Final Report

CHEMICAL ADMIXTURE FOR HIGHWAY CONCRETE:
FUNDAMENTAL RESEARCH AND A GUIDE TO USAGE

by

Sidney Diamond
Professor of Engineering Materials

Keisuke Matsukawa
Graduate Research Assistant

Joint Highway Research Project

Project No.: C-36-37DD
File: 5-8-30

Prepared as Part of an Investigation
Conducted by
Joint Highway Research Project
Engineering Experiment Station
Purdue University
in cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

Purdue University
West Lafayette, Indiana

March 31, 1992
Revised February 22, 1993
This report is made up of two distinct elements. Part I is a guide to the current status and potential use of chemical admixtures for concrete, designed for the information and guidance of State DOT engineers. A historical prospective is given on chemical admixtures in concrete, and information is provided on the nature and practices of the concrete admixtures industry. Selection of and specifications for admixtures by State DOTs is reviewed, and a guide to the usage of specific classes of admixtures currently and potentially available is provided. Part II consists of a detailed record of laboratory research carried out to develop a pattern for physicochemical investigation of admixture effects. The procedures developed were then applied to the study of the detailed chemical interactions undergone by several different kinds of superplasticizer admixtures studied with a range of cements displaying various characteristics. Specific conclusions were drawn concerning the effects on superplasticizer effectiveness of certain cement characteristics, especially nature of the gypsum component and of cement alkali content.
ACKNOWLEDGEMENTS

The first-named writer is very much indebted to a large number of people who helped in the accumulation of information concerned with State DOT practices and specifications. Representatives of seven state agencies kindly allowed themselves to be interviewed and provided detailed discussions of present practices and future prospects. He is equally indebted to a number of people associated with the chemical admixture industry, for frank discussions concerning current and future products and their characteristics. However, any errors in his interpretations of current practices and characteristics of the various admixtures are the responsibility of the writer.

The writers also wish to thank two of their colleagues at Purdue, Professor W. L. Dolch and Ms. Janet Lovell, for their advice and assistance in various phases of these investigations.

We also thank Ward Malisch and the Aberdeen Group for permission to reproduce the comprehensive listing of chemical admixture marketers given in Part I Table 1.

The understanding and forebearance of the project advisory board members, Messrs. R. Smutzer of INDOT and L. M. Heil, E. Hoelker, and S. Forster of FHWA are acknowledged with great appreciation.
# Table of Contents (Part I)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>INTRODUCTION.</td>
<td>1</td>
</tr>
<tr>
<td>HISTORICAL PROSPECTIVE ON CHEMICAL ADMIXTURES</td>
<td>2</td>
</tr>
<tr>
<td>THE CONCRETE ADMIXTURES INDUSTRY</td>
<td>4</td>
</tr>
<tr>
<td>ADMIXTURE SELECTION AND SPECIFICATION BY STATE DOTS</td>
<td>11</td>
</tr>
<tr>
<td>A GUIDE TO SPECIFIC CLASSES OF CHEMICAL ADMIXTURES</td>
<td>12</td>
</tr>
<tr>
<td>Air Entraining Agents</td>
<td>12</td>
</tr>
<tr>
<td>Accelerators</td>
<td>14</td>
</tr>
<tr>
<td>Retarders</td>
<td>17</td>
</tr>
<tr>
<td>Water Reducers</td>
<td>20</td>
</tr>
<tr>
<td>Water-Reducing Retarders</td>
<td>22</td>
</tr>
<tr>
<td>Water-Reducing Accelerators</td>
<td>24</td>
</tr>
<tr>
<td>High-Range Water Reducers (Superplasticizers)</td>
<td>28</td>
</tr>
<tr>
<td>High-Range Water Reducing and Retarding Admixtures</td>
<td>30</td>
</tr>
<tr>
<td>Admixtures Not covered by ASTM Specifications</td>
<td>34</td>
</tr>
<tr>
<td>Corrosion Inhibitor Admixtures</td>
<td>34</td>
</tr>
<tr>
<td>Antifreeze Admixtures</td>
<td>35</td>
</tr>
<tr>
<td>Waterproofing Admixtures</td>
<td>36</td>
</tr>
<tr>
<td>“Stop-Start” Admixtures</td>
<td>36</td>
</tr>
<tr>
<td>Alkali Silica Reaction Preventing Admixtures</td>
<td>37</td>
</tr>
<tr>
<td>Shrinkage-Reducing Admixtures</td>
<td>37</td>
</tr>
<tr>
<td>SOURCES OF FURTHER INFORMATION</td>
<td>39</td>
</tr>
<tr>
<td>MINERAL ADMIXTURES AND HIGH-PERFORMANCE CONCRETES</td>
<td>39</td>
</tr>
<tr>
<td>Mineral Admixtures</td>
<td>39</td>
</tr>
<tr>
<td>Natural and Artificial Pozzolans</td>
<td>39</td>
</tr>
<tr>
<td>Fly Ashes</td>
<td>40</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>40</td>
</tr>
<tr>
<td>Ground Granulated Blast Furnace Slag</td>
<td>41</td>
</tr>
<tr>
<td>High Performance Concretes</td>
<td>41</td>
</tr>
<tr>
<td>ADMIXTURE COSTS.</td>
<td>42</td>
</tr>
<tr>
<td>A PROSPECTIVE ON THE USE OF ADMIXTURES IN CONCRETE FOR TRANSPORTATION-RELATED STRUCTURES.</td>
<td>45</td>
</tr>
</tbody>
</table>
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Marketers of chemical admixtures as of Jan. 1, 1992</td>
<td>5</td>
</tr>
<tr>
<td>Table 2</td>
<td>Admixture Cost Estimates</td>
<td>44</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>Product sheet describing an admixture marketed specifically for highway applications</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Product sheet describing one of the newer air-entraining agents</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Product sheet describing several different accelerators marketed by a particular manufacturer for different purposes</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>Product sheet describing a water-reducing admixture. Other benefits are also claimed for this product</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>Product sheet describing a water-reducing set-retarding admixture, marketed by the Sika Corporation</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Product sheet describing a water-reducing accelerating admixture. The accelerating component is said to be an &quot;inorganic formate&quot; and the admixture is said to be free of chloride</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>Illustrative product sheet for a high-range water reducer (superplasticizer)</td>
<td>31</td>
</tr>
<tr>
<td>8</td>
<td>Product sheet for a retarding-type high range water reducer</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Product sheet describing a corrosion inhibitor based on calcium nitrite</td>
<td>36</td>
</tr>
</tbody>
</table>
This report is composed of two elements, in conformance with the original project proposal. Part I is a guide to the current status and future prospects of chemical admixtures for concrete, designed for the specific information and guidance of State DOT engineers. Part II consists of a detailed record of laboratory research carried out to develop a protocol for studying the physicochemical aspects of the results of adding admixtures to concrete, and application of this procedure in studying the internal effects produced by a variety of high-range water reducing admixtures (superplasticizers) on a number of different Portland cements.

Part I provides a historical perspective on the growth of the use of chemical admixtures in concrete, starting with air-entraining agents, to the present proliferation of types and of widespread usage in all but highway concretes. A section is provided describing the current composition of the admixtures manufacturing and marketing industry, and details on marketing and technical service practices. Present practices of State DOTs with respect to chemical admixture selection and specification are briefly reviewed. An extensive guide to the various classes of chemical admixture constitutes the main section of Part I. This includes the details of ASTM and AASHTO specification requirements (where they exist); chemistry of the materials most commonly used for each of the specific types; discussions of specific uses, including indications of effectiveness and of problems connected with specific classes of admixture; and representative product sheets provided by different manufacturers. A listing of sources of further information is provided along with a brief section describing mineral admixtures and on their use in conjunction with chemical admixtures to produce current-generation high-performance concretes.

Part II constitutes the basic research component of this report, and deals with the physicochemical effects of superplasticizers as a representative class of chemical admixtures currently at the leading edge of concrete technology. An extensive review of previous research on the processes occurring during the early hydration of cement paste is given, with special attention to major importance of the gypsum component, and to the changes taking place in the pore solution. This is followed by a review of existing knowledge on the performance of superplasticizers and the physicochemical bases for this performance.

The development of a general method for studying the early-stage interactions of chemical admixtures is then described. This consists of a number of kinds of analyses, each repeated at short intervals through the first day of cement hydration, and then at subsequently at greater intervals. These analyses included (a) quantitative measurement of the uptake of the admixture by the hydrating cement by ultraviolet spectroscopy (b) measurement of the changes in the pattern of ion dissolution and retention in the mix water and pore solution brought about by the presence of the admixture, (c) measurement of the changes in the early hydration processes as indicated by the conversion of other forms of calcium sulfate to gypsum, followed by the
conversion of gypsum to ettringite and to monosulfate, as monitored by x-ray diffraction and specially-devised differential scanning calorimetry techniques. The corresponding effects on the physical properties of the fresh cement paste were followed by rheological measurement using a mini-slump cone.

This protocol was then applied to study the effects of several different naphthalene sulfonate and melamine sulfonate superplasticizers on cements of various characteristics.

An extensive list of more than 25 technical findings was compiled, some of them entirely unexpected. The conclusions arrived at from the great mass of technical data and analyses presented included (1) that the influences of the naphthalene sulfonate and melamine sulfonate forms of superplasticizer with the specific cement components are similar to each other, (2) that the rheological effectiveness of superplasticizers depend on maintaining a reasonable concentration of polymer molecules of the proper chain length in solution, in spite of the tendency of the hydrating cement to absorb these molecules, (3) that this balance between absorption and maintenance of superplasticizer in solution was strongly conditioned by whether or not a sufficient concentration of sulfate ions was also maintained - in cases where it was not, the paste stiffened rapidly and the superplasticizer was ineffective, (4) that with superplasticizer present pattern of early cement hydration was considerably modified. For example, the formation of ettringite was very rapid over the first few minutes and then stopped for some hours, in contrast to its slower but continuous rate of formation without superplasticizer, (5) that superplasticizers substantially reduce the amounts of crystalline ettringite and monosulfate products detectable, presumably due to the poor crystallinity of these products formed in the presence of the superplasticizer, and (6) that the alkali ions (most often Na) used to neutralize the sulfonate groups in superplasticizers remain in the pore solution when the superplasticizers are adsorbed, and are converted to alkali hydroxide, thus increasing the potential for alkali-silica reaction.
GENERAL INTRODUCTION

This project was originated with two distinct but related objectives in mind:

1. To review, evaluate, and interpret current practices with respect to the use of chemical admixtures in ordinary concrete. This effort might hopefully lead to a set of recommendations as to how current generation chemical admixtures coming into widespread use in other segments of the concrete based construction industry can best be applied for highway and other transportation-related concretes. The product of this portion of the study was visualized as being in the form of a guide to current types of admixtures and to benefits to be expected from their utilization. Information on comparative costs and cautions concerning proper use and possible problems might be included.

2. To carry out basic research in the area of how chemical admixtures function in concrete. Chemical admixtures are normally dissolved in the mix water. Their effectiveness to a considerable extent depends on maintaining a reasonable concentration level of these materials in the fluid phase of the concrete over the relevant period of activity. Very little information on concentration levels exists. Thus one objective was to develop methods for determining this and measuring changes in concentration over time. We then proposed to use this newly developed technology to study the behavior and interactions of one or more current generation admixtures used with a range of cements, including cements typically encountered in Indiana highway concretes.
This Final Report is thus a composite of two parts, designed separately to meet the two objectives. Separate introductions sections have been provided for each part.

Part I deals with the complicated overall situation with respect to the use of chemical admixtures in concrete, and contains sections on the history of chemical admixtures for concrete, on the unique features of the chemical admixture industry as presently constituted, and on typical practices in State Departments of Transportation with respect to specifications and control of the use of chemical admixtures. It then provides a profile of each of the major types of admixtures used in the various segments of the concrete construction industry, including chemical type, promised benefits, degree and area of current usage, and possible problems. Some idea of the potential for use of the specific admixture in various highway applications is provided.

One of the many complications that has overtaken this study during the course of its compilation is the very substantial growth of the use of certain mineral admixtures, including fly ash of several types, silica fume, and ground granulated blast furnace slag in concrete, both for highway and non-highway applications. The use of mineral admixtures strongly influences the conditions under which chemical admixtures function in concrete, in some cases the reverse is true as well. A section briefly describing these mineral admixtures and their influences on the behavior of chemical admixtures is included at the end of Part 1.

Part II reports the results of a complex and detailed series of laboratory investigations that formed part of the Ph.D. thesis investigation of Dr. Keisuke Matsukawa, carried out under the supervision of the writer. Dr. Matsukawa chose naphthalene sulfonate superplasticizer as his pilot chemical admixture. He developed a specific analysis for the content of this material in the fluid phase: i.e. the original mix water, and after set, the solution remaining in the pores of the hardened cement paste. He then developed the procedure for conducting repeated analyses at short intervals to determine how the concentration changes over time. At the same time he measured the effects produced
by the presence of the admixture on the concentrations of the cations and anions normally present in cement mix water. He also monitored the changing physical properties of the cement paste, and finally, the corresponding changes in gypsum, hemihydrate, and ettringite contents of the solid phase. All of these analyses, taken together, provide for the first time a complete and accurate picture of what the specific admixture at the specific dosage used was doing to the particular cement it was used with. This provides a pattern for laboratory investigations of admixture effects that had not previously been available.

