RESIN CONCRETES: A LITERATURE REVIEW

by

J. E. Dennard, Jr.

September 1972

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station
Concrete Laboratory
Vicksburg, Mississippi

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
MISCELLANEOUS PAPER C-72-21

RESIN CONCRETES: A LITERATURE REVIEW

by

J. E. Dennard, Jr.

September 1972

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station
Concrete Laboratory
Vicksburg, Mississippi

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
Foreword

The literature review reported herein was part of the U. S. Army Corps of Engineers Engineering Studies Program ES 623.6, and was authorized by first indorsement from the Office, Chief of Engineers, dated 20 March 1969, to U. S. Army Engineer Waterways Experiment Station (WES) letter dated 19 February 1969, subject "Project Plan for a Literature Review on Resin Concretes."

The work was performed at the WES Concrete Laboratory under the general supervision of Messrs. B. Mather, Chief, Concrete Laboratory, J. M. Polatty, Chief, Engineering Mechanics Branch, and J. E. McDonald, Chief, Structures Section. This report was prepared by SP5 J. E. Dennard, Jr., of the Structures Section.

COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES during the preparation and publication of this report. Mr. F. R. Brown was Technical Director.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>iii</td>
</tr>
<tr>
<td>Conversion Factors, British to Metric Units of Measurement</td>
<td>vii</td>
</tr>
<tr>
<td>Summary</td>
<td>ix</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Scope</td>
<td>1</td>
</tr>
<tr>
<td>Review of Published Work</td>
<td>1</td>
</tr>
<tr>
<td>Discussion</td>
<td>16</td>
</tr>
<tr>
<td>Conclusions</td>
<td>18</td>
</tr>
<tr>
<td>Recommendations for Future U. S. Army Corps of Engineers</td>
<td>19</td>
</tr>
<tr>
<td>Sponsored Research</td>
<td>20</td>
</tr>
<tr>
<td>Literature Cited</td>
<td></td>
</tr>
</tbody>
</table>
Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>2.54</td>
<td>centimeters</td>
</tr>
<tr>
<td>cubic yards</td>
<td>0.764555</td>
<td>cubic meters</td>
</tr>
<tr>
<td>pounds</td>
<td>0.45359237</td>
<td>kilograms</td>
</tr>
<tr>
<td>pounds per square inch</td>
<td>0.00689476</td>
<td>megapascals (= meganewtons per square meter)</td>
</tr>
<tr>
<td>pounds per square foot</td>
<td>4.882428</td>
<td>kilograms per square meter</td>
</tr>
<tr>
<td>pounds per cubic foot</td>
<td>16.02</td>
<td>kilograms per cubic meter</td>
</tr>
<tr>
<td>pounds per cubic yard</td>
<td>0.5933</td>
<td>kilograms per cubic meter</td>
</tr>
<tr>
<td>Fahrenheit degrees</td>
<td>5/9</td>
<td>Celsius or Kelvin degrees*</td>
</tr>
</tbody>
</table>

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: \( C = \frac{5}{9}(F - 32) \). To obtain Kelvin (K) readings, use: \( K = \frac{5}{9}(F - 32) + 273.15 \).
Summary

Although there seems to be widespread interest in resin concretes, there have been only a limited number of publications on this subject, in contrast to the numerous publications on the specific resins (bonding agents). The publications on resin concretes have mainly been reports of specialized investigations.

Some workers found that by carefully controlling the particle size of the aggregates (or the volume of the voids) and by using special blending techniques, a strong cohesive mix can be obtained using approximately one-tenth the usual amount of resin (approximately 4% by weight versus the normal 40%-50%), thus decreasing the cost of the concrete. Other workers investigated the use of special resins (i.e. furan and silicone resins) to form resin concrete. Still other workers investigated particular characteristics of resin concretes (i.e., the effect of curing on strength, the temperature dependence of strength, the effect of load rate variance, and the maximum strength using various aggregates and mineral fillers). Several authors compared the characteristics of epoxy, polyester, furan, silicone, and portland cement concretes.

The authors generally agreed on the advantages, disadvantages, and applications of resin concretes. The major advantages are high strength, bonding ability, and resistance to wear, moisture, and abrasives. The major disadvantages are high cost of materials, difficulty of handling, and reduction in strength due to temperature increase. The major applications are for joining, repairing, lining, and coating portland cement concrete and for special applications where certain characteristics are needed (i.e. high strength, bonding ability, or chemical resistance).

