

INVESTIGATIONS OF SOME APPLICATIONS
OF EPOXY PREPARATIONS ON THE FARM

by

RAYMUNDO E. JOVELLANOS

B. S. A., University of the Philippines, 1951

A MASTER'S REPORT

submitted in partial fulfillment of the

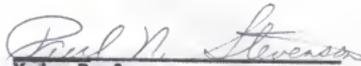
requirements for the degree

MASTER OF SCIENCE

Farm Mechanics
Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1964

Approved by:


Major Professor

LD
2665
R4
1964
J86
Q.2

TABLE OF CONTENTS

INTRODUCTION	1
PURPOSE	4
REVIEW OF LITERATURE	5
MATERIALS AND METHODS	9
Materials Used	9
Preparation of the Materials to be Joined	11
Procedure in Making the Joints.....	12
Curing the Joined Materials	13
Testing the Joints	13
RESULTS AND DISCUSSIONS	14
Results of Tensile Tests	15
Results of Shear Tests	16
SUMMARY	19
ACKNOWLEDGEMENTS	22
LITERATURE CITED	23
APPENDICES	25

INTRODUCTION

The epoxy resins are one of the new major industrial plastics that has found acceptance in all types of industries. The epoxies, as they are often called, have found their way into a variety of uses such as for coating, bonding, embedding, tool-making, etc., in such diverse fields as aircraft manufacture, road surfacing, electronics industries, dam construction, to name a few.

Epoxy resins were first synthesized by Pierre Castan in Switzerland and by S. O. Greenlee in the United States in the late 1930s (11). * The commercial exploration of epoxide resins was begun by I. G. Farbenindustrie in the thirties. German patent 676117 issued in 1939 describes liquid polyepoxide which can be hardened by a variety of methods. And in the United States Pierre Castan was issued U. S. patent 2,324,483 (1943), assigned to the Ciba Company, covering the curing of phenolic epoxide resins with dibasic acids (17).

What then are these epoxies and what can they do? According to Skoist and Somerville (17), an epoxy resin is a viscous liquid or a brittle solid which is of little use until reacted and hardened with other materials. Epoxy belongs to that fabulous class of organic chemical compounds known as polymers. When individual molecules exist as repeated links in a chain of similar units, a polymer is formed. Most ordinary compounds are just aggregates of simple molecules with slight affinity for each other so that they are weakly joined together. Polymers on the other

* Numbers in parentheses refer to the appended references.

hand have fantastically long chains, sometimes numbering thousands of tightly linked units giving these materials great strength. Strong as they are, the long-chain molecules allow slippage between chains like strands of spaghetti when tugged by a fork. A further chemical refinement is achieved by adding random single molecules of some other substance, usually called hardeners, curing agents or activators, which hook on as cross-links at intervals between adjacent chains, tying the whole mass together in a three-dimensional network that is super-strong. (12).

Epoxy adhesives are generally supplied in two-component forms in squeezable containers or tubes for do-it-yourself projects. However, most of the companies engaged in the formulation of epoxy compounds offer a complete line of epoxy products that can be tailored to meet specific needs and amounts in construction and maintenance. Some of the specific requirements that may be expected from epoxy formulations are outstanding adhesion to masonry, metal, and most other materials; excellent resistance to alkalis, oils, and most acids; and remarkable resistance to impact, abrasion and wear. Excellent resistance to weathering as well as to freeze and thaw cycles are also important requirements where extremes in temperatures are to be expected. These specifications can be met by the use of one or more epoxy products to the extent that these qualities are required in the application for which the product is intended.

The epoxy resins possess a number of unusually valuable properties some of which are enumerated above. They are well suited to the formulation of adhesives, sealing liquids, cold solders, castings, laminates and coatings. It is in its use as adhesives for metal-to-metal bonding that the epoxy resins have exceeded all expectations of early users.

Some of the advantages of epoxy adhesive bonding as reported by different authors like Lee and Neville (11), Skeist and Somerville (17), Skeist (16) and Epstein (5) are as follows:

a) Integrity of joined areas is maintained as holes for the insertion of fastening devices are eliminated, countersinking to give a flush surface is unnecessary, and excessive heat of fusion for joining (which can ruin heat treatment or distort parts) is eliminated

b) Smooth contours are the rule rather than the exception because adhesive bonded joints eliminate gaps and bulges common with intermediate fastenings. It has no external projections as with rivets and bolts and its surface is not marred by heat and pressure commonly associated with welded joints

c) Adhesives produce continuous bond and thus distribute stress loads evenly over the entire joined area. This eliminates localized stress concentrations, permits the use of lighter gage materials and produces joints of greater strength and rigidity

d) A continuous contact between joined surfaces insures not only bonding but sealing and waterproofing as well. This means saving in time and cost of separate sealing and waterproofing operations and permits the sealing of joints where it might not otherwise be possible

e) Epoxy adhesives also make possible the joining of dissimilar metals with a minimum of bimetallic corrosion by acting as a continuous insulating barrier between the surfaces. The problem of corrosion due to the use of heat and fluxes is also eliminated

f) Low shrinkage - The epoxies cure with only a fraction of the shrinkage of other types of adhesives; consequently less strain is

built into the joint and the bond is stronger

g) Low creep - The cured epoxies maintain their shape under prolonged stress better than thermoplastics

h) Resistance to moisture and solvents - Once the epoxies harden they become insensitive to moisture, solvents and acids. They are also effective barriers to heat and electric current

i) Cohesion - When the resins are properly cured, the cohesive strength within the glue line is so great and the adhesion of the epoxy to other materials so good that failure under stress often occurs in one of the materials being bonded rather than in the epoxy or at the interface

j) Can be modified - The properties of epoxy adhesives can be changed to suit the purpose by selection of base resin and curing agent or by alloying the epoxy with another resin or by compounding with fillers or modifiers.

All the preceding discussions about the versatility and advantages of epoxy adhesives when used to join various materials to each other or to different materials seem to point out that here at last is the answer to all joining problems. One can also visualize many applications for on-the-spot repairs of farm equipment involving extruded metal parts, cast metal, etc. where welding would not be readily available or would be impractical.

