CHARACTERISATION OF RESIDUAL STRESSES
ON SHOT PEELED COMPONENTS
BY X-RAY STRESS ANALYSIS METHOD

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ABSTRACT

Shot peening is a process which introduces a cold worked surface layer, this introduces favourable residual stresses.

This paper describes the essence of the principles of x-ray diffraction method for residual stress measurements. Advantages and limitations are also listed here.

A comparative study of the residual stress distribution along the depth of shot peened medium carbon low alloy connecting rods is presented in this paper.

The study corroborates the fact that surface residual stress values are indicative of fatigue behaviour and depth profiling will have to be carried out to understand the residual stress distribution in a shot peened component. The efforts should always be made to standardize shot peening parameters like shot speed, shot size, peening time for producing the desired stress profiles and once standardized the value and the type of the residual stress may become the tool for controlling the quality of the component; improving the fatigue properties, also may serve as acceptance / rejection criterion.

1. INTRODUCTION

Residual stresses are those stresses present in a solid in the absence of external forces, excluding gravity. These stresses cause elastic strain and are distributed both on the micro and macro scales [Prevey 87] [Dowling 93b].

Macro stresses are tensor quantities, with magnitudes varying with direction at a single point in a body. These are extended over the distances that are large relative to the grain size of the material. These are of paramount interest in design and failure analysis of engineering components [Prevey 87].

Micro stresses are scalar properties of the sample, such as cold work or hardness, that are without direction and result from imperfections in the crystal lattice. Microstresses are associated with strains within the crystal lattice that traverse distances in the order of or less than the dimensions of the crystals. Microstresses vary from point to point within the crystal lattice, altering the lattice spacing and broadening the diffraction peak [Prevey 87].

Residual stresses that are usually formed when a portion of the components
or workpiece undergoes nonuniform, permanent dimensional change. This can be either plastic deformation, as in for example, cold rolling of metals, or elastic deformation, as in solid-state phase transformation in metals and ceramics. Inhomogeneous plastic deformation may be induced by temperature gradients, as by welding, sintering or heat-treating as well as by forming, pressing or material removal processes such as machining, grinding. Thus, virtually all manufacturing processes used to shape a material into a useful component will cause residual stresses and even processes such as plating or chemical and physical vapour deposition of films. [Dowling 93b]

Although the term stress measurement has come into common usage, stress is an extrinsic property that is not directly measurable. All methods of stress measurement require measurement of some intrinsic property such as strain or force and area and the calculation of the associated stress.

2. METHODS OF RESIDUAL STRESS MEASUREMENT

Residual stress can be measured by destructive or non-destructive techniques, former includes blind hole drilling, strain gauging, while later includes x-ray diffraction, ultrasonic, barkhaussen noise, magnetic acousto-elastic (MAE), etc. [Prask 87][Crecraft 68]. However present paper deals with x-ray diffraction method of residual stress measurement.

X-ray diffraction residual stress measurement is unique in that macroscopic and microscopic residual stresses can be determined non-destructively. In x-ray residual stress measurement, the strain in the crystal lattice is measured, and the residual stress producing the strain is calculated, assuming a linear lattice distortion of the crystal to determine the stress, the strain in the crystal lattice must be measured for at least two precisely known orientations relative to the sample surface. Therefore x-ray diffraction residual stress measurement is applicable to materials that are crystalline relatively fine grained, and produce diffraction for any orientation of the sample. Sample may be metallic or ceramic, provided a diffraction peak of suitable intensity and free of interferences from neighbouring peaks can be produced in the high back reflection region with the traditions available [Cullity 78].

2.1 Principle of X-Ray Diffraction Stress Measurement

Figure 1, shows, [Cullity 78] the diffraction of monochromatic beam of x-rays at a high diffraction angle (2 theta) from the surface of a stressed sample for two orientations of the sample relative to the x-ray beam. The angle psi, defining the orientation of the sample surface, is the angle between the normal of the surface and the incident and diffracted beam bisector, which is also the angle between the normal to the diffracting lattice planes and the sample surface.

Diffraction occurs at an angle 2 theta, defined by Bragg's law : n * lambda = 2 d sin (theta), where n is an integer denoting the order of diffraction, lambda is x-ray wavelength, d is lattice spacing of the crystal planes, and theta is the
diffraction angle. Any change in the lattice spacing, \(d\), results in a corresponding shift in the diffraction angle \(2\theta\). Measuring the change in the angular position of diffraction peak for at least two orientations of the sample defined by the angle \(\psi\), enables calculation of the stress present in the sample surface lying in the plane of diffraction, which contains incident and diffracted x-ray beams [Gisen 36]. Four point method is used in the present investigation.

