight changes in the present methods used. The increase in workability may be explained by the assumption that the air-entraining agents produce well-distributed air bubbles which appear to act as ball bearings and decrease the particle interference of the concrete aggregates.

The effect of entrained air on consistency may be shown by the following simple tests.

If an air-entraining agent is used in a cement paste there is no increase in plasticity of the paste. This may be shown by adding water to standard portland cement and to Vinsol resin cement. Their plasticity as tested by obser-

*Ibid.

vation is about the same.

It is, however, well established that entrained air in sand improves its workability, thus suggesting that this must be due to the action of this air in decreasing particle interference. Henry L. Kennedy of the Dewey and Almy Chemical Co. substantiates this statement with the following test. Identical samples of sand were placed in three beakers, and the first sample was then mixed with water, the result being a harsh mixture readily adhering to the side walls of the beaker. Water plus an air-entraining agent was added to the second sample and after the mixture was thoroughly mixed, the air was drawn out by a vacuum, the result being the same as found in the test of the first sample. The third sample was treated with an air-entraining agent in the same way as the second sample, but the air was not withdrawn. The result was an extremely plastic mixture.

Since air-entraining agents act principally on fine aggregate, or the sand constituent of concrete, it follows that lean mixes will entrain correspondingly more air than rich mixes since they have a relatively high amount of fine aggregate. Therefore, the amount of entrained air progressively diminishes with increasing cement content which infers that a maximum cement content will be reached at which the percentage of entrained air is so reduced that no improvement in consistency is obtained despite the presence of an air-entraining agent.

Bond -- Many investigators have found that, in general, decreases in bond strength vary directly as decreases in compressive strength. However, a comprehensive series of tests by C. E. Wuerpel reported in the First Interim Report of the U. S. Engineers, June 1943, shows no decrease in bond when an air-entraining agent was present. These tests, however, showed a 20% increase in compressive strength due to the use of air-entraining materials. Tests by Kennedy showed a decrease of 20% in bond strength due to the use of air-entraining materials.

Mixing time -- Prolonged mixing causes excess air-entrainment, and consequently the time of mixing should be carefully regulated. A mixing time of 1½ minutes should be ample enough to incorporate all of the required air into the mix.

Strength -- Entrainment of air causes a decrease in density and consequently a decrease in strength--tensile, compressive, and flexural. The air-entraining agents themselves may be detrimental to concrete thus causing a further reduction in strength. This is indicated by the fact that with certain agents, rich mixes which contain less entrained air than lean mixes show the same decrease in strength. Explanation for the large decrease in strength due to entrained air is that bulking of the mortar due to the increased air content has an effect similar to that obtained when additional water is added to the mix producing the same consistency by bulking. The reduction in strength has been found to be from 15 to 20 per cent when the water has been reduced so that the concrete will have a consistency comparable to that of concrete made in the absence of an air-entraining agent when the agent used causes a 3-4 per cent increase in volume of air content. At identical water-cement ratio, the presence of an air-entraining agent in the same amount may cause decreases in strength of as much as 40 to 60 per cent.

Proportioning or Design of Mix -- The cement content per unit volume of concrete will decrease when air-entraining agents are used due to the bulking effect caused by entrained air. It is desireable to recover some of the loss in strength caused by increased air content by maintaining the same cement content per unit volume in air-entraining portland cement concrete as is used in concrete made with standard portland cement. However, even though some of the lost strength is recovered, the increase in cement content per unit volume will cause a decrease in the amount of air and thus lessen the durability qualities of the concrete. Specifications will determine whether to maintain the same cement content or not, but since concrete strengths in highway work greatly exceed required strengths, the decrease in strength due to the decrease in cement content per unit volume can easily be afforded. Mixing water may be reduced by approximately 0.3 gallons per sack of cement with the degree of workability of the concrete remaining about the same, thus increasing the strength and partially compensating for some of the strength lost due to the increased air content. The amount of sand in the mix may also be reduced if desired due to the increase in mortar caused by the bulking effect of entrained air.

## Experimental Results

The problem of finding an accurate and single field method for determining the amount of air in concrete was attacked by first considering three basic methods of determining air-entrainment: (1) by volumetric measurements, (2) measurements by weighing, and (3) using chemical means of replacing or drawing out the air.

