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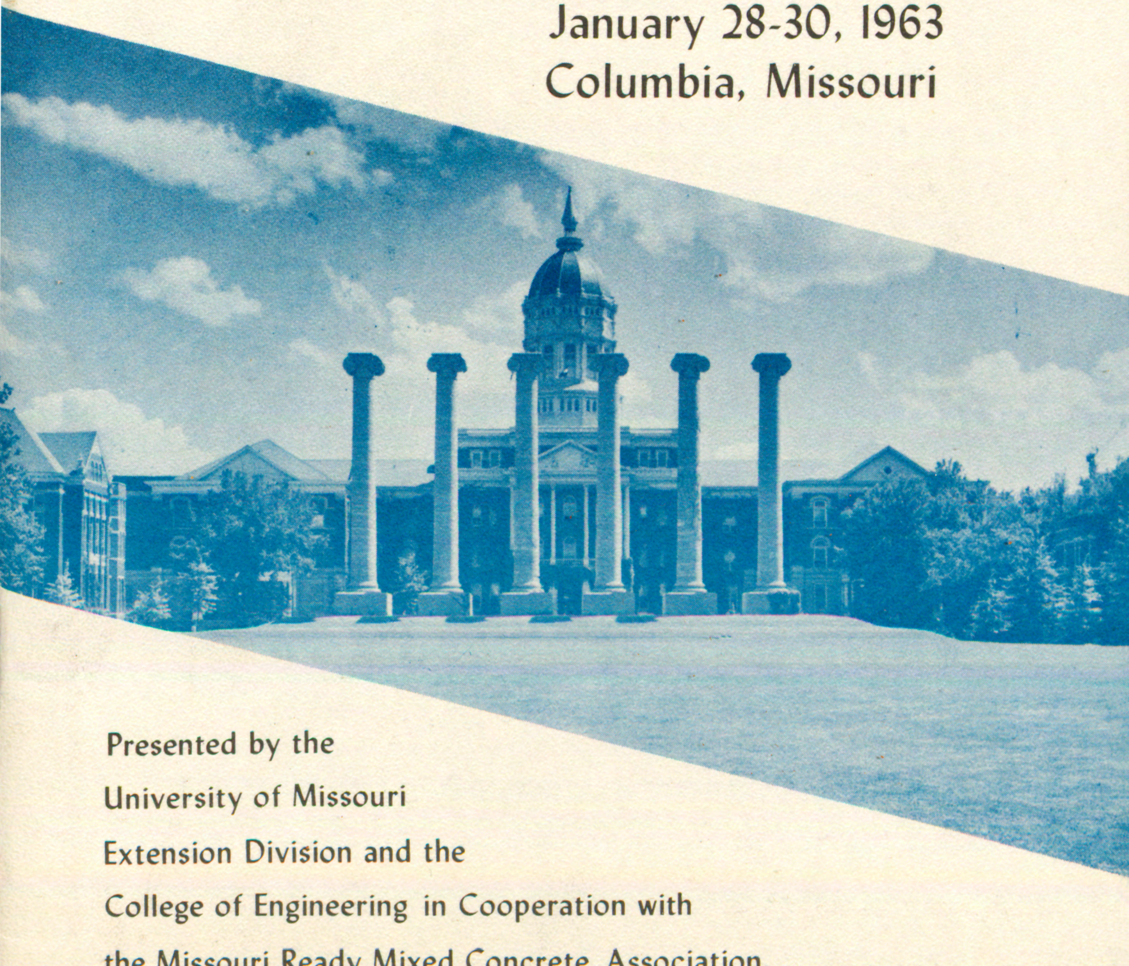

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CONTROL OF READY-MIXED CONCRETE

R. C. Blankenship

The ready-mix producer is a manufacturer of a basic building material. In being a manufacturer he differs from the dealer in building components such as aluminum windows or siding. While he has all of their problems of sales and delivery, he is faced with the additional responsibility of providing good quality control of the concrete he manufactures.

Fortunately, the problems of quality control are constantly being simplified through research by the National Ready-Mixed Concrete Association, the Portland Cement Association, certain committees of the American Concrete Institute and the American Society for Testing and Materials, universities, governmental agencies and many others.

Good control consists of choosing the ingredients, handling and storing them properly, accurately batching and mixing them and delivering the concrete to the job in good condition.

Since 70 to 80 percent of the materials in the mix are aggregates they should be chosen with great care, tested at regular intervals, and handled in a manner which will reduce segregation to a minimum. In addition, any one of several methods of compensating for moisture in the aggregates may be utilized.

Batching equipment should be checked at regular intervals for accuracy.

Mixers should also be maintained regularly and always operated at the recommended speed and number of revolutions to insure thorough mixing.

Drivers should be acquainted with proper methods of discharging the mixer to reduce segregation of the concrete in the forms.

As much as is practical, the temperature of the concrete should be controlled within certain limits both in the winter and the summer. Cold concrete requires extended curing time. Concrete which is too hot may require excessive mixing water, and may crack and have low strengths.

Effectiveness of control of quality should be constantly checked by testing. A single test, or tests at long intervals indicate nothing except the quality of a single batch. It should be the aim of the producer to manufacture quality concrete batch after batch, day after day. Testing will indicate whether or not he is succeeding, and if he is not, which part of the operation is at fault.

ADMIXTURES

George Southworth

As a preface to my remarks on the subject of "admixtures", I might comment that this subject would not have been scheduled for a program such as yours 30, or even 20 years ago. Many of you have been involved with concrete long enough to recall that the first thing you learned about admixtures was that they were not to be used. It must seem strange, therefore, that more and more time on programs such as yours is being devoted to discussions of admixtures of one type or another.

What has brought about this change in attitude? Or, even more important, what was the basis of the original prejudice against admixtures? And, does that basis for prejudice still exist? Is there any foundation to the idea that admixture companies peddle patent medicines?

To understand the bias against admixtures which existed until about ten years ago, you must recognize that, in relation to the history of construction, concrete is almost a brand new material. Man has been building with stone and wood for thousands of years. The use of mortars in stone work dates back to antiquity. But portland cement, as we know it today, was not invented until the early eighteen hundreds, and portland cement concrete, as we know it today, came into general use around the year 1900. In the history of construction, that is only yesterday.

I doubt that anyone will disagree if I say that concrete is the best building value in the history of man. To fill molds or forms of pre-determined shape and size with a plastic material of low cost and have that material harden like stone into the desired shape and size has made possible the kind of construction we see on all sides. It is easy to see why this new material was welcomed with such enthusiasm; enthusiasm that led to the adoption of slogans like "Concrete for Permanence".

All too soon, however, the early owner of a concrete structure found himself faced with costly repair bills. Floors wore out under steel-wheeled traffic. Exposed walls scaled and spalled. Cracks developed. Aggregate pop-outs occurred. It seemed that concrete could not live up to its advance billing. The plain truth was that too much was expected of concrete and not enough was done to help it meet those expectations. Nevertheless, an atmosphere existed in which concrete men were willing to try anything and everything offered to them as a cure for their difficulties.

In this atmosphere the first concrete admixture companies thrived. Little is known, even today, about the chemistry of concrete. Far less was known then. It is obvious that the early admixture was not a scientific approach to any of the problems of concrete. A common practice was to use a material whose action was known, such as calcium chloride, as a base, and sometimes as the only component, and by clever camouflage and a fancy name and by even fancier claims, market an admixture at ten or fifteen times its real worth. Calcium chloride has some merit in concrete but only when it is bought at calcium chloride prices and for the purpose for which calcium chloride is intended.

The performance of these early admixtures bore little or no similarity to the claims made for them. It is small wonder that many construction men developed a strong resentment not only against the materials but against the companies who made and sold them. Often, the first advice the old timer would give the apprentice was, "Don't ever use an admixture, son."

Few of these early admixture companies survived. Those who did found that the reputation admixtures had gained made it necessary to produce products which would do more than was claimed for them. Scientists, engineers and chemists studied the problems of concrete and, as they gained some knowledge of the chemistry of the cement hydration process, they were able to formulate materials that did contribute to the improvement of concrete in both the plastic and hardened states. One of the important discoveries that led to these improvements was the water-cement ratio law, established by Duff Abrams in 1916, almost a century after the invention of portland cement.

Although better admixtures were manufactured, the early history of these materials prevented wide spread acceptance. When Dr. P. H. Bates of the National Bureau of Standards stated, in 1935, that admixtures represented the brightest prospect for improving concrete, there was still so much prejudice that it is doubtful if more than ½ of 1 percent of the concrete contained anything more than cement, aggregates and water.

During the mid-thirties, important discoveries were made by the research departments of the two leading manufacturers of chemical treatments for concrete. One of these involved the use of calcium lignosulfonate, a material previously used in a number of industries as a dispersing agent for finely divided materials. The other covered the use of adipic acid salts. Both materials were found to impart desirable qualities to concrete in which they were used. In both cases, the effects on both plastic and hardened concrete were studied thoroughly before the materials were offered for sale.

In the marketing of these products, great care was taken to avoid exaggerated claims. As you would expect, however, at least the usual number of troubles were experienced. Perhaps the most common complaint was that of excessive retardation. Further research and field experience enabled these manufacturers to control and, when desired, overcome the retarding effects.

As the use of these admixtures became more widespread, it was evident that the chemistry of concrete varied from locality to locality and that performance of an admixture would also vary. To insure maximum benefit to the user, a thorough knowledge of local materials and conditions was of paramount importance. Of necessity, the man charged with the responsibility for selling an admixture had to be responsible, also, for its successful and satisfactory use. As a result, extensive training programs were instituted to bring up-to-date information on concrete technology to the field man. Such information soon established him as a source of assistance in many concreting problems not related, often, to the use of his material.

The soundness of this approach was proven by increased acceptance of admixtures. During the fifties, it was interesting to note that technical papers devoted more and more time and space to admixture discussions. The program of the Annual Convention of the American Concrete Institute referred more and more to admixture concrete. The culmination of a long, uphill struggle took place in San Francisco in October of 1959 when the American Society for Testing and Materials devoted an entire day to a Symposium on the "Effect of Water-Reducing Admixtures and Set-Retarding Admixtures on Properties of Concrete". The papers presented at this symposium have been published by the ASTM as Special Technical Publication No. 266.

This recognition of the value and importance of admixtures in today's concrete has been quite gratifying to those companies who have devoted their research, engineering and field efforts to the improvement of concrete and mortars. At the same time, it has also caused a great deal of concern to these same companies since this recognition has attracted a large number of new enterprises to this field. A few of these have been engaged in other phases of the construction or chemical industries but there are many which have been organized almost overnight. As a result, the producer of ready-mixed concrete is besieged, daily, by a parade of admixture representatives with the "as good as, but cheaper than" approach.

Separating the wheat from the chaff becomes more of a problem. The fact that a producer has been in the admixture field for a long time offers assurance that he knows concrete but it does not guarantee that his product is the best for the money. By the same token, a product cannot be assumed to be worthless simply because it is a newcomer. In discussing water reducers and set-retarders, it is well to consider not only their action in concrete, but the various ways in which a consumer may evaluate them and determine which to use.

It should be pointed out that great care was taken in the ASTM Symposium to refer to Water-Reducing Admixtures as one class and to Set-Retarding Admixtures as a second class. An admixture may fall in both classes or it may be in one class without necessarily having any properties in the other class. For example, a water-reducer often does not qualify as a set-retarder and there are a few set-retarders which do not reduce water.

Some materials which do both may give good water-reduction but inadequate set-retardation; or, by the same token, others with excellent set-retardation have only average water-reducing ability. There are relatively few materials that perform outstandingly in both categories.