PURPOSE

It is the purpose of this study, therefore, to (a) investigate the possible uses of commercially available epoxy adhesives for repairs of farm implements, (b) determine the influence of some materials as modifiers and (c) learn the effect of heat applied sometime during the

ouring process on the resulting joint.

REVIEW OF LITERATURE

In an article in the Implement and Tractor magazine, Huggins (10) discussed the merits of the use of epoxy adhesives for the repair of aluminum oil coolers of tractors in the field. Although aluminum is becoming more and more common as a component of farm machinery very few farm repair shops are equipped with the proper facilities for working on aluminum parts and are therefore reluctant to make repairs on them. Welding, brazing or soldering aluminum require expensive equipment as well as skills which are only acquired after long practice. These are the principal reasons why most farmers are not ready to attempt repairs on aluminum parts.

Epstein (6) reported that epoxy-based adhesives have found extensive usage in joining a wide variety of materials to one another particularly where high strength and ease of application are desired. In addition, resistance to various chemicals and weathering permits the use of these types of adhesives wherever corrosion-resistant joints are necessary.

In an earlier work Epstein (5) summarized the advantages of epoxy-based adhesives for metal-to-metal bonding as follows:

- a) Ability to join dissimilar metals
- b) Elimination of the need for high temperatures during joining
- c) Elimination of the need for piercing materials to be joined
- d) Ability to fasten articles to extremely thin metal structures without distortion
- e) Leak-proof joints

- f) Corrosion resistance
- g) Insulation and vibration dampening properties
- h) Structural advantages such as uniform stress distribution, increased service life, smooth contours and surfaces, and reduced weight
- i) Reduced production costs

Similar advantages were also reported by Skeist (16).

Charlton (4) reports that epoxy adhesives are primarily metal adhesives and other resins are alloyed with them to impart some characteristics lacking in the emulsified adhesive. He further states that the reasons for the great diversity of adhesive formulations are the very dissimilar requirements for performance that occur because of the many places where adhesives can be used and the wide compatibility of epoxies and their ability to bond to most materials.

According to Lee and Neville (11), the thermosetting epoxy resins possess a number of unusually valuable properties immediately amenable to use in the formulation of adhesives, sealing agents, cold solders, castings, laminates and coatings. As adhesives, epoxies will give excellent bonds to steel, aluminum, brass, copper and most other metals as well as to glass, wood, concrete, paper, cloth, etc. Their high cost, however, has confined their use in areas where conventional adhesives like animal and vegetable glues do not produce effective bonds.

Epoxy-based adhesives have been developed primarily for the aircraft industry in the search for better materials for the production of aerodynamically sound and smooth surfaces as a result of the demand for supersonic aircraft. How successful this search was, can be judged from

the fact that according to Beasely (2) the "epoxies have replaced rivets and welding in the fabrication of one of our fastest jet bombers, the B-58 Hustler." This is the reason for the increasing use and development of epoxy resins and combination of them for effecting durable high strength bonds in aircraft design and assembly. And with the advent of satellites the report of Royall and Matlock (15) that epoxy passed its toughest test in outer space as shown by the success of the Courier I-B satellite will surely help focus more attention on the importance of epoxy adhesives.

Encapsulation of electronic components with the use of epoxy resins was reported by Ringwood (14). He noted that by careful control on materials and the regulation of processing conditions, low-cost high reactivity epoxy compounds can be utilized in the production line for encapsulating electronic components. In fact, epoxy resins have almost completely replaced polyesters and phenolics as potting and encapsulation compounds and are also making a strong bid as magnet wire insulators.

Formo and Bolstad (7) reported tensile bond strength of over 12,500 pounds per square inch were exhibited when bonding steel to steel and over 8,700 pounds per square inch when bonding aluminum to aluminum. They found further that epoxy bonding of aluminum showed about twice the bond strength and many times the reliability found when compared to a soldering method.

Development of ready-to-apply epoxy adhesives has brought about greater interest in epoxies for joining according to Gould (9). The new product is an answer to the various complaints about pot life, need for skilled workers and multiple step procedures that was characteristic of

earlier epoxy adhesives.

In an earlier report, Gould (8) discussed a new one-component epoxy-based adhesive that can be used directly from the container. The savings in cost and time in the elimination of measuring, weighing and mixing operations makes the new adhesive more appealing to prospective users than earlier two-component formulations. In addition, the new adhesive is also thixotropic which means complete absence of drip or flow either before or during the curing process.

The work of Theakston and Ogilvie (18) on the use of adhesive to fasten metal roofs as reported in the Agricultural Engineering Journal deserves special attention. Although the results were not generally satisfactory their work suggests a promising solution of a perennial problem of sheet metal roofing on the farm.

Numerous industrial uses of epoxies have been mentioned. To give a complete account of the present and potential applications would be beyond the scope of this work. Suffice it to say that we have just barely scratched the surface of the future uses of epoxy preparations.

On the other hand it must not be construed, however, that epoxy adhesives are the "cure all" for all fastening or bonding problems. On the contrary, adhesive bonding also has its limitations just as do the other methods. Even the best of the available synthetic resin adhesives have maximum operating temperature ranges in the vicinity of 500°F while riveted and brazed joints can operate at considerably higher temperatures.

Chemists and plastic engineers are constantly striving to produce improved epoxies with higher heat resistance for high temperature adhesives on missiles, binders for abrasive wheels and other demanding appli-

cations on industry's expanding frontiers. It is, therefore, very likely that the day is not far off when an epoxy adhesive will be discovered that can overcome the present limitations and extend their uses even beyond our present wildest imaginations.

MATERIALS AND METHODS

Materials Used

To determine the proper approach to the study under consideration a survey of the materials and testing facilities available was conducted. As a result of this preliminary survey it was decided that the study would be conducted by using cast-iron and aluminum since these materials are readily available and at the same time represent the two major components usually found in majority of farm implements and machinery. In addition these materials can be readily adapted to the testing facilities available.

Preliminary tests were conducted to determine the most appropriate procedure to follow in the preparation of the materials to be joined and their subsequent testing using commercially available epoxy adhesives. The following preliminary tests were conducted.