A research program to provide a basis for development of reliable design criteria and construction techniques for use of resin concrete in such Corps of Engineers applications as intake control gates and navigation lock filling and emptying gate chambers is proposed.
RESIN CONCRETES: A LITERATURE REVIEW

Introduction

1. At present the price of suitable epoxy and polyester resins (or other resins) makes resin concretes highly noncompetitive for most conventional applications, but it is expected that the price will decrease as resin production increases. Then it is anticipated that resin concretes because of their unique properties will find a widening field of application. Among the unique properties of resin concretes are their high tensile, shear, bond, and compressive strengths, adjustable modulus of elasticity, high corrosion resistance, low permeability, rapid strength development, excellent insulation properties, etc. Among the applications that are currently being studied or contemplated are radar dome housings for communication and tracking gear, protective and strengthening layers on structural members, repair of structures (e.g., bridges, pavements, navigation locks, dams, etc.), deep-sea structures, and desalination plants.

Scope

2. This report attempts to review the state-of-the-art and to indicate areas for further research by reviewing and abstracting available literature on resin concretes. The available literature is summarized, test results are given, and conclusions and recommendations are included.

Review of Published Work

3. One of the first publications on resin concrete was, appropriately, a cost reduction analysis by A. S. Michaels. Mr. Michaels found that synthetic, resin-bonded compositions were used infrequently in the fabrication of structural elements in buildings primarily because of the
high cost of such compositions relative to conventional inorganic-bonded compositions. In normal usage approximately 40%-50% by weight of epoxy resin is required to produce a composition of suitable mechanical properties. The cost would be greatly reduced if a technique could be found for the preparation of durable resin-bonded particle structures where resin requirements were about one-tenth these quantities. By aqueous-dispersion-blending techniques, using dimethylaminomethyl phenol to promote resin adhesion, it is possible to produce strong, durable structures from sand-epoxy resin compositions containing very little resin. Resin requirements for successful bonding also decrease with increasing grain size—for narrow size distribution sand—and can be further reduced by combining relatively large with very small, particle-size solids. With 3.5% resin by weight, a fine-coarse sand blend composition with a tensile strength of about 1100 psi* can be prepared.

4. In November 1960, A. W. Flandro² made a study of the complete replacement of portland cement in concrete with a polyester resin. Several mix designs and curing procedures were tested. A modulus of rupture of approximately 800 psi and a compressive strength of nearly 16,000 psi were obtained with an optimum mix containing approximately 450 lb per cu yd of resin and oven cured at 350 F. The resin concrete weighed approximately 143 lb per cu ft and cost about $125 per cu yd.

5. A special report³ for Engineering News-Record in 1962 stated that resins are expensive, but their strength is greater than that of the materials they are used on, their ability to bond is exceeded by no other organic compounds, and they are not affected by chemicals, petroleum products, salts, sewage, caustics, or most acids. They can be cured in minutes when necessary. Where any of these characteristics is important, the most expensive epoxy can be extremely economical. For example:

Terrazzo floor surfaces are now being installed with epoxies as the matrix rather than portland cement. Among the advantages: epoxy terrazzo can be troweled on 3/16 inch thick instead of 1 to 2 inch and it weighs

* A table of factors for converting British units of measurement to metric units is presented on page vii.
about 2 lb. per square foot as opposed to 12 to 18 lb. for conventional terrazzo. Resin terrazzo is not affected by chemicals, oils, salts, caustics or most acids.

6. Epoxy-sand mortars are widely used for skid-resistant surfacings of bridge decks. They are particularly effective on open grid steel decks, which are extremely slippery when wet. When necessary, a bridge deck can be surfaced and opened to traffic within 2 to 3 hr.

7. G. B. Welch (et al.) of the University of New South Wales, Australia, investigated epoxy resin concrete. They believed that epoxy resin concretes would be excellent to use for special structures of thin section, where high strength, some flexibility, and impermeability to water were required (for example, shells and boat hulls). These men presented the results of experimental investigations of a number of epoxy concretes to indicate important physical properties of these new materials. Figures for elastic modulus, Poisson's ratio, curing shrinkage, thermal movement, etc., were also given for typical epoxy concrete mixes, together with details of different aggregate gradings and resin formulations examined. The important influence of varying the composition of the epoxy binder, by including a flexibilizing modifier to increase flexibility, was demonstrated by the results, and a satisfactory compromise that gives intermediate properties was included.


While it is true that numerous laboratories have examined the problems raised by these new materials, resin concretes, and their applications in building, there is scarcely a field in which the research worker and the practical man are so little informed as to the work of their colleagues. And yet, the relative novelty of this field should be an additional reason for intensifying collaboration among laboratories and should, for logical reasons, promote exchange of information.

One of the objectives of this new symposium by correspondence is precisely to provide a field of comparison for the various experiences acquired by the development of methods for testing resin concretes. Some of these tests must have required specially designed apparatus, or at least a modification of
standard apparatus; here also information is lacking. And it would certainly be valuable to be able to compare points of view on the interpretation of results. This symposium should also permit an exchange of views on the use of resin concrete in building and the prospects that can already be discerned as to its future applications. Finally, the participants are requested to present any suggestions they might have as to tests to be undertaken with a view to determining all useful characteristics of resin concretes.

