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The effect of plasticity on the ability of the deep hole drilling technique to measure axisymmetric residual stress

A.H. Mahmoudi [a], C.E. Truman [b], D.J. Smith [b], M.J. Pavier [b,*]

[a] Department of Mechanical Engineering, University of Bu-Ali Sina, Hamedan, Iran
[b] Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1 TR, UK

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ABSTRACT

Mechanical strain relief covers a class of techniques for measuring residual stress in engineering components. These techniques work by measuring strains or displacements when part of the component is machined away. The assumption is that such strain or displacement changes result from elastic unloading; however, in components containing high magnitudes of residual stress elastic–plastic unloading may well occur. Such elastic–plastic unloading introduces errors into the measurement of the residual stresses and these errors may be large. This paper addresses the performance of the deep hole drilling technique, a mechanical strain relief technique particularly suitable for large section components. First a plane strain analysis is presented that quantifies the errors associated with plasticity for different magnitudes of residual stress. A three dimensional finite element analysis is then carried out that shows larger errors may be obtained than those suggested by the plane strain analysis. A method for reducing the magnitude of the error is investigated. Finally, the results of an experimental measurement of residual stress are presented where substantial plasticity occurs. The work demonstrates the potential vulnerability of mechanical strain relief methods to plasticity and introduces methods for quantifying the resulting errors. It also provides further evidence that modifications to the standard DHD technique can be made to make the technique less susceptible to error when plasticity occurs.

1. Introduction

Techniques for measuring residual stress involving the removal of material associated with measurement of strain or displacement are termed mechanical strain relaxation (MSR) techniques. There is a wide variety of such techniques, some classed as semi-destructive where material removal is limited and others as wholly destructive. Examples of semi-destructive techniques are centre hole drilling [1], slotting [2,3] and the Sachs method [4] while an example of a wholly destructive technique is block removal, splitting and layering (BRSL) [5].

The deep hole drilling (DHD) technique is a semi-destructive MSR technique where a small hole is drilled through the thickness of a component. Fig. 1 shows the steps involved in the technique. First a small reference hole, typically about 3 mm in diameter, is drilled through the component to be measured (step 1). Next the diameter of this reference hole is measured accurately using an air probe (step 2). These measurements of diameter are made at a number of angular positions and depth intervals. A column of material containing the reference hole is then trepanned from the component using electro-discharge machining (step 3). Finally the diameter of the reference hole is re-measured at the same angular positions and depths as before (step 4). The change in diameter of the reference hole is used to determine the residual stress field. It is assumed that the relaxation of residual stress caused by the introduction of the reference hole is negligible and that the residual stresses are relaxed in a linear elastic manner. Further details of the DHD technique may be found elsewhere [6].

All MSR techniques for measuring residual stress assume that the change in strain occurs elastically for then the residual stresses may be calculated directly from the measured change. If, however, the residual stresses are close to yield, plasticity may occur when material is removed and there will be no straightforward relationship between the measured strain change and the residual stress. Indeed, it may not have been evident that plasticity has occurred and that the assumptions inherent in the measurement are no longer true. There have only been a limited number of investigations on the influence of plasticity on mechanical strain relaxation techniques. Lin and Chou [7] reported errors of nearly 50% in measurement of residual stresses in the centre hole drilling technique due to local yielding. There are other reports on the effect of plasticity on the centre hole drilling technique [8–10] and

* Corresponding author.
E-mail address: martyn.pavier@bristol.ac.uk (M.J. Pavier).

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