MEASUREMENT OF STRESSES INDUCED BY SHOT PEENING

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ABSTRACT

The stress state induced by shot peening is a measure of the quality of the peening process. In this paper the centre hole drilling technique is described and compared with X-ray techniques.

KEYWORDS

Residual Stress, Experimental Stress Analysis, X-rays, Shot Peening.

INTRODUCTION

Shot peening is employed as a stress corrosion preventive, or for improving the fatigue lives of components. The effect of shot peening is to introduce a surface compressive stress which is also effective to a particular depth immediately below the surface, and depends on the size and type of shot, and on the shot peening treatment variables, such as the shot velocity, angle of impact and nozzle diameter. The introduction of a particular depth of compressive stress is pertinent for situations where wear, abrasion or mechanical damage are prone to remove the protective compressive layer. Thus, when designing a shot peening treatment to resist such damage, it is essential to have a firm knowledge of the depth of compressive surface layers introduced.

Many techniques are available for stress measurement, but two of the most commonly employed are the X-ray technique (Hawkes, 1957; Kirk, 1970) and the centre-hole drilling technique using an end mill (Bathgate, 1968; Beaney, 1974) or air abrasive (Beaney, 1976) cutting. Some techniques such as ultrasonic stress measurement are potentially feasible for the applications considered here, but do require considerable development for measurement of stress versus depth.

This paper describes the use of the centre-hole drilling technique with an incremental analysis for the measurement of stress as a function of depth, and outlines the relative merits of this method compared with X-ray techniques.

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THE CENTRE HOLE DRILLING TECHNIQUE

The technique, described in detail by Beaney and Procter (1974), is the forming of a blind hole and measuring the surface strain change by a three element strain gauge rosette. The rosette elements measure the radial strains with the hole centre as the origin. The measured strain changes, as a hole of equal diameter and depth is formed, and calibration coefficients are used in formulae to determine the mean residual stress field over the full hole depth. Strain gauge rosettes are commercially available for 0.8mm, 1.6mm and 3.2mm diameter holes with the same geometry relative to the nominal hole diameter. Alternatively a rosette can be made with individual gauge elements. It is important that the forming of the hole produces little or no damage effect at the gauge position which could result in an apparent strain component, the hole produced is parallel sided with an approximately flat base, and for an incremental analysis the relieved strain/hole depth relationship can be obtained.

Two methods of producing the hole are discussed. The use of an end mill (Beaney and Procter, 1974) results in a damage effect which is accountable for in aluminium and mild steel but which renders the technique unusable in work hardening materials. A parallel sided flat based 'square' hole results and the relieved strain/hole depth relationship can be easily obtained. The use of an air abrasive technique (Beaney, 1976) caused no damage effect but the hole geometry varies with depth, the base is not flat and a relieved strain/hole depth relationship is difficult to obtain using commercially available equipment.

The determination of the residual stress variation with depth is described by Owens (1980). The three elemental strain changes measured for a hole depth increment are factored by the strains that would be produced had the residual stress field in that increment been uniform over the full hole depth. The formulae for mean stress calculation (Beaney and Procter, 1974) are used.

All coefficients are obtained from experimental calibrations and the most consistently used method is the application of a uniform uniaxial stress field, because of its ease of application and good repeatability.

The sensitivity factor varies with the hole and gauge geometry and is the ratio of the applied and relieved strains for the full hole depth.

The 'Poisson' factor is the absolute ratio of transverse and longitudinal relieved strains for the full hole depth.

The incremental relieved strain factors are determined from a convolute inversion of the measurement position relieved strain/hole depth relationship and that obtained in a uniform, uniaxial calibration. The principal stress direction and ratio must be determined for the measurement position increment and superposition modifications made to the uniaxial calibration data for biaxial stress fields.

The calibration has been extended to include a finite element analysis (Owens, 1980) with good agreement with the experimental results. With a finite element analysis reproduceable, accurate, 'residual' stress fields can be applied to the model. It was determined that the accuracy of the calculated stress/depth relationship decreased as the uniform uniaxial stress field is deviated from.

Peening induces a high compressive stress either at or close to the surface which reduces exponentially with increasing depth. The finite element study indicates that the calculated stresses are 20-30% greater than the absolute residual stress state. However, the technique has been successfully used for a long period as a qualitative method of stress determination for stress states induced by peening with an estimated accuracy of within 10%.

Finite element calibrations are continuing and the method of analysis is being further improved. It is considered that a biaxial, exponentially decaying stress field should be used as the calibration standard for use with measurements on peened surfaces. The accuracy of stress measurement will then be significantly increased and a quantitative analysis will result.