9. Participants were asked to submit detailed contributions, bibliographies, and original reports on their work, whether theoretical or practical. These documents were to be distributed to all participants for study, comments, critiques, and replies by the author.

10. In general comments for the symposium, it was reported that resin concretes are superior to ordinary concretes in their tensile strength, bonding to support, time of set, impact strength, resistance to the effects of chemical agents, and lower shrinkage. Resin concretes have mainly been used in special cases where they appear to be the only solution such as structural repair, thin fragile parts in which ordinary concrete cannot be used because of its fragility, and in cases that require bonding characteristics superior to ordinary concrete perhaps due to the presence of excessive moisture or the thin layers required.

11. Mr. R. Bares (et al.) submitted a detailed report of a practical application of synthetic construction material.

The Institute of Theoretical and Applied Mechanics of the Czechoslovak Academy of Sciences began its research into resin concrete in 1958 when the Czechoslovak building industry began to feel an acute need for a new, high-quality structural material resistant to various aggressive effects and characterized by high strength. Various aspects of selection of a suitable bonding agent on the basis of synthetic macromolecular materials were considered. Extraordinary chemical resistance, availability of raw materials, simple production and a consequently low price, i.e. circumstances of particular importance for the building industry, decided in favor of furan resins. The criterion of strength was not decisive, the majority of bonding agents being characterized by a strength
of the same order which in any case cannot be prac-
tically utilized to the full.

Among the furan resins we considered the furfuryl-
 alcohol or furfurylalcohol-furfurylaldehyde polyconden-
sates as the most suitable for the given purpose. The
material which resulted from the use of these resins
as bonding agents for mineral aggregates was given the
name of Berol. Our research in this respect was brought
to certain practical applications, one of which is illus-
trated.

The use of Berol pipe cores for the construction
of drainage piping in chemical plants with highly aggres-
sive effluents (pH varying between 2 and 13) is less
expensive than the traditional masonry sewers with
heavy lining or stoneware piping. As regards Czechoslo-
vak prices a Berol pipe line is 25% cheaper than an
identical stoneware pipe line and 15% cheaper than a
masonry sewer. Apart from the economy it reduces
labour requirements 2.5 times. It is obvious that the
production of Berol pipe cores carried out on a larger
scale will lead to a further reduction of their costs.
The use of Berol pipes without concrete casing is
hindered by still uncompleted research, particularly
of the creep of Berol, and by a relatively higher final
price. Research work in this field is being further
pursued.

These results were achieved above all because of
proper understanding of the properties of the new mate-
rial acquired through an analysis of the results of a
testing programme extending over a period of several
years. Simultaneously these tests also revealed that,
of course, many things still remain unknown to us so
that it is impossible to generalize the conclusions and
hypothesis hitherto achieved in their full extent and
apply them to the whole branch of new heterogenous ma-
terials with markedly different mechanical (mainly rheo-
logical) properties of their aggregates and bonding agent-
resin concretes. Nevertheless, we believe that the
publicizing of our experience might afford certain clues
to those concerned with the research of resin concretes.

For further progress and the solution of impending
problems it will obviously be necessary to mobilize (and
often extend) our knowledge of material mechanics. We
do not expect any great contribution from a common rheo-
logical approach. It is hardly possible to attain concrete
information by means of abstract approximations. We believe
that the physical nature of problems connected with the
properties of resin concretes (and generally speaking,
of all heterogenous bound porous materials) requires further study from the standpoint of physico-chemical mechanics. It is just physico-chemical mechanics which, as a thermodynamic discipline, bases its way of thinking not only on the molecular physics of solids, but also, and chiefly, on the physical chemistry of surface effects and disperse systems. If the foremost research centers direct their efforts in this direction, we can hope to master soon the properties of resin concretes to perfection, to say nothing of the probable elucidation of some new ideas on the properties of traditional non-metallic structural materials.

12. Mr. T. Sneck reported to the symposium that his tests of furan resin mortars and concretes were similar to those of Mr. Bares and associates, who reported them in detail. Mr. Sneck went on to say that building research today is paying much attention to the classification of the functional requirements of different building elements. When materials are chosen to meet these requirements plastics may play an important part because of the great possibilities to create tailor-made products. Resin mortars and resin concretes have to be remembered in this connection.

13. Dr. J. Mlodecki participated in the symposium with a paper on the application of isobutoxysiloxane resin to the manufacturing of resin concrete. This paper discussed the use of isobutoxysiloxane resin for the manufacture of resin concretes either as an auxiliary agent modifying the characteristics of epoxy and polyester concretes or as the sole binder of asbestos, and natural aggregates. He described the method for manufacturing isobutoxysiloxane resins, their characteristics, the method of forming and testing samples of isobutoxysiloxane resin concretes, and the results of tests carried out.