The tentative admixture specification adopted by ASTM in 1962 recognized the fact that some admixtures have only one purpose or action while others may be capable of performing both as water-reducers and as set-controlling agents. C494-62T establishes performance standards for five admixture categories which are:

Type A Water Reducers
Type B Retarders
Type C Accelerators
Type D Water-Reducing Retarders
Type E Water-Reducing Accelerators

Unfortunately, the performance requirements have not been set as high as they could be. For example, only 5 percent water reduction is required for Types A, D and E. Type B, Retarders, are permitted to produce strength only equal to 90 percent of an untreated mix. No type is required to produce long-term strength in excess of a plain mix. A limit of 5 percent is set on bleeding or water gain but the stipulation is made that only bleeding which takes place after the mortar has a penetration resistance of 100 psi shall be included. It is unlikely that any bleeding at all would occur when the concrete has reached that degree of stiffness.

The important point is, of course, that ASTM has recognized the value of these materials through the adoption of this specification. As further data are developed with the use of admixtures under C494 more realistic values will undoubtedly be set.

In the selection of a specific admixture, thought should be given to the most essential objective in its use. The need for substantial water reduction is frequently, if not always, the factor of greatest importance. It would appear desirable, therefore, to evaluate admixtures primarily on their ability to reduce water and, where set control is required, give that feature secondary consideration as long as the control is adequate for the work in question. To be more specific, when an admixture is to be used primarily for controlling the rate of hardening, it would seem desirable to use one that enhances the other properties of the concrete to the greatest extent. For example, retardation can be secured with some carbohydrates, soluble zinc salts or soluble borates but, since these contribute little or nothing to the concrete beyond retardation, their use is not justified.

Since all air entraining agents have water-reducing properties, ranging from two to as much as five gallons of water per cubic yard in lean mixes, it becomes necessary to consider the air entraining properties of so-called water-reducing admixtures. When the water reduction is of the same order as that normally associated with the increase in air content, it may well be that the material is a simple air-entraining agent. Typical of such performance is good water-reducing ability in lean mixes and relatively small reductions in rich mixes.

The better water-reducing agents are capable of effecting a reduction in water in excess of that which would be achieved by the same increase in air content with a foaming-type agent and are also capable of maintaining the degree of reduction throughout a range of mixes from lean to rich. The most important examples of such materials are organic substances which can be covered by a fourfold classification:

1. Lignosulfonic acids and their salts;
2. Modifications and derivates of lignosulfonic acids and their salts;
3. Hydroxylated carboxylic acids and their salts;
4. Modifications and derivatives of hydroxylated carboxylic acids and their salts.

Admixtures of these types have been widely used in progressively increasing amounts for the past 25 years. They originated in research by Scripture, Tucker, and Winkler. These admixtures have been included in an estimated 350 million cubic yards of concrete in the United States and Canada, and they are being used now in about 40 million cubic yards of concrete per year. In addition, admixtures of these chemical types are being used extensively in Europe and Asia, as well as in North and South America.

The characteristic constituent of water-reducing admixtures of Classes 1 and 2 are calcium, sodium or ammonium salts of lignosulfonates produced during the sulfite process of wood pulping. Lignosulfonates contain varying proportions of wood sugars; the proportion of such sugars occurring in waste sulfite liquor should be reduced to small proportions during the processing of lignosulfonates for use in concrete. The essential constituent of admixtures of Classes 3 and 4 are sodium, calcium or triethanolamine salts of such compounds as hydroxylated adipic acid and gluconic acid; compounds of this class can be produced by fermentation or oxidation of carbohydrates like glucose, dextrose or starch. In Classes 2 and 4 the lignins and organic acids are combined with organic or inorganic compounds which act as accelerators, retarders, catalysts, air-entraining agents, or possibly air-detraining agents to produce special effects in performance of the admixture.

Many of the ingredients of water-reducing admixtures can be purchased from prime manufacturers by prospective admixture suppliers or consumers as finished or crude products, by-products, or waste products and used or sold for use in concrete. There is no doubt that with proper selection of the raw materials and control of the formulation of multicomponent admixtures satisfactory results can be obtained.

The concrete producer may follow any of three courses in securing an admixture:

1. He may buy from a broker or private labeler raw or processed chemicals under a trade name. These products are often packaged at the pulp mill or other prime manufacturer in the vendor's bags.
2. He may secure these same products direct from the prime manufacturer or pulp mill at a lower price, but unlabeled.

or

3. He may purchase his admixture from an established manufacturer who assumes responsibility for the performance of his product and thus also assumes the responsibility for locating sources of suitable raw materials, researching and engineering the use, improvement and modification of these materials for concrete, formulating, processing and controlling successive shipments to assure uniformity, packaging and storage to prevent deterioration, providing field service to assure proper use.

While materials in Classes 1 and 3 are generally available, most of the materials or combinations in Classes 2 and 4 are covered by existing patents and are available only from the established manufacturers. These are usually the materials of greatest interest to the ready-mix producer since they have controlled setting properties.

What should a consumer expect to obtain for the somewhat higher cost paid for manufactured admixtures in contrast to purchase of the raw materials? Use of a manufactured multi-component admixture will provide the following benefits to varying degrees, depending upon the policies and practices of the admixture supplier: (1) Selection of raw materials from prime chemical suppliers; (2) quality control over raw materials received for purity, performance, and uniformity; (3) processing or modification of chemicals to suit the needs of the finished product; (4) blending or reaction of constituents of multi-component admixtures; (5) quality control of the finished product to assure that satisfactory standards of composition, quality, performance and uniformity are met; (6) packaging in convenient containers or packages to assure freedom from contamination and deterioration; (7) development and supplying of suitable dispensing equipment; (8) technical literature and assistance in use of the admixtures and in other operations pertinent to the manufacture and use of concrete; (9) continuing research to improve the versatility and performance of admixtures and of concrete itself.

Water-reducing admixtures are available as water-soluble powders, powders containing a high proportion of water-insoluble fillers, water solutions of varying concentration, or 100 percent active liquids. The powders may be added with the cement or the aggregate. Water-soluble powders commonly are dissolved in water and added as a solution. For more accurate control, the solution form is preferred. Liquids may be added with the gaging water or with non-absorptive aggregates or added after the other constituents of the concrete have been partially mixed.

The rates at which admixtures are employed in concrete vary from about 2 oz. per sack of cement liquid or dry to not more than 16 oz. per sack of cement, dry. A cubic yard of concrete may contain as little as 12 fluid oz. of an admixture and seldom over 6 lbs. of dry powder. The dosage is small, the effects are substantial. A comparatively insignificant quantity of material can cause a great change in the properties of approximately 4000 lbs. of other materials. It is apparent, therefore, that great care must be exercised in the addition of these admixtures to the concrete. Gross overdoses may produce erratic setting times. Under all conditions, the addition of admixtures should be accurately controlled and as automatic as possible to eliminate the human element. Dispensers are available at nominal cost and often at no cost on a loan or lease basis. These range from manually operated to completely automatic requiring neither setting nor discharge, these operations being tied in with the cement beam and aggregate, cement or water discharge.

When relatively small dosages are used, the accuracy of measurement becomes extremely critical. This is overcome by diluting liquid materials or dissolving powders into fairly dilute solutions so that they can be metered or measured in a greater volume, and are thus easier to control. A pint of solution per sack of cement provides sufficient bulk that any errors or malfunctions of equipment are noticed and corrected immediately. The water used in preparing these solutions or dilutions is always considered as part of the mixing water and the mixing water is adjusted accordingly just as it would be for the moisture in the aggregates.

In general, trial mixes should be prepared and tested to determine the type and rate of use of the admixture to achieve optimum properties of concrete containing the concrete-making materials available at the concrete plant or job. Should the ready-mix producer purchase raw materials for use as an admixture, or purchase through a broker or private labeler, provisions should be made to determine that the materials are uniform from shipment to shipment. Unproved products should be avoided unless investigated in detail to ascertain the effect of the admixture on such properties of concrete as water reduction, air entrainment, working qualities, finishability, rate-of-hardening, early and utlimate strength, resistance to freezing and thawing and volume stability under conditions pertinent to the work.

Water-reducing admixtures produce many important modifications of the properties of concrete. Admixtures based upon salts of lignosulfonates may be used to decrease the time of hardening to about 50 percent or to extend the time of hardening up to about 160 percent of that of equivalent plain concrete. These types of admixtures generally entrain 2 to 4 percent of air, although some types entrain more air under given conditions. If air entrainment is excessive, an air-detraining admixture may be employed. Bleeding and tendency toward segregation are typically decreased.

Hydroxylated carboxylic acid salts are non-air-entraining retarders, although the proportion of an air-entraining admixture required to entrain a given percentage of air is less than that required to entrain that percentage of air in plain concrete. Retardation can be varied over a wide range by use of different formulations. Water reduction effected ranges typically from 5 to 8 percent at given air content. The rate and capacity of the concrete to bleed and settle is increased.

On work where retarded sets are required such as bridge deck concrete placed over cambered steel in warm weather, piers, other massive placements, or any type of concrete where cold joints must be avoided, and slab concrete placed in hot weather, the retarding properties must be fully evaluated. It is common to test for retardation by measuring resistance to penetration of the fresh mortar or by measuring the bond of fresh concrete to steel pins. The latter method may show better correlation with performance in the field since it uses whole concrete and not screened mortar.

Some of the available retarding agents provide control of set by rate of dosage. In some respects, this is advantageous; in other respects, it can present some serious problems. The degree of retardation can be more precisely controlled if dosage rates are adjusted. It must be recognized, however, that other properties of the concrete which are affected by water content will be subject to variation as the admixture dosage is increased or decreased. There is also the problem of correctly anticipating the ambient temperature when thin sections are involved. The set of concrete is a chemical action and, as such, is accelerated by heat and retarded by cold. If ambient temperature should change by 10° it could mean excessively retarded concrete or insufficiently retarded concrete, depending on whether the change was minus or plus from the estimated temperature.

One of the more promising of the set-retarders is designed to control the hydration process of portland cement. Field experience indicates that concrete in 90° weather has about the same setting properties as normal concrete at 70°. In 70° temperature, the treated concrete has only moderate retardation and at 50° exhibits no retarding tendencies. This gives the engineer a built-in protection against erroneous estimates or unanticipated changes in ambient temperature.

The purposes for which water-reducing admixtures and set-retarding admixtures are used in concrete construction are:

1. Economy of proportioning of the concrete mixture, such as use of minimum cement content, use of aggregates which otherwise require high water content, and improved uniformity of concrete.

2. Economy of concreting operations such as reduction of the total cost of concrete-making materials, early form removal and re-use, and ease of placing and finishing.
3. Meeting requirements of job specifications, such as maximum permissible water-cement ratio, early strength development, development of required strength and elasticity, and retention of workability.
4. Improvement of the quality of fresh concrete, such as improved and prolonged workability, reduced water content for given consistency or increased slump at constant or reduced water content, improved finishing qualities, control of bleeding and segregation, and control of plastic cracking.
5. Improvement of quality of hardened concrete; such as increased early and ultimate strength and elasticity, decreased permeability and absorption, increased resistance to freezing and thawing and to scaling, increased abrasion resistance, decreased crack development, and increased bond with reinforcement.
6. Inducing desirable properties, such as controlled retardation to compensate for adverse ambient conditions or to permit introduction of special concreting practices.