The first procedure tried was to see if the air could be forced out by boiling. The main problem at first was to prevent the flash setting of the concrete under the influence of heat. This was accomplished by boiling a mixture of concrete and water with three trials showing no apparent setting of the concrete. However, the length of time needed to boil the concrete and the inconvenience of supplying enough heat in the field were prohibitive, and this method was abandoned.

A comparison of methods using volumetric measurements and measurements by weighing showed that a method using volumetric measurements would be more accurate, require a smaller amount of equipment, and require equipment less delicate in nature than methods using measurements by weighing.

After much thought and reference reading, a trial method was chosen which was based on the same principle as the A. S. T. M. method for determining the air content of concrete, this principle being the replacing of the air in the concrete by inundating the concrete with water and shaking the mixture, the air voids then being theoretically filled with water.

Equipment used in this method consisted of a cylindrical container which could be made airtight, a gaging device to measure the height of a liquid surface, and graduates to measure the amount of water used.

A container was designed which approximated the one used in the A. S. T. M. method and consisted of a cylindrical container made of a twelve inch length of five inch standard pipe with a circular base welded on one end, a rubber gasket, and a clamping device. A hook gage for measuring the height of the liquid surface was also designed.

Since the above equipment was not available at once, it was decided to use a bituminous still of approximately one liter capacity and run tests on a mortar in an attempt to prove the accuracy of the method. The still consisted of a cylindrical container which could be made airtight with a quick clamping device, and a hook gage was also made and used to measure liquid levels.

The procedure used in running tests with the mortar was as follows:

1. The container was filled to the top with rodded mortar and weighed. (This is done to provide a check on the experimental results and would not be done in the field tests).
2. Part of the mortar was then taken from the container until the container was approximately three-fourths full.

3. The surface of the mortar was then leveled, and a film of water was spread over the surface by means of a pipete so as to disturb the surface of the mortar as little as possible when additional water was added.

4. A known quantity of water was carefully added to the contents of the container until the tip of the gage point just broke the surface of the water.

5. The container was sealed and turned end over end and rolled forty times, and then the process was repeated thirty times.

6. The container was then opened and the water level raised to the gage point by adding a known amount of water. Since the air voids in the mortar were theoretically filled by the water when the mixture was shaken, the last addition of water represents the amount of air in the mortar.

7. The shaking process was repeated until two cubic centimeters or less of water was needed to bring the water level up to the gage point. If the container is shaken as specified in step five, the mix will not have to be shaken a second time.

Eight tests were run using a mortar having a 1:3 cement-sand ratio and a 0.9 water-cement ratio. A test on this mix using a water-cement ratio of 0.8 gave poor results due to the mix being very dry and unworkable. Data on unit weights and specific gravities of the materials used were obtained from the records of the Michigan State Highway

Department. Oxford sand (saturated) which has a bulk specific gravity of 1.792, apparent specific gravity of 2.66, and absorption factor of 1.13%; and Petoskey standard portland cement with a bulk specific gravity of 1.536 and apparent specific gravity of 3.12 were the materials used in the mix. The cement and sand were mixed, and then the water was added and mixed. Time of mixing was two minutes, and the mix was allowed to stand for three minutes before the test began. The procedure as outlined above was then followed, and the data on the succeeding page was gathered.

Discussion:

All measurements were volumetric, and consequently no corrections had to be made for the variation in volume of water due to changes in temperature. Volumetric measurements of water were accurate to within one gram or less due to the accuracy of the hook gage. The first five tests were run with a sand which was not saturated, and consequently the results of those five tests differed from the last three due to the fact that some of the mixing water was absorbed by the sand. The average per cent of entrained air in the concrete in the first five tests found by experimentation was approximately 5½% while the average for the remaining tests was approximately 4¾%. The higher percentage of air found in the first five tests probably due to the fact that the sand used in these tests was not saturated, and consequently the experimental results may be said to be consistent and reproducable. The method used to check the experimental results was to compute the absolute volumes of

