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Photo Elastic Coating Materials in Thermo-Photo Elasticity

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Abstract: *In the combine use of thermo-photo elasticity Photo elastic – coating materials plays vital role. Photo elastic - coating materials must have thermal conductivity & thermal expansion equal to that of structural materials, and if strain-optical sensitivity did not vary with temperature. Surface strains induced by external loading and by thermal stresses can be performed in the temperature range of -60^0 F to + 350^{0}F which may extend to + 500^{0}F for short period. The objective of this paper is to describe the applicability of the photo elastic coating materials & their coating method for problems involving temperature changes.*
Keywords: *Adhesive, coating, Photo elasticity, Thermo elasticity*

I. Introduction

In the experimental approach of Thermo photo elasticity for the analysis of stress & strains in structures resulting directly from the temperature change, thermal stress analysis as well as the analysis of externally loaded bodies photo elastic-coating is very important. If an ideal coating material is used, the required extension of existing techniques would be trivial. This ideal coating material would exhibit several important qualities in addition to a high linear strain-optical sensitivity, especially :-
1) Thermal conductivity equal to that of the work piece.
2) Coefficient of thermal expansion equal to that of the structure or work piece.
3) Strain-optical sensitivity invariable with temperature.[5]

1.1 Thermo elasticity

Thermo elastic stress analysis (TSA) is a relatively new technique of experimental mechanics which is based upon the change in temperature experienced by a body when it is subjected to a change in the applied stress condition. Conventional thermo elastic analysis produce data of the dynamic change in the sum of principle stresses from a body experiencing some loading. Photo elastic stress analysis is based upon the optical phenomenon of temporary double refraction or birefringence. [1]
Change in temperature of the specimen work piece is given by :
$\Delta T = -\frac{\propto . T}{\rho . Cp}\Delta\sigma =$ A.S. -- (1)
Where
$\Delta T$is the temperature change of the material,
$\propto$is the coefficient of thermal expansion (CTE) of the material,
$\rho$is the material density,
Cp is the specific heat of the material at constant pressure,
T is the absolute temperature of the specimen, and
$\Delta\sigma$is the change in the sum of principal stresses.
A = Calibration factor
S= Detector signal. [1]

1.2 Photo elasticity

In photo elastic data, continuous fringe order N and isoclinic angle θ, a series of images can be recorded either sequentially or simultaneously using different quarter wave plate and polarizer. [11]
The light intensity at a general point i (x,y) on a model illuminated in a circular polariscope can be described by [3]:
$i(x, y) = i_m + i_v \{\sin 2(\beta_p-\psi_p) \cos\propto - \sin 2(\theta-\psi_p) \cos(\beta_p-\psi_p) \sin\propto$-------------------------------(2)
Where
i_m is the intensity of stray light,
i_v is the maximum light intensity achievable when all the optical elements and the principal stress axes of the model are aligned
β_p is the orientation of the output polarizer or analyzer relatives to the input polarizer,
ψ_p the orientation of the output quarter wave plate retarder relatives to the input polarizer,

θ the orientation of the principle stress directions of the model or isoclinic angle, and
∝the relative retardation which is related to the fringe order N as follows:
$\propto = 2\pi N$ -- (3)
Four of these variation ∝, θ, i_m and i_v are unknown, and therefore a minimum of four separate photo elastic data sets with different orientations of ψ_p and β_p are required to determine the unknowns at every point over a data image. [1]
In refection photo-elasticity, the relationship between the isochromatic fringe order N and the principal stresses σ_1 and σ_2 in the surface of the components can be written as:

$$\sigma_1 - \sigma_2 = \frac{E_S}{E_C} \cdot \frac{1+\nu_c}{1+\nu_S} \cdot \frac{Nf_c}{2hc} = \frac{Nf_\sigma}{h} \qquad (4)$$

Where
Es is the young's modulus of component surface.
ν_s is the Poisson ratio of component surfaces
E_C = is the young's modulus of reflective coating or photo elastic coating
ν_c = is the poisson ratio of reflective coating or photo elastic coating
hc = Thickness of reflective coating or photo elastic coating.
fc = Material fringe constant of reflective coating or photo elastic coating. [10]

II. Photo Elastic Coating Materials

2.1 Types of coating materials
The photo stress coating materials are grouped into Three types
A. High Modulus materials.
B. Medium Modulus materials.
C. Low Modulus Materials.[6]

According to the texture of structural part which is to be tested, which is flat surface or complex surface, further categorization is done.