- a) To compare the "Leech" brand epoxy with other brands of epoxy formulated outside the state of Kansas
- b) To determine whether the cast-iron rods should be joined without any prior preparation, that is with matching ends, with machined ends or at random whether the ends match or not
- c) To determine the possibility of using fillers or modifiers with the epoxy

d) To be able to specify the proper dimensions of the materials to be joined that the testing apparatus can handle

e) To determine the need for any chemical cleaning of the surfaces to be joined.

The results of the preliminary tests were as follows:

a) No appreciable differences were observed between the joints made with any of the epoxy preparations tested.

b) The cast-iron rods joined with their ends machined first were consistently stronger than those whose ends were not machined even if the ends were properly matched.

c) The use of the modifier, calcium carbonate, showed an increase in strength of the bonds made as compared with the bond made with the epoxy alone.

d) The minimum dimensions for the cast-iron rods that will fit the testing apparatus was 2.0 inches long and 1.0 inch in diameter. The aluminum strips should be at least 2.0 inches wide and 8.0 inches long.

e) There was a need to use some kind of a chemical degreasing compound to insure good bonds although not one of the manufacturers of the epoxy adhesives tested mentioned this need in their directions for using their products.

Since the results of the preliminary tests showed no major differences in the performance of the different brands of epoxy tested, the "Leech" brand of epoxy was selected to be used in this study for the reason that it is readily available to Kansas farmers and is being formulated at Hutchinson, Kansas. (Plate I)

Preparation of the Materials to be Joined

The aluminum strips used in this study were cut out of the aluminum sheets in the Farm Mechanics laboratory, Department of Agricultural Engineering while the cast-iron rods were obtained from the Department of Applied Mechanics. (Plates II and III)

The preparation of the aluminum strips consisted of making strips 2.0 inches wide and 8.0 inches long from a 1/4-inch X 4.0' X 5.0' aluminum sheet and an equal number of strips 2.0 inches wide and 4.0 inches long. The longer strips were joined end-to-end leaving an eighth-inch gap. The shorter strips were overlapped at the joints on both sides (Plate II and Figure 1). All the areas to be joined were roughened by brushing with a wire brush.

To insure proper testing for tensile strength the cast-iron rods were machined at both ends, turned on the lathe to a uniform diameter of 1.0 inch and provided with threads at the opposite ends where the joint is to be made. The final dimensions of the cast-iron rods were 2.0 inches long, one-half of the length was threaded with standard seven threads to an inch and a diameter of 1.0 inch. (Plate III and Figure 2).

The facilities in both the agricultural engineering and industrial engineering shops were used in the preparation of the materials used in this study. Arrangements were also made with the Department of Applied Mechanics for the use of their testing facilities.

The materials to be joined were divided into groups representing the different treatments to be tested. Each group consisted of sufficient number of cast-iron rods and aluminum strips to provide six samples for each treatment. The experimental treatments used in this study were

as follows:

Treatment I Cast-iron rods and aluminum strips joined with epoxy only (Unmodified).

Treatment II Same joints were made but this time the epoxy was modified with calcium carbonate.

Treatment III Same joints were made but the epoxy was modified with wheat flour.

Each group or treatment was divided further into sub-groups which were designated as follows: one-half to be cured for 24 hours under room temperature and the other half to be cured for 23 hours at room temperature followed by the application of heat (200°F) for one hour during the curing period. The purpose of this treatment was to determine the effect of the application of heat during the curing period upon the strength of the resulting bond.

For modifiers or fillers, calcium carbonate and wheat flour were selected because they are two of the most common inert materials readily available on the farm. These two substances may also provide answers to the questions on the adaptability of organic or inorganic materials as modifiers of epoxy formulations.

Procedure in Making the Joints

In treatment I approximately equal amounts of the resins and the hardener were placed on a clean mixing board and thoroughly mixed with a putty knife. The areas of the materials to be joined were then cleaned or degreased by wiping each surface with an oil-free cloth soaked in carbon tetrachloride. The epoxy was then applied as thinly as possible

on the surfaces to be joined and the pieces were squeezed together by hand and laid aside to cure. In the case of the aluminum strips, weights were placed on top of the newly-joined pieces to prevent the strips from getting out of alignment.

Similar procedures were followed for Treatments II and III except for the addition of the modifiers. In Treatment II the two components of the epoxy were first mixed together and then an approximately equal amount of calcium carbonate was added and mixed thoroughly with the epoxy. The same procedure was used for Treatment III but this time wheat flour was used instead of calcium carbonate for the modifier.

Curing the Joined Materials

The joined materials were set aside and allowed to cured and harden. One-half was held at room temperature (approximately 70°F) for 24 hours while the other half was cured at room temperature for 23 hours plus one hour at 200°F. A gas-fired oven was used for this purpose.

Testing the Joints

To determine the strength of the resulting joints, testing was done approximately 24 hours after the joints were made. The tests were conducted at the Department of Applied Mechanics with the use of the Baldwin Emery Fate Load Testing Machine (Plate IV). Tensile tests were made on the cast-iron rods while the aluminum strips were subjected to shear tests. The results of these tests are presented in Tables 1 to 5.

RESULTS AND DISCUSSIONS

The epoxy used in this study consisted of two components, one part is the resin, a clear syrup-like substance that had to be mixed with the other part, the hardener, in order to secure a bond. The hardener has a thicker consistency. It is amber in color and characterized by a somewhat repugnant odor. When equal amounts of each component are thoroughly mixed the resulting mixture assumes a cream color and slowly starts to get thicker and thicker until it finally hardens. It was easy to apply but had a tendency to run off the edges if applied too thickly. This epoxy has a pot life of approximately one hour.

The addition of modifiers resulted in a thicker consistency of the mixture and reduced the tendency to run off the edges during the curing. On the other hand, the addition of calcium carbonate and wheat flour as modifiers shortened the pot life of the resulting mixture to about 30 minutes or one-half of the original pot life of the unmodified epoxy. It was observed that while the epoxy mixture is in the process of curing or hardening, the newly joined parts must be laid out on a level surface to prevent the parts from slipping out of alignment, whether modifiers were used or not. Clamping may be helpful but was not used in this study.