Another consideration, almost equaling the quality of the admixture in importance, is the quality of field service offered by the manufacturer. Companies operating in the admixture field that have their own research, engineering and manufacturing facilities are represented in the field by competent concrete technicians. These representatives are able to assist you not only in proper use of their own material but often can give you helpful information on techniques, equipment and concrete materials that can help to assure you of better over-all results. A company can be judged by its representatives and that is especially true in the admixture field.

There may be an inference in this statement that some admixture manufacturers should still be viewed with distrust. I doubt that that is the case, but the fact remains that a great many new companies have entered this field in recent years. Some of these have been engaged in the construction or chemical industries and can be counted on for thoroughly researched and well-engineered products. On the other hand, there are some who are completely unfamiliar with either chemical manufacture or construction and lack the capital required for adequate research and engineering. Their knowledge of what is required of today's admixture will have to be gained on the job where their material may be used. The difficulties that can result from such field experimentation may lead some to believe that the old timer was right when he warned against the use of admixtures.

Why does this condition exist? First of all, the basic patents which covered calcium lignesulfonate and adipic acid in combination with portland cement have expired, making the original components available to anyone. Secondly, there is such a wide interest in admixtures now that it appears to the novice that he can enter the market and enjoy overnight success. He fails to consider the expense involved in necessary research, engineering and manufacturing and the time and expense required to develop a competent field service organization. He also does not recognize that today's good admixture is a processed material and not something which can be bagged and labeled at a pulp plant. Today's admixture has the same resemblance to that covered by the original patents as a diamond has to anthracite coal. The chemical difference may be small but that difference is extremely important.

Will history repeat itself in the admixture industry? We who have worked hard to secure acceptance of our materials in concrete hope not. We hope the newcomers will recognize their responsibility to live up to the confidence expressed by Dr. Bates back in 1935 when he said, "If we accept cements as they are now produced, there seems to be no brighter prospect of improving these throughout their entire life than by the use of admixtures."

LIGHTWEIGHT AGGREGATES AND CONCRETE

Daniel P. Jenny

Today we hear much in the technical literature about the use of light weight concrete. Many significant concrete projects around the country are built with lightweight concrete—the thin-shell roof of the ultra-modern TWA Terminal Building at Idlewild, the floor slabs and beams on the amazing 60-story Marina Towers in Chicago, the back-up concrete on thousands of square feet of decorative precast wall units on the Pan-Am Building over Grand Central Station in New York, and the very extensive site-precast elements in connection with Dodger Stadium. It is used in prestressed concrete, hyperbolic-paraboloid roofs, multi-story frame and floor jobs designed by either elastic or ultimate strength methods, prestressed, long-span folded plates or barrel shells, floating docks, barges, bridge decks, in composite design—in short, in practically every application of normal weight concrete where a reduction in dead weight leads to significant savings in cost of structure.

LIGHTWEIGHT AGGREGATES

Although there is much advancement in the use of structural lightweight concrete, and certainly an outstanding potential for the future, there is unfortunately still much confusion as to what is meant by lightweight concrete.

Based on an individual's personal experience it could mean any number of things. It could mean a gaseous or foam concrete using specially prepared chemicals; it could mean no-fines concrete using ordinary sand and gravel aggregate or crushed stone on a gap-graded basis; it could mean normal weight aggregate concrete with an excessive amount of entrained air; or it could mean a concrete that is made using a lightweight aggregate.

Narrowing the discussion to the use only of a lightweight aggregate to obtain lightweight concrete could still mean many things. First of all we have to define what is meant by lightweight aggregate and here we can fall back on ASTM Designation C-330, "Tentative Specifications for Lightweight Aggregates for Structural Concrete". Among the various criteria, we can single out the fact that the aggregate must have a unit weight of 70 lb. pcf or less (as compared to normal weight aggregate that weighs in the neighborhood of 100 pcf). But all the materials that meet this very general requirement are capable of producing a "spectrum" of concrete weights that varies from a low of 15 pcf to a high of 120 pcf. Let's use this idea of a spectrum and see wherein the various materials in use today fit. (Fig. 1)

At the low end of the scale we have the "super" lightweight aggregates, vermiculite and perlite. They are capable of producing a highly insulative concrete but with compressive strengths ranging from 200 or 300 psi to a maximum of 1000 psi. This concrete is used as an insulative roof fill over a structural system or as fireproofing and is generally applied by licensed applicators or subcontractors. The aggregate also finds widespread use in making lightweight plaster.

At the high end of scale we have structural concrete ranging in unit weight from 85 to 120 pcf and capable of developing compressive strengths from 2500 psi to 5000 and 6000 psi or even more. Note that all of the materials shown here are not necessarily able to produce the high strength concretes without the addition of natural materials and/or excessively high cement factors.

Between the two extremes, with strengths from 1000 to 2500 psi and unit weights between 50 and 85 pcf, are fill concretes, that have some insulative value, some inherent strength. Depending on the materials and the techniques of using them these concretes may have properties of finishability or wearability and at the high end of their range may be used in making small precast products and the like.

Concrete used in making lightweight concrete block falls in the range of weight from 70 pcf to 110 pcf and includes all of the materials shown except the "super" lightweight aggregates.

Of the aggregates in the structural concrete range, pumice, scoria and tuff are natural lightweight materials generally found in volcanic deposits in the West. They have generally poor concrete making properties and are primarily used in making block or in fill concrete. With the use of natural sands some of the material is capable of making a fairly good concrete, but it is still difficult to obtain high strengths.

Coal cinders are rapidly diminishing in availability and that which is available is used principally in concrete block and to a limited extent fill concrete. It has poor and variable concrete making properties and is not currently used as a structural lightweight aggregate.

Sintered expanded shale and expanded slag are primarily block aggregates and have fair concrete making properties. When used alone they have difficulty in achieving high strength even with high cement factors. Of the two, the sintered expanded shales are used to a larger extent in structural uses.

The rotary kiln expanded shales have good to excellent concrete making properties and achieve high strength with reasonable cement factors. In addition they have all of the other desirable properties of quality concrete. It is the principal aggregate used today in making structural lightweight concrete with about 75 to 80 percent of all lightweight concrete made with this aggregate. It is also used in making quality lightweight concrete block.

All of these structural aggregates with increased air contents are capable of producing fill concrete at lower unit weight and with a corresponding reduction in strength. Of course the spectrum becomes quite confused when materials are blended with each other (rarely done) or when mixed with natural sand (frequently done) or when the air contents vary from low to excessive.

THE LIGHTWEIGHT AGGREGATE INDUSTRY

The whole lightweight aggregate industry represents some 250 plants in the United States and Canada and an annual production in the order of 15 million tons. For the confusion of engineers and potential users there are close to 150 different trade names for the various aggregates. But to assist engineers and users there are associations representing the different types of lightweight aggregate—the Vermiculite Institute with headquarters in Chicago, the Perlite Institute of New York, The Expanded Clay and Shale Association representing the sintering grate producers and operating out of Allentown, Pa., the Expanded

Shale, Clay & Slate Institute representing the rotary kiln producers and the National Slag Association for the expanded slag producers both in Washington, D. C. and the Pumice Association headquartered in Phoenix, Ariz. Each has technical data available on its material and each in interested in developing more information on the properties of its material and of course in promoting its use. In addition, many of the individual producers are thoroughly familiar with their aggregate and are another good source of information.

It was mentioned above that about 75 to 80 percent of all the structural lightweight concrete in use today is made with rotary kiln expanded shales. Because much of the recent growth, and most of the future potential, in lightweight aggregate use has been in the structural market, there has been a sizeable increase in number of rotary kiln producing plants from 13 plants about 10 years ago when the Expanded Shale Clay & Slate Institute was organized to a present 46 plants in the U.S. and another 10 in Canada. Additionally there are 3 or 4 plants currently under construction and quite a few are expanding capacity. We can see from this increase in capacity the rapid growth in this one type of lightweight material.

LIGHTWEIGHT AGGREGATES COMPARED TO NORMAL WEIGHT AGGREGATES

Of interest to any ready-mix producer contemplating use of structural lightweight aggregates are the general characteristics—and the differences from the ordinary aggregates he is accustomed to using. Certainly knowledge of the properties of the particular aggregate or aggregates being used; and their behavior in concrete mixes, will eliminate most, if not all, the so-called difficulties or problems that are often associated with lightweight concrete. Some of these properties and differences will be discussed briefly.

Maximum size of lightweight aggregates is generally smaller than most normal weight materials. For expanded slags and shales, the top size is usually ⅜ to ¾ in., although some of the rotary kiln shales may be available up to 1 in. in size. When comparing normal weight and lightweight concrete in certain respects for example optimum air content, there is little or no difference if this factor of top size is taken into consideration.

Particle shape of the lightweight materials is quite varied. Some materials are very angular, rough, and irregular, and surfaces tend to be pitted and harsh. Others may be slightly angular and slightly cubical with fairly regular surfaces, and still others are rounded and smooth. This characteristic is often a clue as to cement contents, proportions, workability and other factors.

Apparent *specific gravity* of the particles is very low, as compared to conventional aggregates, since the expanded particles contain voids or dead air spaces. However, it is dfficult to determine the value because of the problem of getting a saturated, surface dry condition especially in the fine fractions. The specific gravity varies with the size of particle, with the larger pieces having the lowest gravities, while the smaller particles are heavier.

Absorption of lightweight aggregates is high compared to that of normal weight materials. Values in the range of 5 to 20 percent by weight are common, but again an accurate determination of the amount is difficult. Of equal importance is a measure of the *rate of absorption* which suggests the best batching procedure for a given material.

Strength of the aggregate particles varies from type to type. Some may be weak and friable, whereas others are tough and hard. This property may not necessarily preclude its use as a structural lightweight concrete.

Unit weight is significantly lower and this is the important property that leads to economy in structures even though the aggregate cost may be higher. The 30 percent weight reduction in structural lightweight concrete makes concrete a practical material in many instances where normal weight concrete was not feasible before.

Although a lightweight aggregate from a single source is usually quite consistent in physical characteristics—and should be expected to be so—there are differences between sources even though the materials are of the same general type. However, our laboratory investigations of concrete making properties show that with the expanded shales from different producers, the variations are no more, often less, than that which occurs between different sources of hard rock aggregates.

MIX DESIGN FUNDAMENTALS

Properly executed mix design based on trial mix procedures, as well as adequate control measures, are as necessary for lightweight concrete as for normal weight concrete. The same basic rules apply to both. Lightweight concrete obeys the same water-cement ratio law that applies to normal weight concrete. However, the total amount of mixing water used pcy of lightweight concrete is generally always higher than is the case with comparable normal weight mixes. There is no cause for alarm if we realize that the lightweight aggregate particles absorb more water than hard rock aggregates. Dry material that has an absorption of 7 to 15 percent will absorb approximately 15 to 32 gal. of mixing water pcy of concrete. This water is not available to the cement paste in the mix during the hydration process and therefore bears no influence on the water-cement ratio. Thus the *net* effective water-cement ratio of the lightweight concrete is practically identical, at comparable compressive strengths, with that of normal weight concrete.

The effect of having this absorbed water in the aggregate is far from a disadvantage. The water remains in the aggregate during the initial hardening periods and during the normal curing time. Then when the concrete begins to dry out this 15 to 32 gal. of moisture becomes available to the cement paste as moisture equilibrium within the concrete progresses. The absorbed water acts as a reservoir of internal curing water which is available for the continued hydration of the cement even after normal curing procedures have been discontinued.