1. Sheets for coating Flat parts
Pre-manufactured sheets are most economical for testing Flat parts.PS -1, PS-3, PS-4, PS-6, PS-10.
The standard size for all sheet material is 10 x 10 inch for PS-1 and for remaining plastic sheet sizes various 10 x 20 inch, 20 x 20 inch. Thickness of sheets range from 0.010 inch to 0.120 inch. All sheets are calibrated for strain sensitivity. PS-1 sheets are provided with a reflective backing. All other sheets are clear. All sheets are supplied with a protective paper coating.

2. Liquids for coating complex shaped parts.
Liquids plastic materials are used for making coatings for structures with complex contours which can not be coated with flat sheets. Plastic liquids : PL-1, PL-2, PL-3, PL-6, PL-10.
The plastic liquids are carefully provided to the contoured surface with resins and sufficient hardener.
A) High modulus coating materials are PS-1 sheet, PS-10 Sheet, PL-1, & PL-10 liquid. Excellent high sensitivity plastic for accurate analysis in the elastic and elasto-plastic ranges of most metals.
B) Medium-modulus coating materials are PS-3 sheet & PL-2 Liquid, Generally used for analysis of non-metallic materials.
C) Low modulus coating materials are PS-4 sheet, PS-6 sheet and PL-3 & PL-6 Liquids used for analysis of parts having extra high elongations, such as rubber.

2.2 Adhesives Recommended for bonding different plastic sheets & contoured sheets made from plastic liquids. [9]

Table 1 Adhesives for coating materials.

Coating Material	Adhesives	Curing Time	Applications
High Modulus			Testing on Metals concrete, Glass, and hard plastics in the elastic & elastoplastic ranges.
PS-1 (Reflective backing)	PC-1C	12 hrs at room temp.	
PS -1	PC -10	3 to 4 hrs at room temp	
PS -10			
Pl -1			
PL-10			
Medium Modulus			Testing on soft materials such as rubber, plastics and wood.
PS-3	PC -6	24 hrs at room temp.	
PL -2			
Low modulus			

PS – 6	PC - 9	24 hrs at room temp.	
PL -6			
PL -3	PC -11	24 hrs at room temp.	
PS – 4	PC – 12	36 hrs at room temp.	

III. Procedure For The Successful Photo Stress Plastic Coatings

For doing coating on any test part material following four steps should be followed.

A. Coating preparation.
B. Surface preparation.
C. Adhesive preparation.
D. Bonding procedure.

A. Coating preparation

Use of flat sheets for flat surfaces and polymerized sheets first be "contoured" to the curved surface and then be allowed to fully polymerize while on the surface of the part.

- Cut the photo sheet to match the edges of the test part.
- Providing holes to accommodate bolts, rivets in the test part.
- Planning the location of seams (or junctures) between adjacent plastic sheets. [7]

B. Surface preparation

Surface preparation of the test part includes following four steps.

B.1Preliminary cleaning and Degreasing of work piece:

The surface of work piece which is to be coated should be cleaned by washing it down with acetone, isopropyl alcohol. Vapor degreasing or hot-solvent dipping may be convenient for larger parts.
Cleaning of surface should be done by hand or disc sanding, grit blasting, wire brushing or any other convenient method. Rough initial degreasing is recommended. [7]

B.2 Abrading of Work piece

Surface of the work piece should be cleaned with sand blasting or disc sanded (Sand or grit blasting) also to gel desired surface texture. Generally for large surface area sand or grit blasting is preferred.[7]

B.3Conditioning of work piece

Surface of the work piece should be conditioned. Conditioning of surface is done by lapping lightly with abrasive paper (120 x 220 grit) wetted with conditioner A. After the surface has been lapped, it should be washed with conditioner A & wiped dry. Paper towels or gauze sponges are convenient for washing and drying. Washing and drying should continue until the towels or sponger are no longer discolored, when the conditioner A is wiped dry. Conditioner A should not be allowed to dry on the surface. [7]

B.4 Neutralizing

Wet paper towel or gauze sponges with neutralizer 5A and scrub the cleaned area. Keep the area wet and do not allow the neutrizer 5A to dry. Dry the wetted area with clean towels or gauze sponges, talking care not to drag contaminants into the cleaned area. [7]

C. Adhesive preparation

Adhesive is the mixture of Resin and Hardener. 1 gram of adhesive mixture covers 10 squares cm or 1.5 squares inch area of work piece. While preparing Adhesive following precautions should be followed. Use Hand gloves in hand, spectacles on eye & mask on face to prevent from exothermic fumes during mixing Resin and Hardener. Accessories required for mixing procedure: Paper cup, Wooden stirrer, Glass sheet, Surface plate, Flatness indicator., Bonding tape, Scissor or Cutter. Preferably Maximum 30 gm adhesive mixture at a time is recommended. But adhesive mixture at most 100 grams could do but the mixing time would be required 10 min and there is a possibility of more increase in temperature of mixture during stirring due to which mixture may become hard & will be unusable. Therefore if 100 grams mixture is required do it into two or three cups. Adhesive should be prepared at room temp.