The most valuable properties are possessed by epoxy resin concretes. They distinguish themselves particularly by excellent adhesion and mechanical strength. Polyester resin concretes are not adequately water-resistant. In comparison with epoxy concretes they possess worse adhesion and are less durable; they are, however, considerably cheaper. Furan concretes are marked by high chemical resistance, while phenol-formaldehyde resin concretes—by less creep. Resin concretes have already found
practical application in building for various special purposes, such as, repairing, joining and lining portland cement concrete.

Great possibilities of improving the concretes obtained under application of organic resins as well as of obtaining new varieties of resin concretes seem to be offered by certain silicone resins. Silicone resins are marked by considerably better durability as well as better heat- and frost-resistance than organic resins. It has been roughly estimated that they are about ten times as durable as organic resins. Moreover, on the basis of the partly inorganic structure of these compounds, it is to be expected that they may possess high resistance to the action of continuous loading.

In view of the above it has seemed advisable to check:

1) the possibilities of improving certain properties of epoxy and polyester concretes, particularly their durability, and lessening creep by adding silicone resin to them, as well as:

2) properties of concretes obtained under application of silicone resin with various fillers.

The isobutoxysiloxane resin has been singled out as a silicone resin.

The following conclusions were reached:

It is possible to obtain resin concretes under the application of organic resins both epoxy and polyester with the addition of isobutoxysiloxane resin—with very good strength properties. The addition of isobutoxysiloxane resin in the amount of 11 and 25% of the weight of the organic resin slightly lowers but does not essentially reduce the bending and compressive strengths of epoxy and polyester concretes. The method of hardening the respective concretes seems to have an important influence on their strength properties.

The application of isobutoxysiloxane resin as addition to epoxy and polyester concretes would be advisable, should further tests confirm the rightness of the assumptions that this resin, as a silicone one, in view of its characteristic properties, should decrease creeping and increase the durability of these concretes, and should also improve other properties essential for certain applications such as frost- and heat-resistance, electro-insulating properties, etc. Tests of a number
of other properties of the said concretes are then necessary.

Under the application of the isobutoxysiloxane resin as binder as well as of asbestos as filler, it is possible to obtain materials of good strength properties, however considerably lower than concretes manufactured under the application of the organic resins tested. These materials may be applied in the cases when the strength requirements to be met are not very high; however other properties of the material are important particularly electro-insulating and thermic properties, frost-resistance, and durability which characterize materials made from silicone resins.

14. C. K. Warren⁹ participated in the symposium with a paper discussing his research into the effects of aggregate size and gradation on resin concretes. Mr. Warren listed three main variables involved in the production of resin concretes: the resin system, the selection of aggregates, and the technique employed. He decided to select a technique and suitable resin system that promised the highest strengths at low resin concentrations. Then, after optimizing the technique, the main investigation was directed toward determining the effect of variations in the aggregate gradings. A more detailed and systematic study of the different resin systems and techniques was left for a later study.

15. Mr. Warren began his tests using the technique outlined by A. S. Michaels.¹ However, Mr. Warren found that by reducing the amount of dispersing water to the minimum consistent with the ease of mixing and by eliminating xylene from the formulation he obtained greater strengths which were reproducible. Mr. Warren made some interesting observations.

Assuming efficient mixing, the resin forms a uniform coating over each particle except at the inter-particle joints, where surface tension effects result in an accumulation of resin. In such a simple one-sand system, where the binding medium has a greater intrinsic strength than the aggregate, the strength of the final product must depend on three factors:

1) The number of inter-particle joints per cross-sectional area.
2) The strength of each inter-particle joint.
3) The strength of the resin envelope around each particle.
Clearly, as the sand becomes coarser, (1) decreases, while (2) and (3) increase, because of the diminishing surface area and consequent thickening of the resin film.

Another factor which may become appreciable with the coarser sands is that as the particle size increases, the contact faces at the inter-particle joints begin to approximate to plane surfaces, hence, at any particular thickness of resin film the cross-sectional areas of the joints are correspondingly greater.

The complexity of an apparently simple system can be appreciated if the interplay of these four factors is considered.

Workability, segregation and compaction considerations appear to decree that a resin concrete should have a continuous matrix of fine sand, and the curves show plainly that for highest strengths, this must be of about 18-25 mesh grading.

The results obtained with two-sand mixes require little comment. The curves illustrate the effect of varying both the ratio of coarse to fine sand by weight, and the ratio of coarse particle size to fine particle size. Highest tensile strengths were obtained with a diameter ratio of 14:1 and a weight ratio of 2:1, whereas for compressive strength the optimum weight ratio was nearer 3:1. However, these figures will almost certainly vary with resin concentration and it would be unwise to extrapolate them to include other systems, except with extreme caution and taking into account the availability of resin in the system.