Because of this absorption characteristic and because dry aggregates tend to segregate and the fines blow away it is generally not advisable to batch concrete with dry aggregate. However, when dry aggregate or aggregate with a low percentage of its total moisture used, it is reasonable to have a pre-mix period in which all of the aggregate and a half to two-thirds of the mixing water are brought together first and the water demand of the aggregate satisfied thereby.

If this is not done there is generally a noticeable loss in slump between the batch plant and the job with attendant difficulty in placing and finishing the concrete.

The usual practice is to furnish the aggregate in a uniform moisture condition somewhat well below the saturation point. Then the pre-mix cycle may be dispensed with and the aggregate handled the same as normal weight aggregates in the batching plant. At one time it was recommended that the lightweight aggregate be fully saturated before use and it was felt that this was the better procedure. But because there is often a large and variable amount of free water available, control of the concrete is difficult. An even more potent argument against this practice is that tests have shown that concrete made with saturated aggregate is substantially less durable than using the same aggregate in a moisture condition less than saturated.

A second consideration in mix design which is a departure from current practice with normal weight aggregates is in the percentage of fines to total aggregate. It is generally higher ranging from 40 to 70 percent by volume depending on the material, its fineness modulus and its particle shape. Certain materials are comparable to sharp, angular sands and crushed rock and thus it is necessary to provide more fine material to give a dense, workable mix. For the same reason entrained air is recommended for use with lightweight concrete to lower the quantity of mixing water, improve the workability and to give plasticity to the mix and prevent segregation during vibration and placing operations. Air-entrainment, of course, increases resistance to freezing and thawing in exactly the same manner as it aids the durability of normal weight concrete. Structural concrete varying in strength from 2500 psi to 5000 psi should have air contents varying from 8 percent down to 4 or 5 percent for the high strength concrete. These air contents are consistent with normal weight concrete having the same top size of aggregate as the lightweight aggregate.

MIX DESIGN METHODS

There are three methods most generally used in designing lightweight structural concrete.

1. *Volumetric.* The first method is the one most commonly used, especially when the concrete producer becomes familiar with a given material. The initial design is based upon known volumes of moisture free aggregates. Mixing water is added by trial until desired slump of concrete is obtained. Following achievement of satisfactory trial mix, the known moisture-free volumes of aggregates are then converted to batch weights from previous unit weight determinations made on the separate aggregate sizes. These batch weights are corrected in the field for such moisture as may be carried by the aggregates at the time of batching.

This particular method assumes that, once the weight pcf of the separate sizes of aggregates is determined, no appreciable variation in the weight-to-absolute-volume relationship will occur. This is not entirely true inasmuch as the actual specific gravity of expanded shale aggregate increases as the particle size decreases. Any change in gradation will, therefore, affect the absolute volume yield of the fixed weights of combined aggregates in the mix. This will accordingly effect a change in yield.

2. *Absolute Volume.* The second method, and one not too commonly used, involves the determination of absorption and of specific gravity on the separate sizes of aggregates in a saturated, surface dry condition. These values are then used to calculate the absolute volumes of the aggregates in the initial design as is customary with dense heavyweight aggregates. Since the values obtained for absorption and saturated surface dry specific gravity cannot be relied upon for lightweight aggregate under present test methods, it is felt that the utilization of these values can lead to variations in yield that are beyond acceptable tolerances.

3. *Specific Gravity Factor.* The third method of design of lightweight concrete is of comparatively recent origin, and is known as the specific gravity factor method. It is thoroughly outlined in the ACI Standard 613A-59, "Recommended Practice for Selecting Proportions for Structural Lightweight Concrete" and should be used when developing trial mixes for various strength to cement content to unit weight relationships. And it is definitely recommended for use where mix designs must be made without prior experience and information on the specific materials involved.

In this method, instead of selecting a water-cement ratio, a cement factor for a given required strength level is chosen. Then aggregate proportions are assumed and water is added to achieve a required slump. The moisture content of the aggregate is pre-determined by drying to constant weight. The initial mix is then made up using known weights of damp aggregates, cement, air-entraining agent and total mixing water required for desired slump. When the trial mix is completed, the wet concrete is checked for weight pcf in order to calculate the actual yield of concrete produced. The percentage of entrained air is likewise determined. No concern, whatever, is given to either the absorption, unit weights, or specific gravity of the aggregates.

From the pre-determined aggregate moistures, we are able to convert the damp batch weights to a dry basis, thus determining the total weight of water in the mix including the water added and the water contained in the damp aggregates.

With this information available, we are able to calculate the absolute volume contributed to the concrete yield from the known factors; namely, the weight of cement used, the weight of the total water in the mix, and the volume of the entrained air in the mix. The difference found to exist between the total actual yield, and the sum of the absolute volumes of cement, water and entrained air, is therefore the absolute volume contributed to the concrete by the total weight of aggregates used. Through utilization of our regular formula for calculation of specific gravity from known weight and known absolute volume, we arrive at a *specific gravity factor* for the lightweight aggregate at hand. This value does not represent true specific gravity. It actually represents a measured factor of relationship between the dry weight of aggregate used and its contribution in yield to the mix.

The specific gravity factor method of design or control works equally well with either all-lightweight mixes or in semi-lightweight concrete where natural sand is used as the fine aggregate.

MIX DESIGN EXAMPLE

For the purpose of illustration, let us set up a hypothetical trial mix with expanded shale, determine the specific gravity factor from this mix and then utilize this factor for final correction of the mix to provide accurate yield and cement factor on the second trial mix.

Let us assume that the following requirements are desired:

6 bags cement pcy

4 percent entrained air in concrete

Let us also assume that 6.0 percent moisture in the fine aggregate and 8.0 percent moisture in the coarse aggregate has been determined. The following trial mix is prepared:

TABLE I

	Pounds as batched (moist aggregates)	Pounds Water in aggregates	Calculated to dry aggregates, Pounds
Cement, Type I	564		564
Expanded Shale, Fine	1200	72	1123
Expanded Shale, Coarse	680	54	626
Water (for desired slump)	375	126	501
Air entraining agent, (3 oz.)			
Total Batch	2819		2819

Determined:

Slump & workability as desired

Entrained air content is 4%

Unit weight wet concrete is 101 lb. cu. ft.

Then: $\frac{2819}{101} = 27.91$ cu. ft. concrete produced.

Wgt. dry aggregate = 1754 lb.

Vol. dry aggregate = 15.89 cu. ft.

27.91 - (abs. vol. of cement + water + air) =

27.91 - (2.88 + 8.03 + 1.11) = 15.89

$$SGF = \frac{1754}{15.89} \div 62.4 = 1.77$$

We have obviously over-yielded in our first mix with the result that our cement content is 5.80 rather than the desired 6.00 bags of cement pcy.

To correct the batch weights to yield the 27.00 cu. ft. of concrete desired we will change the weight of water proportional to the yield obtained and the yield desired, and change the weight of aggregate as indicated by the Specific Gravity Factor determined. The procedure is as follows:

TABLE II

$$501 \text{ lb. water} \times \frac{27.00}{27.91} = 485 \text{ lb. water in new mix.}$$

Then the known factors will provide:

	Pounds	Absolute Volume
Cement	564	2.88 cu. ft.
Water	485	7.77 cu. ft.
Entrained Air (27.00 x .04)		1.08 cu. ft.
Total of known factors		11.73 cu. ft.

Then: 27.00 - 11.73 = 15.27 cu. ft. required from total aggregates.
15.27 x 62.4 x 1.77 SGF = 1687 dry pounds of aggregate required.

Inasmuch as the percentage of fine aggregate to the total aggregate was 64.3 percent in the initial mix, the same ratio of fines to coarse will be maintained, which calculates to 1085 dry pounds of fine aggregate to 602 dry pounds of coarse aggregate.

The corrected mix will accordingly set up as follows:

TABLE III

	Calculated Pounds Dry Basis	Pounds Water in Aggregate	BATCH WEIGHTS Pounds, corrected for Aggregate Moisture
Cement	564		564
Expanded Shale, Fine	1085	69	1154
Expanded Shale, Coarse	602	52	654
Water	485	121	364
AEA (3 oz.)			
Total Batch	2736		2736

This one change in water weight and one change in aggregate weight as calculated from the specific gravity factor will result in accurate desired yield of concrete so long as the entrained air content is maintained at the initial design level of 4 percent.

FIELD OPERATIONS AND CONTROL

Stockpiling. As is the case with normal weight concrete, the handling, storage and observance of uniform moisture content in the aggregates as batched is highly important to the maintenance of uniform quality of lightweight structural concrete.

Lightweight structural aggregates have a unit weight approximately half that of sand and gravel or crushed stone. It is accordingly more subject to segregation, and to the losses of fines through wind movements during handling. Generally the material is furnished in a moist condition to prevent segregation or loss of fines during handling and shipping. The discharging of clam-shell buckets from unnecessary heights above the storage is to be avoided. Discharging from conveyors or open chutes at abnormal heights is likewise to be avoided.

Moisture Control. Uniformity of moisture content in the aggregate storage piles or bins is one of the most essential requirements to successful control of yield, slump and concrete quality. The application of uniform quantities of water through a series of sprays above unloading or distributing conveyors is excellent practice. Several other logical methods of assuring uniform moisture content throughout the storage piles of aggregates can be and are used.

The next question of interest is, "How much moisture should be contained by the aggregates at the time of batching?" Generally speaking, sufficient water should be added to assure aggregate moisture content of from 5 to 8 percent, or roughly, half the amount required to satisfy the total absorption of the aggregate at hand. "Pre-soaking" or "pre-saturation" is not necessary and may lead to difficulty in slump control during batching and handling.

Concrete Control. The control of structural lightweight concrete in field operations is relatively simple. Certain checking procedures which apply to heavyweight as well as lightweight concrete must be recognized and acted upon if uniform quality of concrete is to be achieved and maintained.

Scheduled determinations on the entrained air content of the concrete should be made in order to permit such changes in the amount of air-entraining agent as will maintain the desired percentage of entrained air content. The unchanged use of any given amount of air-entraining agent is not a safe procedure because the air generated can and does vary with changes in temperature and particular mixer action. The generation of too much entrained air can cause serious over-yielding with resultant decrease in the cement content of the concrete.

Air contents should be determined by ASTM Method C 173—the volumetric method using the Roll-a-meter. Pressure meters are not satisfactory for use with lightweight concrete mixes unless they have been specially calibrated or the procedure adjusted for the individual mix being tested.

Similarly, periodic slump measurements indicate necessary changes in the mixing water to be added at the plant and, if too erratic, show up non-uniformity in the moisture condition of the aggregate.

Scheduled determinations on the unit weight of fresh concrete should likewise be made. This unit weight, when divided into the total batch weights being used, checks the yield of the concrete being produced.

If the unit weight of the concrete varies more than 2 pcf from the established fresh weight, the change is generally due to changes in air content or in moisture, and this shows up in the other two control measurements. If not, there may be a change in aggregate gradation, possibly a change in the specific gravity of the aggregate, or a change in the handling and batching procedures and these should be checked out immediately and corrected.

In reviewing these simple control procedures it becomes obvious that approximately fifteen minutes, several times each batching day, is all that is required to provide the information essential to proper control of lightweight concrete quality.

PLACING, FINISHING AND CURING

The procedures for placing, finishing and curing of lightweight concretes are, in general, the same as for any concrete. It should be deposited as close as possible to its final location in the structure to avoid excessive lateral movement and overworking. Vibration should be used with care and sparingly to avoid segregation and loss of air. While overworking, overvibrating, etc., will cause segregation in any concrete, the reaction in lightweight concrete is different from that in normal weight concrete. Instead of the aggregate particles tending to go to the bottom of the concrete layer, the lightweight coarse aggregates rise or float to the surface, making finishing more difficult. This should not be a problem with a properly designed mix subjected to reasonable handling procedures, but because of this tendency the use of jitterbugs is recommended on slabs to help level and consolidate the concrete.