The load data in the tensile and shear tests conducted on the joined materials is presented in Tables 1 and 2. The area of contact was 0.7854 and 8.00 square inches for the cast-iron rods and the aluminum strips, respectively. It can be seen in Table 1 that the group which was cured at room temperature (70°F) for 24 hours produced average loads in pounds as follows: 2371.66 for the joints made with the unmodified epoxy,

2568.33 for the epoxy modified with calcium carbonate, and 2806.66 for the epoxy modified with wheat flour. In the other group where curing at room temperature for 23 hours was supplemented with one hour at 200°F, the average loads were 2571.66 pounds, 2721.66 pounds and 3366.66 pounds for the joints made with unmodified epoxy, epoxy modified with calcium carbonate and epoxy modified with wheat flour, respectively.

Table 2 presents the results obtained with the aluminum strips joined and cured in a similar manner as those of the cast-iron rods discussed above. The average load for the group that was cured at room temperature for 24 hours were 5166.66 pounds when unmodified epoxy was used for joining, 5044.66 pounds with the epoxy modified with calcium carbonate, and 6841.66 pounds when the wheat-flour-modified epoxy was used. The application of heat even for only one hour during the curing period resulted in much stronger bonds as shown by the following average loads obtained in the group cured at room temperature for 23 hours plus one hour at 200°F - 10805.00 pounds, 13616.66 pounds and 17730.00 pounds for the joints made with the unmodified epoxy, epoxy with calcium carbonate and epoxy with wheat flour, respectively.

Results of Tensile Tests

Table 3 shows a comparison of tensile stress of cast-iron rods joined by the unmodified epoxy, epoxy with calcium carbonate, and epoxy with wheat flour when cured at room temperature (70°F) for 24 hours as well as when cured with the application of heat (200°F) for one hour after preliminary curing for 23 hours at room temperature. In the former group, that is room temperature curing alone, the average tensile stress

was 3017.57 pounds per square inch for the joint made with unmodified epoxy, 3204.31 pounds per square inch for the epoxy with calcium carbonate, and 3573.50 pounds per square inch when wheat flour was used as the modifier of the epoxy.

The introduction of heat for one hour during the curing period seemed to result in a much stronger bond as was observed in this study. The average tensile strength obtained were 3274.33 pounds per square inch, 3465.11 pounds per square inch, and 4286.56 pounds per square inch for the joints made with the unmodified epoxy, epoxy with calcium carbonate, and epoxy with wheat flour as modifier, respectively.

Result of Shear Tests

A comparison of the shear stress of the aluminum strips used in this study for determining the effects of different treatments when using epoxy adhesives for joining aluminum, is presented in Table 4. When the joints were cured under room temperature (70°F) conditions for 24 hours the average shear stress of the joints made with the unmodified epoxy was 645.83 pounds per square inch as compared with 630.58 pounds per square inch and 855.21 pounds per square inch for the joints made with the epoxy modified with calcium carbonate and when wheat flour was used as the modifier, respectively. On the other hand, when the joints were subjected to an increase in temperature (200°F) for one hour after being cured at room temperature for 23 hours, the shear stress was increased by approximately two to three times that when curing was done at room temperature only. This is shown by the average shear stress of 1350.62 pounds per square inch, 1752.08 pounds per square inch, and 2216.25 pounds per

square inch for the joints made with the unmodified epoxy, epoxy with calcium carbonate, and epoxy with wheat flour. In either case, wheat flour seem to be a better modifier than calcium carbonate under the conditions of this study. This also substantiates the results of the tensile tests of cast-iron rods discussed earlier in this report.

The statistical analyses of the results of this study are presented in Tables 5a and 5b. Table 5a shows the analysis of the data on the tensile stress of cast-iron rods while Table 5b presents the analysis for the shear stress results for the aluminum strips. It can be observed in Table 5a that the treatments and methods of curing produced significant results at the 5 per cent level indicating that there were true differences between the treatments, that is, the use of unmodified epoxy, epoxy modified with calcium carbonate as well as the epoxy modified with wheat flour, produced different results. The two methods of curing also have affected the strength of the bonds to a considerable degree. On the other hand there is no indication of any effect brought about by any combination of treatments and methods.

The findings on the shear stress tests on aluminum strips were all highly significant at the 5 per cent level, Table 5b. This indicates that there are significant differences among the treatments and methods of curing used as well as an indication of an interaction between the treatments and the methods of curing. This means that the use of the modifiers plus the introduction of heat during the curing period produced stronger bonds with the epoxy used in this study. A comparison of the results between calcium carbonate and wheat flour as modifiers shows that wheat flour produced joints that are significantly stronger than those obtained

with the use of calcium carbonate. Calcium carbonate-modified epoxy joints, however, were also generally stronger than the joints made with the unmodified epoxy.

The differences in the results on "treatment by method effects" in Tables 5a and 5b may be partly explained by the greater area under stress in the shear test as compared to that in the tensile test. The joint subjected to the tensile stress was only 0.7854 square inch while for the shear test the area under stress was 8.00 square inches. Another possible explanation may be the adaptability of this type of epoxy to shear rather than to tensile loads. It is hoped that future investigations along these lines may bring out the reasons for this inconsistency.

The overall results seem to indicate a definite trend towards an increase in the effectiveness of the bond as a result of the use of fillers or modifiers, with wheat flour joints significantly stronger than joints made with epoxy and calcium carbonate, and much more so when heat is introduced sometime during the curing period. In all tests wheat flour seems to be a more desirable modifier than calcium carbonate since there is an indication of an interaction between wheat flour as a modifier and the use of elevated temperatures during the curing period. A possible explanation is the fact that wheat flour which is mostly starch, undergoes faster chemical change when heated than calcium carbonate thus creating a stronger connection with the molecules of the epoxy resin, resulting in more effective bonding. It would be safe to suspect that similar materials like for example corn starch, rice flour, etc. may exhibit comparable affinity to the type of epoxy preparation used in this work.

The optimum curing period, the maximum temperature and length of exposure to such temperature as well as the most desirable type of modifier to be used under a variety of conditions to obtain a maximum bond when using epoxy adhesive formulations for varying loads are also some of the questions that this study helps to bring into focus for future investigations. Studies along these lines would increase our knowledge of the capabilities and limitations of epoxy adhesives and will provide immeasurable contributions especially for underdeveloped areas where metal joining equipment and facilities are beyond the reach of majority of the farmers. It would also make possible less costly but reliable on-the-spot field repairs of farm implements thus reducing "down time" and increasing the probable usefulness of these machines.