16. Mr. R. Bares submitted a thorough commentary on Mr. Warren's contribution to the symposium. A summary of his comments follows.

In order to understand the properties and behaviour of resin concretes, it is apparently necessary to investigate a wider range of mixes (as to binder-aggregate ratio) than the majority of the authors have hitherto done. In research thus conducted the importance of the volume weight of the mix as a characteristic of resin concretes should not be underestimated. On the other hand, strength values, even though important from the point of view of technology, cannot be considered to be sufficient criteria for assessing the mixes.

It is necessary to bear in mind that every property of resin concretes is a function of

A) the properties of the binder--

Every property of the binder represents a certain
limit of the corresponding property of the resin concrete which may be exceeded only in case the internal stress of the material is particularly favorable with respect to the property under consideration.

B) the proportion (in volume) of the binder in the mix--

The proportion (in volume) of the binder in the mix is a measure of the effect of the property of the binder on the property of the resin concrete.

C) the volume of voids in the aggregate--

The ratio of the binder volume and the volume of voids between aggregate particles in the material determines the degree of cohesion or at least the compactness of this material. It also determines the macrostructural stress under load.

D) the mechanical interaction between binder and aggregate in dependence on the conditions of curing--

The conditions of curing resin concrete determine the combination of properties brought about by the supplied volumes of bonding agent and aggregate, i.e. by the primary internal stress of the material.

E) the mechanical interaction of the material and the environment--

The interaction of resin concrete and environment is decisive in inducing secondary internal stress in the material.

17. Mr. Bares then illustrated his findings from several results of his experiments with various resin concretes (bonded with epoxide, polyester, phenol-formaldehyde, and furan resin, and sand as aggregate).

18. Mr. D. Jejcic authored a general report on the symposium on resin concretes. Resin concretes were found to be useful for complementing ordinary concrete or in special applications requiring their particular characteristics. Resin concretes were not viewed as a replacement for ordinary concrete due to the high cost of the resin concrete. Epoxy binders are considered first because of their excellent strength, adhesion, chemical resistance, and moisture tolerance. However, the manufacture of epoxy is complicated and thus its cost is high. The cost of polyester and furanic resins is about one-sixth that of epoxies, and they can be cured at a lower temperature, and have a strength at low concentrations
(10% by weight) nearly equal to that of the epoxy resins. However, the polyester and furanic binders are much less tolerant of moisture than the epoxy resins.

19. There has been some study directed toward the application of resin concretes in thin layers to protect other surfaces from corrosion or wear.

At present, it is difficult to estimate the properties that should be demanded of binders in order to ensure their good performance under service conditions. Tests have been undertaken by Mr. Kriegh* with a view to sorting out the rational criteria to be applied to epoxy binders modified by polysulphides; these tests have established the minimum values that can be required for tensile strength, elongation, toughness, modulus of elasticity and adhesion.

20. R. A. Breckenridge11 (et al.) of the U. S. Naval Civil Engineering Laboratory published a report in November 1966 on reinforced plastics as structural materials. The purpose of their report was to describe the state-of-the-art in using reinforced plastic as a structural material, defined as applications in which the reinforced plastic carries at least a portion of the structural load. Polyester resin types were the most commonly used. The abstract of their report stated:

A survey is made of existing knowledge regarding the use of reinforced plastics as the load-carrying members in structural systems. Examples are given of existing applications in large buildings, motels, houses, special uses, marine surface craft, deep submersible hulls, and in other areas. A review is made of structural shapes that are commercially available. The basic materials, i.e., resins and reinforcements, are briefly discussed, and the various methods of combining them into a finished item are mentioned. The physical properties are summarized, and the areas of potential degradation are discussed. Problems in the design of reinforced plastics are considered.

The areas in which there appears to be good potential for increased structural applications are presented; those that might be of greatest interest to NFEC include (1) antenna-support systems,

* Kriegh, Department of Civil Engineering, University of Arizona, Tucson. Mr. Kriegh also presented a paper in the symposium entitled, "Protective and Skid-Resistant Coatings for Concrete Bridge Decks."
(2) waterfront structures and facilities, (3) structures in remote areas that require shipping or that present maintenance problems, and (4) advanced-base structures that must be built under the pressure of military exigency.