Finishing should be possible in the conventional manner, and curing recommendations, of course, are identical to those for ordinary concrete. Moist curing is essential to a good job, and the longer the moist curing period that can be used, the better.

SOME THOUGHTS FOR READY-MIX PRODUCERS

1. Do not look at lightweight concrete as competition with regular concrete. Lightweight concrete, because of its reduced weight often can put concrete in the picture in long spans, tall frames, cantilever designs where otherwise steel or other materials would be more economical.

—It has helped raise the height limit of reinforced concrete frames so that concrete frames are used today that 10 years ago would have been uneconomical.

—Secondly, if a frame job does go to steel, lightweight concrete still can be used for structural floors and for beam and column fire-proofing because of weight reduction again and its better fire-resistant qualities.

2. Work together with the aggregate supplier to provide the best and most honest price for the lightweight concrete—too many instances of high premiums because the plant is not set up to handle another ingredient or simply because of unfamiliarity with the material.

3. Realize that reduced weight of material means less wear and tear on equipment. A 5-yd. load of normal weight concrete amounts to 10 tons or thereabouts. The same volume in lightweight is only 6⅔ tons.

4. Once you've handled the material and become familiar with its properties, you will learn that it is basically no different from handling normal weight concrete and that it observes the same basic rules that apply to quality concrete.

With constantly increasing use of lightweight aggregates, more and more ready-mix producers will soon find themselves in the lightweight concrete business. With reasonable adherence to the practices for producing any "good concrete", and with cooperation with the aggregate producer in utilizing his material to the best advantage, such use will not only be successful, but will extend the applications of concrete in the construction field.

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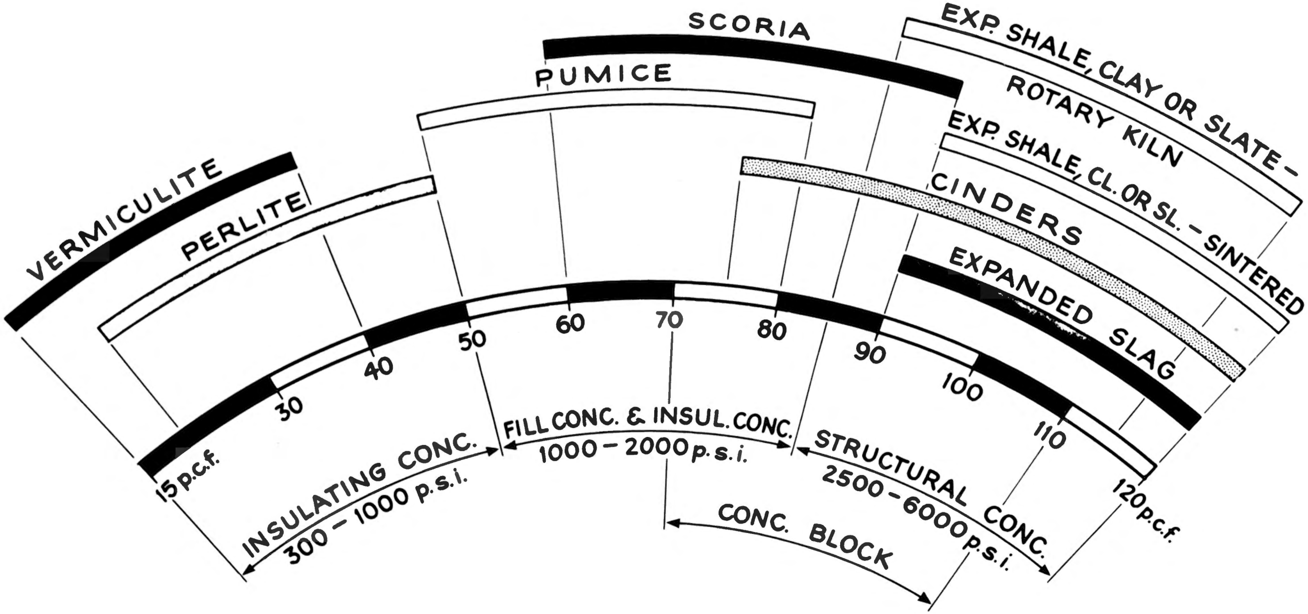

SPECTRUM OF LIGHTWEIGHT CONCRETES

SPECIAL PROBLEMS OF CONCRETING

Robert Brown

According to your printed program, this discussion session is entitled "Special Problems of Concreting". Since most of the enrollment in this course consists of ready-mix producers, I would like to add a subtitle (quote) "From One Producer's Point of View". Twenty odd years ago I got into this mess, which is now known as the ready-mix industry, quite by accident by taking a six-week job on a plant order desk. Having studied mechanical engineering and having been raised in a small town, I had only a vague idea what concrete was and had never even seen a commercial ready-mix operation. At any rate, about the second or third day I picked up the phone and the voice on the other end said, "Hey, Mr. Cement Man, this here is Miz Jones over on fifth street that you just sent that load of cement to. Man, I didn't want that stuff, I wanted that Smo-o-o-o-o-th kind." And so I was introduced to the subject of "special problems of concreting". Well, the industry has come a long way in that length of time, and so have the problems.

By way or orientation, it might be well to project a very brief outline of just what we are going to cover in the next hour. Most "problems" in concreting come in a retrospective manner in the form of failures, so first we will discuss recognition, causes and control of common failures. This will provide us a basis from which to proceed to special problems of hot and cold weather, quality of concrete in the structure and customer relations. Since we only have an hour in which to discuss the problems of a lifetime and since I have always felt that the maximum benefit is produced by open forum discussion, I will hit the high spots, so to speak, and then try to answer any specific questions on points of particular interest, so it would be a good idea for each of you to make a few notes as we go.

Before I get into specifics, there is one general point I would like to make, and to do so, I would like to quote from an article in a recent issue (September, 1962) of Architectural Forum Magazine: "An understanding of concrete begins with the realization that it is more a process than a material—an intricate series of decisions and actions rather than a ready-made tool." I think that the more we, as ready-mix producers, understand about all the problems involved in achieving the finished product, the better we will be able to avoid them.

Common failures in concreting can be grouped into two broad classifications: structural and surface. While most of us own an ulcer or two which can be directly attributed to an occasional low-cylinder break, actual structural failures in commercial structures are very rare. They can, of course, be caused by either of two things: inadequate design or inadequate quality of material. The tendency toward overdesign both in the structure and in the mix, plus the increased control level generally associated with commercial work, will usually be adequate to prevent serious structural failures. Structural failures in residential work and the like are not so uncommon. Usually, these failures take the form of structural cracking and are generally caused by underdesign. Let's examine a typical case—say, a diagonal crack running downward from the corner of a window in a residential basement wall. Since cracks are the direct result of tension stresses which exceed the tensile strength of the concrete, and since concrete inherently is a material of low-tensile strength, the control of this type of cracking becomes primarily a design problem, related in this case to the reinforcing required to withstand the stress, and the footing design which is supposed to be adequate to prevent stresses from getting out of hand at any given point, anyway. At any rate, variations of as much as 20 percent in the *tensile* strength of the concrete would be only in the order of magnitude of 100 psi, which would be less than the reinforcing value of one very small rebar.

Most of the "common failure" problems facing a ready-mix producer are flatwork surface problems and can be subclassified as scaling, pop-outs, and surface cracking. Scaling is the result of internal pressures concentrated slightly below the surface to such a degree that separation of the top layer of mortar results, usually just above the coarse aggregate. These pressures are ordinarily brought about by the formation of ice crystals during freezing, or of salt crystals during drying if the slab has been subjected to salt treatment for the purpose of ice removal. We could spend the entire period on this phase of the subject, but breifly the mechanics of the problem are quite basic. Bleed-water rising during the finishing operation becomes trapped below the top mortar resulting in a weak, porous layer. If moisture is present in this layer at the time of freezing, the ice crystal expansion simply forces off the layer above. Salt solution entering the slab from above creates much the same pressure forces when it dries out and the salt returns to the crystalline state, causing expansion. Proper finishing technique *can* adequately prevent the trapping of bleed water if properly done, but unfortunately we cannot always rely on getting proper finishing. If any surface manipulation is carried on while there is free water on the surface, and particularly if the surface is closed up with metal tools before the bleeding is complete, scaling is almost inevitable if the slab is subjected to freezing and thawing. For this reason, after much research air entrainment was introduced into the picture. Certain chemicals have been found to possess the ability to entrain literally millions of tiny air bubbles into the mix which causes at least three desirable changes in the physical characteristics of the concrete—two in the plastic state and one in the hardened state. First, these air bubbles serve as a lubricator and therefore reduce the water requirement for a given slump, the advantages of which are obvious. Further, they block the capillary channels through which the bleed water rises to the surface. With the proper amount of entrained air, the bleeding can be essentially eliminated and trapping water below the surface mortar becomes a virtual impossibility. With the mix water held uniformly in place, the slab will not form a weak top mortar layer to scale off. There is still another benefit. In the hardened state, these tiny air bubbles form expansion chambers into which the ice or salt crystal formation pressures can be absorbed. In this respect the size and spacing of the bubbles is important. Since this can only be determined by microscopic examination, it is somewhat necessary to rely on the integrity of the manufacturer of the air-entraining agent. However, adjustment of the quantity of agent used in order to control the quantity of entrained air within desirable limits is the responsibility of the producer and frequent control testing is an absolute must.

Pop-outs, as the name would imply, are holes formed by the expansion of unsound particles just below the surface. Usually this problem is the direct result of pieces of shale or other highly-absorptive material in the coarse aggregate and can only be corrected by eliminating the condition which caused it.

Surface cracking is a very common problem and one which prompts a great many complaints. By surface cracking we mean those cracks which occur at early ages and penetrate to a depth of perhaps ½ in. or less, and we can classify them into three basic types: plastic shrinkage cracking, crazing or map cracking, and thermal shrinkage cracking. Plastic shrinkage cracks are caused by excessive water loss from the surface at very early ages when the mass is fairly plastic but the surface is beginning to become rigid. They are big ugly cracks and usually the deepest of all surface cracks. Ordinarily they have no directional pattern, and rarely branch off or extend to any edge of the slab. Many factors contribute to the rate of water loss from a slab surface, so it is impossible to outline the conditions under which these cracks may be expected. Some of the more important of these factors are relative humidity, air temperature, slab temperature, wind velocity, exposure to direct sun, and some of the physical properties of the mix itself. Obviously windy days with low humidity are best avoided if at all possible. Windbreaks and fog nozzle spraying will help. Temperature effects are often tricky. While plastic shrinkage cracking is usually most troublesome in August, I have seen some exceptionally bad cases in the middle of the winter. Overheating of the concrete is usually the villain in such cases. The evaporation rate increases radically with an increase in the differential between air and slab temperature. While a 20° differential will rarely cause cracking, you can almost count on it at 50°. Hence 60° concrete in 40° weather is much superior to 90° concrete in this respect. Also overheating is often responsible for thermal shrinkage cracking. In appearance, these cracks are usually smaller than plastic cracks and are sometimes interconnected. Their frequency of occurrance is not great and it is probable that in many instances they are mistaken for plastic cracks.