The pattern was then applied to various dosage levels of two different naphthalene sulfonate superplasticizers on three different cements. Subsequently the pattern was applied to study the effects of malamine sulfonate superplasticizer.

The effectiveness of superplasticizers was found to be intimately associated with the concentration of sulfate ions being maintained in the mix water by the particular materials used. In order for a superplasticizer to maintain its dispersing action and not undergo slump loss, it must maintain a reasonable concentration in solution. Cement mixes that do not do so were found to stiffen and set prematurely. This response was found to be specifically associated with a low concentration of sulfate ions solution; adding sulfate reduces the early uptake of superplasticizer and allows the admixture to continue to function properly.

The superplasticizer level in solution was found generally to be quickly reduced by uptake into the early cement hydration products. The degree of this uptake was inversely correlated with the maintenance of superplasticizer effectiveness. Surprisingly, it was found that the early uptake of superplasticizer by some cements was, under some circumstances, spontaneously reversible after a few hours.

It was found that the pattern of ettringite development in early cement hydration, which strongly influences setting behavior, is much affected by the by the presence and concentration of the superplasticizer.
Most commercial naphthalene sulfonate superplasticizers are alkali neutralized. It was found that the use of such an admixture strongly affects the alkali and OH ion relationships that develop in the pore solution of the resulting concrete. The neutralizing alkali ions (normally Na+) are immediately detected in the mix water. As the dissolved superplasticizer polymer chains are taken up by the hydrating cement, the sulfonate (SO3H-) charged sites on the chains are lost to the solution, but they are immediately replaced by an equivalent number of hydroxyl (OH-) ions. The net effect is a permanent increase in the concentration of OH- ions, and a corresponding greater potential for subsequent alkali aggregate reactions.

Studies were also carried out on the behavior of melamine sulfonate superplasticizers. These constitute a second family of superplasticizers that are not used as widely as naphthalene sulfonates superplasticizers, but still account for a significant proportion of total usage. They were found generally to behave in the same manner as naphthalene sulfonate-based admixtures.

While these studies did not specifically address the effects of mineral admixtures (i.e. fly ash, silica fume, etc.) on the behavior of the chemical admixtures studied, the basic knowledge developed provides a means of predicting what such joint effects might be. Thus it represents a permanent contribution to understanding the chemical fundamentals of what may take place when complex combinations of admixtures are used in concrete, for highway purposes or otherwise.
PART I

CHEMICAL ADMIXTURES IN HIGHWAY CONCRETE: BACKGROUND, HISTORY, AND FUTURE APPLICATIONS
INTRODUCTION

The historical background to this compilation stems in part from, and relates directly to, the changing nature of State agencies responsible for highways and other transportation facilities. Historically, the present State Departments of Transportation are direct lineal descendants of state highway departments, which had as their prime and often sole charge the construction and maintenance of highway networks. A typical example is the present Indiana Department of Transportation (INDOT), which came into existence in 1989 as a direct descendent of the former Indiana Department of Highways (IDOH). There has been comparatively little new construction activity since highway departments changed over to DOTs, and practices, at least with respect to concrete, have probably not changed very much.

By far the largest volume of concrete placed under State Highway Department auspices was for highway pavements, with much smaller volumes being specified for appurtenant structures and specialized structures such as bridge decks. Separate specifications have been, and continue to be listed for bridge deck concrete and for "structural" concrete; such concrete necessarily is of higher standard than the specifications usually require for pavement concrete.

Historically, the only chemical admixtures normally specified for pavement concretes were air entraining agents, used to insure an adequate air-bubble system for freeze-thaw durability. Other admixtures often were permitted, especially for structural and bridge deck concrete. While these admixtures were specified on the basis of their meeting AASHTO (and indirectly, ASTM) standards, they have been selected and used primarily on the representations of admixture suppliers and the experience of local contractors.

The actual extent of use of admixtures on highway jobs has always been much less than on building construction and other concrete applications. Consequently, State Highway Department engineers, even concrete specialists in the central state highway laboratories and offices of the Engineer of Materials, seem to had only limited opportunities to become familiar with them. A further factor was (and is) the relative uneasiness of most civil engineers in dealing with complex chemical matters. Thus
when present trends began to develop involving the development of many new chemical admixtures, widespread use of these in conjunction with fly ash and in some cases silica fume, and highly successful applications of both to building construction and other non-highway applications, the need for additional guidance specifically directed toward State DOT engineers became manifest. This portion of the final report represents an attempt to at least partially meet this need.

To some extent the time scale under which this work was undertaken, and delays due to the writer's medical difficulties, have reduced the need for this report. Other agencies have been active in the intervening period in promoting and providing guidance on admixture use. For example, the Federal Highway Administration has in the past few years conducted a series of demonstration project meetings under the designation "Effective Utilization of Portland Cement Admixtures", to acquaint State DOT engineers with the fundamentals of chemical admixtures in concrete. Transportation Research Board Committee A2-E05 has recently published a 50-page guide on "Admixtures and Ground Slag for Concrete" (Transportation Research Circular 365, Dec. 1990). The American Concrete Institute has maintained an active program of seminars in various locations entitled "How to Effectively Use the Newest Admixtures", and a Seminar Course Manual (SCM-23 (90)) is available. Nevertheless, the writer feels that this compilation still can fill an important need.

HISTORICAL PERSPECTIVE ON CHEMICAL ADMIXTURES

For many years concrete "recipes" contained only Portland cement, coarse and aggregate, sand, and water. The use of other prospective components, including chemical admixtures, were actively discouraged by well respected and influential agencies on the grounds that they were simply not needed and could be detrimental.

After the accidental discovery that air-entraining agents might be successfully used in concrete to prevent freeze-thaw damage, and the widespread adoption of this first chemical admixture, the way was opened for the development and marketing of a great variety of chemical materials to use in concrete mixes for a variety of perceived purposes. Companies specializing in this area were founded, and a recognized chemical admixture industry came into being. In the United States, after a period of development, ASTM codified these chemical admixtures into several classes, based on their intended effects. Set accelerators, set retarders, water reducers, and combination pur-
pose admixtures were recognized and standardized tests were adopted to measure and hopefully predict their effectiveness. AASHTO subsequently adopted essentially the same system for the special needs of highway and transportation agencies.

More recently, the class of "official" chemical admixtures has been broadened to include superplasticizers ("high-range water reducers") and combined superplasticizer-retarders.

However, the "official" admixtures have been in recent years augmented by a rapidly growing collection of chemical admixtures designed for new purposes. Prominent examples include admixtures to help prevent corrosion of steel in concrete, "stop-start" admixture packages that permit a suspension of the hardening of fresh concrete and its resumption after as much as several days, antifreeze admixtures, admixtures to reduce the cracking induced by excessive shrinkage by lowering the surface tension, and others. These are in addition to specialized admixtures designed for use by cement manufacturers (i.e. grinding aids) and admixtures for specialized forms of concrete construction such as shotcrete, pumping aids, etc.

The picture has become even more complex with the much more widespread use of mineral admixtures such as silica fume, fly ash, and ground granulated blast furnace slag. Silica fume acts in concert with superplasticizers to substantially reduce the water demand in concrete, to a far greater extent than can be accomplished by superplasticizers alone; however, by itself, silica fume generally increases water demand. In consequence, high performance concrete based on silica fume incorporation necessarily requires accompanying use of superplasticizer (or sometimes very heavy doses of water reducers). Some fly ashes have similar characteristics, and high performance concretes based on fly ashes usually also require heavy doses of one or the other of these chemical admixtures. However, fly ashes and slags are also widely used in more conventional concrete, including concrete for highway purposes. Indeed, chemical admixture manufacturers are currently marketing "new generation" admixtures, such as air entraining agents, said to be designed to work specifically with concrete containing mineral admixtures.

Because of this proliferation, the present state of affairs with regard to chemical admixture selection and use in concrete may be even more confusing than it has been previously. Certainly combinations of chemical admixtures are more frequently prescribed, and combinations of chemical and mineral admixtures are becoming recognized tools in the design of practical concretes. The potential for problems, particularly for problems reflecting negative interactions, is thus multiplied. On the other hand, the new tools have provided so much improvement in concrete properties and in potential
durability that their judicious use cannot be avoided if the responsible engineer is to properly fulfill his function in producing the best and most durable transportation structures at the least cost.

THE CONCRETE ADMIXTURES INDUSTRY

To understand how and what admixtures should be used in a given situation, it is helpful to understand how concrete admixtures are produced and marketed. Such information is not usually available in published form, and because of this some State DOT engineers tend to be a little bewildered by some of the seemingly arcane practices associated with the concrete admixtures industry.

Concrete admixture marketing began in the United States. The first products marketed to concrete producers were air entraining agents, based on a waste product derived from tree stumps ("vinsol" resin, short for "very insoluble" resin - material left over after various more soluble components had been extracted for other uses). Waste products of various kinds have been widely used in chemical admixture industry formulations since then.

However, in more recent years, admixture manufacturers have typically moved beyond by-product compounding, and have employed extensive technical staffs and conducted highly sophisticated chemical and manufacturing research to formulate and efficiently produce their newer products.

The chemical admixtures industry in the United States has grown from a few producers to a relatively large number of firms. The journal "Concrete Construction" annually publishes a classified list of suppliers of various materials to the concrete construction industry. In the December 1991 issue, the lists include 38 suppliers of accelerating admixtures, 30 suppliers of air-entraining agents, 26 suppliers of retarding admixtures, 29 suppliers of water reducing admixtures, 33 suppliers of superplasticizers, and 17 suppliers of corrosion inhibiting admixtures. The separate lists, of course, contain many duplications, and "only" 65 separate firms are included. The combined listing of all of these firms is provided as Table 1, through the kind permission of Concrete Construction.

These firms encompass a wide variety of sizes and characteristics. The industry has historically consisted of a small group of companies marketing nationally, and a rather larger group of companies marketing regionally, often with limited product lines, but sometimes with great success due to their ability to service local markets. While market share figures are not ordinarily released, it is generally understood that
### Table 1.
Marketers of Chemical Admixtures as of Jan. 1, 1992
(Listing Provided through the Courtesy of the Aberdeen Group, Publishers of *Concrete Construction*)

<table>
<thead>
<tr>
<th>1. Air-Entraining Agents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti Hydro</td>
</tr>
<tr>
<td>Arcal Chemicals</td>
</tr>
<tr>
<td>AXIM Concrete Technologies</td>
</tr>
<tr>
<td>Carroll</td>
</tr>
<tr>
<td>Conchem</td>
</tr>
<tr>
<td>Concrete Producers Dept Store</td>
</tr>
<tr>
<td>Cormix Construction Chemicals</td>
</tr>
<tr>
<td>DFC</td>
</tr>
<tr>
<td>Durafiber Group/</td>
</tr>
<tr>
<td>Hill Brothers Chemical</td>
</tr>
<tr>
<td>Elastizell</td>
</tr>
<tr>
<td>Euclid Chemical</td>
</tr>
<tr>
<td>Fox Chemical</td>
</tr>
<tr>
<td>Fritz Chemical</td>
</tr>
<tr>
<td>Gibo</td>
</tr>
<tr>
<td>W R Grace</td>
</tr>
<tr>
<td>Handy Chemicals</td>
</tr>
<tr>
<td>I A I</td>
</tr>
<tr>
<td>M &amp; L Testing Equipment</td>
</tr>
<tr>
<td>Master Builders</td>
</tr>
<tr>
<td>W R Meadows</td>
</tr>
<tr>
<td>Monex Resources</td>
</tr>
<tr>
<td>Monex Resources</td>
</tr>
<tr>
<td>Nor-Crete</td>
</tr>
<tr>
<td>PQ</td>
</tr>
<tr>
<td>Select Products</td>
</tr>
<tr>
<td>Sika</td>
</tr>
<tr>
<td>Speeco Industries</td>
</tr>
<tr>
<td>Sternson Group</td>
</tr>
<tr>
<td>Texmastic International</td>
</tr>
<tr>
<td>Universal Fastening &amp; Concrete Accessories</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Accelerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti Hydro</td>
</tr>
<tr>
<td>Aqua-Flo</td>
</tr>
<tr>
<td>Arcal Chemicals</td>
</tr>
<tr>
<td>AXIM Concrete Technologies</td>
</tr>
<tr>
<td>Carroll</td>
</tr>
<tr>
<td>Chemtech Laboratories</td>
</tr>
<tr>
<td>Chargar</td>
</tr>
<tr>
<td>Conchem</td>
</tr>
<tr>
<td>Concrete Producers Dept Store</td>
</tr>
<tr>
<td>Compco</td>
</tr>
<tr>
<td>Compex Marketing &amp; Mfg.</td>
</tr>
<tr>
<td>Cormix Construction Chemicals</td>
</tr>
<tr>
<td>Dow Chemical U S A</td>
</tr>
</tbody>
</table>

| Durafiber Group/          |
| Hill Brothers Chemical    |
| Dur-O-Wal                 |
| Euclid Chemical           |
| Foxroc                    |
| Fox Industries            |
| Gemite Products           |
| W R Grace                 |
| Handy Chemicals           |
| A C Horn                  |
| I A I                     |
| Lafarge Calcium Aluminates|
| Lambert                   |
| Master Builders           |
| W R Meadows              |
| Monex Resources           |
| National Varnish          |
| Nordic's-Viking Concrete Products|
| Quikrete Companies        |
| Sika                      |
| Southern Grouts & Mortars |
| Speeco Industries         |
| Spray-Crete Industries    |
| Texmastic International   |
| Universal Fastening & Concrete Accessories |

