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PHOTOSTRESS SPRAY

TECHNIQUE DEVELOPMENT,

REA 111-9133

REPORT NO. ERR-AN-027

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PHOTOSTRESS SPRAY TECHNIQUE
DEVELOPMENT, REA 111-9133

INTRODUCTION:

Photostress is the trade name of a photoelastic coating technique developed in this country by Dr. Felix Zandman for the Budd Company, Instruments Division. (1,2)

The only commercially available materials for this purpose are handled by the Budd Company in the form of plastic sheets and liquid plastic. The sheet is manufactured in three thicknesses; 0.048, 0.072, and 0.120 inches.

Sensitivity increases with an increase in thickness of the plastic. In normal application, an attempt is made to obtain the highest sensitivity (consequently, the greatest thickness) available. However, for high strength materials (such as in 17-7 PH stainless steels) that are designed for use up to the vicinity of their yield strength, high sensitivity is not necessary. As a matter of fact, high sensitivity causes such a complexity of fringes at high strains, that evaluation is often hampered.

Flat sheets can be used on flat surfaces only.

The liquid plastic is available with a catalyst which sets up the plastic in a matter of a few hours. The manufacturer recommends pouring the mixed plastic into a flat mold. The sheet is removed from the mold before polymerization is complete and molded onto the specimen to be coated. In addition, the liquid can be applied by dipping, or plastered on the specimen like butter. The manufacturer's brochure does not mention spraying, but Dr. Zandman has indicated that this method is undesirable. Apparently the primary problem encountered was that of the epoxy type plastic setting up in the gun during spraying.

A superficial review of literature showed no indication of spray coa ıgs being used in this country.

OBJECTIVE:

To develop a spray technique for applying photoelastic coating to stress analysis specimens.

CONCLUSIONS:

1. Excellent photoelastic coatings can be applied by use of normal paint spray equipment under laboratory conditions.

2. Satisfactory coatings can be sprayed in the field under controlled conditions.

RECOMMENDATIONS:

In the review of literature related to photoelastic plastics, it became apparent that the use of three-dimensional photoelasticity has reached an advanced stage of the art. In one case, a complete scale model of a nuclear reactor was cast (using epoxy resins) that provided a complete stress analysis at a tremendous saving. (3)

It is recommended that a program be initiated to obtain materials and train personnel for the purpose of performing three-dimensional photoelastic analysis for the following reasons: (1) frequently, a model study provides as much information as a full scale hardware test at a sizable saving and (2) model testing during initial design can be a valuable tool to minimize costly re-design.

DISCUSSION:

Since the problem of spraying epoxies seemed to be one of controlling the setting of the plastic, the initial approach was to slow down the reaction. Two areas were investigated, namely: (1) temperature control of the plastic and (2) variation of catalyst.

Since the chemical reaction of the epoxy is exothermic, the setting time was increased by cooling of the mixture. Although this allowed free passage of the plastic through the spray gun, the resulting coating took too long to set up, causing running and, in general, an unsatisfactory surface.

Concurrently, an investigation was made in epoxy-paint spray equipment. Spray guns, designed for usage with materials that require mixing two or more components, are very complicated. This equipment consists of a spray gun that mixes the liquids just prior to atomization, some sort of proportioning machine, suitable containers, and associated hoses. A ten gallon capacity gun of this type can be obtained from Gusco* for slightly more than $4000.

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* Gusco Process, Equipment, A. Gusmer, Inc., Woodbridge, New Jersey

Actually this specialized equipment does not solve all the problems, it is costly, and it is designed to handle large quantities of liquids.

The third approach, variation of catalyst, eventually produced satisfactory coatings. The properties of epoxies do not change with a variation of 50% of the catalytic curing agent. (4) As a matter of fact, tertiary amines used as curing agents can be varied from 5 to 15 percent (by weight) without altering the properties of the resin. (It should be noted here, that the exact formula of Photostress and the associated hardener is proprietary information of the Budd Company). In addition, no theoretical calculations for determining optimum cure cycle have yet been devised. (See, for example, reference 4, p 53).

For these reasons, a simple, unsophisticated, method of investigation was carried out.

The first problem to solve was that of preventing the plastic from setting in the gun. This was solved by using 10% (by weight) of Shell Epon Curing Agent H 2 instead of the commercial Photostress hardener. The resulting mixture sprayed satisfactorily but did not harden sufficiently. The percentage of curing agent was increased in 5% increments to 35% with a corresponding decrease in setting time. However, the setting time was still greater than 48 hours and the resulting coating was not as hard as was desired.