Crazing or map cracking, as it is often called, is another frequent problem. It is the direct result of excessive drying shrinkage during the several hours after the completion of the finishing operation, and can be identified by the relatively small pattern or very tiny cracks resembling mosaic tile work. The solution is basic—any good curing procedure followed early enough will usually prevent their formation. It is simply a matter of preventing the slab from drying out and thereby losing volume before it has gained enough strength to withstand the stresses involved.

Another problem which is sometimes the cause of complaints is surface dusting. It is related in some respects to the scaling problem in that it is often caused by reworking bleed water into the surface during finishing, resulting in a high water-cement ratio at the surface with consequent low strength at that point. Such a slab is very low in abrasion resistance. Another contributing factor is overworking which can be critical if the mix contains an excess of inert fines. If brought to the surface during finishing, this can be quite troublesome. Still another cause of surface dusting is carbonation. This is quite a different sort of problem since it involves a bit of chemistry. If a wet slab is subjected to an atmosphere high in carbon dioxide content, the carbon dioxide will react with the cement to form a soft unsound surface to a depth of perhaps ⅛ in. Without getting into the chemistry of the matter, it is important to remember that water is a necessary part of this reaction and that carbon dioxide is not injurious to a slab after it is a day or two old. Adequate membrane or polyethylene film curing is usually effective, but wet curing, even with burlap, doesn't help in the least. As is often true the best remedy consists of elimination of the cause before the problem arises. Unvented space heaters are almost always the cause and as ready-mix producers, who are apt to get blamed for anything that happens, your best weapon here is prevention. Acquaint your drivers with the problem and keep them on the lookout for potential dangers.

At about this point it should become pretty obvious that what we have always known but often forget is still true—most of our problems are in one way or another related to water. Now I don't want to infer that we can solve all our problems by selling only dry, stiff concrete, or that we can sidestep their solution by indignantly shouting, "Somebody added some water and loused up the mix". But on the otherhand, we shouldn't lose sight of the fact that we can minimize many of our problems by minimizing the water requirement of our mixes. There are several factors influencing the water requirement of concrete. Of course, the slump required to please the customer can't be established by the producer, but there are many things which he can do. Elimination of excessive fines from the material and resisting the temptation to oversand the mixes will help. Since fine material has much more surface area than coarse, more water is required to lubricate it. As mentioned before, some of the lubrication can often be done with entrained air. Also avoiding high concrete temperatures will help since water requirement increases rather sharply above 80°. Overmixing often results in slump loss, requiring additional water to restore it. There are many small things a producer can do.

Probably the biggest source of water saving available to a producer is a good water-reducing admixture. I am sure Mr. Southworth covered that matter thoroughly yesterday, but I'd like to say that in the opinion of *this* producer a *good* water-reducer, properly used, is capable of being the best problem solver since whiskey. However, nothing is a panacea, and I must emphasize that admixtures are not an all-purpose tool to be used indiscriminately. Their use involves a thorough understanding of concrete which again is "more a process than a ready-made tool"

There are many special problems associated with hot and cold weather. We all have read somewhere or other that the ideal temperature for curing concrete is about 70°, and we are all aware that concrete behaves differently at temperatures very much above or below that point. In hot weather we find our customers complaining that it sets up too fast, that the strengths are not as high as they were a couple of months ago, that our rock is getting dirty and they can tell by the cracks, or *why* don't we put back that sack of cement we've been cheating them out of so they can finish it like they used to. In cold weather, the strength is going down again, it doesn't set up fast enough (we're leaving out that chloride we charged them for), etc. etc. etc. I'm sure you're all familiar with the problems.

Obviously the best approach from our side of the fence is to keep the temperature as near 70° as practical. Since a pound of water will carry 4 to 5 times as much heat as a pound of any of the other materials, most of the temperature control is applied to the water. In summer, water from underground mains or tanks is much cooler than that stored or piped above ground. Some help can be obtained sprinkling aggregate piles and bins to take advantage of the evaporative cooling. Shading bin tops, etc., will also help. In severe cases, ice can be substituted for part of the mix water. Ice will provide about 8 times as much cooling as the same amount of 60° water. Hot cement also contributes not only to increasing the mix temperature but also to increasing the water requirement. In cold weather certain precautions in heating practice are necessary. If water is heated above 160°, it should be premixed with the aggregate a minute or two to avoid scalding the cement. If it is necessary to heat the aggregates, be very careful not to get spotty overheating, especially at the bottom of a bin. And remember that the same laws of thermodynamics apply to heating as to cooling. You can lose as much heat in 1 lb. of ice as in 8 or 10 lbs. of water, so avoid frozen lumps of material. Actually, it takes relatively little heat to warm up a dry aggregate even at zero—it's the ice that gives the trouble.

Above all, encourage good job practice among your customers. If you don't already know their problems and what they should be doing to help themselves, find out and pass the word around. Acquaint them with such things as temperature-strength relationships. The dividends in the form of reduced complaints will be phenomenal.

Occasionally a read-mix producer must expect to become involved in a controversy regarding quality of concrete in the structure. Most of the cases discussed under "common failures" are potential examples but perhaps more serious than mere cracking and scaling are the controversies concerning strength. Many things influence the strength values obtained by tests of both the fresh and of the hardened concrete, but there is very little in the way of testing errors which can bring about a misleadingly high result. In other words there is practically nothing a lab man can do to a cylinder, or a construction crew to a load of concrete, which can make it any better than it actually is, but there are many things which can be done to make it worse. On the testing side there are such items as improper cylinder castings, handling, storage, transportation, curing, capping and even inaccurate testing and reporting. While most physical laboratories are generally regarded as invincible, still they are commercial operations manned by hired help who are subject to the same human shortcomings as the rest of us. Then too in many cases the casting and early handling are done by someone else, often with little or no technical training. On the construction side of the picture the actual strength in place may be considerably impaired by poor placing practices or inadequate curing and protection. These are a few of the outside influences from which any producer will sometime be called upon to defend his product.

Of course, not all the problems are external by any means. The common cylinder test is at best a sampling and only a relatively large number of such tests will provide a reliable basis for estimating the actual uniformity of the concrete as produced, much less in place. It is physically impossible to produce concrete without strength variations, as we all realize, so we must concern ourselves with limiting these variables. The effects of allowing them to get out of hand are well illustrated in the ACI Manual 214, "Recommended Practice for Evaluation of Compression Test Results of Field Concrete", and I heartily recommend it for your reading schedule if you haven't already done so. Then too, there are within-batch variations due to inadequate mixing. The range of these two types of variations will determine how much you will have to over-design to be reasonably sure of meeting a given strength specification.

As I have mentioned before from time to time customer education can be a very valuable tool in our business. There are many printed pieces available from various sources for this purpose, but it's still pretty hard to beat the personal approach. When a customer has trouble, get out and help him as much as you can. You will find it will promote a degree of customer acceptability you never dreamed was attainable.

THE PROBLEMS OF PROCESSORS OF AGGREGATE FOR CONCRETE

Henry Gish

As producers of aggregates and also ready-mix operators, our problem is to accept the stuff Mother Nature has provided, with a spark of gratitude that it is no worse than it is, and using our heads try to come up with aggregates that will make durable concrete and incidentally get us by the inspectors. Here in our state of Missouri, U.S.A., and that is the only area we are going to talk about, we have not fared too badly with the hand we have been dealt in the aggregates game. Most of our aggregates have a reasonably satisfactory service record, even though some laboratory reports may take a dim view of our products. We do have problems with deleterious substances, usually only small amounts, but occasionally a lot, which calls for specific beneficiation measures.

Our coarse aggregates are predominantly crushed limestone although in the St. Louis area a substantial quantity of gravel is produced. The Mississippi ledge in the south and east and the Bethany Falls ledge in the west make up the bulk of the limestone sources in Missouri. Of the two formations mentioned, the Mississsippi appears to be the better from the standpoint of deleterious material content. At the top of the Mississippi, in what is designated as the Burlington ledge, we understand shale and chert seams were the cause of much trouble in the past, but where outcroppings of this formation were formerly worked in open quarries, operators have gone to mining operations in the recovery of the lower and more acceptable ledges of the Mississippi formation.

In the Kansas City area the producing ledge is the Bethany Falls, a part of the Pennsylvanian formation. This is a massive formation about 24 ft. thick, containing numerous fine shale seams, and bedded on a shale floor. The service record of Bethany Falls rock has for the most part been good, although in some instances slip-shod production methods have permitted excessive amounts of floor shale to get into the product, and inevitably this has brought down strong criticism and sometimes rejection from the purchasing agencies. Floor shale gets into the product by blasting too close to the floor and by careless handling of loading machinery, causing the shale to be scouped up with the shot stone. Excessive percentages of shale in crushed stone is probably the most troublesome problem with which we must contend, and it is solved only by most careful mining and loading methods, and by stationing shale pickers at the primary crusher. Occasionally mud seams are encountered in weathered sections of a ledge, and usually where this condition exists the stone is discarded or used as base material. One rock producer has installed a log washer to clean up the product of a quarry which was badly contaminated with mud seams. The previously mentioned "fine shale" seams in the Bethany Falls ledge are the source of the objectionable "cap shale" and "skin shale" on the aggregate. Much work has been done in the past to reduce or remove this unsound coating. Scrubbing in log washers, and fractionation in impact crushers, which in some instances do improve the product, have practically no effect on Bethany Falls stone. Heavy media separation has also been explored but without significant success. The quantity of objectionable coated pieces usually varies between 6 and 8 percent, and while its presence in concrete, especially in excessive amounts, does definitely lower the resistance of concrete to laboratory freeze-thaw exposure, very few, if any, actual examples of concrete distress have been traced to skin or cap shale in the aggregates. Like many other mildly deleterious substances in aggregates, their otherwise bad influence is quite effectively nullified through the use of air entrainment. Floor shale, on the other hand, does make its presence evident quite early, especially if the contamination is in excess of ½ to 1 percent. Shale particles show up in the surfaces of slabs as pop-outs after only a few freeze-thaw cycles, but as stated, if the percentage of shale is in the lower range mentioned, this results only in impairment of the surface, and seldom if ever is it the cause of structural distress. Repeating our previous statement concerning the control of shale contamination, extraction methods have availed little or nothing, and so far the only effective control for shale contamination is to exclude it before it gets to the crusher and this calls for constant vigilance.

Dust of fractionation is also a front runner in the list of deleterious materials with which quarry operators must contend. Most specifications will permit a maximum of 1½ percent of rock dust, and referring to the tests conducted by Goldbeck of the National Crushed Stone Association, 1½ percent of stone dust has only a negligible effect on either the strength or the durability of concrete.

A popular method of controlling the dust content in crushed stone is rescreening the product over a ⅛ to 3/16 in. opening screen just prior to loading for delivery. Also limiting the distance through which the stone falls into bins and stock piles can reduce the formation of dust. However, conditions do arise where these methods are inadequate, such as damp stone with an adhering dust coating. This condition can occur following a rain or on a warm humid day if the stone is processed directly from a cool mine. Relief from this dust contamination usually calls for washing, either in a conventional log washer, or by installing water sprays over a final screen. For this use a spray pressure of 50 lbs. or more is essential to efficient dust removal. Another frequent trouble maker is dust collecting in the valley angles of bin hoppers, and also in segregated pockets in stock piles. These conditions frequently cause a slug of dust to show up in a single, or possibly in several batches of concrete. Several preventive measures are suggested. First, storage bins in which dust collects in the valley angles should be periodically drawn down and the valleys cleaned out. A further preventive measure would be the elimination of valley angles by using only conical hoppers. Finally, rescreening all coarse aggregate on top of the batching plant will insure the control of dust from a contaminated stock pile, and also provide a means for dividing the aggregate into various sizes and storing them in separate bins from which the desired blend of sizes may be readily made.