<table>
<thead>
<tr>
<th>3. Retarders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti Hydro</td>
</tr>
<tr>
<td>Arcal Chemicals</td>
</tr>
<tr>
<td>AXIM Concrete Technologies</td>
</tr>
<tr>
<td>Boremco Specialty Chemicals</td>
</tr>
<tr>
<td>Conchem</td>
</tr>
<tr>
<td>Concrete Producers Dept Store</td>
</tr>
<tr>
<td>Cormix Construction Chemicals</td>
</tr>
<tr>
<td>Durafiber Group/</td>
</tr>
<tr>
<td>Hill Brothers Chemical</td>
</tr>
<tr>
<td>Euclid Chemical</td>
</tr>
<tr>
<td>Foxroc</td>
</tr>
<tr>
<td>Fox Industries</td>
</tr>
<tr>
<td>Fritz Chemical</td>
</tr>
<tr>
<td>Gelashich International</td>
</tr>
<tr>
<td>W R Grace</td>
</tr>
<tr>
<td>Heermann &amp; Reimer</td>
</tr>
<tr>
<td>I A I</td>
</tr>
<tr>
<td>Master Builders</td>
</tr>
<tr>
<td>Monex Resources</td>
</tr>
<tr>
<td>Old North Mfg</td>
</tr>
<tr>
<td>Onoda</td>
</tr>
<tr>
<td>L M Scofield</td>
</tr>
<tr>
<td>Sika</td>
</tr>
</tbody>
</table>
4. Water Reducers

- Anti Hydro
- Arcel Chemicals
- AXIM Concrete Technologies
- Berylex National Sales
- Boremco Specialty Chemicals
- Conchem
- Concrete Producers Dept Store
- Cormix Construction Chemicals
- Durafiber Group/
  Hill Brothers Chemical
- Euclid Chemical
- Fosroc
- Fox Industries
- Fritz Chemical
- Geislich International
- Gibco
- W R Grace
- Haarmann & Reimer
- Handy Chemicals
- I A I
- Lambert
- Master Builders
- Monex Resources
- Nox-Crete
- L M Scofield
- Sika
- Specco Industries
- Specrete-IP
- Texmastic International
- Universal Fastening &
  Concrete Accessories

5. High Range Water Reducers
(Superplasticizers)

- Anti Hydro
- Arcel Chemicals
- AXIM Concrete Technologies
- Boremco Specialty Chemicals
- Conchem
- Concrete Accessories
- Concrete Producers Dept Store
- Cormix Construction Chemicals
- Durafiber Group/
  Hill Brothers Chemical
- Euclid Chemical
- Fosroc
- Fox Industries
- Fritz Chemical
- Gemite Products
- Geochemical

6. Corrosion Inhibitors

- Atlas Minerals & Chemicals
- Concrete Producers Dept Store
- Elkem Materials
- Fosroc
- Fox Industries
- Gemite Products
- W R Grace
- I A I
- IPA Systems
- Master Builders
- Monex Resources
- Nox-Crete
- Nordic’s-Viking Concrete Products
- Nox-Crete
- Onoda
- Sika
- Specco Industries
- Universal Fastening &
  Concrete Accessories
significant portion of the market is dominated by the two largest producers, W. R. Grace and Master Builders, Inc. Informed estimates suggest that their combined share of the total chemical admixture market in the United States may be in excess of 70%. Other large producers include Cormix (incorporating admixtures formerly marketed by the Gifford Hill Co.), Euclid Chemical, Fosroc, Monex Resources, and Sika.

The large firms (and some that are not so large) are often owned by international conglomerates, many foreign owned. They have access to current technology drawn from many chemical and physical fields, and maintain extensive and well-equipped laboratories. Chemical admixture industries are very active in European countries and in Japan. While the industry was started in the United States, like many others, leadership may have passed to overseas competitors. The European industry, in particular is well organized and there is an active European Federation of Concrete Admixtures Associations (EFCA) headquartered in Frankfurt.

In the United States, recent experience indicates that the stability of various companies fluctuates drastically. Buy-outs, reorganizations, and sales of product lines are common. The industry is hotly competitive; new developments formulated by one firm are often quickly matched by competitors. Patent positions play an important role; the larger companies have extensive legal staffs and file many patent applications.

Despite this emphasis on modern technology and international development, marketing strategies seem not to have changed very much. From the beginning, technical service and problem solving have been most important components of the marketing effort, to a much greater extent than in other fields. Admixture suppliers have traditionally supplied a "full service" package to their customers, and have included the costs of such services in the price of the admixture. These services often include provision for providing and maintaining admixture dispensers, monitoring large jobs, and investigating causes of field problems.

This tradition generally continues, although some firms now market admixtures on a commodity basis, without the service, but at lower prices. Indeed, there are some indications that a few ready mix concrete producers are blending at least some of their own concrete admixtures from industrial raw materials.

Specific admixtures are often marketed under a general product line designation, and differentiated from each other by supplementary letter or numbers.

The usual practice in the industry is to guarantee that any product delivered will conformance with ASTM (or AASHTO) specifications, but not to guarantee that the specific product will always be formulated from the same components, nor indeed to identify the components beyond certain vague class designations. This industry prac-
tice is unlike that in most European countries, where admixture manufacturers typically are required to disclose the actual chemical ingredients used in their products. Thus in the United States the actual composition of a given admixture may change without the name of the admixture being changed. Indeed, different formulations may appear under the same product name in different regions. Conversely, the same product may carry different names in different markets.

Certain firms produce a specially-designated line of admixtures for the highway pavement market, which may or may not include the same materials produced for sale to the general concrete industry. Typically such admixtures are provided only in bulk, rather than in pre-packaged containers. A product sheet describing one such admixture ("Masterpave") is provided as an illustration in Figure 1. This and other product sheets reproduced in this report are for illustrative purposes only; no endorsement of any of the specific products or of the claims listed is expressed or implied.

Admixture companies characteristically produce a product sheet for each of their admixtures. These typically contain (1) a description of the product (2) the advantages claimed, (3) applicable ASTM or other standards that are claimed to be met (4) recommended dosage rates, (5) technical data (6) information on compatibility with other products (7) precautions that should be observed. Manufacturers generally advise close conformance to the suggested dosage rates and to the listed precautions. Manufacturers providing service to clients will generally, but not always so indicate by some statement like "For further assistance, consult your local X Company representative."

The product sheet that was shown in Figure 1 to illustrate a special product aimed at transportation departments is rather less specific than most product sheets aimed at the general market. Most product sheets are rather more detailed in the information provided. Product sheets from various manufacturers are included as illustrations in the various sections describing specific types of admixtures. Again, no endorsement of these specific products is implied.

One particular component of some admixtures deserves special mention. It has been well established for many years that the presence of chlorides in concrete promotes corrosion of embedded steel, and efforts have been made by many in the concrete field to eliminate all possible sources of chloride in reinforced and prestressed concretes. In accord with this trend, the current version of the ASTM standard specification for chemical admixtures for concrete (C 94 - 90) carries the proviso (Section 5.4) that "At the request of the purchaser, when the admixture is to be used in prestressed
MASTER PAVE
Admixture Products Information

**DESCRIPTION:**
Master Pave is a ready-to-use, liquid admixture expressly recommended for pavement concrete. It meets ASTM C 494 requirements, specifically:

- Increased Strength—compressive and flexural

**ADVANTAGES:**
Master Pave admixture aids in the production of concrete which has the following special qualities in the plastic or hardened state:

<table>
<thead>
<tr>
<th>Plastic Concrete</th>
<th>Hardened Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Workability using less water</td>
<td>Improved Workability using less water</td>
</tr>
<tr>
<td>Reduced Segregation</td>
<td>Reduced Segregation</td>
</tr>
<tr>
<td>Increased Placing Rate</td>
<td>Increased Placing Rate</td>
</tr>
<tr>
<td>Greater Edge Stability and Stump Control</td>
<td>Greater Edge Stability and Stump Control</td>
</tr>
<tr>
<td></td>
<td>Higher Early Strength</td>
</tr>
</tbody>
</table>

**WHERE TO USE:**
This admixture can be used in all paving-related concrete requiring normal set in combination with all the benefits of an effective, water-reducing admixture. Master Pave admixture is chloride-free (less than 10 ppm by weight of cement). Master Pave admixture can be used with all air-entraining admixtures approved under AASHTO CRD and ASTM specifications, including Master Builders air-entraining admixtures. When used in conjunction with another admixture, each admixture must be dispensed separately into the mix.

**QUANTITY TO USE:**
Master Pave admixture is recommended for use at a rate of 4 to 6 fl oz per 100 lb (260 to 390 ml per 100 kg) of cement for most concrete mixes using average concrete ingredients. Because of variations in job conditions and concrete materials, dosage rates other than the recommended amounts may be required. In such cases, contact your local Master Builders representative.

---

**Figure 1.** Product sheet describing an admixture marketed specifically for highway applications.
<table>
<thead>
<tr>
<th><strong>PACKAGING:</strong></th>
<th>MASTERPAVE admixture is supplied in bulk.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEMPERATURE</strong></td>
<td>Care should be taken to prevent MASTERPAVE from freezing. If it freezes, thaw at 35°F (2°C) or above and completely reconstitute by mild mechanical agitation. Do not use pressurized air for agitation.</td>
</tr>
<tr>
<td><strong>PRECAUTION:</strong></td>
<td>For additional information on MASTERPAVE admixture or on its use in developing a concrete mix with special performance characteristics, contact your local Master Builders representative.</td>
</tr>
</tbody>
</table>

**MASTER BUILDERS**

IMPROVING CONCRETE WORLDWIDE

CLEVELAND, OHIO 44122

© 1986, Master Builders, Inc

Form MPAVE 3a
Printed in U.S.A., 1986
concrete, the manufacturer shall state in writing the chloride content of the admixture and whether or not chloride has been added during its manufacture*.

While comparatively little prestressed concrete is used for transportation purposes, highway bridge decks are heavily reinforced, and in most of the country are heavily subject to steel corrosion damage. Under the circumstances, the restriction of this provision to prestressed, rather than to both prestressed and reinforced concrete, seems curious. Some state DOTs have instituted more stringent requirements as part of their standard specifications. For example, the Indiana Department of Transportation specification carries provisions to the effect that no chloride can be deliberately added to an admixture in its formulation, and the total percentage of "incidental" chloride must be specified by the manufacturer.

**SELECTION AND SPECIFICATION OF ADMIXTURES BY STATE DOTS**

In the United States chemical admixtures for concrete generally are supplied as conforming to one or another of the relevant ASTM standards: ASTM C 260 - 86, Standard Specification for Air-Entraining Admixtures for Concrete; ASTM C 494 - 90, Specification for Chemical Admixtures for Concrete, and ASTM C 1017 - 90, Standard Specification for Chemical Admixtures for Use in Flowing Concrete. For highway and transportation use, the American Association of State Highway and Transportation Officials has adopted the substance of two of these specifications as M-154 (for ASTM C-260), and M - 194 (for ASTM C-494). The specification for admixtures for flowing concrete has so far not been adopted by AASHTO.

In addition to the standard specifications referenced above, most State DOTs add specific requirements and exceptions based on local experience or practice. The volume of highway and transportation business has been historically great enough that suppliers will ordinarily meet such local amendments.

The usual practice is for prospective admixture suppliers to submit samples and results of testing directly to the relevant division of the State DOT. If the results are satisfactory the supplier is placed on the "Approved List" of suppliers for that particular class of material.

Some chemical admixtures, particularly the newer ones, are not covered by ASTM or AASHTO specifications. In some cases at least, appropriate specifications are under development, but the process is slow and because of commercial considerations the necessary consensus may be difficult to reach.
A GUIDE TO SPECIFIC CLASSES OF CHEMICAL ADMIXTURES

Air Entraining Agents

As has been previously mentioned, air-entraining agents were the original chemical admixtures, and are probably still the most widely used of the various types. Their widespread use is based not only on their ability to prevent freezing and thawing damage, but also on the desirable "buttery" character induced into the consistency of the fresh concrete. Other perceived benefits include lower permeable and absorptivity of the hardened concrete, and in some cases possibly increased resistance to the effects of sulfate attack and of alkali aggregate attack.

