Fifth International Conference on Composite Science & Technology
AMERICAN UNIVERSITY OF SHARJAH
P.O. Box 26666, Sharjah, UAE

# Residual Stress Distributions Produced by Inconvenient Storage Conditions

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**ABSTRACT:**

Residual stresses constitute an integral part of the total stress acting on any component in service. The importance of residual stress is due to its uncertain nature of stress patterns that are generated after fabrication or in some instances are due to the casting, welding, molding or heat treatment operations. The storage conditions may be a major source of residual stresses. This study investigated the possible existence of residual stress in Asbestos/Cement ( A/C) pipes. Two experimental techniques were used to determine the magnitude and nature of residual stresses: the hole drilling/strain gauge technique and the photoelastic sensitive coating technique The results of the study showed a wide range of stress variation and indicated that the storing conditions play usually a major role in creating residual stresses.

**Key Words:** Residual stress, hole drilling, photoelastic coating, surface strain relaxation

## INTRODUCTION:

The residual stresses in structural components are usually introduced in the manufacturing process, or due to improper storage. In some instances these stresses are due to the casting, welding, and molding or heat treatment operations. In other instances the residual stress

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appears further in the life of the structure. In many cases theses stresses are the predominant factor contributing to structural failures. The residual stresses can be measured only after being relieved. These stresses are first reported by Mathar [1]. The residual stresses were measured using the hole drilling method which is semi-destructive [2, 3]. Detailed study of the nature and origins of residual stress across a range of scales were classified in [4,5]. The accuracy of the hole-drilling method and its relation to the operator was reported by Redler [6]. Photoelastic Sensitive Coating has been also used for visualizing the residual stresses [7].

## THEORETICAL BACKGROUND:

### a. Hole drilling strain gauge method

The introduction of a hole even of small diameter into a residually stressed body relaxes the stresses at that location. A rectangular rosette as shown in Fig 1 was installed on the pipes to experimentally measure the strains $\varepsilon_a$, $\varepsilon_b$, and $\varepsilon_{c,}$ which will be substituted in the following mathematical relations to obtain the principal stresses $\sigma_1$ and $\sigma_2$ and the principal direction β. Knowing that E and ν are the modulus of elasticity and the Poisson's ratio of the A/C respectively.

$$\sigma_1 = [\varepsilon_c(A + B\cos 2*\beta) - \varepsilon_a(A - B\cos 2\beta)]/[4*AB\cos 2\beta] \quad (1)$$

$$\sigma 2 = [\varepsilon_a(A + B\cos 2\beta) - \varepsilon_c(A - B\cos 2\beta)]/[4AB\cos 2\beta] \quad (2)$$

$$\tan 2\beta = [\varepsilon_c - 2\varepsilon_b + \varepsilon_a]/[\varepsilon_c - \varepsilon_a] \quad (3)$$

Where:

$$A = \frac{1+\nu}{2E}(\frac{1}{r^2})$$

$$B = -\frac{1+\nu}{2E}[(\frac{4}{1+\nu})\frac{1}{r^2} - \frac{3}{r^4}]$$

$$r = \frac{R}{R_o}$$

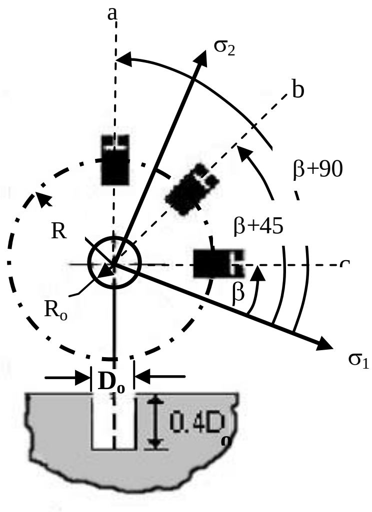


Fig. 1 Strain gauge rosette arrangement for determining residual stress.