21. Mr. K. B. Hickey prepared a comparison of concrete and epoxy materials.

Laboratory tests of the physical properties of epoxy mortars and epoxy concretes were conducted to determine the structural compatibility of these materials with portland cement concretes. Tests indicate good structural compatibility of physical properties except for thermal expansion and other volume changes. Epoxy mortars and concretes possess almost no measurable creep at zero degrees F, but have compressive creep and elasticity characteristics at 73 degrees F very close to portland cement concrete. Mixes employing minimum volumes of epoxy have thermal expansion values about 2-1/2 times the expansions of portland cement concretes; larger amounts of epoxy increase expansion. No shrinkage after the initial hardening was measured in the epoxy mixes, but portland cement concrete does shrink and expand during moisture changes. Abrasion resistance and unit weight properties are similar. Mortars and concretes using epoxy resin binder are much stronger than cement concretes in compression, flexure, and tension; are much more resistant to breakdown in freeze-thaw conditions; and absorb much less water during soaking. All physical properties tested and compared indicate that epoxy mixes using small amounts of resin are more compatible with portland cement concrete than mixes containing large amounts.

22. Dr. H. G. Geymayer authored a report on the use of epoxy or polyester resin concrete in the tensile zone of composite concrete beams.

This report describes the results of an investigation into the feasibility of combining the high compressive strength of portland cement concrete and the superior tensile strength of epoxy or polyester resin concrete into a composite beam. This would increase the beam's flexural strength and improve the corrosion protection for the reinforcement at large deflections by eliminating tensile cracks.

The report describes in detail the development of high-strength resin concrete mixtures and summarizes the most important engineering properties of the selected mixtures. Also included are the results of
third-point loading tests of 12 reinforced and unreinforced composite beams with 1-1/2- and 3-in.-thick layers of epoxy and polyester resin concretes. These results are compared with results of tests of two reference beams without resin concrete layers and with analytical results.

The study led to the following principal conclusions:

a. Properly designed resin concrete layers at the tension face of concrete beams can be used to moderately increase the strength and rigidity of reinforced concrete beams, or to upgrade the flexural strength of unreinforced beams by a factor of two to three.

b. More important than their influence on strength is the ability of resin concrete layers to provide a noncracking moisture barrier or corrosion protection practically up to beam failure.

c. The epoxy resins appeared to be more suitable for this application than the polyester resins investigated due to lower shrinkage and exotherm as well as higher tensile strength and tensile strain capacity.

d. In proportioning resin concrete mixtures, early attention should be directed to properties other than strength (such as shrinkage, exotherms, coefficient of thermal expansion, creep, sensitivity to environmental factors, etc.).

23. Mr. L. Knab \(^{14}\) authored a paper on the effect of load rate variance on polyester concrete.

The effect of the variance of load rate on the engineering properties of a plain polyester concrete system was investigated. Both the tensile and compressive phases of the system were evaluated. In the tensile phase, the load rates ranged from slow static through the dynamic range; whereas in the compressive phase, the load rates varied from very slow static through very high static. Tests were conducted using one type of a polyester resin combined with a feasible gradation of a standard reproducible aggregate. Wherever possible, standard ASTM tests for portland cement concrete were used with each load rate held constant throughout the testing time of each specimen.

Ultimate stress, modulus of elasticity, and the
strain at ultimate stress were the basic engineering properties considered. Significant variation of these properties in both the tensile and compressive phases was obtained by varying the load rate. This investigation conclusively showed that the polyester concrete system studied will withstand both slow and fast static loading conditions in both tension and compression.

24. Mr. F. B. Bull* undertook a research program to test concretes with varying amounts of epoxy resin added to the normal portland cement concrete. The concretes were tested under four different curing conditions: air curing (with no artificial control on temperature or humidity), fog room curing under standard control conditions, curing under water, and steam curing. The epoxy resin was added in 5%, 10%, and 15% amounts of the weight of portland cement used. The results were disappointing in that the increase of strength was marginal only, and thus there does not appear to be any economic case for the use of epoxy under these conditions. Increases of strength due to the addition of epoxy resins were greatest in the steam cured specimens.

25. T. G. Clendenning** has conducted an investigation of the use of epoxy resin concrete for constructing small compression footings for winter powerline construction. It was decided to investigate the relation between temperature and the material properties. The compressive strength of the material decreased from a value of 12,000 psi at room temperature to 735 psi at 300 F. In addition to this effect, it has been shown by others that the specific creep of epoxy concrete is highly temperature dependent. If the type of epoxy resin concrete Mr. Clendenning investigated were to be used in the tension zone of a flexural member, or any other structural application possibly subjected to high temperatures such as those that may occur during a fire, the results could be disastrous.

26. Mr. D. R. Bloss15 (et al.) authored a report on the development

---

* F. B. Bull, Professor of Civil Engineering, University of Adelaide, Australia, letter to Bryant Mather, Chief, Concrete Division, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
** T. G. Clendenning, Research Engineer, Ontario Hydro, letter to Bryant Mather, Chief, Concrete Division, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
and evaluation of a high-strength polyester synthetic concrete.