Segregation in stock piles and bins is a problem frequently encountered in ready-mix plants. It is most serious where a wide range separates the fine and coarse sizes. However, now that the trend is toward the use of smaller maximum sizes such as 1 in. and ¾ in. the problem of segregation in coarse aggregates is greatly reduced. A frequently unprofitable side result of the general adoption of smaller sizes in aggregates is the inevitable production of much larger percentages of fine materials as by products of the crushers. These fines must be disposed of in markets other than ready-mix plants and since their tonnage can conceivably be doubled in the switch to smaller sizes, their disposal can become an economic problem.

Improper sampling of storage bins and stock piles for testing purposes can also pose a problem for a ready-mix operator. Most of us can recall instances of aggregate rejection merely because the sample was not representative of the pile due to indifference or ignorance on the part of the one collecting the sample. To obtain a fair sample it is usually necessary that a shovel be used to dig into the pile around its periphery at six or more locations depending on its size, in order to as nearly as possible eliminate errors due to segregation. Furthermore, the sample should be reduced to test size by quartering or with a standard sample splitter.

Sand production in Missouri is largely concentrated along the state's two main rivers, the Missouri and the Mississippi. Both streams produce sound durable aggregates with only minor quantities of deleterious materials, principally in the form of lignite. The gradation of the product can be either good or indifferent, depending on the particular location being dredged. Sand produced in the channel of the stream is usually well graded, having 10 percent or more retained on a #8 sieve, 20 percent plus or more on a #16 sieve, and having a fineness modulus of at least 2.60. However, sand produced from bars in shallow water and outside the main channel is usually low in plus 8 and plus 16 material and very high in #30 to #50 materials. In some instances the fineness modulus will drop to 2.10 or even less. To bring this low-grade sand up to specification requirements this excessive middle bulge must be reduced by classifying. For this purpose water scalping classifying tanks are well adapted and are in common use. While the improvement in gradation could also be accomplished by screening, this is a more expensive operation and poorly adapted to large volume production. At some seasons of the year small sticks and vegetable matter pass through the scalping screen and must be eliminated by an apparatus such as the screw classifier-dewaterer. Vegetable matter and lignite if present will usually produce a dark color in the colorimetric test, and may cause the rejection of the sand. However, if the deleterious material is confined to lignite the sand will be acceptable provided it can be shown that the tensile strength of mortar made from the contaminated sand is not more than 10 percent less than the strength of standard sand specimens.

Since lignite does constitute the principal contamination in our sands a method now in use for its removal is described in some detail.

DEVELOPMENT OF LIGNITE REMOVAL EQUIPMENT

Lignite appears in Missouri River and Mississippi River sand as relatively soft, black particles, which over the years has defied removal by screening, classifying or any of the other heretofore known methods of beneficiation. In dredged or commercially produced sand the lignite content may vary from a trace to as much as 0.25 percent. While this amount of inferior material in an otherwise sound aggregate might not cause its rejection on a durability or strength qualification, however, in any structure where the surface of the concrete is exposed, as in floor or paving slabs, the presence of even small percentages of lignite has usually disqualified these sands as an aggregate.

Due to its relatively low specific gravity, 1.35, the lignite tends to float and concentrate at the surface of a slab and this seriously disfigures or impairs the finish and leaves a more or less pitted surface. Test slabs have indicated that a maximum of only .005 percent lignite can be tolerated if a blemish free surface is to be assured.

Efforts to eliminate lignite had been in progress for many years, but it was not until about five years ago that we worked out an efficient and dependable scheme to get the job done. It was evident from our studies that if a sufficiently heavy sand-water pulp could be maintained, and subjected to moderate agitation, the lignite could be floated in much the same manner as coarse aggregates are beneficiated in the well known sink-float process. It was further developed that a sand-water pulp specific gravity of about 1.70 would readily float the lignite, and that this pulp density was not difficult to realize in an appropriately designed apparatus. The trick, as we saw it, lay in holding the sand-pulp surface always at the skimming level so that the floating lignite could be swept off without excessive loss of fines.

Our first approach on a commercial basis was made by adapting an ordinary Eagle double screw washer to the special job of floating the lignite and discharging it over the wier. Our experience with these machines showed that their principal deficiency was the very brief period afforded for the separation of lignite from the sand before the dewatering screws carried it up and out to the finished pile. Many attempts were made to improve the operation, but these details are being omitted for the sake of brevity.

After about two years of operation with these machines, an idea for a machine having a horizontal screw, operating in a horizontal trough with wiers extending for a considerable distance along both sides of the trough was developed. A pilot plant embodying this idea was built and tested and at once the superiority of this arrangement became apparent, since it provided facilities for a much extended period for the elimination and a short path for the discharge of the deleterious material. The design also permitted scaling up the apparatus to a much greater capacity.

Designs were then worked up for a machine having an estimated capacity of 150 tons per hour and arrangements were made with Eagle Iron Works of Des Moines to build the skimmer. This machine has an over-all length of 29 feet, exclusive of screw drive mechanism, and includes first a mixing or feed compartment 5 ft. long by 4 ft. wide containing 30 in. diameter screw flights. Next is the separating or skimming compartment 20 ft. long by 30 in. wide, containing 24-in. diameter screw flights. Also adjustable wiers and collecting troughs are constructed on both sides of the compartment. Finally a discharge hopper 4 ft. by 4 ft. into which the cleaned sand is pushed by the screw flights. River water is supplied to the feed and skimming compartments through a perforated false bottom in the skimmer body, and at the discharge end beyond the screw an inclined baffle in the bottom of the trough produces a partial dewatering and raising of the sand level. Also a spray bar over this portion assists in keeping any floating lignite from entering the discharge hopper.

The discharge hopper is equipped with two of the well known automatically controlled hydraulic power discharge valves which have their sensing vanes set at the desired sand level to secure efficient skimming over the wiers. These valves discharge the clean sand on a 100-ft. centers radial stacker belt.

Raw sand is fed by a Syntron feeder from an overhead 260-ton bin.

The screw flight is driven by a 25 h.p. motor at 25 r.p.m. and about 400 gals. per minute of river water is required for the skimmer trough and spray bar.

Capacity checks on this machine indicate that a rate of 125 tons per hour is readily maintained and the cleaning efficiency is in the bracket from 93 to 97 percent, depending somewhat on the fineness modulus of the sand.

Total cost of installation, not including raw sand bin, was $26,500.00.

Operating cost, including power, labor, maintenance and depreciation, is about six cents per ton.

SKIMMER

Some observers have raised the objection that the skimmer wastes too much fine sand in the deleterious substance discharge over the wiers. While it is true that fine sand is discharged along with the lignite, this fine fraction can be easily reclaimed by passing the wash water over a screen having about a #16 mesh opening which will scalp off the lignite while allowing the fines to pass through into a suitable fine sand recovery apparatus. However, since much of the Missouri River sand contains excessive amounts of fine material, we find that the skimming process very definitely benefits the gradation by raising the fineness modulus in an amount from 0.12 to 0.20, depending on the fineness modulus of the raw feed. This feature alone has proved to be an important money saver in permitting the operator to salvage otherwise unacceptable sand by bringing the fineness modulus up to an acceptable figure. It should be added here that lignite particles finer than a #16 screen do not show up in the surface of finished concrete.

TESTING AGGREGATES AND CONCRETE

V. B. Saville

Ready-mix concrete plants started in Missouri more than thirty years ago. At that time a door appeared to open for the improvement of portland cement concrete in construction work. I can recall at that time this new method appeared to offer great opportunity for improvement in portland cement concrete. Unfortunately, the quality which I had dreamed of has not materialized in many instances. Too often buyers use ready-mix concrete largely because it is more economical or more convenient. Many suppliers of the product have not stressed a quality material. This is not a healthy situation. The ready-mix concrete industry could do well to pattern after E. I. DuPont's President Copeland, when in effect, he said, "If we do not keep abreast of time with products, someone else will succeed us".

A major difficulty in the industry can be explained in a statement made by Mr. William Avery, editor of "Concrete Construction", in an address before the Missouri Ready-Mixed Concrete Association in Jefferson City, Missouri, on December 10, 1962. In effect, Mr. Avery said that many suppliers of ready-mixed concrete are in the business as a sideline. He further stated that your customer today may be your competitor tomorrow. These statements should be a challenge to every producer of ready-mixed concrete. He should resolve that he makes the best possible product, and that he has the best technical information available in his community on the subject of portland cement concrete. No hospital, regardless of its building and equipment, can survive unless it has an able staff of physicians. No ready-mixed concrete plant not equally well-equipped can be sure that today's customer may not be tomorrow's competitor.

You are perhaps already sold on the vital importance of quality in ready-mixed concrete. You would not be at this meeting if you were not convinced that quality is imperative.

Someone might ask, "How do I start? How can I develop a market that can't be taken away over night?" Let us consider that question. The up-to-date plant, in my opinion, needs at least six things: market, money, materials, management, plant, including transportation, equipment and concrete quality know-how or technology to manufacture quality concrete.

Let me touch briefly on the first four. The need of a market is self-evident. The same goes for adequate finances. Aggregates of suitable quality must be economically available. By selective production most aggregate producers in Missouri can supply satisfactory aggregates for portland cement concrete work.

Good management is self-evident. Anyone who has been in business will recognize that no operation can succeed unless it is well managed.

This brings us down to the last two items, plant and technical skill. In building or laying out a plant, in my judgement, you would do well to follow the specifications of the National Ready-Mixed Concrete Association. The requirements can be found in NRMCA Publication No. 109 entitled, "Recommended Guide Specification Covering Plant and Accessory Equipment for Ready-Mixed Concrete in Construction for Highways". You may ask, "How far should

I go in following the specifications of the Association?" Only you can answer that question. Do you propose only to supply what the buyer demands, or do you propose to develop a product which will discourage all potential competitors?

I desire to expand somewhat on the specification previously referred to. A storage space of generous size should be provided for the storage of coarse aggregate. This will add flexibility to the plant in supplying concrete with various maximum sizes of coarse aggregate. An ample space should also be provided for fine aggregate so that material delivered to the plant may have an opportunity to drain and be ready for use only after it has reached a constant moisture content.

A ready-mixed concrete plant without a concrete technician is like a hospital without a doctor. Every high-class ready-mixed plant must have someone responsible for the control of quality. This man must have a reasonably good knowledge of concrete. He needs facilities for making tests and authority at the plant on matters relating to quality of the product.

To the ready-mixed concrete producer who wants uniform production of top quality concrete, I recommend that he follow the pattern established in North Carolina. The Association there has developed a plan in conjunction with the Highway Department for the qualifications of concrete plant technicians. It is covered in a report given by Mr. J. E. Thompson, State Materials Engineer of North Carolina, before the Midwestern Ready-Mixed Concrete Association at the University of Illinois in December, 1961.

Here in brief is the procedure. The prospective concrete technician prepares himself to meet a rigid examination. This examination consists of four parts.

Part 1 deals with a closed book examination concerning fundamental knowledge on concrete and its ingredients.

Part 2 consists of an open-book examination on matters relating to mix design, estimates of strength, and concrete mixes suitable for the wide variety of construction purposes.

Part 3 is a laboratory demonstration of the skills necessary to perform the essential tests.

Part 4 is actual performance at a ready-mixed concrete plant.