The residual stress determined using x-ray diffraction is the arithmetic average stress in a volume of material defined by the irradiated area, which may vary from square centimeters to square millimeters, and the depth of penetration of x-ray beam. The choice of a diffraction peak selected for residual stress measurement impacts significantly on the precision of the method. The higher the diffraction angle, the greater the precision.

Fig. 1.
2.2 Requirement for Samples

Form: Polycrystalline solids, metallic or ceramic, moderate to fine grained.
Size: Various, with limitations dictated by the type of apparatus, the stress field to be examined, and x-ray optics.
Preparation: Generally none, large samples and inaccessible area may require sectioning with prior strain gauging to record the resulting stress relaxation.

2.3 Estimated Analysis Time

It may vary depending on the diffracted x-ray intensity and technique used. 15 to 20 minutes is the typical analysis time for one measurement with four angle (multiple exposure) technique.

3. GENERAL USES

- Determination of subsurface residual stress distribution.
- Measurement of residual stresses associated with failures caused by fatigue or stress corrosion.
- Measurement of residual stresses for optimizing the processes and products along with quality improvements in rolling, machining, shot peening, forging, extrusion, welding, distortion control in heat-treating etc.

RESIDUAL STRESS VS DEPTH BELOW S/F
INDIAN CONROD

Graph 1
Graph 2

4. EXPERIMENTAL WORK

In the present paper comparative study of residual stress variations in the Indian make and imported conrod was carried out.

Forged and normalised Indian and imported conrods of AISI 4140 steel hardened and tempered to 241 to 302 BHN in the shot peened condition were selected for the study.

Residual stresses were measured on the column portion near to the small end of the conrods after electro-polishing the cold worked layer produced during shot peening to the required depth below the surface.

The values of residual stresses thus obtained were plotted against the depth below the surface. The graphs thus obtained provided important information on the residual stress distribution in these conrods.
5. RESULTS AND DISCUSSION

As can be seen from the graph 1 and graph 2, the residual stresses on the surface of the conrods in both longitudinal and transverse direction are compressive as indicated by the negative sign. The value is -274.4 MPa and -223.4 MPa on the surfaces of Indian and Imported conrods respectively. As the depth below the surface increases, the residual stresses rises to a more compressive value and a peak value is attained at a certain depth. This value is remaining almost constant for few microns and then starts decreasing continuously to attain the surface residual stress value. If further electropolished residual stresses may cross zero to attain tensile value.

It is obvious from the graphs that the residual stress values on the surface are indicative and depth profile will have to be carried out to understand the stress distribution pattern and it is reported that the maximum of residual stress has direct bearing on the improvement of fatigue life behaviour of the component. The present study indicates comparable fatigue behaviour to both conrods.

6. CONCLUSION

i. Residual stress distribution produced by shot peening of conrods typically exhibit the "hook" as seen in graph 1 & 2 with the lower amplitude of compression at the immediate surface after shot peening.

ii. The shot peening operation induces compressive residual stresses on the surface of the component.

iii. The peak value of the residual stresses is of prime concern when fatigue resistance is considered. The peak value of the residual stress is some depth below the surface, and this depth needs to be found out.

iv. The lower compressive stress achieved at the surface may be related to the extensive cold working of the material and a resultant increase in yield strength at the surface.

v. The values of residual stresses in longitudinal and transverse directions vary and this difference needs critical analysis depending upon the working stresses developed in the component.

vi. This investigation indicated that shot peening could relocate the maximum compressive residual stress below the surface. This condition could benefit surfaces requiring grinding for special dimensional requirements, repair zones where softening due to overlap or back tempering could have resulted or application where subsurface stresses were a concern.

vii. It is reported [Coster 87] that the residual stress pattern is governed by typical shot peening cycle, time of peening, shot size, shot speed, shot hardness, angle of impingement, etc. Further study will have to be carried out for standardizing these parameters for producing suitable stress pattern for the given application.
ACKNOWLEDGEMENT

We express our gratitude to Dr. V.D. Kodgire Head of Metallurgy Department, for his encouragement and sincerely thank for timely guidance and help extended for carrying out this research work.

7. REFERENCES