ASTM C 260 (and its AASHTO M-154 equivalent) specify certain performance characteristics not related to the primary function of the admixture, namely (a): a limitation on bleeding compared to the bleeding of the same concrete without the admixture; (b) a limitation on changes in setting time (no more than 1-1/4 hour retardation or acceleration); (c) limitations on both compressive strength and flexural strength reductions at any age of test (to no more than 10% of the reference strength without the admixture), with the flexural strength limitation being optional, and (d) a limitation on length change, to be no greater than 120% of that of the reference concrete after 14 days of drying. Strangely, the dosage of the admixture for these tests not prescribed, and is presumably the manufacturer's normal recommended dose rate.

The primary functional requirement specified for air entraining agents is that resistance to freezing and thawing measured by Procedure A of ASTM Test Method C-666 be established at a relative durability factor of 80%. Again, the dosage of air entraining agent to use to establish such effectiveness is not specified.

In point of fact, the effectiveness of a given air entraining agent in preventing freeze-thaw damage is well understood to be a function of the stability of the entrained air void system under the necessary field handling conditions, and in the last analysis, to the success of the agent in achieving a bubble spacing factor of the order of 0.01 in. or less. The freeze-thaw resistance of concrete is usually linked to the total air volume percentage, which may be specified differently for different classes of concrete and different conditions of exposure. However, the air entraining agent specifications neither
require nor permit the option of determining the effectiveness of a given air entraining agent in producing a given level of air entrainment or a given bubble spacing factor at any particular dosage rate.

Air entraining agents are ordinarily adsorbed at air-water interfaces, and reduce the surface tension of the water significantly. Some air entraining agents (those with insoluble calcium salts) precipitate solid or gelatinous films around entrained air bubbles. The sand content and gradation influence the amount of air entrained, especially in lean mixes, and such factors as cement content, consistency of fresh concrete, mixing effectiveness, temperature, and vibration may affect the air bubble system produced by a given air entraining agent.

Air entraining agents have been formulated from various classes of compounds. The classic "vinsol resin" products are primarily impure abietic and pimeric acids derived from pine stumps or from tall oil processing and neutralized, commonly with sodium hydroxide. Alkyl aryl sulfonates (which are classic detergents) alkyl sulfates, and phenol ethoxyates are among the other classes of compounds that have been used.

One of the particular characteristics that set air entraining agents apart from most admixtures is the extremely low dosage of active ingredient actually used. Air entraining agents are usually supplied as liquids which lend themselves to accurate batching by automatic dispensing equipment, but the actual content of surfactant batched is normally very low; values substantially less than 0.1% by weight of cement have been quoted. The small materials cost is usually offset by the greater yield (air being substantially less expensive than the volume of concrete it displaces), and by other savings sometimes attained in redesigning the concrete mix - for example reducing the sand content. The resulting very low net cost of the air entrainment is one factor responsible for its widespread use.

The dosage requirements in field applications, while small, may be influenced by mineral admixtures, especially silica fume and fly ash. The carbon content of the fly ash is of particular importance, since some of the admixture may be quickly adsorbed by the carbon and its air entraining effect lost. The influence of silica fume is less straightforward, but there have been suggestions that some traditionally effective air entraining agents do not produce as satisfactory an air bubble system when used with concrete containing silica fume. Partly in response to such concerns, some manufacturers have recently marketed "new generation" air entraining agents said to be specially effective with concretes incorporating silica fume and fly ash.

According to the current listing of producers of various types of concrete admixtures published in the December 1991 issue of Concrete Construction, 30 different firms
Currently market air entraining admixture in the United States. The actual variety of products sold is substantially larger than this, some firms marketing a number of different air entraining agents.

A representative product sheet for one of the newer air-entraining agents is provided for illustrative purposes as Figure 2.

**Accelerators**

Accelerators are a class of chemical admixtures used primarily to facilitate cold weather concrete placement. A subsidiary use of these materials is to overcome a tendency to slow set; for this purpose they may be an element in a carefully compounded "prescription" admixture which otherwise would cause excessive retardation.

There is considerable confusion in the field as to whether accelerators are primarily supposed to accelerate concrete setting, or to accelerate the rate of strength gain after setting. ASTM C 494 -90, Standard Specification for Chemical Admixtures for Concrete, defines a Type C (accelerating) admixture as one that does both, but the two uses are not necessarily equally addressed by a given kind of accelerating admixture. The performance requirement of that specification for Type C admixtures requires that the time of initial set be advanced at least 1 hour, but not more than 3-1/2 hours, from that of the reference concrete, and the time of final set be advanced at least 1 hour. With respect to early strength gain, the requirement is that the 3-day compressive and flexural strengths be increased at least 25% and 10%, respectively, over that of the reference concrete. The specification also requires that there be no loss in compressive strength at 7 or 28 days, and that compressive strengths at 6 months and 1 year be at least 90% of those of the reference concrete. With respect to flexural strengths, the permitted effect over time is somewhat different; the specification is that there be no loss in flexural strength compared to the reference concrete at 7 days, and that the flexural strength at 28 days be at least 90% of that of the reference concrete. There are subsidiary requirements on shrinkage, and on freeze-thaw durability for air-entrained, concrete used with an accelerating admixture.

Historically the premier accelerating admixture has been calcium chloride, which is still the most effective accelerator available, and is extremely inexpensive to boot. Accelerators based on calcium chloride are available in liquid (solution) or in solid form, and are extensively marketed. However, as indicated earlier, the association of chloride at moderate concentration with corrosion of steel in concrete has rendered calcium
Admixture for Entraining Air in Concrete

DESCRIPTION: MICRO-AIR is an air-entraining admixture which gives concrete extra protection by creating ultra-stable air bubbles that are strong, small and closely spaced—a characteristic especially useful in the types of concrete known for their difficulty to entrain and maintain the air content desired. Even when used at a lower dosage rate than standard air-entraining admixtures, MICRO-AIR meets the requirements of ASTM C 260, AASHTO M 154, CRD-C 13 and other Federal and State specifications.

ADVANTAGES OF AIR ENTRAINTMENT:
- The entrainment of optimum air content in concrete results in the following improvements in concrete quality:
  - Increased resistance to damage from freezing/thawing cycles and to scaling from deicing salts
- Reduced permeability
- Reduced segregation and bleeding
- Improved plasticity and workability

ADVANTAGES OF MICRO-AIR:
- Greatly improved stability of air entrainment
- Improved air void system in hardened concrete
- Improved ability to entrain and retain air in low slump concrete
- Features/Benefits:
  - Contains high-carbon content for use with concrete containing large amounts of fine materials
  - High-temperature concrete, high strength concrete and concrete with extended mixing times

NOTE: As stated in ACI 212 and other publications, when two or more admixtures are used, they must be added to the mix separately (through dispensers or manually) and must not be mixed with each other prior to adding to the concrete mix. For optimum, consistent performance, the air-entraining admixture should be dispensed on damp, normal or heavy weight coarse aggregate. When using lightweight fine aggregate, field evaluations should be conducted to determine the best location to dispense the air-entraining admixture—on the damp fine aggregate or with the initial batch water.

Figure 2. Product sheet describing one of the newer air-entraining agents.
USAGE INFORMATION:

1. MICRO-AIR admixture is a ready-to-use solution. Do not mix it with any other admixture.

2. Add MICRO-AIR admixture to the concrete mix using a dispenser designed for air-entraining admixtures; or add manually using a suitable measuring device that ensures accuracy within plus or minus 3% of the required amount.

3. There is no standard dosage rate for MICRO-AIR admixture. The exact quantity of air-entraining admixture needed for a given air content of concrete is not predictable because of differences in concrete-making materials. Typical factors which might influence the amount of air entrained are: temperature, cement, sand-grading, sand-aggregate ratio, slump, means of conveying and placement, use of extra fine materials such as fly ash, etc.

4. Measure the air content of the trial mix and either increase or decrease the quantity of MICRO-AIR admixture to obtain the desired air content in the production mix. Check the air content of the first batch and make further adjustments as needed. Frequent checks during the course of the work should be made since factors mentioned in paragraph 3 above may require adjustments in the MICRO-AIR dosage rate. Adjustments to the dosage should be based on the amount of entrained air in the mix at the point of placement.

5. MICRO-AIR admixture should be stored and dispensed at 35°F (2°C) or higher. Although freezing does not harm the product, precautions should be taken to protect it from freezing. If it freezes, thaw and reconstitute by mild mechanical agitation. Do not use pressurized air for agitation.

6. CAUTION: MICRO-AIR admixture is a CAUSTIC solution. In case of contact with skin, eyes or clothing, immediately flush the exposed area with water for at least 15 minutes. Remove contaminated clothing and shoes. Call a physician especially if contact is with eyes. Wash clothing before reuse and discard shoes. Always keep the product out of the reach of children.

PACKAGING:

MICRO-AIR admixture is supplied in 55 US gal (208 l) drums and bulk delivery.

For suggested specification information or for additional product data on MICRO-AIR air-entraining admixture, contact your local Master Builders representative.

©1997, Master Builders, Inc.

CLEVELAND, OHIO 44122

Form P467b
Printed in USA: 781
chloride-based accelerators suspect or entirely banned by many agencies, not only for reinforced and prestressed concrete, but for pavement concrete as well.

Generally speaking, admixture manufacturers have divided accelerators in "chloride-based" (primarily calcium chloride), and "non-chloride" based accelerators, and often advertise non-chloride based accelerators without specifying the active agent being used. Users tend to make the reasonable assumption from this that non-chloride accelerators are all about the same or at least similar to each other in their effects in concrete. This is very far from the truth.

Calcium nitrite is an effective concrete accelerator, but it also has the very desirable property of acting as a steel corrosion inhibitor. It is marketed by at least one firm as a corrosion inhibitor, with the concrete acceleration properties being incidental.

Other non-chloride accelerators market include products based on calcium formate, and especially in complex admixtures, triethanolamine. Little triethanolamine is used by itself. A variety of other organic and some inorganic compounds have been listed in literature as having accelerating properties but are rarely used in commercial practice.

Sodium thiocyanate based accelerators have been marketed by at least one company. However, their use has been questioned for concrete containing steel, on the basis of possible increased susceptibility of the included steel to corrosion. The question is controversial since evidence has been presented by the manufacturer that at the low dosage rate specified sodium thiocyanate based admixtures did not deleteriously affect the corrosion rate or the time to corrosion.

Non-chloride accelerators tend to be fairly expensive and require relatively high dose rates. A considerable potential market would seem to exist for an inexpensive compound that would act as an effective accelerator without deleteriously affecting other properties of the concrete.

An illustrative product sheet is provided as Figure 3. This sheet is from a manufacturer who stresses the availability of several different formulations, including calcium chloride, calcium chloride blended with corrosion inhibiting components, and a chloride-free accelerator; thus the user may make his choice depending on circumstances (and budget).

Retarders

Chemical admixtures to retard the setting of concrete constitute a major class of admixtures. Some admixtures for accomplishing this are specified as "Type B" or
<table>
<thead>
<tr>
<th>RELCRETE Ac</th>
<th>RELCRETE AcP</th>
<th>RELCRETE AcN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESCRIPTION</strong></td>
<td>RELCRETE AcP is a concentrated, complex blend of set accelerating and strength enhancing components including calcium chloride and two corrosion inhibiting components.</td>
<td>RELCRETE AcN is an accelerating admixture formulated from a blend of accelerating components. Chlorides are not used in the manufacture of RELCRETE AcN.</td>
</tr>
<tr>
<td>FEATURES</td>
<td>RELCRETE AcP is also very economical while providing positive safeguards against corrosion of steel reinforcement.</td>
<td>RELCRETE AcN offers optimum acceleration of setting time and early strength development from a non-chloride formulation.</td>
</tr>
<tr>
<td>APPLICATION</td>
<td>RELCRETE Ac is recommended for use in concrete where acceleration of setting time and/or early strength development is required. RELCRETE Ac is not recommended for use in prestressed concrete or for concrete in potentially aggressive environments.</td>
<td>RELCRETE AcN is recommended for use in all concrete applications, including prestressed concrete and concrete to be placed in potentially aggressive environments.</td>
</tr>
<tr>
<td>DOSAGE</td>
<td>The recommended dosage range for RELCRETE Ac is 10 to 50 ounces per 100 pounds of cementitious material. Required dosage will be influenced by cement and fly ash chemistry and ambient conditions.</td>
<td>The recommended dosage range for RELCRETE AcN is 15 to 40 ounces per 100 pounds of cementitious material. Required dosage will be influenced by cement and fly ash chemistry and ambient conditions.</td>
</tr>
<tr>
<td>REINFORCED CONCRETE</td>
<td>In all reinforced concrete mixes, the concrete should be properly compacted and the concrete cover to reinforcement must be adequate as specified by ACI 318.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Product sheet describing several different accelerators marketed by a particular manufacturer for different purposes.
## RECOMMENDED CONCRETE PRACTICES