SUMMARY

Epoxy resins are known to possess outstanding adhesive properties that will make excellent bonds to steel, cast-iron, aluminum, brass, copper and most other metals; to glass, wood, concrete, cloth; to most plastics and to practically almost any material. Although at present most of the epoxy preparations are exclusively for industrial applications, one will recognize that many of these products might conceivably find applications on the farm in the very near future.

Some obstacles to the use of epoxy on the farm may be its high cost as well as the tendency of some resin ingredients to cause skin irritations to some sensitive individuals. The first obstacle may be overcome by increased production and more efficient manufacturing processes. Proper handling especially with the use of gloves may decrease the chances

of direct contact with the epoxy since there is no way of predetermining an individual's sensitivity to these materials.

Some epoxy preparations are not recommended for parts subjected to severe shock or impact. The epoxy tested in this study is one of those belonging to this group. Epoxy adhesives designed for use in structural bonding should be used whenever high strength, resistance to fatigue and reliability are desired. Whenever possible shear loaded joints are preferable to tensile loaded joints.

Although most epoxy preparations available in the local hardware stores do not give specific cleaning procedures to follow it is advisable that more attention must be devoted to proper surface preparation in order to secured a completely satisfactory joint. A thoroughly cleaned, dry and grease-free surface is essential for maximum bonding. Cleaning methods which will produce a break-free water film on metal surfaces are generally satisfactory. The use of commercial degreasers such as trichlorethylene, carbon tetrachloride and others is recommended for surface preparation to obtain maximum adhesion. It is important that one does not inhale fumes from carbon tetrachloride since it can be injurious to health. Improperly cleaned surfaces will cause flaking of the adhesive thus resulting in bond failure.

Fillers or modifiers do more than increase bond strength. They also tend to improve the handling properties of the epoxy, reduce costs, provide the desired pigmentation as well as improve the freeze-thaw-resistance by decreasing the coefficient of expansion of the epoxy system as reported by Skeist and Somerville (17).

The results of this study show that the rate of cure and bond

strength are also greatly affected by the filler or modifier used and by an increase in temperature sometime during the curing period. Curing time was decreased by the use of modifiers and an accelerated temperature seemed to increase bond strength.

No conclusive evidence was found as to the extent of the influence of the type of modifier used as well as the optimum duration of exposure to elevated temperature on the resulting strength of the bond. Numerous questions remain unanswered on the possible uses of epoxy preparations on the farm. A study of short duration such as this can not hope to provide all the answers. It is hoped that these questions will be answered by further studies of longer duration than was possible at this time.

Some of the reported specific applications of epoxy preparations on the farm at the present time are as follows:

- a) Repair of aluminum oil coolers of tractors in the field
- b) Repair of gasoline tanks in place
- c) Repair of leaks on centrifugal pump cases
- d) Repair of leaks in staves, rivets or bolts
- e) Repair of leaks in radiator and plumbing
- f) Sealing joints in steel buildings
- g) To fasten metal roofs
- h) As coating on wood slats for raising swine on slotted floors
- i) Sealing masonry walls and concrete storage tanks
- j) Protecting floors from acids and other corrosive materials especially in dairy barns
- k) Bed anchor bolts in concrete
- l) Skid-proofing around machinery, ramps, etc.

ACKNOWLEDGMENT

The author wishes to express his gratitude to his major professor, Professor Paul N. Stevenson, Associate Professor in Farm Mechanics, Department of Agricultural Engineering for his valuable suggestions and guidance in the course of this study.

Sincere appreciation is also expressed to Dr. George H. Larson, Head, Department of Agricultural Engineering whose understanding attitude enabled the author to undertake this work.

Thanks are also due to Professor Clinton O. Jacobs of the Department of Agricultural Engineering and to Mr. Leslie C. Nelson of the Department of Industrial Engineering for their helpful suggestions in the preparation of the materials used in this study.

To Professor Thomas F. Creech of the Department of Applied Mechanics the author is greatly indebted for his unselfish help in testing the joints without which this study would not have been completed; to the Rockefeller Foundation for its generosity which enabled the author to pursue his graduate work in this country; and last but not least, to my wife, Corazon, whose encouragement contributed in no small measure to the completion of this work.

LITERATURE CITED

- (1) Bandaruk, M. Epoxy-base adhesives in the aircraft industry. S. P. E. Journal. Vol. 2, No. 50; 20-23. August, 1956.
- (2) Beaseley, Donald R. Diepoxies with improved properties. S. P. E. Journal. Vol. 15, No. 4: 289-291. April, 1959.
- (3) Black, John M. and R. F. Blomquist. Metal-bonding adhesives with improved heat resistance. Modern Plastics. Vol. 32, No. 4: 139-147, 237. December, 1954.
- (4) Charlton, John. Alloying with epoxies. Modern Plastics. Vol. 32, No. 1: 240-243. September, 1954.
- (5) Epstein, George. Adhesive Bonding of Metals. New York: Reinhold Publishing Corporation, 1954. 218 p.
- (6) Epstein, George. Epoxy resins. Modern Plastics Encyclopedia. Vol. 35, No. 1A: 105-111. September, 1957.
- (7) Formo, Jerome and Luther Bolstad. Where and how to use epoxies. Modern Plastics. Vol. 33, No. 11: 99-104. July, 1955.
- (8) Gould, Bernard. New epoxy adhesive. Materials and Methods. Vol. 42, No. 6: 140-142. December, 1955.
- (9) Gould, Bernard. No-mix epoxy joins metal fast. Iron Age. Vol. 179, No. 8: 94-95. February, 1957.
- (10) Huggins, H. D. Field repair of aluminum oil cooler. Implement and Tractor. Vol. 78, No. 11: 53-55, 63. May, 1963.
- (11) Lee, Henry and Kris Neville. Epoxy Resins - Their Synthesis and Characteristics. New York: McGraw-Hill Book Company, 1957. 305 p.
- (12) Metaseal Epoxy Products Unnumbered Pamphlet. The American Metaseal Corporation. Detroit, Michigan.
- (13) Middleton, J. C. Adhesives and sealers - New developments. S.P.E. Journal. Vol. 16, No. 6: 644-646. June, 1960.
- (14) Ringwood, Arthur F. Epoxy resins for the encapsulation of electronic components. S. P. E. Journal. Vol. 16, No. 1: 93-100. January, 1960.
- (15) Royall, W. B. and R. W. Matlock. Epoxy passes toughest test: Outer space. Modern Plastics. Vol. 39, No. 2: 100-101, 205, 210. October, 1961.