The next approach was to try a low percentage of Photostress hardener by itself. Using 5% Photostress hardener did not yield a satisfactory coating. No attempt was made to increase the percentage of Photostress hardener due to the unsatisfactory coating and fear of approaching the quick setting point too quickly.

Next, various percentages of the two catalysts were combined until eventually a mixture of 8% Photostress hardener and 10% of the Shell Curing Agent H-2 produced a satisfactory coating that hardened completely in less than 12 hours in the laboratory.

The first successful coats were sprayed on flat stock tensile coupons and were approximately 0.005 inches thick. The next logical step was to try to increase the thickness of the coatings to approximately 0.020". This was accomplished by spraying several layers, placing the specimen in an oven, and repeating the process. Thicknesses up to 0.040" were produced in this manner on flat stock.

Adapting the technique to curved surfaces merely required care in handling and good paint spray technique.

All coatings were applied under laboratory conditions to this point.

Attempts at field application pointed up the problems of a constant temperature source and a fairly clean environment. In one application, (a 19" x 39" flat stainless steel sheet) outdoors, the coating was satisfactory until some flies and bugs settled down on the specimen! The outer surface then required sanding down, and new coats were applied.

Various specimens have been satisfactorily coated with Photostress using a spray technique. (See Figure 1)

TECHNIQUE:

The following procedures have been found to work satisfactorily:

Laboratory Technique

1. Remove paint, foreign bodies and grease with paint remover, stripper, or thinner.
2. Swab surface generously with MEK or trichloroethylene. Wipe with Kleenex. (Note: Use Kleenex for one wipe only; then throw away)
3. Swab surface with Acetone. Wipe with Kleenex.
4. Roughen surface with a one inch strip of 180 grit Silicon Carbride Paper saturated with Budd Company Metal Conditioner #1. Remove residue with one stroke of Kleenex.
5. Swab surface with Metal Conditioner and remove with Kleenex.
6. Apply Budd Company GA-1B neutralizer and remove with one stroke of Kleenex.
7. Warm part to 170-190°F with heat lamp or oven.
8. While part is being warmed, weigh out between 50 and 150 grams of Photostress Liquid Plastic. Type A. (Use beaker or glass custard cup.) Weigh out 8% Photostress hardener and 10% Shell Epon Curing Agent H-2 in separate containers.
9. Carefully introduce H-2 into the plastic and mix with glass stirring rod in such a manner as to minimize formation of bubbles.
10. Add Photostress hardener to mixture and mix thoroughly, again being careful to avoid bubbling.

11. Select spray nozzle compatible with size of surface to be coated. Adjust gun pressure to 50 psig ± 5 psig.
12. Spray plastic on specimen, being careful to prevent coating from running.
13. Spray 3-4 coats on specimen allowing 10-15 seconds between coats to allow plastic to flow.
14. Return specimen to oven or place under heat lamp at 170-190°F for about 30 minutes.
15. Spray MEK through spray gun before plastic can set up.
16. Repeat steps 7, 12, 13, 14 and 15 as many times as needed for the thickness desired.
17. Coating should not be used within 24 hours of last spray. Note: If coating is allowed to cure for several days, before adding new coats, surface should be wiped clean with GA-1B neutralizer.

Field Technique

1. Steps 1 through 6 are identical to laboratory technique.
7. If surface is a thin sheet, place heat lamp bank behind specimen and adjust temperature of surface to 150-170°F.
8. While specimen is being warmed, weigh out from 50 to 150 grams of Photostress Liquid Plastic, Type A, in a glass beaker or custard cup. Also, weigh out 8% Photostress hardener and 15% Shell H-2 in separate containers.
9. Carefully and thoroughly mix resin with H-2, avoiding introduction of bubbles.
10. Add Photostress hardener and mix carefully with glass stirring rod.
11. Select spray nozzle compatible with size of surface to be coated. Adjust gun pressure to 50 psig ± 5 psig.
12. Spray plastic on specimen being careful to avoid running. (It is wise to protect area to be sprayed from the wind and elements. Photostress on the face is messy and on the clothing, impossible to remove!)
13. Spray 3-4 coats on specimen allowing 10-15 seconds between coats to allow plastic to flow.
14. Allow coating to dry hard before adding additional coats. (Clean with neutralizer if necessary). Spray MEK through gun to remove all traces of resin.