**b: Photoelastic sensitive coating method**

A photoelastic contoured sensitive coating of a ring form is bonded to the A/C pipes along the hoop at randomly selected positions. Observations of the coating by means of a reflection polariscope give a fringe pattern which related to the surface strains of the specimen. The difference in the principal stresses for the specimen is given by:

$$\sigma_1^s - \sigma_2^s = \frac{E^s}{E^c}\frac{1+\nu^c}{1+\nu^s}\frac{Nf_\sigma}{2h^c} \tag{4}$$

$$\tau_{xy}^s = \frac{E^s}{E^c}\frac{1+\nu^c}{1+\nu^s}\frac{Nf\sigma}{4h^c}\sin\vartheta \tag{5}$$

Where:

$E^s$, $E^c$: are elastic modulus of the A/C and of the coating material respectively
$\nu^s$, $\nu^c$: are Poisson's ratios of the A/C and of the coating material respectively
$h^c$: thickness of photoelastic coating
N, θ : isochromatic parameter and isoclinic parameter respectively
$f_\sigma$: optical stress constant of the coating material

## EXPERIMENTAL WORK

Eleven pipes of 11 cm diameter and 4 m length were selected randomly from different lots and different storage layers. Some of the pipes were exposed directly to the sun while others were resting on an unleveled ground. The measuring stations are shown in Fig.2. Surface preparation for strain gage installation may induce residual stresses which affect residual stress measurements [8]. Therefore, the hole is normally drilled to a depth corresponding to at least $0.4\ D_o$ (ASTM E837), [2], and [9,10]. To minimize the cause of inaccuracy due to heat generated during drilling, blowing cold air is a practiced technology. An alternate technique is to use continuous flow of cold liquids. However, both techniques were not applicable in our case due to the consideration of Asbestos as a carcinogen material and its ability to absorb liquids.

The local heat increase around the holes in the case of blind hole has been taken into consideration by selecting suitable arrangement of the strain gauges in Wheatstone bridge circuit. The observation showed that temperature-increase changes the measured strains in a negative sense. The apparent strains versus time till steady states were recorded in figures 3-a and 3-b as samples of the data.

For photoelastic coating method a two component epoxy is mixed in the laboratory and it is casted in a sheet form to the required thickness. After a certain degree of polymerization it becomes a deformable plastic sheet without photoelastic memory. The flexible sheet is pressed gently to the pipe under study to get its surface shape. At advanced stage of polymerization a photoelastic memory is developed. Residual stresses when released by cutting cause internal strains, that can be recognized in a form of fringes. These fringes are called isochromatics, which are fringes of equal principal stress differences [6].

A reflective adhesive is used to glue the coating to the pipes.

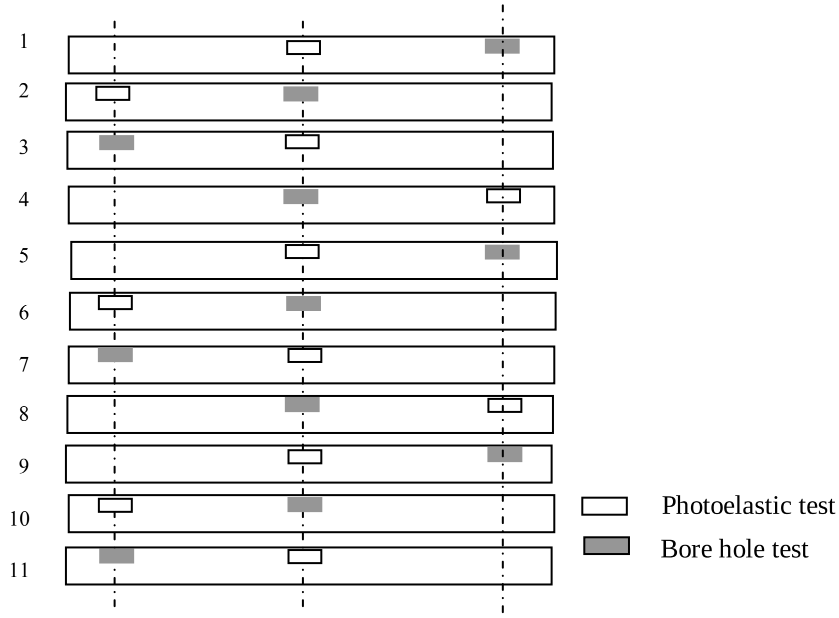


Fig. 2 Random choice of the places of the strain gauges and photoelastic tests

**ANALYSIS AND CONCLUSION:**

Regarding measurements of strains produced by relaxation of surface stresses; obviously the principal directions β and (β +90) as demonstrated in figure 1 can be calculated using eq. (3). From the measured strains, the residual stresses were calculated and plotted in Fig 4. The principal directions do not show any preferable direction, which is normal in the case of residual stresses. However, β varies between -25.50 and 43.60 degrees.