COMPARISON OF HOLE DRILLING & X-RAY METHODS

General

X-ray stress measurement is primarily employed for surfaces only - the penetration being typically 25μ in the case of copper radiation in aluminium alloys. In order to measure stress-vs-depth, incremental surface layers must be removed followed by re-measurement at the newly created surface making corrections for the amount of metal removed (Moore and Evans, 1958). At the current time, the process is lengthy and time consuming for a stress-vs-depth measurement, but nevertheless, it is employed (Olver, 1976). There are possible problems associated with the preparation of the surface, preferred orientation effects, large grain size and heavily worked surfaces. The latter is particularly relevant to shot peening since inaccuracies may arise due to broadening the diffraction lines. The technique examines an area of only 1-2mm^2 and is, therefore, suitable if there are large stress gradients in the surface.

Repeatability

Both techniques are reliable in this respect. X-ray stress measurement made on the same positions give virtually the same results. Errors may be due to exact location, variations in film measurement, etc (marion and Cohen, 1974). On peened surfaces, hole drillings made in different locations give very similar stress/depth curves (Birley and Owens, 1980).

N.D.T. Considerations

It is often assumed that drilling holes in structures is destructive. In fact, hole drilling need not be any more destructive than X-ray measurements made to the same depth. Both techniques, in fact, may be regarded as non destructive when the portion of metal removed does not affect the performance of the component. There are many instances where components containing holes are still in service (Birley and Owens, 1980). On the other hand, when the metal is removed from thin sheet, or from critical load bearing areas, both techniques must be regarded as destructive.

Portability & Accessibility

There are a limited number and types of portable (or transportable) X-ray devices for measuring stresses. The problem is not usually one of portability, but one of accessibility to the workpiece, which depends on size and shape of the measuring equipment and geometry of the fabrication being examined. There are many locations on complex structures which cannot be measured by either technique, and many which can be measured by X-rays and not by hole drilling and vice versa. The X-ray technique has the additional inconvenience of having to satisfy safety precautions. These often have to be negotiated locally in the field, but generally do not present much of a problem.

Speed of Operation

The time taken for incremental measurements by hole drilling can be as little as 15 mins. from installation of the equipment to completion of the readings (Birley and Owens, 1980). The data is then analysed by computer and, if required, facilities could be made available on site to calculate the stress depth relationship.

Conventional X-ray film and diffraction methods require lengthy exposures, and 1¼ hours may be typical for a surface stress measurement in steel using the diffractometer. It is now possible to use equipment including Position Sensitive Detectors (PSD) (James and Cohen, 1978; Siemens Ltd, 1979), which considerably reduce exposure time, and software which greatly reduce processing time. For example the Portable Stress Goniometer with PSD (Siemens Ltd, 1979) can provide a stress measurement in just over one minute. Available in the U.S.A., there is a fully portable device which is body held and is pointed at the position required during an exposure time of as little as 6 seconds. When measuring the depth of the compressively stressed layer, the problem still remains of having to remove material and make corrections, both of which are time consuming. A portable self-contained electropolishing device is, however, currently being developed which will rapidly remove surface layers with minimal damage and at controlled rates (Chadwick 1980).

Comparison of Stress Values

The authors' experience of comparing the two techniques is that of employing X-rays to determine surface stresses and hole drilling to determine stress/depth relationships. Where workers have compared results of the two techniques (Bathgate, 1974; Bathgate, Hatt and Birley, 1978; Birley and Owens, 1980; Hatt, 1974), good agreement has been found. It is debatable whether such agreement is real or fortuitous for two reasons. Firstly, the X-ray results may depend on the energy (therefore penetration) employed, particularly when the stress gradient with depth is non-linear. Secondly, the hole drilling technique described above, is subjected to error in the immediate sub-surface layers, the response of the gauges will be influenced by their position in a non-linear surface gradient, and the calibration which is used is obtained in a uniform gradient and is therefore, not strictly applicable.

Shot Peening Reliability & Quality Assurance

Having selected a shot peening treatment, it is essential to ensure that the component contains the correct level of stress, that all parts are correctly treated, and that different plants give similar results. The first two requirements are achieved by means of controlling the Almen Strip to set the intensity, and ensuring the appropriate coverage of the surface. Periodic checks with stress measurements made on peened coupons can be made for added confidence. It is emphasised that it is not necessary to make stress measurements on an actual component. Regarding the third requirement of inter-plant calibration, the operating guidelines for one plant may produce a different intensity of treatment on another plant because, for example, air pressures may be measured at slightly different parts of the equipment, or that measurement devices may differ with respect to calibration or accuracy. Almen Strips may be used when making slight adjustments to the operating conditions, and stress measurements are made to confirm that new operating parameters produce the correct stress distribution.

CONCLUSIONS

The advantages and disadvantages of the X-ray and hole drilling techniques have been compared and it is shown that the centre-hole drilling technique is particularly suitable for assessing shot peening where a knowledge of the stress distribution with depth is required. It may be necessary to employ one in preference to the other after consideration of factors such as accessibility to the position being measured on a structure, safety, portability of the equipment particularly for field applications, and the potential danger of introducing holes into critical load bearing areas.

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