## TESTS ON MORTAR

| Test | First Addition | Vol. of Tested Mix | Subsequent Additions | % by Vol. of Entrained Air |
|---|---|---|---|---|
| 1 | 174 cc. | 686 cc. | 34 cc. | 4.96 |
| 2 | 187 | 673 | 38 | 5.65 |
| 3 | 144.5 | 716 | 40.5 | 5.66 |
| 4 | 185.5 | 675 | 36.5 | 5.41 |
| 5 | 174 | 686 | 38.5 | 5.61 |
| 6 | 177 | 703 | 36 | 5.12 |
| 7 | 178 | 702 | 32 | 4.56 |
| 8 | 171 | 709 | 34 | 4.80 |

Check:

| Test | Wt. of Mix | Vol. of Mix | Apparent Vol. of Mix | Vol. of Entr. Air | % by Vol. of Entr. Air |
|---|---|---|---|---|---|
| 1 | 2010 gr. | 908 cc. | 879 cc. | 29 cc. | 3.20 |
| 2 | 2023 | 908 | 886 | 22 | 2.42 |
| 3 | 2026 | 908 | 886 | 22 | 2.42 |
| 4 | 2029 | 908 | 888 | 20 | 2.21 |
| 5 | 1990* | 908 | 871 | 37 | 4.08* |
| 6 | 2055 | 908 | 898 | 10 | 1.10 |
| 7 | 2066 | 908 | 902 | 6 | 0.66 |
| 8 | 2048 | 908 | 894 | 14 | 1.54 |

*Very dry mix.

Apparent Specific Gravity = 2.289

the materials used in the mix and from this to find the absolute volume of the mix. From these results the absolute (or apparent) specific gravity of the mix was computed (as shown below).

Apparent Specific Gravity of Mortar:

| | Weight (gr.) | | | Absolute Vol. (cc.) |
|---|---|---|---|---|
| Water | 388 | | | 388 |
| Cement | 650 | 650/3.12 | = | 208 |
| Sand | 2340 | 2340/2.66 | = | 880 |
| | 3378 gr. | | | 1477 cc. |

Apparent Sp. Gr. = 3378/1477 = 2.289

The weight and volume of the mix were known, and the apparent (or absolute) volume of the mix was found by dividing the weight by the apparent specific gravity of the mix. The difference of the measured volume and the apparent volume divided by the measured volume gave the per cent of air in the mortar. The results obtained by this method were always lower than the experimental results, which gave the impression that more air than is normally found in a mortar was incorporated due manipulation or from some other source. The amount and vigor of mixing varied due to the fact that it was done by hand, but this evidently did not effect the consistency of the results. The method of checking was assumed to be satisfactory since those results and the experimental results were in approximately the same ratio for each test (compensating for the fact that the last three tests were made with saturated sand). Since the percentages

of entrained air as determined in the checking process were influenced greatly by the absolute specific gravity of the mix which was in turn determined by the absolute specific gravities of the materials used, the latter were investigated and computations made assuming the maximum and minimum specific gravities of the materials. The variation in the percentage of air in the mortar was plus or minus one-half of one per cent. Consequently, the possibility of error in the absolute specific gravities of the materials was ignored.

The experimental results may be said to be more correct since mortar is usually assumed to have a larger percentage of air than a concrete which usually has a little over one per cent air content. However, the results obtained by the method used for checking give approximately the same air content in mortar that is found in concrete. This may be said to be true since the mortar is usually assumed to fill all of the voids found in the concrete, and consequently the air content of mortar would be the air content of the concrete. No definite answer, however, can be given to explain the inability of the above method of checking to agree with the experimental results despite the consistency of the latter.

Conclusions:

The experimental procedure used gives consistent results, but since the method used for checking produces correspondingly lower results, the experimental percentages found may not definitely assumed to be the correct percentages of air in the mortar.

Since tests on the mortar did not give very conclusive results, a concrete mix was designed and tested with the apparatus shown at the end of this report.

The testing procedure used was similar to that used in the mortar tests and was as follows:

1. The container was filled approximately two—thirds full of rodded concrete and then weighed (for checking purposes only--not weighed in the final field method).
2. A known amount of water was then added to the container until the water surface was just broken by the hook gage.
3. The container was then sealed and turned end over end and rolled twenty times, and then the process was repeated twenty more times.
4. The container was then opened, and a known amount of water added until the water surface was just broken by the hook gage. This amount of water represented the air content of the concrete. The shaking process was repeated until only one or two cubic centimeters of water were needed to bring the water level up to the gage point. If the method of shaking described in step three is followed, the mix will not have to be shaken a second time.