- (16) Skeist, Irving (ed). Handbook of Adhesives. London; Reinhold Publishing Corporation, 1962. 682 p.
- (17) Skeist, Irving and George Somerville. Epoxy Resins. New York; Reinhold Publishing Corporation, 1958. 293 p.
- (18) Theakston, F. H. and J. R. Ogilvie. The use of adhesives to fasten metal roofs. Agricultural Engineering. Vol. 45, No. 4: 202-203, 207. April, 1964.

APPENDIX

EXPLANATION PLATE I

Two-component epoxy formulation used in this study

Plate I



NEW EPOXY ADHESIVE
always the best

other PRODUCT

LEECH PRODUCTS, INC. LEAR HOUSEHOLD WEATHERSTRIP ADHESIVE LATEX PATCH PLASTIC ALUMINUM MODEL CEMENT (Wood and Plastic) WHITE RESIN (Squeeze Bottle) CONTACT CEMENT LIQUID SOLID NEW WOOD

EPOXY ADHESIVE
always the best

LEECH PRODUCTS, INC. RICE ONLY 98

AS ADVERTISED IN THE SATURDAY EVENING POST

SEE BACK SIDE FOR DIRECTIONS & USES

PLATE I

EXPLANATION PLATE II

The aluminum strips used in this study. Note the method of joining on the left. The area in contact for this treatment was 8.00 square inches.

Plate II



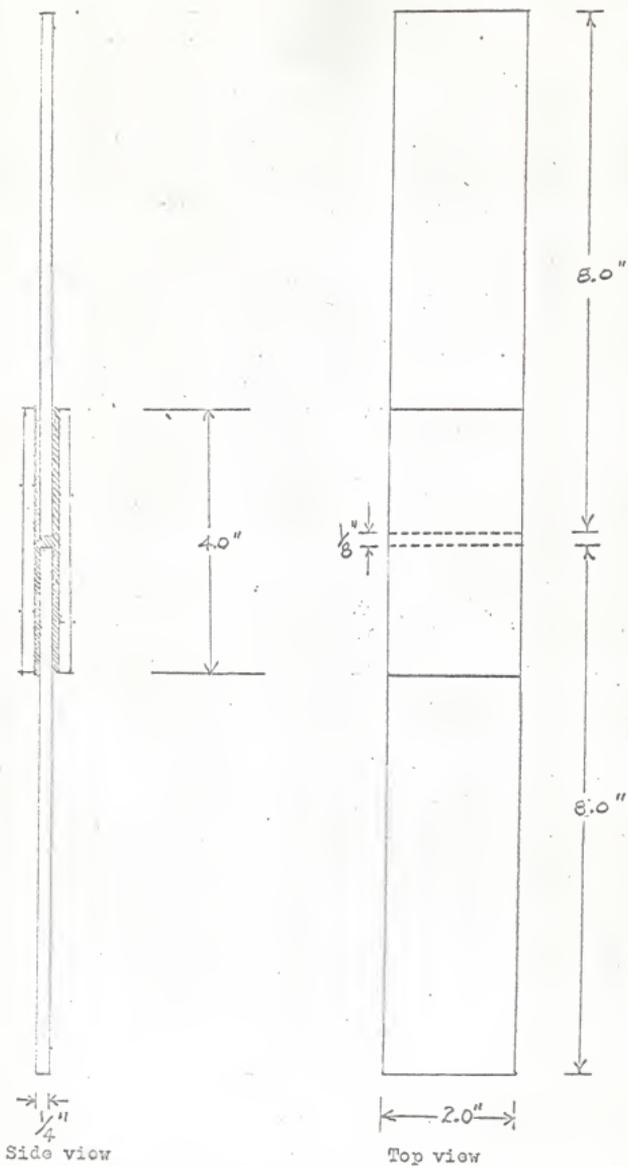


Figure 1. Dimensions and method of joining the aluminum strips. Shaded portion indicates where the joint was made.

EXPLANATION PLATE III

Left to right: The "raw cast-iron rod" obtained from the Department of Applied Mechanics; the joined pieces ready for testing, and two views of the cast-iron rod after it was machined and threaded. The area in contact for this test was 0.7854 square inch.

Plate III



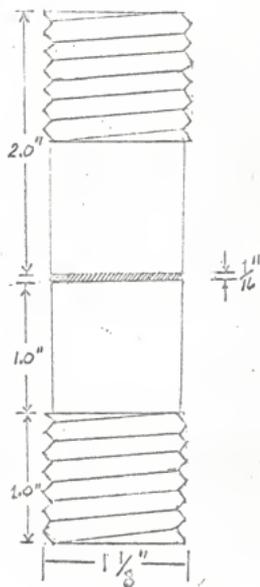


Figure 2. Dimensions and method of joining the cast-iron rods. Shaded portion is the joined area.

EXPLANATION PLATE IV

The Baldwin-Emery Tate Load Testing Machine
in the Department of Applied Mechanics laboratory
which was used in testing the strength of the
joints.