The relatively great values of standard deviation in comparison with mean value as shown in Fig.4 demonstrate the wide range of stress variation. Changing the storage conditions may alter residual stress distributions with time. It has been noticed that pipes 2,4, and 5 which were stored on the top, possess closer stress level, while the pipes 1,8,and 9 which were resting directly on the ground, illustrate different stress states. One can conclude that a special attention to ground leveling and good ventilation should be considered in storage places.

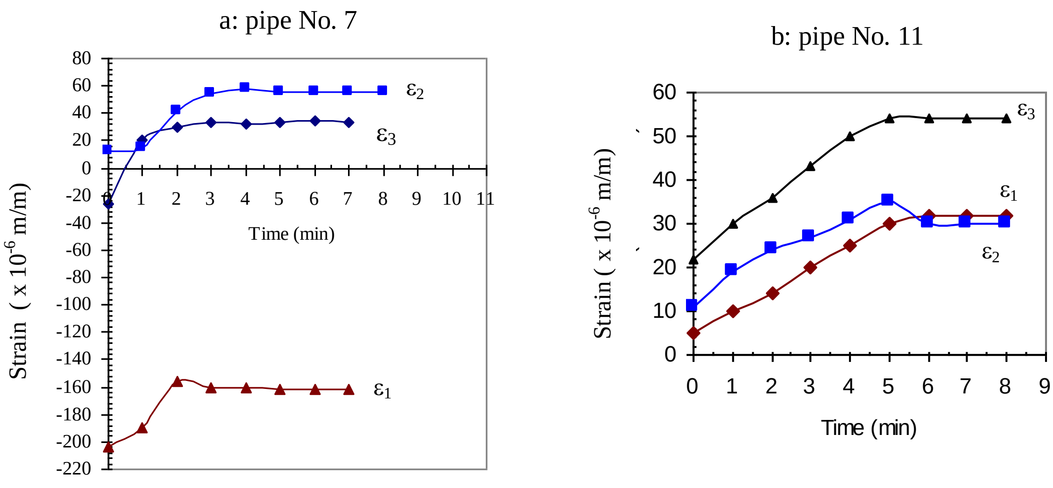


Fig. 3 Residual strain distribution with time for pipes 7 and 11

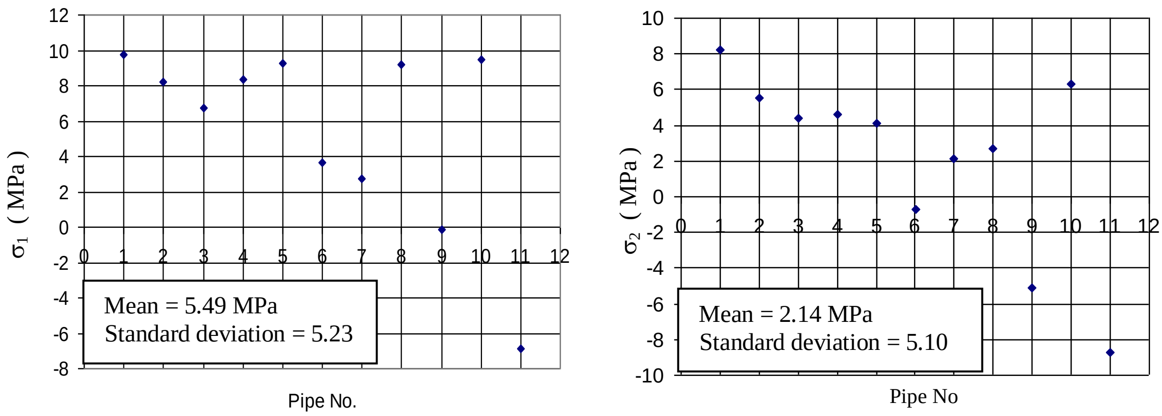


Fig. 4. Principal stress distribution for the 11 pipes ( E= 15000 MPa, and ν = 0.18)

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