Time permitted only three tests to be run using this method, but the results from these tests were consistent

enough to warrant no further tests although more test data would have been preferred.

The concrete mix used in the tests had a 1:2:3 cement-sand-gravel ratio and a 0.65 water-cement ratio. The materials used in the mix were Oxford sand (saturated) which has a bulk specific gravity of 1.727, apparent specific gravity of 2.66, and absorption factor of 1.15%; Petoskey standard portland cement with a bulk specific gravity of 1.506 and absolute specific gravity of 3.12; and a coarse aggregate having a bulk specific gravity of 1.754, apparent specific gravity of 2.70, and absorption factor of 1.13%. The solid materials were first mixed, the water then added, and the batch mixed for one and one-half minutes and then let stand for three minutes before the test began. The procedure as outlined above was then followed, and the data on the succeeding page gathered.

Discussion:

The results obtained from these tests furnished proof that the method used for finding the air content of concrete is sufficiently accurate for field use. Not only were the results consistent, but the method used for checking these results produced theoretical percentages which checked the experimental percentages in each case, although in each case the theoretical percentages were slightly low. The method used for checking the experimental results was the same as was used to check the amount of air in the mortar, and consequently the method will not be reviewed. Computations for finding the absolute specific gravity of the mix are

# TESTS ON CONCRETE

| Test | First Addition | Vol. of Tested Mix | Subsequent Additions | % by Vol. of Entrained Air |
|---|---|---|---|---|
| 1 | 1385 cc. | 2395 cc. | 46 cc. | 2.005 |
| 2 | 1362 | 2398 | 43 | 1.794 |
| 3 | 1300 | 2480 | 41 | 1.653 |

Check:

| Test | Wt. of Mix | Vol. of Mix | Apparent Vol. of Mix | Vol. of Entr. Air | % by Vol. of Entr. Air |
|---|---|---|---|---|---|
| 1 | 5688 **gr.** | 2395 cc. | 2350 cc. | 45 cc. | 1.879 |
| 2 | 5702 | 2398 | 2357 | 41 | 1.709 |
| 3 | 5913 | 2480 | 2442 | 38 | 1.532 |

Apparent Specific Gravity = 2.420

listed below.

| | Weight | | | Absolute Volume |
|---|---|---|---|---|
| Water | 697 gr. | | | 697 cc. |
| Cement | 1235 | 1235/3.12 | = | 396 |
| Sand | 2962 | 2962/2.66 | = | 1114 |
| Gravel | 4315 | 4315/2.70 | = | 1598 |
| | 9209 gr. | | | 3805 cc. |

Apparent Specific Gravity = 9209/3805 = 2.420

In order to insure satisfactory results, both the fine and coarse aggregate were thoroughly saturated with water. The sand was saturated two days before the tests were to be run and stored in airtight cans for the two day period so as to be sure that the water was thoroughly incorporated in the sand. The cone method was used to determine when the sand had reached the saturation point and consisted of tamping a sample of sand into a container shaped like the frustrum of a cone open at both ends and then removing the cone to see whether the sample would keep its shape. Water was added or subtracted until the compacted sample was such that the outer edges of the top surface crumbled leaving the rest of the top surface intact. The coarse aggregate was immersed in water for two days and then immediately used in the mix without surface drying. Corrections for the amount of surface water on the coarse aggregate were therefore made and applied to the mix design.

As in the mortar, the mixing was done by hand and consequently varied in amount and vigor for each test. The variation in mixing, however, had no noticeable effect upon the results which may have been due to the fact that the mixes were quite sloppy. Sloppy mixes were used to reduce the effect of variations in hand mixing and handling on the final results since it has been shown in tests in recent years that experimental results in tests of air content in concrete are more consistent or reproduceable if the mix is sloppy and workable than if the mix tends to be dry and unworkable.

Conclusions:

Experimental results show that this method of finding the air content of concrete is satisfactory for field use due to its simplicity and accuracy. However, there are evident disadvantages of this method which have been found during the experimental work. These are listed below.