<table>
<thead>
<tr>
<th>COLD WEATHER CONDITIONS</th>
<th>CURING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete should not be placed if ambient temperatures are expected to remain below 40°F unless concrete temperatures can be maintained above that level. Concrete should not be placed in frozen forms, even when accelerating admixtures are used, as concrete harden on frozen ground may take many hours to reach initial and final sets. Additionally, strength gain may be adversely affected.</td>
<td>Proper concrete curing practices are essential for achieving optimum concrete performance. Sufficient moisture and favorable temperatures must be maintained in order for the concrete to develop desired properties. This is especially important during the first seven days.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WINDY CONDITIONS</th>
<th>QUALITY CONTROL</th>
</tr>
</thead>
</table>
| Cracking caused by plastic shrinkage due to high rates of evaporation may be controlled by the following methods:  
  - Erection of windbreaks  
  - Use of fog sprays or other suitable curing methods  
  - Use of suitable admixtures | Recommended AGC or NRMCA procedures should be followed for the addition of materials, mix cycle time and plant slump control. Plant control should also include frequent air checks in accordance with ASTM C-473 or C-231. |

### SOUTH WESTERN REGIONS
- San Antonio, Texas  
  512-341-6182
- SOUTHERN REGION  
  Atlanta, Georgia  
  404-931-2889

### CORPORATE OFFICE
- San Antonio, Texas  
  512-349-4000

### SOUTHEASTERN REGION
- Auburn, Alabama  
  803-607-6608

### MID- ATLANTIC COAST REGION
- Greensboro, North Carolina  
  919-372-4006

*MONEX RESOURCES offers a full range of admixtures and fly ash for the ready-mixed concrete and concrete product industries. In addition, custom and specialty formulated products are available outside the advertised range.*

*NOTE: The information contained in this data sheet is to the best of our knowledge true and accurate, but as we cannot control the final use of the product, there are no warranties expressed or implied regarding the product's use or performance. Persons receiving this information should make their own tests to determine the suitability thereof for their particular purpose.*
"retarding" admixtures in the ASTM C-494 specification. There is a considerable degree of overlap with Type D admixtures, which are water-reducing retarders. Indeed, most substances used as retarders are also intrinsically water-reducers in the sense that they are surface active and reduce the water demand. For example, of the various classes of substances that were said by one authority to be commercially used as retarders (lignosulfonates and their derivatives, hydroxycarboxylic acids and their salts and modifications, sugars and other carbohydrates, and heptonates related to sugars and starches), only sugars and other carbohydrates were said not to have intrinsic water reducing properties.

A considerable number of inorganic acids and salts, especially those whose calcium salts are insoluble and form films around cement particles, also act as retarders. However, for various reasons they are not much used in practice.

Unlike accelerators which provide some acceleration of both setting and strength gain after setting, retarders function primarily as set control agents. They are of course used mostly in hot weather to overcome the rapid setting pattern that is a natural feature of high ambient temperature. Retarders are particularly helpful in lengthening the permissible period after batching that vibration can be used, and in avoiding cold joints by enabling adjacent layers to be vibrated into each other.

ASTM C-494 requires Type B retarders to increase initial set time at least 1 hour and not more than 3-1/2 hours, and to increase final set time not more than 3-1/2 hours. Compressive and flexural strengths after 3 days are required to be at least 90% of the control concrete, and there are restrictions on the amount of increase in shrinkage that may be induced. Despite the fact that retarders are most commonly used at high ambient temperatures, the time of setting measurements are specified to be carried out at 73° F.

**Water Reducers**

Water reducing admixtures (Type A in the ASTM C-494 classification) are designed to reduce the water demand of a given concrete mix while at the same time not markedly influencing other characteristics such as air entrainment behavior or setting time. The action is often described as a "plasticizing" action, and accordingly, water reducing admixtures are sometimes called plasticizers. The specific admixtures marketed under this category, however, have only a limited water-reducing effect at dosages that can be used, and ASTM C-494 requires that only a 5% reduction in water demand be demonstrated. A newer category of chemical admixtures that are much
more effective in reducing water demand, the so-called superplasticizers or high-range water reducers (HRWRs) are designated as Type F admixtures. These must provide at least a 12% reduction in water demand to meet the specification requirement.

Nearly all, if not all, of the surface active materials used as water reducers also have some retarding action. To accommodate the desire for the plasticizing effect without at the same time causing extensive retardation, most commercial water reducers are compound admixtures, in which an accelerating agent is included to compensate for the retardation caused by the active plasticizing chemical. In past years, chloride-bearing accelerators were commonly used; currently, because of the growing sensitivity of many agencies to incorporation of any chloride in concrete, a non-chloride accelerator, usually triethanolamine, is often used. If large amounts of accelerator are used, an accelerating water-reducing admixture can be produced.

In addition to the water-reducing effect, ASTM C-494 Type A admixtures are required to maintain both initial and final set times to not more than 1 hour earlier and 1-1/2 hours later than those of the control concrete. The water reduction is required to effect a compressive strength increase of 10% over the control concrete at 3, 7, and 28 days. Long term compressive strengths and flexural strengths at any age must be at least equal to the controls. A limited increase in shrinkage is tolerated.

Commercial water-reducing admixtures are generally formulated from one or more of a restricted class of materials: lignosulfonates, hydroxycarboxylic acids, and hydroxylated polymers of various kinds. However, many other substances have been reported to have similar effects.

Lignosulfonates are derived from the sulfonation of wood pulp, and tend to be relatively high molecular weight polymers of complex and ill-defined molecular structure. Wood sugars of various kinds are usually present. Since these sugars would induce excessive retardation, they are usually removed from lignosulfonates used as Type A water reducers. Lignosulfonates also tend to entrain air, and an air-detraining agent is sometimes incorporated into the final admixture.

Hydroxycarboxylic acids used in water-reducing admixtures include citric, tartaric, mucic, gluconic, salicylic, heptonic, and malic acids. Unlike lignosulfonates, these tend to be pure chemicals. They are generally used in the form of sodium salts, which are very soluble, and they tend to have a considerable retarding action at higher dosage levels.

Hydroxylated polymers used in water reducers are usually partially-hydrolyzed polysaccharides derived from corn starch or other naturally occurring sources. They are
hydrolyzed to relatively low molecular weights, and do tend to exert a retarding action in addition to their water-reducing effect.

The term "water-reducer" is something of a misnomer. The admixture may usefully be incorporating into concrete without changing the water content, so as to increase the fluidity or workability of the mix. The slump increase produced is a function of the dosage level. Over the usual range and with properly designed concrete, a given dosage will produce about the same slump increase regardless of the initial slump of the concrete to which it is added. For a given dosage, hydroxycarboxylic acid-based water reducers are slightly more efficient than lignosulfonate-based water reducers.

The increase in workability is usually partly lost during the hour or two after mixing. Notwithstanding that the slump loss over time with plasticized concrete is usually greater than without admixture present, the residual slump at any given time is generally greater.

When the mix is redesigned to take advantage of the reduced water demand, the effectiveness of the plasticizer depends somewhat on the specific mix. Greater water reductions are possible at lower cement contents (greater aggregate : cement ratios); at higher original slumps; and if delayed addition is used.

A typical product sheet for a water-reducing admixture is provided as Figure 4. The manufacturer here claims superior finishing characteristics as well as the specified water reducing effect.

**Water-Reducing Retarders**

Water-reducing and retarding admixtures are classified as Type D admixtures in the ASTM C 494 specification. Paradoxically, since most water reducing admixtures do have retarding effects, these dual-purpose admixtures may be in fact simpler substances than single-purpose admixtures that are supposed to only retard set.

Many water reducing retarders are based on lignosulfonates; generally they contain high sugar contents, to help provide the requisite retarding action. Water-reducing retarders based on hydroxycarboxylic acids and on hydroxylated polymers are also commonly used.

The ASTM functional requirements for this type of admixture separately address the water reducing and the retarding functions. The water demand must be reduced at least 5% compared with the control concrete. The retardation effect is required to result in initial setting between 1 hour and 3-1/2 hours later, and final setting not more than 3-
DESCRIPTION
PSI 400N is a non-airsetting, highly concentrated, multi-component, liquid water-reducing admixture for use in concrete. PSI 400N reduces the quantity of mixing water required to produce concrete of a given consistency while providing greater economy for a given strength. It increases strength and significantly improves water-tightness, workability and finishing characteristics.

PSI 400N water-reducing admixture is compatible with air-entrained or non-air-entrained concrete mixes but does not of itself increase air significantly. Specifiers and users of PSI 400N admixture can be assured of superior results in both the plastic and hardened state of all concrete. Its superior finishing characteristics provide concrete that is free from blemishes, pitting and other undesirable surface defects. PSI 400N is manufactured in our own plants under rigid quality control standards.

ADVANTAGES
PLASTIC CONCRETE
• Reduces mixing water for given consistency
• Improves workability
• Reduces segregation
• Improves placing and finishing characteristics
• No effect on setting time

HARDENED CONCRETE
• Increases compressive, flexural and bond strength
• Reduces cracking and shrinkage
• Reduces permeability—increases watertightness
• Increases resistance to freezing and thawing
• Provides improved finished appearance
• Reduces bleeding (ASTM C-232)

APPLICABLE STANDARDS
ASTM C-494 Type A
CRD C-87

TECHNICAL DATA

DOSEAGE RATE
3-4 fl. oz. per 100 lbs. cement

TYPICAL COMpressive STRENGTH (psi)
5% sacks cement per c.y. Tested at same slump

<table>
<thead>
<tr>
<th>Strength (psi)</th>
<th>3 days</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5000</td>
<td>2500</td>
<td>2700</td>
</tr>
</tbody>
</table>

TYPICAL INITIAL SET TIME
5.5 sacks cement per c.y. Tested at same slump

<table>
<thead>
<tr>
<th>Set Time</th>
<th>4% hours</th>
<th>6% hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI 400N@3 oz./100# cement</td>
<td>4% hours</td>
<td>6% hours</td>
</tr>
<tr>
<td>PSI 400N@4 oz./100# cement</td>
<td>6% hours</td>
<td>6% hours</td>
</tr>
</tbody>
</table>

COMPATIBILITY
PSI 400N is compatible with air-entrained cements and all approved air-entraining agents. Also compatible with calcium chloride and accelerators.

PRECAUTIONS
PSI 400N can be dispensed at temperatures as low as 23 degrees. Care should be taken to prevent freezing below this temperature; however, freezing does not damage the material if subsequently agitated after thawing.

PSI 400N, being chloride-free, is recommended for pre-stressed concrete, concrete containing dissimilar metals, and all other uses.

TECHNICAL SERVICES
A trained Gifford-Hill representative is available to all specifiers and users to assist and advise in specifications, dispenser installation and field service.

MOUNTAIN CREEK TOLL BRIDGE, Dallas, Texas
Texas State Department of Highways and Public Transportation
J. D. Atkins, General Contractor

Figure 4. Product sheet describing a water-reducing admixture. Other benefits are also claimed for this product.
1/2 hours later than the control concrete. The limitations on the effects on strength and shrinkage are the same as those for Type A water-reducing admixtures.

Use of a single admixture for both the water-reducing and retarding effects has the obvious advantage of simplicity. However, the balance between the two functions is not easily tailored for particular situations. One can increase the dosage, which will lead to both additional retardation and additional water reduction, or decrease it and undergo reductions in both effects. Nevertheless as a practical matter, water reducing retarders are widely used and generally work well. They tend to be relatively inexpensive.

Occasionally water-reducing retarders are implicated in false-setting problems, and their use with cements that tend to be false setting should be carefully monitored. What appears to happen is that the admixture coats the interground hemihydrate in the cement sufficiently to interfere with and slow down its usual rapid conversion to gypsum. The gypsum formation may be delayed until after the usual mixing cycle. A thickening and in extreme cases, a false setting effect is produced that interferes with proper concrete placement. Usually a second mixing or an extended mixing will cope with this effect.

A product sheet for a polymer-type water-reducing retarder is provided for illustrative purposes as Figure 5.

**Water-Reducing Accelerators**

These admixtures, unlike most water-reducing retarders, are formulations containing a substantial amount of separate set-modifying, i.e. accelerating, component. This is necessary to overcome the intrinsic retarding effect and then provide the desired additional accelerating effect.

These admixtures are classified as Type E in the ASTM C-494 specification. The specific functional requirements combine those for Type A (water-reducing) and Type C (accelerating) admixtures. The late strength requirements are those of Type A.

Unlike water-reducing retarders, this category of admixtures is relatively little used in practice. The need to regulate the degree of acceleration needed to overcome cold-weather or other problems is perhaps more difficult to satisfy in a combined admixture.

An illustrative product sheet is provided for an admixture of this type as Figure 6. Note that the manufacturer stresses that the acceleration is accomplished using a non-
Plastocrete 161R
Polymer-type, water-reducing, set-retarding admixture

Description: Plastocrete 161R is a polymer-type admixture. It is a non-air-entraining, water-reducing, set-retarding admixture. Plastocrete 161R contains no chlorides. It meets the requirements of ASTM C-494 Type D.