This report presents the results of the selection and subsequent testing of a high-strength synthetic concrete. The program was initiated to select a material of maximum compressive strength (20,000 psi desirable) using conventional aggregate with synthetic bonders and to obtain its optimum characteristics by testing.

The selection of materials program used a number of resin types with varying aggregates. It was found that the strength of concrete was limited to about 15,000 psi using conventional aggregates. The most promising material in combination with Type III cement (used as a mineral filler) was found to be the only concrete to exceed the 20,000-psi compressive strength goal. The resin-cement ratio was found to be optimum at about 1:2 by weight.

The polyester resin with Type III cement was subjected to a series of tests and the results were compared with the characteristics of standard portland cement concrete. Standard 3- x 6-inch test cylinders were used for unconfined static and dynamic compression and split tensile testing. Triaxial compression, direct shear, and bond with steel tests were performed on standard 2- x 4-inch test cylinders. Variables of aging, temperature and workability were also investigated. Handling, placement and mix techniques for small-scale applications were developed and the cost of materials estimated.

This investigation revealed that the high-strength synthetic concrete's value lies in its compressive strength of 20,000 psi and above. The nominal modulus of elasticity after two days and at room temperature is about $1.4 \times 10^6$ psi. Direct tension values are in excess of 2000 psi.

Major drawbacks of this material include extreme reduction of strength with temperature (6000 psi at 210°F). Costs are in excess of $250 per cubic yard for materials alone, plus high placement costs due to special handling requirements. Handling is difficult because the material has a short pot life and must be mixed in small batches. It also has a very high exothermic reaction. This causes considerable shrinkage in large pours and requires pouring in layers not to exceed 4 or 5 inches. The potential application of this synthetic concrete is therefore limited to specialized use where these qualities would be advantageous.
27. V. I. Solomatov published a book in Moscow in 1967 entitled Polymer-Cement Concretes and Polymer Concretes. The book was translated from the original Russian by the Computer Branch of the U. S. Atomic Energy Commission. This book is the first attempt at generalization and systematization of theoretical and practical knowledge of the technology and use of polymer-cement concretes and polymer concretes—the new high-strength, stable materials whose properties can be changed at will within wide limits. Their high static and dynamic strengths and their resistance to wear and chemicals permit their wide use for chemical-resistant equipment, storage vessels, and pipelines for corrosive or biologically active liquids, chemical-resistant floors, sewage systems, and many other purposes. The book was written for construction engineers and for industrial workers who use construction materials. This book with 250 references is a very thorough attempt at summarizing the theoretical, experimental, and practical studies and applications of polymer-cement concretes and polymer concretes.

Discussion

28. Although there seems to be widespread interest in resin concretes, there have been only a limited number of publications on this subject—in contrast to the numerous publications on the specific resins (bonding agents). The publications on resin concretes have mainly been reports of specialized investigations.

29. Michaels investigated the possibility of reducing the cost of resin concrete by reducing the resin content using aqueous dispersion techniques. By increasing the grain size (for narrow size distribution sand) and adding some very small, particle-size sand, he obtained a composition having 1100-psi tensile strength using 3.5% resin by weight instead of the normal 40%-50% resin by weight.

30. Bares used furan resin and mineral aggregate to form a resin concrete which he named Berol. Berol pipes with portland cement concrete casings were found to be 25% cheaper than stoneware pipe and 15% cheaper than masonry sewer and thus excellent for piping for aggressive effluents from factories.
31. Mlodecki investigated the use of isobutoxysiloxane resins. He found the addition of this silicone resin to epoxy and polyester resins does not essentially reduce the strengths of these resins in concrete and should (due to the properties of the silicone resin) decrease creeping and increase durability, frost- and heat-resistance, and electroinsulating properties of the resin concrete.

32. Warren altered Michaels' method for reducing resin content by using less mixing water and no xylene in the dispersing agent. Incorporating these changes, he found that the resin concrete could be optimized by controlling aggregate size and gradation. Bares disputed this method—feeling that the mix is actually optimized by controlling the volume of the voids, and further that the other variables in a mix are: properties of the binder, proportion (by volume) of binder, mechanical interaction between binder and aggregate, and mechanical interaction between the concrete and the environment.

33. Breckenridge discussed the state-of-the-art of reinforced plastics as load-carrying members in structures. Hickey found that resin concretes (with relatively low resin content) are compatible with portland cement concretes, the main differences being creep (at varying temperatures), shrinkage, and thermal expansion.

34. Geymayer reported on increasing the strength (either rigid or flexural), cracking resistance, impermeability, and chemical resistance of beams by composite construction using a resin concrete layer in the tensile zone.

35. Knab studied the effect of load rate on polyester concrete. He found that a polyester concrete system will withstand both slow and fast static loading in tension or compression. And Bull added small amounts of epoxy to portland cement concrete under four different curing conditions. There resulted only marginal increases in strength.