1. The amount of water which is added immediately after the mix has been rodded in the container has been found to be so large as to make it prohibitive to use graduates for measuring the water. A 250 cc. graduate which is the largest that can be used and still satisfy the requirements for accuracy is too small to handle the amount of water required in a short enough period of time. Therefore the water for the first addition has to be measured by weighing which would require a balance in the field.

2. A test using Vinsol resin cement in the mix was run, and the air space between the liquid level

and the top of the container which varies from 90 to 150 cc. was almost completely filled with foam in which is approximately 35% water. Although the volume of this foam could be estimated with a reasonable degree of accuracy, it is desired that a more accurate determination than estimation of the amount of foam be found since one or two cubic centimeters of water can make an appreciable difference in the resulting percentage of air in the concrete as determined by this method.

3. The use of the hook gage as a measuring device requires that the container be kept as level as possible, and that much care be exercised when using the gage. Although this method of measuring exceeds the requirements as to accuracy, the care which must be exercised in keeping the container level and motionless makes a simpler method of measuring desireable.

Although these disadvantages are all of importance, a few corrections and changes in the equipment and procedure used should produce a highly efficient field method for determining the air content of concrete.

## AUTHOR'S NOTE

J. C. Pearson who perfected the method of determining the air content in concrete which is listed in the A. S. T. M. specifications and which is mentioned in the preceeding pages of this report recently revealed a field method for determining air content which was based upon the same principles as his A. S. T. M. method and the method discussed in this paper.

The procedure in his new method was the same as the method developed in this paper except for a few differences which overcome almost all of the disadvantages listed on the preceding page.

These differences are:

1. The container consists of a cylindrical container of exactly one-tenth cubic foot capacity and an inverted cone with a graduated measure projecting up from the apex of the cone. The inverted cone is clamped to the top of the cylinder to form the complete container.
2. The one-tenth cubic foot container is first filled with rodded concrete and, since the volume is then known, the amount of the first addition of water is not required to be known which eliminates the need of a balance in the field.
3. Water levels are kept in the graduated measure and can be read to the nearest cubic centimeter which eliminates the chance of error and the careful manipulation required when a hook gage is used.

4. The graduated measure is long enough so that the foam resulting from shaking is wholly included in the measure and its volume thus being able to be determined.

The only disadvantage apparent at this time of this method is the susceptibility of the graduated measure to breakage.

BIBLIOGRAPHY


"Air-Entraining Portland Cements Eliminate Pavement Scaling", Concrete Highways, Winter, 1943.

"Cement Durability Program", First Interim Report--U. S. Army Engineers, June, 1944.

"Elimination of Pavement Scaling by Use of Air-Entraining Portland Cement", Portland Cement Association, August, 1943.

"Function of Entrained Air in Concrete," Henry L. Kennedy, A. C. I. Journal, June, 1943.

"Method for Determining the Air Content of Freshly Mixed Mortars and Concretes", J. C. Pearson and H. G. Collins, A. C. I. Proceedings, Jan.-Feb., 1936.

"Michigan's Experiences in the Use of Air-Entraining Materials for Concrete Pavement Construction", E. A. Finney, October, 1943.

"Pavement Scaling Successfully Checked", C. L. Moore, Engineering News-Record, October 10, 1943.

"Plain Concrete", E. E. Bauer, McGraw-Hill, 1936.

"Utah Studies Pavement Scaling", Western Construction News, December, 1940.

"Vacuum Method of Measuring the Air Content of Fresh Concrete", G. L. Figman, A. C. I. Journal, November, 1941.

DATA ON AIR-ENTRAINING

TEST APPARATUS

Bituminous Still Used to Test Mortar.

Volume of container (to hook gage) = 860 ± 0.5 cc.
(first five tests)

880 ± 0.5 cc.
(last three tests)

Volume of container (to top) = 908 ± 0.5 cc.

Weight of container (minus cover) = 1744.8 ± 0.05 gr.

Apparatus Used for Testing Concrete.

Volume of container (to hook gage) = 3780 ± 0.5 cc.

Volume of container (to top) = 5872 ± 0.5 cc.

Weight of container (minus cover) = 15.656 ± 0.03 lb.

= 7102 ± 5 gr.