Plate IV

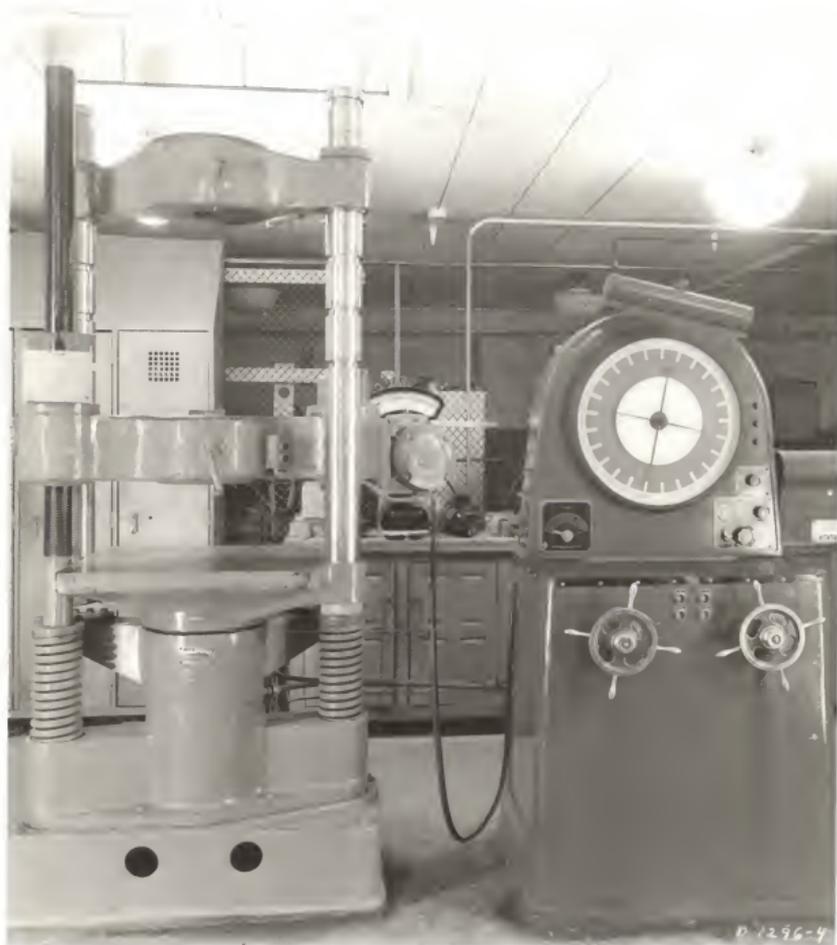


Table 1. Test data on cast-iron rods joined by unmodified epoxy, epoxy modified with calcium carbonate and epoxy modified with wheat flour and cured under two methods of curing.*

METHOD OF CURING	L O A D I N P O U N D S		
	Unmodified Epoxy	Epoxy Modified with Calcium Carbonate	Epoxy Modified with wheat Flour
Cured for 24 hours	2330.00	2990.00	2880.00
at room temperature, 70°F.	2500.00	2310.00	2790.00
	2620.00	2780.00	2930.00
	2200.00	2450.00	2550.00
Average:	2180.00	2210.00	3050.00
	2400.00	2370.00	2640.00
	2371.66	2568.33	2806.66
Cured for 23 hours	2690.00	2750.00	3270.00
at room temperature, 70°F, plus one hour	2580.00	2850.00	3600.00
	2150.00	2170.00	3570.00
	2800.00	2820.00	3000.00
at 200°F.	2770.00	2980.00	3460.00
	2440.00	2760.00	3300.00
	2571.66	2721.66	3366.66

*Area under load was 0.7854 sq. in.

Table 2. Test data on aluminum strips joined by unmodified epoxy, epoxy modified with calcium carbonate, and epoxy modified with wheat flour and cured under two methods of curing.*

METHOD OF CURING	L O A D I N P O U N D S		
	Unmodified Epoxy	Epoxy Modified with Calcium Carbonate	Epoxy Modified with Wheat Flour
Cured for 24 hours at room temperature, 70°F.	5860.00	4040.00	7420.00
	5060.00	4680.00	6260.00
	6440.00	4200.00	5890.00
	4000.00	6080.00	6840.00
	4920.00	6000.00	7040.00
Average:	4720.00	5268.00	7600.00
Cured for 23 hours at room temperature, 70°F, plus one hour at 200°F.	5166.66	5044.66	6841.66
	10350.00	13400.00	16750.00
	12020.00	16100.00	18600.00
	11560.00	12400.00	15790.00
	10690.00	12960.00	19600.00
Average:	10000.00	13600.00	17400.00
	10210.00	13240.00	18240.00
Average:	10805.00	13616.66	17730.00

* Area under load was 8.00 sq. in.

Table 3. Comparison of tensile stress of cast-iron rods joined by unmodified epoxy, epoxy modified with calcium carbonate and epoxy modified with wheat flour under two methods of curing.*

METHOD OF CURING	TENSILE STRESS IN POUNDS PER SQUARE INCH		
	Unmodified Epoxy	Epoxy Modified with Calcium Carbonate	Epoxy Modified with Wheat Flour
Cured for 24 hours	2966.64	3806.98	3666.92
at room temperature,	3170.36	2941.18	3552.34
	3335.88	3539.60	3730.58
70°F.	2801.12	3106.70	3246.75
	2775.64	2813.85	3883.37
	3055.77	3017.57	3361.34
Average:	3017.57	3204.31	3573.50
Cured for 23 hours	3425.00	3501.40	4163.48
at room temperature,	3284.95	3627.45	4583.65
	2737.46	2762.92	4545.45
70°F, plus one hour	3565.06	3590.53	3819.70
	3526.74	3794.24	4405.40
	3106.69	3514.13	4201.68
at 200°F.			
Average:	3274.33	3465.11	4286.56

*Area under stress was 0.7854 sq. in.

Table 4. Comparison of shear stress of aluminum strips joined by unmodified epoxy, epoxy modified with calcium carbonate and epoxy modified with wheat flour under two methods of curing.*

METHOD OF CURING	SHEAR STRESS IN POUNDS PER SQUARE INCH		
	Unmodified Epoxy	Epoxy Modified with Calcium Carbonate	Epoxy Modified with Wheat Flour
Cured for 24 hours at room temperature 70°F.	732.50	505.00	927.50
	632.50	585.00	782.50
	805.00	525.00	736.25
	500.00	760.00	855.00
	615.00	750.00	880.00
Average:	590.00	658.50	950.00
Cured for 23 hours at room temperature, 70°F, plus one hour at 200°F.	645.83	630.58	855.21
	1293.75	1675.00	2093.75
	1502.50	2012.50	2325.00
	1445.00	1550.00	1973.73
	1336.25	1620.00	2450.00
Average:	1250.00	1700.00	2175.00
	1276.25	1655.00	2280.00
Average:	1350.62	1752.08	2216.25

*Area under shear stress was 8.00 sq. in.