36. Clendenning found that there are significant strength decreases in resin concrete with temperature increases. Bloss investigated the maximum compressive strength that can be obtained with various mixes of resin concrete. He found that the maximum compressive strength is limited to about 15,000 psi using conventional aggregates. One mix (using type
III portland cement as a mineral filler) reached 20,000-psi compressive strength.

37. Solomatov\textsuperscript{16} authored the only publication found that summarized the existing knowledge (theoretical and practical) on resin concretes.

**Conclusions**

38. The authors generally agreed on the major advantages, disadvantages, and applications of resin concretes.

a. The advantages are:

- High strength (both compressive and tensile)
- High static and dynamic resistance
- High bonding strength
- Moisture tolerance of bond
- Impermeability
- Durability
- High early strength (adjustable time of set)
- Impact resistance
- Low shrinkage
- Creep resistance
- Cracking resistance
- Adjustable flexibility
- Adjustability of composition to suit particular needs
- Resistance to wear, chemicals, abrasives, oils, salts, caustics, and frost penetration

b. The disadvantages are:

- High cost of materials (resins)
- High cost of handling (special equipment, etc.)
- Short pot life (requires small batches)
- Reduction in strength with temperature increase
- Shrinkage in large pours
- Difficult handling and placement (due to toxic effects and bonding characteristics)

c. Possible applications are:

- Structural repair
- Thin fragile parts
- Wearing surfaces
- Moisture barrier
- Chemical protection barrier
- Corrosion protection barrier
- Piping for aggressive effluents
- Functional tailor-made building elements
- Antenna-support systems
Waterfront and underwater facilities
Rapid construction (high early strength)
Cracking resistance
Storage vessels
Chemical-resistant equipment and floors
Sewage systems

39. The authors generally agree that resin concretes are not a replacement for portland cement concrete in the construction industry but are another construction material that may be used to complement portland cement concrete structures. Resin concretes may be used for joining, repairing, lining, coating, and bonding portland cement concrete. Also, resin concretes are applicable in situations where certain characteristics are needed, i.e. high strength, impact resistance, impermeability, frost-penetration resistance, low shrinkage, superior bonding, wear resistance, chemical resistance, etc. Thus, the authors think that resin concretes are another construction material that should be used in situations which suit (or require) their particular characteristics.

40. Epoxy resin concrete generally exhibits higher strength, better bonding, higher moisture tolerance, and better chemical resistance than the other resin concretes. However, the manufacture of epoxy is complicated and thus its cost is higher. The polyester and furanic resins cost much less than the epoxy resins, can be cured at a lower temperature, and have strength at low concentrations nearly equal to that of the epoxy resins. However, the furanic and polyester resins are less tolerant of moisture and have lower adhesive and durability values than the epoxy resins. The silicone resins have generally the same characteristics as the polyester and furanic resins. However, the silicone resins seem to have the potential to exhibit much greater durability than the epoxy resins. More research is required to determine the actual durability values of silicone resin concrete.

Recommendations for Future U. S. Army Corps of Engineers Sponsored Research

41. The common use of conventional concrete in highly abrasive
environments such as intake tower control gates and navigation lock filling and emptying gate chambers has led to frequent and costly repairs. It is anticipated that the use of resin concrete with its increased abrasion resistance in such areas, either as new construction or in the repair of existing such structures, would reduce the frequency and cost of repairs. It is suggested that research be concentrated, for the time being, on the development of sufficient information to provide a basis for reliable design criteria and construction techniques. It is believed that a useful guidance document for field usage of resin concrete could be developed with a minimum of laboratory testing to supplement existing data. Subsequent laboratory and field prototype tests of selected structures would provide a basis for modification of the field guidance document as necessary.

**Literature Cited**


# Abstract

Although there seems to be widespread interest in resin concretes, there have been only a limited number of publications on this subject, in contrast to the numerous publications on the specific resins (bonding agents). The publications on resin concretes have mainly been reports of specialized investigations. The authors generally agreed on the advantages, disadvantages, and applications of resin concretes. The major advantages are high strength, bonding ability, and resistance to wear, moisture, and abrasives. The major disadvantages are high cost of materials, difficulty of handling, and reduction in strength due to temperature increase. The major applications are for joining, repairing, lining, and coating portland cement concrete and for special applications where certain characteristics are needed (i.e., high strength, bonding ability, or chemical resistance). A research program to provide a basis for development of reliable design criteria and construction techniques for use of resin concrete in such Corps applications as intake control gates and navigation lock filling and emptying gate chambers is proposed.
<table>
<thead>
<tr>
<th>KEY WORDS</th>
<th>LINK A</th>
<th>LINK B</th>
<th>LINK C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>