15. Repeat steps 7 to 14 as often as necessary to obtain desired thickness.

16. Do not use plastic within 24 hours of last spray.

RESULTS:

The ultimate success of a program of this nature is proven if the finished product is usable. In this case, the technique is usable only if the resulting photoelastic patterns can be related to strain in the material. Since stress is more or less proportional to strain, stress may then be related to photoelastic fringes.

In oblique incidence, the maximum and minimum principal stresses (σ_1 and σ_2 respectively) may be obtained as follows:

$$\sigma_1 = \frac{8.2 \times 10^{-6}}{d} \times \frac{E_w}{Kt} \times n_1 + \frac{n_2}{2} \qquad \text{(I)}$$

$$\sigma_2 = \frac{8.2 \times 10^{-6}}{d} \times \frac{E_w}{Kt} \times n_2 + \frac{n_1}{2} \qquad \text{(II)}$$

where

σ_1 = maximum principal stress (psi), measured by Photostress technique

σ_2 = minimum principal stress (psi), measured by Photostress technique

d = compensator constant

E_w = Y ung's Modulus for the parent material (psi)

K = Strain-Sensitivity Constant of the Photostress Plastic

t = Thickness of Plastic (in.)

n_1 = number of graduations that Babinet compensator moves through, perpendicular to the direction of σ_1.

n_2 = number of graduations that Babinet compensator moves through, perpendicular to the direction of σ_2.

In the case of a simple tensile coupon, the value of σ_1 is readily calculated and σ_2 is zero. Since all other values are known except K, the strain-sensitivity constant can be calculated. This value is ideally 0.1 and the manufacturer's machined flat sheets range from 0.08 to 0.10. In the sample calculations that follow, the average value obtained for five load levels was 0.07234. Other values were as follows:

$$d = 50 \qquad E_w = 27 \times 10^6 \text{ psi} \qquad t = .028 \text{ inches}$$

$$n_1 = -46 \qquad n_2 = 24$$

To obtain a true value for K, the value for σ_1 will be calculated using an assumed value of K.

For simplification of calculations, K was assumed as 0.1.

The constant value for all load levels was:

$$= \frac{8.2 \times 10^{-6}}{d} \times \frac{E_w}{Kt} = \frac{8.2 \times 10^{-6}}{50} \times \frac{27 \times 10^6}{(0.1)(.028)}$$

$$= 1580$$

Then

$$\sigma_1 = 1580\left(n_1 + \frac{n_2}{2}\right)$$

$$\sigma_2 = 1580\left(n_2 + \frac{n_1}{2}\right)$$

$$n_1 + \frac{n_2}{2} = -46 + \frac{24}{2} = -34$$

$$n_2 + \frac{n_1}{2} = 24 - \frac{46}{2} = 1 \neq 0$$

In order for σ_2 to be equal to zero, the term $n_2 + \frac{n_1}{2}$ must equal zero. This error could be a human error in reading the Babinet compensator. As a matter of fact, an error of only one or two graduations on this scale indicates a high degree of individual proficiency.

Also

$$\sigma_1 = 1580\ (-34) = 53700 \text{ psi}$$

Note: Minus indicates direction of movement of Babinet compensator; it does not indicate compression.

Very thin specimens are reinforced slightly by photoelastic coatings. Therefore the indicated value of 53,700 psi must be corrected by using a value of 0.969 obtained from the correction curve, p 23 of reference 6.

$$\sigma_1 \text{ (corrected)} = \frac{(53700)}{.969} = 55\ 500 \text{ psi}$$

$$_T = \frac{P}{A} = 75{,}000 \text{ psi}$$

where $_t$ = theoretical stress

P = load on specimen as obtained from loading machine

A = area of the specimen alone

Since the σ_1 value is different from the calculated 75,000 psi, it can be stated that the assumed value of the strain-sensitivity constant of 0.1 was in error.

The true value should be:

$$K = \frac{55\ 500}{75\ 000} (0.1) = .0740$$

Since the average strain-sensitivity constant for five loading conditions was 0.07234, the percentage of error is 2.24%.

The sprayed-on coating has introduced no particular problems for photography. Effective color photographs have been taken utilizing the photographic technique as reported in reference 7.

REFERENCES

1. Felix Zandman

   Photostress, Principles and Applications

   Tatnall Measuring Systems, A Division of the Budd Company.