Where to Use: Use where retardation is needed. Use where high strength, cost-effective concrete is needed. Use where increased workability is needed. Use in mixes with a reduced cement content. Use in all concrete where high quality is required.


Dosage: 3-5 fl oz/100 lb cement.
Packaging: 5-gal pails, 55-gal drums, and bulk.

Shelf Life: Unlimited. Protect from freezing.

Storage Conditions: Store above 30°F. Protect from freezing. If frozen, thaw and agitate before using.

Color: Dark brown.

Mixing: Add correct amount of Plastocrete 161R at the concrete plant. Add manually or by automated dispenser directly into sand at weigh hopper or into the water line at the batch plant.

Limitations: Do not mix with air-entraining agent. Protect from freezing.

Caution: See product label, Material Safety Data Sheet, Tech Data Sheet, or contact Technical Service Department.

Figure 5. Product sheet describing a water-reducing set-retarding admixture, marketed by the Sika Corporation.
CONPLAST NC
Chloride free, accelerating, water reducing admixture.

USES
To accelerate the setting and early strength gain of Portland Cement concrete and mortar mixes without the introduction of chloride.
Acts as a plasticizer, giving significant increases in both ultimate and early strengths. Typical applications include precast concrete, concrete placed in cold weather, concrete for repairs and mortars for brickwork.

ADVANTAGES
- Chloride Free: Safe with all prestressed and steel reinforced concrete.
- Anti-frost: Early setting provides improved resistance to frost attack and earlier finishing.
- High Early Strength: Reduces form stripping time.
- Water Reducing: Plasticizing action facilitates water reduction and increased ultimate strengths.
- Versatile: Can be used with all types of Portland Cement and equally with all concrete and bricklaying mortar mixes.
- Low Temperature Use: Particularly effective in concrete at low temperatures. Allows continued placing of concrete. Enhances cold weather concrete applications by reducing the water content and accelerating hydration of cement.

DESCRIPTION
CONPLAST NC is an admixture designed for use with every type of Portland Cement. It is guaranteed completely free of all forms of added chloride and is supplied as a light straw colored liquid instantly dispersible in water.
The main active ingredient is an inorganic formate.

The addition of the material to Portland Cement concrete and mortar mixes reduces setting times and accelerates the rate of strength gain and resistance to frost attack.
CONPLAST NC is also a plasticizer which, where required, enables the water/cement ratio to be reduced while still maintaining workability. Such reduction will result in significant increases in both ultimate and early strengths.

STANDARDS
CONPLAST NC complies with the requirements of ASTM specification C494 Type C.

PROPERTIES
- Calcium Chloride Content: Nil
- Specific Gravity: 1.27 at 70°F.
- Freezing Point: -3°F.
- Air Entrainment: Less than 1% additional air is entrained.

Compatibility: May be used with all types of Portland Cement complying with ASTM specification C150. Not suitable for use with high alumina cement.

The effects of CONPLAST NC are highly effective with Portland Cement mortar mixes. This avoids the use of chloride in brickwork while providing early strength and frost resistance.
CONPLAST NC is generally compatible with other FOSROC admixtures, however, they should always be dispensed separately.

Setting Time: The addition of CONPLAST NC to Portland Cement concrete mixes accelerates both the setting and rate of strength gain.
Compressive Strength/Density: Accelerates the rate of strength gain.

The strength improvements are most significant during the first 16 hours. If no change is made in the water/cement ratio, the ultimate strengths will be similar to those obtained using the same mixes without CONPLAST NC.

FOR MORE TECHNICAL INFORMATION 1-800-841-0445

Figure 6. Product sheet describing a water-reducing accelerating admixture. The accelerating component is said to be an "inorganic formate" and the admixture is said to be free of chloride.
Durability: Accelerated corrosion testing of steel in concrete has shown that CONPLAST NC does not affect the protection of steel afforded by cement against corrosion, even at 4 times the recommended dosage level.

INSTRUCTIONS FOR USE

Dosage:
The optimum dosage for standard concrete and mortar mixes with all grades of Portland Cement is best determined by site testing.

As a guide, the rate of addition is generally in the range of 30-45 fl. oz./100 lbs. of cement.

Overdosing:
An overdose of double the recommended amount of CONPLAST NC will result in a slight increase in initial acceleration, but will not alter the ultimate strength or characteristics of the cured concrete or mortar.

Dispensing:
The correct quantity of CONPLAST NC should be measured by means of a recommended dispenser. FOSROC's Technical Department should be consulted regarding suitable equipment and its installation.

The measured quantity of CONPLAST NC should be added directly into the mixer. Best results are obtained when added at the same time with the mixing water or at the end of the batch cycle.

When the air temperature, at placing, is below 50°F ACI 306 recommended practice for cold weather concreting should always be followed.

STORAGE

CONPLAST NC has a minimum shelf life of 12 months providing the temperature range does not exceed 10°F to 125°F. If these conditions are exceeded FOSROC should be contacted for advice.

PACKAGING

CONPLAST NC is supplied by bulk delivery or in 55 gallon drums.

WARRANTY

FOSROC warrants its products to be free of defects in material and workmanship. Under this warranty, we will provide, at no charge, product in containers to replace any product proved to be defective when applied in accordance with our written instructions and in applications recommended by us as suitable for the product.

All claims concerning product defects must be made within 12 months of manufacture. Absence of such claim in writing during this period will constitute a waiver of all claims with respect to such product.

This warranty is in lieu of any and all other warranties express or implied and Fosroc shall have no other liability of any kind inducting liability for consequential damages.

FOSROC INC.
(Formerly Preco and Celtite CPD)
65 SKYLINE DRIVE
PLAINVIEW, NEW YORK 11803
516-935-9100 - FAX: 516-935-9143
chloride accelerator (an "inorganic formate"), and is therefore safe for prestressed and steel reinforced concrete.

High-Range Water Reducers (Superplasticizers)

The development of this class of chemical admixtures has marked a considerable revolution in the concrete field. In particular the availability of superplasticizers, used in conjunction with silica fume and fly ash, has made possible the development of a whole new class of high-performance concretes. Superplasticizers can be, and are, used in more conventional concretes, and in this section uses with conventional concretes are discussed. High performance concretes will be discussed in a special section later in this report.

Superplasticizers are specified as Class F admixtures in the ASTM C-494 scheme. The operational requirement is that a water reduction of at least 12% be achieved. The reduction in water content is required to produce compressive strength increases of at least 40% at one day, with progressively lesser increases required at later ages. At 6 months and later, the compressive strength is only required to match that of the control concrete. Only a modest flexural strength effect is required, the only increase specified being 10% at 3 days.

The specification also includes requirements of only modest changes in set time and modest shrinkage increases; these are identical to the corresponding requirements for water reducers.

None of the water reducers discussed previously, with the possible exception of a few modified lignosulfonate products, can be used in concrete at high enough dosages to meet the performance required from superplasticizers; retardation, air entrainment, and possibly other undesired side effects interfere. Rather, superplasticizers generally speaking, represent entirely new chemical classes of admixture. Two families are commonly recognized; those based on naphthalene sulfonate and those based on melamine sulfonate, with the former far more commonly used. Actually, at least one admixture company has provided a superplasticizer blend containing both, and has claimed certain advantages for such a blend.

"Naphthalene sulfonates" are actually naphthalene formaldehyde sulfonic acid salts. They are produced by sulfonating naphthalene, polymerizing or "condensing" the sulfonated naphthalene with formaldehyde, and then neutralizing the sulfonate groups on the resulting polymer backbone with Na or Ca. Optimal chain length of the polymer
is of the order of 10, but commercial products contain varying chain lengths, and often some sodium sulfate (if Na-neutralized).

"Melamine sulfonates" are sulfonated melamine formaldehyde salts, produced by a rather more complex process, and are of a much higher degree of polymerization, on the order of 100 or so. These materials were actually developed for other purposes, and subsequently were found useful in concrete. In contrast, naphthalene sulfonates were a later, and deliberate development for use in concrete.

The general effects of the two classes of superplasticizer are markedly similar to each other. Both act as strong deflocculants, converting the fresh cement paste into a Newtonian fluid of relatively low viscosity. There is usually strong absorption of the superplasticizer by the earliest cement hydration products, often leading to an inadequate later concentration and pronounced loss of the dispersive effect, manifested as slump loss. Delayed addition of at least some of the superplasticizer tends to combat this effect.

In research reported in Part II of this final report, it has been shown that the effect of the superplasticizer is dependent on such cement characteristics as alkali content, the form of the interground gypsum compound, and other factors.

As with water reducing admixtures, superplasticizers may be used either to produce more fluid concrete (when the water content is not changed), or much stronger concrete, if advantage is taken of the water demand reducing effect to actually lower the water content. Obviously intermediate effects can be obtained by partial reductions in water content.

Because of the higher dosages that can be (and are) used, the superplasticizers tend to have quantitatively much greater effects than water reducers. They can be readily used to produce "flowing concrete". Such concrete is almost entirely self-compacting concrete of extreme slump, but produced at normal water contents, and generating normal or greater than normal strengths. ASTM provides a separate specification (C 1017 - 90) to cover superplasticizers intended for such use.

While superplasticizers can be and are used at much higher dosages than conventional water-reducing admixtures, the dose-response relationship for plain concrete is such that increased dosage beyond some particular level (of the order of 1% or 2% of the weight of the cement) has little marginal effect. Once the cement is fully deflocculated, little further increase in response can take place.

The ASTM C 1017 - 90 specification ("Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete") recognizes Type I ("plasticizing") and Type II ("plasticizing and retarding") admixtures as separate types. Both types are
required to produce at least a 3 1/2 inch increase in slump and compressive and flexural strength levels of at least 90% of the reference concrete at all ages. The superplasticizing admixture is required to have only minimal effect on the setting time.

Flowing concrete, as might be expected, tends to have a tendency to bleed and segregate as the result of the loss of “body” in the fresh concrete. This can usually be counteracted by appropriate adjustment on the mix design, especially by increasing the proportion of fine sand.

For applications in which higher strength rather than flowing concrete are desired, the extent of water reduction obtainable can be very much higher than the 12% minimum value specified in ASTM C-494. At high dosage levels, water reductions up to about 30% can be obtained with many naphthalene sulfonate or melamine sulfonate type superplasticizers, especially if they are added after a few minutes delay. Very much increased strengths can be produced at these lower water contents, even without going to silica fume or fly ash additions.

It is of course possible to use superplasticizing admixtures to reduce the cement content, i.e. by maintaining a constant or nearly constant water:cement ratio as the water demand is reduced. This of course results in an increased proportion of coarse and fine aggregate. Sometimes only the coarse aggregate content is allowed to increase. The resulting economy can partially offset the extra cost of the superplasticizer.

A illustrative product sheet for this class of admixture is provided as Figure 7.

**High-Range Water Reducing and Retarding Admixtures**

These admixtures, classified as Type G in the ASTM C 494 classification, combine both superplasticizing and retarding effects, usually by blending a naphthalene or melamine sulfonate superplasticizer with a conventional retarder. The functional requirements combine the retarding action requirements specified for Type B retarders with the at least 12% water reducing action specified for superplasticizers. Because of the retardation, the 1-day strength requirement for superplasticizers (at least 140% of the control concrete) is reduced to 125% of the control concrete.

Usage of such admixtures appears to be relatively restricted compared to the usage of non-retarding superplasticizers, although this may change in the future.

An illustrative product sheet describing a specific product falling into this class of admixture is provided as Figure 8.
Figure 7. Illustrative product sheet for a high-range water reducer (superplasticizer).
EUCON 537
High Range Water Reducing Admixture
Retarded Set Type

EUCON 537 is a fifth generation admixture formulated specifically to extend the working time of flowing concrete at temperatures up to 130°F. At normal dosage rates, EUCON 537 complies with the parameters of ASTM C 494 Type G admixture. EUCON 537 has been formulated without any added chlorides and complies with ACI 201 and ACI 318 requirements for minimal chloride content.

WHERE USED
EUCON 537 can be added to the concrete at the ready mix plant or at the jobsite. EUCON 537 is compatible with vinyl resin type air-entraining admixtures and many other admixtures; however, all admixtures must be added separately to the mix. EUCON 537 is recommended for all types of concrete including reinforced, prestressed, high strength, parking structures, industrial slabs, watertight concrete and lightweight concrete.

ADVANTAGES
1. EUCON 537 produces "flowing" concrete with controlled delay of slump loss and workability.
2. EUCON 537 greatly reduces water requirements.
3. EUCON 537 reduces segregation and bleeding in the plastic concrete.
4. EUCON 537 reduces cracking and permeability of hardened concrete.
5. EUCON 537, when used to produce flowing concrete, significantly reduces concrete placement time and cost.