Table 5a. Analysis of Variance for data of Table 3.

Sources of Variation	D/F	Sum of Squares	Mean Square	F-ratio
Treatments	2	3,789,022.89	1,894,511.44	18.07 *
Methods of curing	1	1,411,621.21	1,411,621.21	13.54 *
Treatment X Methods	2	339,177.60	169,588.80	1.63 ns
Error	30	3,128,714.97	104,290.49	
Total	35	8,668,536.67		

* $F_{.05}(2,30) = 3.32$ and $F_{.05}(1,30) = 4.17$ Snedecor, George W., 246-248.

Table 5b. Analysis of Variance for data of Table 4.

Sources of Variation	D/F	Sum of Squares	Mean Squares	F-ratio
Treatments	2	1,814,474.17	907,237.08	56.74 *
Methods of curing	1	9,842,860.44	9,842,860.44	615.56 *
Treatment X Methods	2	648,975.11	324,487.55	20.29 *
Error	30	479,700.72	15,990.02	
Total	35	12,786,010.44		

* $F_{.05}(2,30) = 3.32$ and $F_{.05}(1,30) = 4.17$ Snedecor, George W. 246-248.

DEFINITION OF TERMS ^{1/}

Colorants - are inorganic or organic pigments, usually added to the epoxy before cure. Many inorganic pigments are suitable: titanium dioxide for white, carbon black, cadmium yellows, oranges and reds, the iron earths, chrome green, etc. Inorganic pigments are generally relatively stable to heat.

Embedding - generally refers to casting the component and resin in a mold that will be removed afterwards.

Fillers or modifiers - are inert solid particles which are incorporated into an epoxy in order to reduce the resin content. The ideal filler improves the composition of the epoxy system in properties in which the pure epoxy is lacking, without causing serious impairment of the resin's more desirable characteristics. Fillers may also improve heat resistance, shrinkage on curing and thermal expansion coefficient.

Thixotropic - complete absence of drip or flow either before or during cure.

Thixotropic or thickening agents - are finely divided particles which clot a liquid epoxy so that it will not drain from an inclined or even a vertical surface. They may be porous granules such as special silicas and bentonites; platelets such as mica or short fibers such as asbestos or chopped glass fiber.

^{1/}Irving Skeist and George Somerville. Epoxy Resins. 1958.

Impregnating - as applied to resin usage, refers to the "flowing" of liquid resin into the interstices of a component so that it becomes void free. Impregnation is done either by dipping the unit into the resin or pouring the resin into the unit.

Potting - as used by epoxy users generally refers to that process by which the mold is left around the component permanently.

Pot life or work life - refers to the time during which the blended epoxy-hardener mixture remains usable, that is before becoming too viscous to handle or spread.

Reinforcements - are fibers in the form of cloth, mat or chopped strands or staples. They form a continuous framework which buttresses the resin. The fibers may be mineral, e.g. glass and asbestos; vegetable, e.g. sisal and cotton; synthetic, e.g. "Orlon", "Dynel", "Dacron" or metallic.

INVESTIGATIONS ON THE APPLICATIONS
OF EPOXY PREPARATIONS ON THE FARM

by

RAYMUNDO E. JOVELLANOS

B. S. A., University of the Philippines, 1951

An Abstract of a Master's Report

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Farm Mechanics
Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1964

Epoxy-based adhesives, although recently introduced have found extensive usage in joining a wide variety of materials to one another as well as to different materials particularly where high strength and ease of application are desired. This ability to join dissimilar metals without the need for piercing or heating the materials to be joined seems to suggest that epoxy adhesives may be adapted to on-the-spot repair jobs on the farm.

This study was conducted, therefore, to (a) investigate the possible uses of commercially available epoxy adhesives for repairs of farm implements, (b) determine the influence of some materials as modifiers, and (c) learn the effect of heat applied sometime during the curing period on the resulting joint.

The materials used in this study consisted of a commercially available two-component epoxy adhesive, cast-iron rods, aluminum strips, modifiers and a degreasing agent. The cast-iron rods which measured 2.0 inches long and 1.0 inch in diameter were machined at both ends and one-half of their lengths was threaded with standard seven threads to an inch. The 1/4-inch aluminum strips were cut to dimensions of 2.0 inches by 8.0 inches and 2.0 inches by 4.0 inches. The shorter pieces were used to overlap at the joints of the longer strips. Calcium carbonate and wheat flour were used as the modifiers of the epoxy to determine which of these two substances is the more desirable modifier for the epoxy being tested,

Three experimental treatments were employed. Treatment I involved the joining of the cast-iron rods and the aluminum strips to each other using the epoxy alone, (unmodified). Treatments II and III were similar to Treatment I except for the use of calcium carbonate as the modifier

of the epoxy in Treatment II and the addition of wheat flour to the epoxy in Treatment III.

The resulting joints were cured using two methods. The first method consisted of room temperature (70°F) curing for 24 hours while in the other method the joints were first cured at room temperature for 23 hours and then subjected to 200°F temperature for one hour.

Tensile and shear tests were conducted on the cast-iron rods and the aluminum strips, respectively, approximately 24 hours after the joints were made. The tests were conducted in the Department of Applied Mechanics with the use of the Baldwin-Emery Tate Load Testing Machine.

The findings of this study indicate that the epoxy adhesive tested may be adapted to shear loaded joints but not for parts that are subjected to severe shock or impact. Wheat flour as a modifier produced significant results as compared to calcium carbonate as the modifier or to the unmodified epoxy. The use of elevated temperatures sometime during the curing period produced highly significant results when used in conjunction with wheat flour as the modifier.

The use of commercial degreasers like for example trichlorethylene or carbon tetrachloride and many others is recommended for proper surface preparation in order to secure maximum adhesion. A thoroughly cleaned surface is one which produces a break-free water film on metal surfaces.

Careful handling of the epoxy- may decrease the chances of direct contact with the epoxy which to some individuals may cause some sort of skin irritations. It is recommended that whenever possible persons who will handle epoxy preparations must do so with gloves to reduce the possibility of direct contact since there is no way of predetermining an individual's sensitivity to epoxy resins.