2. Felix Zandman and Marc R. Wood

   "Photostress, A New Technique for Photoelastic Stress Analysis for Observing and Measuring Surface Strains On Actual Structures and Parts"

   Product Engineering, September 1956

3. M. M. Leven

   "Epoxy Coating Resins Simplify Three Dimensional Photoelasticity"

   Product Engineering, July 1957

4. Henry Lee, Kris Neville

   Epoxy Resins

   McGraw-Hill, 1957

5. Tatnall Bulletin BN-8003

   Operating Instructions, OI/Z Meter

6. Zandman, Redner and Rieger, SESA Paper No. 588

   "Reinforcing Effect of Birefrigent Coatings"

7. W. E. Witzell, R. A. Weissinger

   "Still Photographic Method for Photoelastic Coating Technique"

   Strain Gage Reading, October 1960

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FIGURE 1. LIST OF SPECIMENS

Specimen Type	Number of Specimens	Coating	Coating Thickness	Coating Quality	Sensitivity
Cantilever Beam	5	12% H-2		Unsatisfactory	Did not harden
Cantilever Beam	5	20% H-2		Unsatisfactory	
Cantilever Beam	5	30% H-2		Satisfactory	Insensitive
Tensile Coupons	* 6	5% P/S		Splattered but hard when heated	
Tensile Coupons	4	5% P/S 10% H-2		Satisfactory	
Tensile Coupons	4	7% P/S 10% H-2	.010	Satisfactory	Insensitive
Tensile Coupons	4	7% P/S 10% H-2 Heat to 180°F	.010	Satisfactory	Apparently normal
Tensile Coupons	4	7% P/S 10% H-2 Heat to 180°F	.022	Good	Normal K ≈ .07
Cantilever Beam	2	7% P/S 10% H-2 Heat to 180°F	.035	Excellent	Normal
Spot Yield 31" Specimen	1	8% P/S 10% H-2 Heat to 180°F	.022	Good	Normal
Cylinder, Al. 6" Diameter. Wall Thickness = .060"	1	8% P/S 10% H-2 Heat to 180°F	.020	Good	
Crack Propagation Specimen CRES 301 XFH	1	8% P/S 10% H-2 Heat to 180°F	.014	Satisfactory	Normal
Crack Propagation Specimen CRES 301 XFH (Field Technique)	1	8% P/S 15% H-2 Heat to 180°F	.028	Satisfactory	Normal

* Two of the specimens heated to 180°F between coats.

H-2 is Shell Epon Curing Agent H-2

P/S is Photostress hardener

FIGURE 2

Cantilever Beams With 0.035 Inch Thick Coating

Notice clarity of writing on surface of the metal.