ENGINEERING DATA
Water content, maximum percent compared to control 70-80%
Rate of slump loss, 9" slump concrete, at 72°F 1/2" to 1½" first hr.
Rate of slump loss, 9" slump concrete, at 90°F 1½" to 1½" first hr.
Compressive Strengths vs. control:
   1 day                          up to 140%
   3 days                        140-160%
   7 days                        150-155%
   28 days                      125-135%
Relative Durability - freeze thaw resistance 98.7%

DIRECTIONS FOR USE
Quantity - EUCON 537 is used at a range of 6 to 32 ounces per 100 pounds cement. When EUCON 537 is added, at a rate of 12 ounces per 100 pounds cement, to a 1" to 3" slump concrete, it will produce flowable concrete with a slump of 7" to 10".

Figure 8. Product sheet for a retarding-type high range water reducer.
The slump loss will be greatest up to six hours (6) at a temperature of 72°F and up to three hours (3) at a temperature of 120°F when proper quantities of EUCON 537 are used. Variations in slump loss and setting characteristics are a function of the amount of admixture used, cement characteristics and the mix design selected. An increase in concrete temperature will cause an increase in slump loss and a decrease in initial set time.

When designing mixes for use with EUCON 537, ACI 211.1 or ACI 211.2 recommendations should be followed. After the initial mix is established, the sand to coarse aggregate ratio would probably be adjusted upward 5% to 15% to compensate for the water reduction expected, and to maintain homogeneity of the "flowing" mix. For "flowing" concrete, charge all concrete materials into the mixer and mix five minutes or 70 revolutions to a 3" slump as required by the project specifications. Add EUCON 537 and mix an additional 50 to 60 seconds per yard, and then discharge.

For high strength concrete, (over 6000 psi in 28 days), add EUCON 537 with approximately 80% of the mixing water and mix 5 minutes or 70 revolutions minimum. Add allowable additional water carefully to obtain the right slump and mix for 30 to 60 seconds per cubic yard.

### Suggested Quantities per 100# Cement vs. Air Temperatures

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Suggested Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>80°F</td>
<td>10-16 oz.</td>
</tr>
<tr>
<td>90°F</td>
<td>10-18 oz.</td>
</tr>
<tr>
<td>100°F</td>
<td>10-20 oz.</td>
</tr>
<tr>
<td>110°F</td>
<td>110°F.</td>
</tr>
<tr>
<td>120°F</td>
<td>120°F.</td>
</tr>
<tr>
<td>130°F</td>
<td>130°F.</td>
</tr>
</tbody>
</table>

**FORMWORK**

Forms for walls or narrow sections must be watertight, strong, and have good bracing. During the "flowing period" when the concrete is at a slump of 7"-10", the concrete will exert a higher pressure at the base of the form than conventional concrete. Formwork for slabs is the same as for conventional concrete.

**PLACING**

Concrete with EUCON 537 will spread up to 15' when discharged from the chutes of mixer trucks. A 10 yd. load of concrete can be easily emptied in less than five minutes at the rate of 80 cubic yards per hour.

Concrete will flow down a slope of 5° and in some cases, with extension chutes, it can be discharged direct from the mixer trucks a total distance of 40 to 45 feet.

**CAUTION**

The use of EUCON 537 varies with every application. Therefore, the Engineering or Technical Services Department of The Euclid Chemical Company should be consulted concerning its use.

To prevent rapid loss of workability at concrete temperatures higher than 75°F, or in windy weather, apply the precautionary methods recommended in ACI305 R-77 report, "Hot Weather Concreting".
Admixtures Not Covered by Existing ASTM Specifications

The chemical admixture types discussed so far are all covered by ASTM specification. This by no means exhausts the list of chemical admixtures used in concrete or promoted for such use. Some additional admixtures are in process of having specifications compiled and approved; others are used without such specification. The chemical admixtures field is in an active state of development, and chemical admixtures to address new functions are being continuously developed and marketed. The admixtures discussed below probably comprise most, but not necessarily all, of the types available for general concrete use. Admixtures for specialized concretes, such as shotcretes, polymer-modified concretes, or calcium aluminate cement concretes, or for grouts, are not considered.

Corrosion Inhibitor Admixtures

The corrosion of reinforcing and prestressing steel in concrete due to chloride ions has been a major problem in the transportation and highway fields. Bridge decks and other concrete bridge elements, and parking garages have been particularly affected.

For a number of years the main preventive measure specified has been the use of epoxy-coated steel. It now appears that this strategy, at least as has been practiced under current specifications, is flawed. Accordingly, new importance is expected to be placed on the use of corrosion inhibitor admixtures in such concretes.

While a number of chemicals posses corrosion inhibition properties, one admixtures marketed commercially is based primarily on calcium nitrite. This material, when added at the normal dosage rate, functions also as a relatively strong accelerator. It also normally increases the ultimate strength of the concrete. When the accelerating effect is not desired, for example in hot weather concreting, a suitable retarder may be added to overcome this effect. It is usually recommended that the two admixtures be added separately.

The effectiveness of calcium nitrite has been extensively documented in various FHWA and other studies. One study has suggested the possibility of superior corrosion resistance might be obtained from a mixture of calcium nitrate and sodium molybdate, but such combined corrosion protection admixtures have not been extensively tested.
Calcium nitrite is used at relatively high dosages, of the order of 2% by weight of cement. The dosage level may have to be increased if very high contents of chloride are expected. The increased costs involved are considerable, but where corrosion risks are high, the expected cost is usually considered to be modest in comparison with the expected benefit, even if high dosages are required.

An illustrative product sheet describing a calcium nitrate based corrosion-preventing admixture is reproduced as Figure 9.

More recently, a corrosion prevention admixture based on an entirely different system has been introduced by another major manufacturer. This material is a water-based combination of organic amines (to form a barrier film) and esters (to render the cement paste hydrophobic), and is said to prevent or delay corrosion by forming a hydrophobic barrier to chloride and moisture penetration into the concrete.

### Antifreeze Admixtures

Antifreeze admixtures are designed to prevent damage due to freezing in fresh concrete, and to permit continued hydration at temperatures less than 32° F. They have been little used in the United States because of concerns connected with their possible influences on corrosion, on alkali-silica reaction, and on air-entrainment. However, at least one antifreeze admixture, said to be free of chloride, has been marketed for several years by a major admixture producer in the United States. Its effects have been described in a recent paper, and are said to include acceleration of both setting and strength gain, as well as antifreeze action.

Compounds that have been used for antifreeze purposes include ammonium hydroxide, various calcium and sodium salts (including nitrate, nitrite, and chloride), potassium carbonate, and urea. In a recent study reported by an agency of the U.S. Army Corps of Engineers, sodium and calcium nitrite mixtures and sodium nitrite-potassium carbonate mixtures were found to be particularly effective. Both these mixtures were additionally recorded as having significant accelerating effect, but both increase the alkali burden of the cement. A new antifreeze admixture free of both chloride and alkalis has recently been marketed in Japan, which is said to contain calcium nitrite and nitrate and polyglycol ester derivatives, and thus be free of this additional alkali burden.

Use of antifreeze admixtures may turn out to be an appropriate and cost-effective way to protect transportation-related structures where early freezing cannot be prevented.
**Waterproofing Admixtures**

Concrete waterproofers are admixtures added in the mix water that are designed to increase the solid-water contact angle of the hardened concrete sufficiently so that the concrete is rendered water repellent, or "waterproofed". These materials are sometimes referred to as "integral" or "internal" waterproofers, to distinguish them from external coatings designed to do the same job. The waterproofing action functions only for water under modest pressures, but renders concrete, once dry, much more difficult to rewet and resaturate. This confers some benefit in freezing and thawing and sometimes in alkali-silica reaction and steel corrosion situations. Waterproofers are also used for architectural concrete, with benefits such as reduced possibility of efflorescence and better surface appearance being claimed. Precast architectural panels are a common application.

Three different classes of waterproofing admixtures are generally recognized: liquid fatty acids (typically mixtures of oleic and other liquid fats); emulsions of waxes of various kinds, and finely divided waxy solids such as calcium or aluminum stearate.

Waterproofing admixtures are much more commonly used in Europe than in the United States, although they are marketed by several admixture producers in this country. No ASTM standards exist. Nevertheless, the possibilities for their use in transportation related structures involving vertical surfaces where appearance is important should not be overlooked.

"Stop-Start" Admixtures

These are novel and highly sophisticated chemical systems designed to permit the setting and hydration of concrete to be stopped on application of one agent and resumed at some later period when the "stopped" concrete is remixed with the second agent. Usually additional fresh concrete must be blended with the "stopped" concrete when hydration is to be resumed.

These systems were developed more as management tools in concrete operations than as admixtures designed to affect the ultimate properties of the hardened concrete. In particular, they have been marketed as an environmental tools to reduce or eliminate the volume of waste concrete and concrete washings that result from ordinary concrete operations, especially transit-mixed operations.

"Stop-start" admixtures are marketed by several of the largest admixture manufacturers. The chemistry of the effects produced is not widely understood, and the
chemical systems themselves are not disclosed. There are no existing ASTM standards for this class of admixture.

Alkali Silica Reaction Preventing Admixtures

These fall into the category of potential, rather than actual commercially marketed admixtures, although there are indications that one or more admixture companies might market such a product in the near future.

Alkali silica and to a lesser extent alkali carbonate reactions in concrete have led to a number of serious problems, and pavements and other transportation-related structures are not immune.

Approaches toward prevention by means of chemical admixtures have in the past been concentrated on lithium and barium compounds. There is considerable current interest on lithium compounds, and on several new classes of possible admixtures: sodium silicohexafluoride and modified silanes (alkyl alkoxy silane).

State DOTs that operate in areas where alkali silica reactions have been recognized as serious problems might be well advised to follow developments in this field and consider the use of such admixtures when they have become available.

Shrinkage-Reducing Admixtures

A class of chemical admixtures designed to reduce drying shrinkage by decreasing the capillary tension produced on evaporation of water from the hardened cement paste has been developed and marketed in Japan. These admixtures are organic surfactants, said to be based on alcohol alkylene oxide adducts. It is not known whether or when such admixtures will be marketed in the United States, but they may potentially useful in reducing or eliminating shrinkage cracking in pavements and other transportation-related structures.

SOURCES OF FURTHER INFORMATION

There is a large body of published research information on chemical admixtures. However, the specific manufacturer or brand name is rarely mentioned in research papers, making the information less useful than it might be. On the other hand, where the research was done by a specific admixture company, the brand name might be men-
tioned or easily inferred, but sometimes the objectivity of the results might be called into question.

Unfortunately, primary research sources tend to be relatively unavailable to most engineers associated with state DOTs.

Accordingly, the temptation to provide a long list of paper citations has been resisted. The citations given below are to books, technical compilations, and other sources that provide a condensed body of information, rather than to individual papers.

Books:


Committee Reports, compilations, and conference proceedings:

ACI Committee 212, "Chemical Admixtures for Concrete," Report ACI 212.R-91.CT92, American Concrete Institute, P. O. Box 19150, Detroit, MI 48219, 32 pp. (1991).

ACI, "Concrete Admixtures," A special issue of Concrete International containing 7 papers on chemical admixtures (March 1991).


ACI Education Department, "How to Effectively Use the Newest Admixtures," Course Manual SCM-23, American Concrete Institute, P. O. Box 19150, Detroit, MI 48219, 256 pp. (1990).

V. M. Malhotra, ed., "Superplasticizers and Other Chemical Admixtures in Concrete," Publication SP-119, American Concrete Institute, P. O. Box 19150, Detroit, MI 48219, 665 pp. (1989). Note: this is a compilation of 33 individual papers.
V. M. Malhotra, ed., "Developments in the Use of Superplasticizers," Publication SP-68, American concrete Institute, P. O. Box 19150, Detroit, MI 48219, 561 pp. (1981). Note: this is a compilation of 30 individual papers.


V. M. Malhotra, ed., "Superplasticizers in Concrete," Publication SP-62, American Concrete Institute, P. O. Box 19150, Detroit, MI 48219, 427 pp. (1978). Note: This is a compilation of 20 individual papers).


MINERAL ADMIXTURES AND HIGH-PERFORMANCE CONCRETE

Mineral Admixtures:

It is customary to divide concrete admixtures in to separate categories of chemical admixtures (the subject of this report), and so-called "mineral admixtures". Loosely, the latter comprise natural and manufactured pozzolans, fly ash, silica fume, and ground granulated blast furnace slag, although the latter is sometimes split off as a cementitious component rather than a mineral admixture.

There are various interrelationships that necessarily develop between chemical admixtures and mineral admixtures when both are incorporated into concrete. In recent years in the U.S., the use of mineral admixtures, especially fly ash, has become almost universal in ready mixed concrete, and very widespread in other concretes, including concrete for transportation related structures and pavements. Slag has recently become more widely available, and its use is greatly increasing, as is silica fume for special structures. Accordingly, chemical admixtures must also be examined as agents that combine with, and interact with mineral admixtures in their joint use in concrete.

A brief synopsis of the composition and relevant behavioral characteristics of common mineral admixtures is provided below.

Natural and artificial pozzolans, in the strict sense, are glassy or amorphous materials, usually highly siliceous, which have been ground to reasonable fineness and are known to function in concrete by relatively slow reaction with the calcium hydroxide de-
veloped in the early cement hydration reactions. Except in a few areas, such materials are little used in the United States.