The concrete technician's work can be divided into three phases. The first relates to the materials entering into the mixture; second, proper proportioning, mixing and discharging the concrete, and finally the transportation of the material to the user. The materials entering into the mix, in general, are coarse aggregate, fine aggregate, cement, water, and in some cases, additives such as air-entraining agents, retarders, calcium chloride and other possible materials. The quality of both coarse and fine aggregates can generally be established from test reports furnished by the aggregate producer or from the Missouri State Highway Department. Samples can be taken, if preferred, and sent to a commercial laboratory for testing. The samples should be truly representative of the material being tested.

Gradation can be determined by routine tests of materials over a set of laboratory sieves. Actual performance of the test is a routine operation. Selection of the sample, however, calls for judgement on the part of the technician. Results of the test can be misleading if the sample does not represent the material. The moisture of the aggregates entering into the mix must be accurately known in order to determine the amount of mixing water to be added as the mixer is being charged.

The quality of the concrete produced is closely related to the care used in selecting materials, accuracy in determining moisture, precision in weighing and thoroughness in mixing the concrete. Uniformity from batch to batch is of great importance. To accomplish this end, experience, care and judgement on the part of the concrete technician are essential.

Cement of certified quality can be procured from the suppliers, and can be checked, if necessary, by sending samples to a laboratory. Additives may be used when desired. Air-entraining agent can be supplied by the cement company or at the mixer.

Entrained air in concrete, in our experience, is a fickle ingredient. The standard ingredients of aggregate, cement and water can be expected to perform with reasonable dependability. This cannot be said of entrained air. It is subject to variation with different agents, temperatures and is influenced by other factors. Frequent tests, therefore, are imperative to keep the entrained air content in due bounds. Entrained air has little effectiveness if the amount is below 3 percent and if the amount is increased beyond 8 percent, strength of concrete generally decreases very rapidly. The problem is further complicated by the fact that the entrained-air test must be run with exactness. This test is run in accordance with ASTM Designation C231-60.

There are occasions when the concrete should be heated. This can be accomplished by different methods. From the temperature of the heated aggregates and water, the technician, from experience, should be able to predict the approximate temperature of the concrete when delivered to the customer.

In batching the aggregates, the material should be handled from storage piles to batching bins in a manner which will create the least segregation or degradation of the aggregate. Scales should be checked at frequent intervals to make sure that they are in excellent condition. It would be wise, in my opinion, to have the scales checked annually by the Missouri Division of Weights and Measures, Jefferson City, Missouri. The batching operator should be impressed with the importance of accurately measuring each ingredient that composes a batch of concrete. The mixer, water measuring device and mixing blades should be in good mechanical condition, and the concrete should be mixed the required length of time.

When the concrete is discharged, the technician should determine the quality of the material delivered. To accomplish this, he needs to determine consistency (which is generally measured by slump), strength (which can be determined by 6″ x 12″ cylinders), and when appropriate, entrained air content and temperature.

A few days ago a man stopped at our Laboratory to see how a piece of machinery was performing. He sold us this machine two years ago, and he merely stopped by to see if everything was functioning to our satisfaction. I think the same philosophy is desirable in the business of the ready-mix concrete producer. If his finished product performs poorly, he will probably take the criticism even though the construction contractor may have been at fault. Consequently, I think the concrete technician should be in close contact with the use of his product, and wherever needed, offer constructive suggestions for the proper placing and curing of the concrete. Here he needs to give considération, at least in some instances, to the maximum size of coarse aggregate being used, consistency, elapsed time between mixing and pouring, finishing problems, if any, proper protection and curing of finished work. He should also be able to supply information to the user regarding increase in strength with age.

The concrete technician's laboratory should be of substantial construction, well lighted, equipped with a work bench, water, a hot plate and suitable space for the storage of records and testing equipment. A moisture cabinet or storage pit should be available for storing and curing specimens. The technician should either have a compression testing machine for testing concrete cylinders, or be in a position to ship the specimens to a commercial laboratory for testing. A list of suitable laboratory equipment can be obtained from the Missouri State Highway Commission's "Instructions to Concrete Proportioning Plant Inspectors". Equipment not listed in the Missouri Manual are a suitable thermometer, pressure type air indicator or Chase meter to determine entrained air. Perhaps most of all, the concrete technician needs to be alert to the vital importance of quality as a major part of the finished product.

The ready-mixed concrete supplier, large or small, should not be discouraged by these rather demanding proposals. With every forward step he makes in improving the quality and uniformity of his product, he will more firmly establish himself as the ready-mixed concrete supplier in his trade area.

CONCRETE PLANT TESTING

Aggregates -- Selection of Sample

COARSE AGGREGATE

QUALITY

BASIC TESTS
- Los Angeles Wear Test
- Specific Gravity
- Absorption
- Freeze-Thaw

OBJECTIONABLE PARTICLES
- Shale
- Clay or Mud Balls
- Soft Stone
- Chert

GRADATION
- Routine
- Correct Size
- Uniform

WT. PER CU. FT.

ASTM C 29-60

% MOISTURE

FINE AGGREGATE

QUALTIY

Mortar Strength
Freedom From
- Silt
- Mud, etc.

Specific Gravity
Absorption

GRADATION

Routine
Correct Size
Uniform

WT. PER CU. FT.

ASTM
C 29-60

% MOISTURE

$$\text{SP. GR.} = \frac{A}{B - C}$$

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

$$\%\ \text{Moisture} = \frac{\text{Wet Wt.} - \text{Dry Wt.}}{\text{Dry Wt.}} \times 100$$

WHERE: A = Wt. in air.
B = Wt. saturated surface dry in air.
C = Wt. saturated sample in water.

SAND

$$\text{SP. GR.} = \frac{A}{500 - W}$$

$$\%\ \text{Absorption} = \frac{500 - A}{A} \times 100$$

A = Wt. grams dry sample in air.
W = Wt. grams water added to flask.

CEMENT

Quality on Certification from Company

WATER

Rarely a Problem

ADDITIVES

Generally Follow Supplier's Recommendations

HEAT

Aggregate 150°F, Maximum

Aggregate and Water 100°F, Maximum when the Cement is Added

Heat when Concrete is Below 45° for Foundations and Below 60° for all other Work.

DETERMINING QUANTITIES FOR ONE CUBIC YARD OF CONCRETE

THREE STEPS IN DETERMINING MIX

STEP 1 -- CHARACTERISTICS OF MATERIALS

STEP 2 -- MIX DESIGN

STEP 3 -- QUANITITES PER BATCH

STEP 1

PHYSICAL CHARACTERISTICS OF THE AGGREGATES:

	Wt. Per Cu. Ft.	Sp. Gr.	Absorp. %	Total Moisture %
Fine Aggregate	113	2.61	0.2	2.0
Coarse Aggregate	95	2.62	1.2	1.5

COMPUTATION OF ABSOLUTE VOLUME FORMULA

$$V_a = \frac{W}{62.4 \times Sp.\ Gr.}$$

V_a of one sack of cement = 0.4782 cu. ft.
V_a of one cu. ft. of fine aggr. = 0.6938 cu. ft.
V_a of one cu. ft. of coarse aggr. = 0.5811 cu. ft.

STEP 2

THE MIX PROPORTIONS AS GIVEN ARE 1:2.0:3.5

	Absolute Volume
Cement -- 1 Sack	= 0.4782 cu. ft.
Fine Aggregate -- 2.0 cu. ft. x .6938	= 1.3876 cu. ft.
Coarse Aggregate -- 3.5 cu. ft. x .5811	= 2.0339 cu. ft.
Water -- 5.5 gals. = 5.5 ÷ 7.5	= 0.7333 cu. ft.
Sub-Total	= 4.6330 cu. ft.
Yield 1 Sack Batch with 5.0% Air = 4.6330/0.95	= 4.8768 cu. ft.
Concrete Desired -- Volume of 1 cu. yd.	= 27.0 cu. ft.
Number of Sacks of Cement required per cu. yd. = 27.0/4.8768	= 5.54 sacks or 1.39 bbls.

or

5.54 One Sack Batches Per Cubic Yard

STEP 3

DRY BATCH WEIGHTS ARE AS FOLLOWS:	Per Cubic Yard
Cement = 5.54 x 1 x 94	= 521 lbs.
F. A. = 5.54 x 2.0 x 113	= 1252 lbs.
C. A. = 5.54 x 3.5 x 95	= 1842 lbs.
Water = 5.54 x 5.5	= 30.5 gal.

SCALE WEIGHTS:	
Cement (No correction)	= 521 lbs.
F. A. = 1252 x (1.000 + 0.020)	= 1277 lbs.
C. A. = 1842 x (1.000 + 0.015)	= 1870 lbs.

GAL. OF EFFECTIVE MOISURE IN FINE AGGR. = (2.0 - 0.2) x 1252 x .0012	= 2.7 gal.
GAL. OF EFFECTIVE MOISURE IN COARSE AGGR. = (1.5 - 1.2) x 1842 x .0012	= 0.7 gal.
TOTAL EFFECTIVE MOISTURE IN AGGREGATES	= 3.4 gal.

MIXING WATER NEEDED	= 30.5 gal.
Water in aggregates	= 3.4 gal.
Water to be added	= 27.1 gal.

TESTS ON CONCRETE

SLUMP	METHOD OF TEST	MAXIMUM
	P. 22 CPPI Manual	Paving 2" Structures 3" to 4"
AIR	METHOD OF TEST ASTM Des. C231-60 Chase Meter	 Paving 5 ± $1\frac{1}{2}$% Structures $5\frac{1}{2}$ ± $1\frac{1}{2}$%
CYLINDERS	METHOD OF Making Storing Breaking	

Heat when below 45°F for foundations: Below 60°F for all other work.

EXCERPTS FROM THE MISSOURI STATE HIGHWAY COMMISSION MANUAL OF INSTRUCTIONS FOR SAMPLING MATERIALS

Detailed Sampling Procedures

13. AGGREGATE

(A) General.

A representative sample of coarsely graded material from a stockpile or loaded car is extremely difficult to obtain, particularly one intended for gradation test. When taken at the plant during production, a sample should, if practicable, be obtained from the loading chute or conveyor belt during loading operations. In sampling from the loading chute, portions should be taken at regular intervals by passing a pan, scoop, or shovel under the full cross section of the chute and these portions combined and reduced by quartering to the laboratory sample. For conveyor belt sampling a pan may be used to obtain portions from the belt at regular intervals. When sampling a loaded car, the sampler must dig down in not less than three well distributed points and then, by bringing a shovel up the sides of the pits thus dug, obtain portions which when combined will be an average of the material in the car. When sampling a stockpile, it is recommended that separate samples be taken from different parts of the pile, care being taken to observe any segregated areas and bearing in mind that the material near the base of the pile is likely to be segregated and coarser than the average of the material in the pile.

Unless otherwise authorized, a sample should represent not more than one carload (approximately 50 tons). When taken from a stockpile, a sample should be selected to represent each 150 tons in the pile.

(B) Coarse Aggregate for Concrete.

A sample of coarse aggregate shall consist of not less than one full sample bag and should be taken as prescribed in Paragraph 13 (A).

(D) Fine Aggregate for Mortar and Concrete.

A sample of fine aggregate (sand) shall consist of not less than one full sample bag and should be shipped in a canvas sack. Do not use a sack which has previously contained sugar, and make sure that the sack has no tears or holes which will allow loss of fines from the sample.

A sample of fine aggregate should be taken as prescribed in Paragraph 13 (a). When sampling sand from a stockpile, the outer layer of material should be removed until damp sand is reached.

NOTE: Sample bags hold approximately 45 lbs. of aggregate.

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