For PS-1A photo stress sheet PC -1C Adhesive was prepared. The proportion of Resin and Hardner for 20 gm total adhesive mixture was calculated in the following way. The amount of Hardener required was calculated in parts per hundred or 'pph' for PC-1C Adhesive the amount of Hardener is 10 'pph'. 10 pph of Hardener means 10 grams of hardener for 100 grams of resin.

For Example: - The required total adhesive mixture was 20 grams.

Resin PC-1C = $20\times\frac{100}{110}$ = 18.18 grams.

Hardener PCH - 1 = $20\times\frac{10}{110}$ = 1.18 grams.

First take two paper cup & weigh the weight of empty paper cup. First add 18.18 gram resin and then add Hardener 1.81 gram in to the paper cup. Mix the adhesive by wooden stirrer uniformly for 4 to 5 minutes smoothly to get a homogeneous mixture while mixing the adhesive do not hold the paper cup in the palm, keep it on the ground or surface plate. The mixing will cause the temperature of the adhesive to rise, gradually at first, then rapidly. When it is well mixed and slightly warm, pour out the mixture on to a flat plate of glass or plastic, so that the mixture cools and remains fluid for longer time. If it is allowed to heat up it will become hard within a few minutes and will unusable. The maximum working time of adhesive mixture from mixing to bonding a sheet on the work piece is 40 min. Hence the time estimation during bonding is very important. Adhesive Mixture was ready to use it on the work piece surface. [9]

D. Bonding procedure :

The Adhesive Mixture of PC-1C which was ready to use, spread the adhesive on the work piece surface; using a paint brush. The layer of adhesive can be thick as approximately 0.8 to 1.6 mm, depending on the regularity of the surface. Then keep that work piece on the flat surface plate to maintain uniform thickness of adhesive mixture on the surface of work piece. Then carefully placed the PS-1A cut sheet from one corner of work piece towards other corner& apply fingure pressure to remove air bubbles. After relaxed the finger any air bubbles found apply some adhesive at the corner and once again apply finger pressure. Then mask the binding tape to the work piece & keep the work piece for $1\frac{1}{2}$hr. After $1\frac{1}{2}$ hr. remove binding tape, clean the corners by isopropyl alcohol & then allow the work piece for 12 hrs curing from the beginning of bonding. [9]

IV. Test Temperature

If the experiment is to be conducted other than room temperature, then variation in the strain-optic coefficient of the coating material with respect to rise in temperature is to be considered.

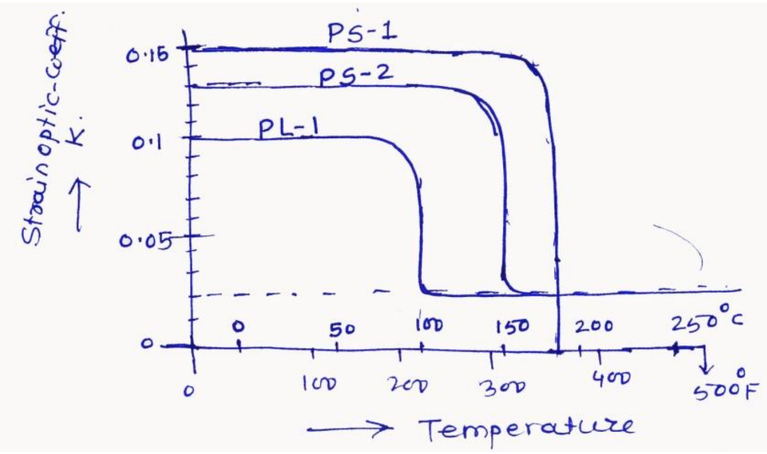

Fig.1 Strain optic coefficient v/s Temperature

From the above graph fig.1 it predicts that PS-1 sheet is having constant strain optic coefficient K up to maximum temperature range 175^{0}C .[7]

V. Conclusion

In this paper we have discussed photo stress coating materials, their uses, Adhesives, Coating steps and how to prepare Adhesive; which is required in the experimental approach to measure the thermal stresses by Thermo-photo elasticity with reflection polariscope.

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