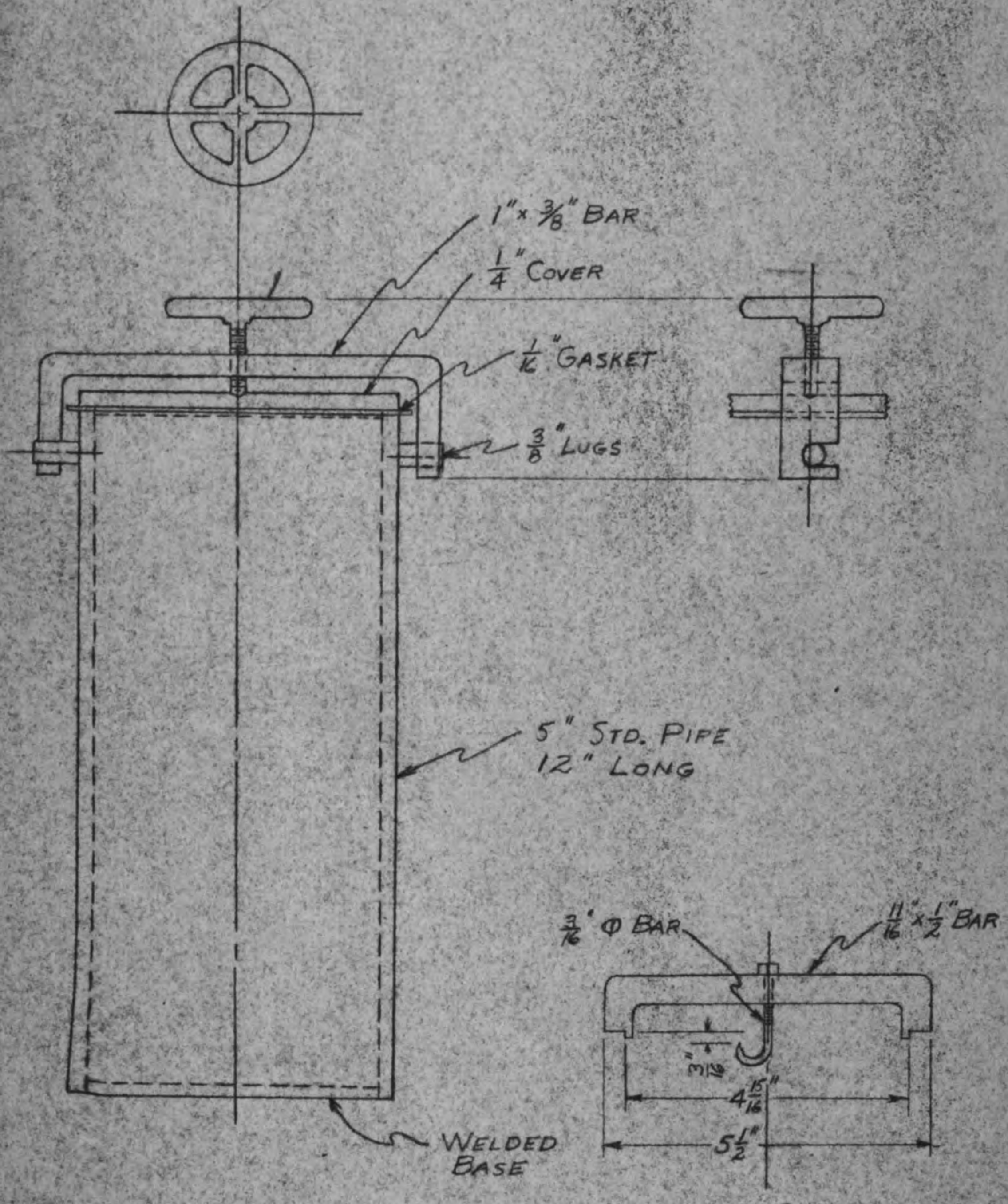
The apparatus for determining the air content of concrete is shown above.

From top to bottom is shown the clamp, cover, rubber gasket, container, and hook gage.


The apparatus for determining the air content of concrete is shown dis-assembled above.

Separate parts are (A) clamp, (B) rubber gasket, (C) container, (D) cover, and (E) hook gage.

# TESTING APPARATUS




1/3 Actual Size

HOOK GAGE

[redacted]