FIGURE 3

Tensile Specimen With 0.022" Coating

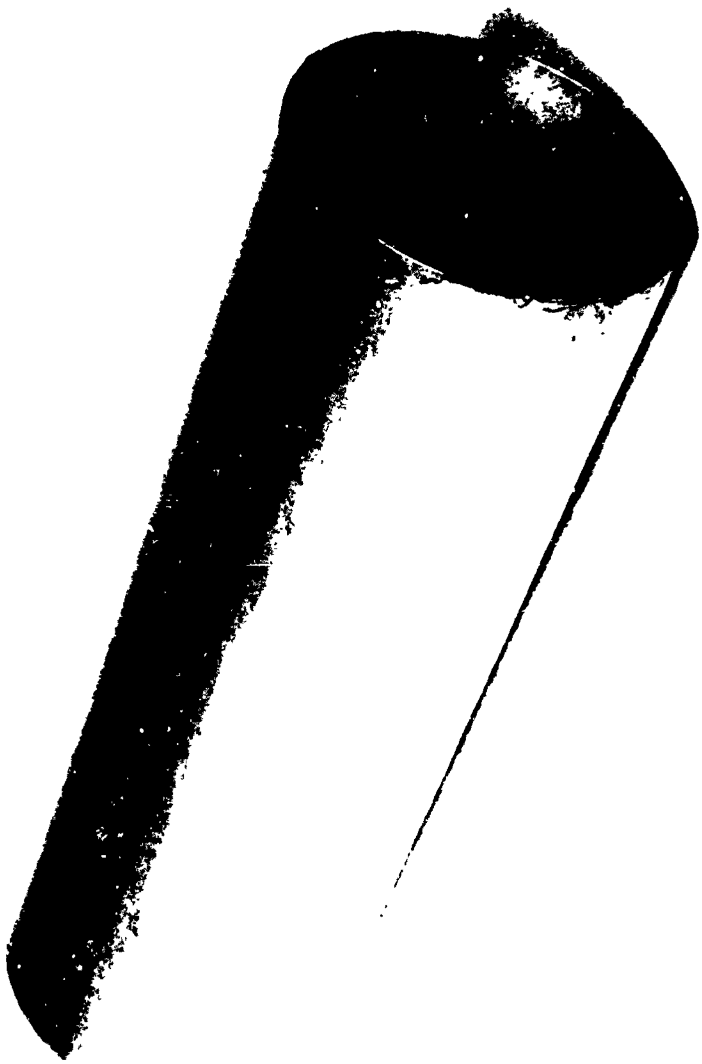

FIGURE 4

Aluminum Cylinder, 6" Diameter, .020" Coating

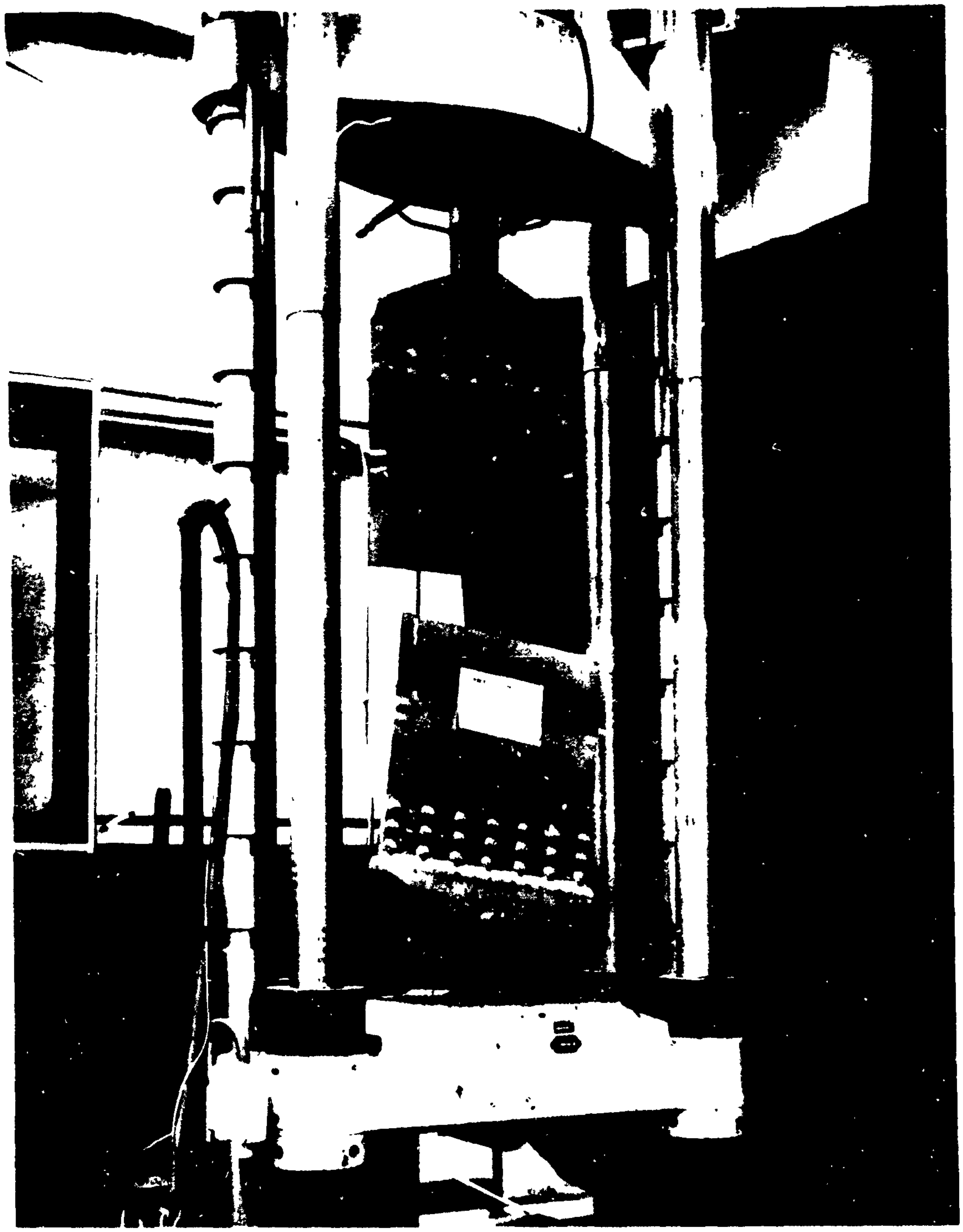

FIGURE 5

Stainless Steel Crack Propagation Specimen

The apparently mottled surface caused very little distortion when viewed through polarizers while under load.