Fly ashes are very specific materials. All are derived as by-products of the combustion of powdered coal in electrical generating plants, usually collected by electrostatic precipitators (although sometimes by baghouse collectors), and are fine enough by nature so that they are rarely ground. Fly ashes are conventionally divided into ASTM Class F and ASTM Class C categories, the division relating primarily to the calcium content, Class C being richer in this chemical element. The division reflects the nature and calcium content of the coal being burned.

Many, but not all, fly ashes are composed primarily of spherical particles, mostly solid, but some hollow. Coarser particles tend to be "slaggy" and not reactive in concrete. Most fine and medium sized fly ash particles are composite in character, being made up of crystalline components embedded in a glass matrix. In Class F fly ashes, the glass tends to be reactive in concrete, with the incorporated crystalline components (quartz, mullite, iron oxides, etc.) being unreactive. Many Class C fly ashes have reactive crystalline components as well as reactive glass.

Reactions of fly ashes in concrete tend to be slow, especially for Class F fly ashes, and are quite complex. Although ASTM and other agencies classify fly ashes as pozzolans, their effectiveness in concrete stems only partly from reaction with calcium hydroxide; much of the benefit seems to develop as a result of the presence of the fly ash stimulating additional cement hydration reaction.

Fly ashes may contain a greater or lesser contents of unburned carbon, derived from the coal. Additionally, some fly ashes are treated with salts, frequently sodium sulfate or sodium carbonate, in the burning operation so as to render them more readily precipitated in electrostatic precipitators. Such fly ashes retain a significant surface contamination of such salts which may influence the behavior of chemical admixtures. Fly ashes with high contents of high-surface area carbon tend to absorb most organic admixtures, and their presence may require significantly increased dosages to maintain effectiveness.

Silica fume is another very specific material whose characteristics reflect its mode of origin. Silica fume is a byproduct of the manufacture of silicon or sometimes ferrosilicon. In such manufacturing processes silica sand and wood chips (with added iron oxide in the case of ferrosilicon) is subjected to high electrical current. The desired reaction is the reduction of the SiO₂ to Si metal, but in the process some unstable SiO is vaporized and condenses in the surrounding atmosphere to particles of very finely divided siliceous glass. The glassy spheres are collected by baghouse separators, and
depending on SiO₂ content and purity, may have remarkably reactive characteristics in concrete.

Silica fume is also classed formally as a pozzolan. However, like fly ash, its behavior in concrete is conditioned only partly by its ability to combine with calcium hydroxide. Like some fly ashes, it stimulates additional cement hydration, but unlike most fly ashes, it has a remarkable filler effect because of its extreme fineness.

Silica fume is commercially marketed in powder form, and also in slurry form. In slurry form, sufficient superplasticizer is normally added to keep the silica fume particles in the dispersed state. However, for some uses, additional superplasticizer may be required for optimum effect.

Ground granulated blast furnace slag is another very specific material. This material is derived from blast furnace slag produced in the iron industry by a process of water quenching of slag (iron impurities) from the molten state (granulation), and subsequent grinding to cement fineness. Such slags are glassy, but have some crystalline inclusions. The glass is rich enough in calcium that in suitable fineness it can function as a slowly reacting hydraulic cement by itself or with the incorporation of a suitable activator. The hydration reaction generates calcium silicate hydrates not unlike those produced by Portland cements. When used in Portland cement concrete the reactions are more complex, and result in a denser and less porous overall hydrated cement structure; the resulting concrete often develops superior durability characteristics.

**High Performance Concretes:**

High-performance concretes constitute a catch-all category of concrete that, loosely speaking, includes concretes of much higher strength, and often of much greater potential durability than normal concretes. These favorable characteristics may be attained by a variety of approaches, but nearly all involve simultaneous use of large amounts of both chemical and mineral admixtures.

It appears in particular that superplasticizers, when used in combination with silica fume, develop a synergistic action that results in a much greater effective dispersing action than when superplasticizers are used with plain Portland cement concrete. This permits batching at a very much lower water content than is normally employable. Under favorable circumstances the cement paste developed in the hardened concrete provides a much denser and more favorable coating for the aggregates. The permeability and ionic diffusivity of the hardened concrete are very much reduced. The "transition zones" around the individual aggregate particles are very much improved so
that bond cracking becomes rare, and the overall compressive and flexural strengths may be radically increased.

Similar results can be obtained with certain fine fly ashes instead of silica fume, and with combinations of fly ash and silica fume. The dispersion may be effectively and more economically obtained by combinations of water reducing and superplasticizing chemical admixtures rather than by superplasticizers alone. The alkali content of the cement, its fineness, and the nature of its gypsum component may also need to be controlled.

Because of the exceedingly low water content at which these concretes are batched, little bleeding takes place. The impermeability of the fresh paste makes it very difficult to convey water from the interior to the surface to replace any water lost in early evaporation. In consequence, curing under continuously and effectively wet conditions are absolutely necessary to avoid plastic shrinkage cracking.

Such high performance concretes are exceedingly expensive and do not lend themselves readily to conventional methods of construction. They are not suitable for paving train operations, but compressive strengths in the laboratory in excess of 100,000 psi. These are laboratory curiosities at present, but may point the way to future systems that might have applications in redesigned transportation system structures.

**ADMIXTURE COSTS**

Decisions on prospective admixture use are not usually taken without some consideration of the costs involved, whether or not a formal cost-benefit analysis is attempted. None of the many literature references cited (including the guides to admixture use developed by committees of the American Concrete Institute and of the Transportation Research Board) attempt to provide cost information.

There are obvious pitfalls in attempting to provide such admixture cost information. Actual costs vary not only with dosage selected, but also with location, with size of the construction operation, and certainly with competitive conditions in the industry. Nevertheless, it is important to have some sense of the costs involved.

I have attempted, with the kind assistance of industry sources, to provide an estimate of the marginal materials cost for each of the kinds of admixtures considered. The calculations have been made in terms of direct admixture cost per cubic yard of
concrete using the approximate average admixture dosage. As the admixture dosage is
usually specified in terms of the cement factor of the concrete, a cement factor must be
assumed; the costs here are calculated on the assumption of a 517 lb/cu. yd. (5-1/2
bags per cu. yd.) cement factor.

The average price per cu. yd. of concrete in various markets is published
periodically by Engineering News Record. Based on these estimates, I have selected a
rough figure of $60 per cu. yd. as representative of the base cost of concrete.

Using these assumptions a good general idea of the costs of the various classes
of admixture can be found from the data in Table 1. The second column of Table 1
contains an estimate of the range of cost for the generally recommended admixture
dose specified per cubic yard of concrete. The third column is a corresponding
calculated percentage increase in concrete cost, using the mean value for the range in
Column 2 and a $60 assumed base cost of concrete.

It is apparent that the various admixtures can be divided into only a few classes
so far as cost is concerned. The writer considers that marginal costs of 2% or less are
trivial; that marginal costs between 2% and 5% are inexpensive; and that admixtures
that add between 15% and 30% to the cost of the concrete are relatively expensive.
Surprisingly, there seems to be a large gap between 5% and about 15%, i.e. what one
might characterize as moderate cost admixtures, do not seem to exist.

With these definitions, it is seen that the cost involved for air entraining agents,
chloride-based accelerators, and water reducers are all trivial; that non-chloride based
accelerators, superplasticizers, retarding superplasticizers, and water-proofers fall into
the inexpensive category; but that corrosion-resisting admixtures, alkali silica reaction
preventing admixtures, and the necessary combination of silica fume and high dosage
superplasticizer to generate high performance concrete are all in the relatively
expensive category.
<table>
<thead>
<tr>
<th>Admixture Type</th>
<th>Cost Per Cubic Yard</th>
<th>Percentage Cost Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-entraining agents</td>
<td>0.07 - 0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>Water-reducing retarders</td>
<td>0.24 - 0.58</td>
<td>0.68</td>
</tr>
<tr>
<td>Water reducers</td>
<td>0.25 - 1.05</td>
<td>1.1</td>
</tr>
<tr>
<td>Chloride-based accelerators</td>
<td>0.65 - 1.51</td>
<td>1.8</td>
</tr>
<tr>
<td>Waterproofer s</td>
<td>1.45 - 3.58</td>
<td>4.2</td>
</tr>
<tr>
<td>Non-chloride accelerators</td>
<td>2.17 - 3.40</td>
<td>4.6</td>
</tr>
<tr>
<td>Superplasticizers</td>
<td>2.40 - 3.75</td>
<td>5.1</td>
</tr>
<tr>
<td>Retarding superplasticizers</td>
<td>2.40 - 3.67</td>
<td>5.1</td>
</tr>
<tr>
<td>Organic corrosion inhibitors</td>
<td>9.10 - 11.50</td>
<td>17</td>
</tr>
<tr>
<td>Calcium nitrite-based corrosion inhibitors</td>
<td>14.00 - 20.00</td>
<td>28</td>
</tr>
<tr>
<td>Silica fume + superplasticizer</td>
<td>14.40 - 15.75</td>
<td>25</td>
</tr>
<tr>
<td>Alkali silica reaction</td>
<td>14.00 - 23.00</td>
<td>31</td>
</tr>
<tr>
<td>mitigating admixtures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anti-freeze admixtures</td>
<td>17.00 - 25.50</td>
<td>35</td>
</tr>
</tbody>
</table>
A PROSPECTIVE ON THE USE OF ADMIXTURES IN CONCRETE USED FOR TRANSPORTATION-RELATED STRUCTURES

Whether to specify or to permit admixture use in particular transportation-related structures, and what admixtures to consider using is a complex technical (and economic) decision that has been often neglected.

In part the decision should be based on the technical requirements of the structure; in part, on appropriate cost-benefit considerations; and in part on questions of familiarity and practicability. In particular, the projected incorporation of several different admixtures in the same concrete often raises concerns about mistakes and over- or under-dosages.

An idea of the costs involved in using particular admixtures has already been provided.

The technical requirements of the structure would normally exercise primary control concerning what, if any, admixtures to incorporate. For example, it is very clear that the benefits of air-entrainment in preventing freeze-thaw damage are so important, that any concrete structure that is exposed to freezing under any circumstances should be air entrained. The fact that the added cost is trivial is welcome, but not governing.

Since bridge decks and other bridge structures are heavily reinforced and exposed to salts or other sources of chloride in most of the United States, and since the mandated use of epoxy coating seems less than completely effective, the incorporation of a corrosion prevention admixture (in addition to the epoxy coating treatment) should certainly be considered despite the relatively high cost involved. Conversely, since most pavement concrete incorporates only load-transfer dowels, such admixtures are obviously not needed and not appropriate.

Many admixtures (such as accelerators and retarders) are primarily processing aids and have comparatively little effect on the properties of the concrete in the final structure. Whether or not they should be are used depends on the details of the
construction process itself. To some extent water reducers and superplasticizers fall into this category. It is evident that heavily superplasticized concrete is inappropriate for the usual highway paving train operation because of the extreme change in rheology of the fresh concrete. On the other hand, the ability to place concrete in “flowing concrete” form is extremely beneficial and appropriate for construction requirements on bridge decks, where congested steel and much different placement requirements obtain.

The potential use of alkali silica preventive admixtures is extremely important in certain geographical areas where potentially reactive aggregates dominate and alternatives are few and expensive. Much of the State of Nevada is one such region. Conversely, alkali silica reaction damage in pavement and other structures in the limestone regions of Southern Indiana is practically unknown, and incorporation of such admixtures in concrete in that area is clearly not appropriate.

Some of the admixtures discussed can be used individually or in combination to “upgrade” the concrete; that is to simultaneous provide stronger, less porous, and consequently more durable concrete. In general terms, admixtures that permit placement at lower water contents, such as water reducers and superplasticizers, if used for this purposes and not merely as a processing aid all into this category. Combinations of such admixtures with appropriate kinds of fly ash or silica form are particularly effective and can lead to distinctively “high performance” concretes, as has been discussed previously. The degree to which such usage is appropriate depends very much on the specific concrete structure involved. Obviously low-volume road pavement structures have less need for such superior (and inherently more expensive) concrete than bridge decks and other critical structures. Technical considerations with respect to the construction process to be used also need to be thoroughly understood, especially those involving proper curing for these low water content, inherently impermeable concretes.

Some consideration about potential problems involving the use of multiple admixtures in the same concrete needs to be expressed. Obviously, the simultaneous use of a number of different chemical substances, each of which needs to be batched accurately, in field construction can lead to problems. Surprisingly, there are comparatively few documented indications of serious difficulties due to mutual interactions of different admixtures, but that could change in the future if the use of multiple admixtures becomes more widespread.
Finally, the promise for the future of shrinkage-reducing admixtures should not be overlooked. All concrete structures shrink, and almost all eventually crack by this mechanism. The effects on pavement integrity of heavy traffic superimposed on shrinkage cracked-concrete is obvious. Should effective commercial admixtures that consistently and reliably prevent shrinkage cracking become available, the potential benefit to pavement structures could be of major importance.