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A simplified 3-D finite element simulation of cold expansion of a circular hole to capture through thickness variation of residual stresses

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Abstract

Cold expansion technique is a mechanical method of inducing beneficial compressive stresses around circular holes to offset the applied tensile stress resulting in improved fatigue life. The beneficial effect derived from the cold expansion process is entirely dependent on the magnitude and distribution of the induced residual stresses around the hole. In the present work a 3-D finite element simulation of cold expansion of a circular hole has been developed employing a new approach. In this approach, expansion is simulated by enlarging the hole layer by layer successively from one side of the plate to the other side resulting in simulation of gradual and complete expansion of the hole in the first stage. This process is followed by removal of applied boundary conditions again layer by layer resulting in gradual spring back of the hole completing the simulation of cold expansion process in the second stage. The present approach is capable of capturing the variation of residual stresses at various sections along the thickness as it happens in the actual split sleeve cold expansion process. The results in terms of the residual stress distribution and its variation along the thickness are presented, compared and found to be in close agreement with the published data.

Keywords: Cold expansion; Fastener hole; Residual stresses; Fatigue life; FE simulation

1. Introduction

Cold expansion technique is a mechanical method of inducing beneficial compressive stresses to offset the applied tensile stress resulting in improved fatigue life due to the decreased severity of the applied stress [1]. Cold expansion technique is a proven technology and has been in use since several decades. Particularly in aerospace structures, the technique is widely used to strengthen and enhance the fatigue life of fastener joints

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by cold expanding fastener holes to a predetermined level with the benefit of no addition of extra material resulting in reduced weight. Application of cold expansion has become a common treatment used at production stage of aerospace structures, apart from being used as a means of repairing fatigue aged fastener holes [2]. The schematic of the cold expansion process is shown in Fig. 1.

The beneficial effect derived from the cold expansion process is entirely dependent on the magnitude and distribution of the induced residual stresses around the hole [3]. The typical distribution of residual stresses around a cold expanded circular hole is shown in Fig. 2. As a result of continuous efforts by many researchers and their contributions in this direction, it is an established fact that the residual stresses induced are distributed in a non uniform manner around the hole and also vary in the thickness direction of the plate. This is due to the very nature of the process and the deformation mechanics involved during cold expansion process.

The intended use of the technique for a particular application should be judged by the possible distribution of induced residual stresses, their magnitude and variations. Because the derived benefits from the application of the technique in terms of enhanced fatigue life is dependent on the above mentioned factors.

Literature survey of cold expansion research has revealed that, it is required to predict/measure the magnitude and distribution of beneficial compressive tangential stress around the cold expanded fastener hole in order to quantify the benefits obtained by cold expansion. In practice experimental, analytical and computational methods have been used to measure/predict the residual stresses around a cold expanded hole [4]. Different approaches followed to predict the beneficial stresses are analytical formulations and numerical methods like finite element analysis [5–9]. Many experimental methods have also been employed to measure the residual stresses.

Analytical methods formulated for predictions of residual stresses are mainly plane stress/plane strain formulations considering expansion of hole to be achieved by applying pressure/displacement followed by elastic/elastic-plastic recovery of the expanded hole upon removal of applied pressure/displacement [4]. But none of the analytical formulation is capable of modeling the thickness effect and to predict the variations of the residual stresses in the through thickness direction.

Although many experimental techniques viz. X-ray diffraction, Neutron diffraction, Sach's boring technique etc. have been tried and employed for measurement of residual stresses, through thickness variation

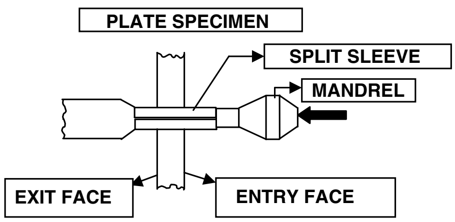

Fig. 1. Split sleeve cold expansion process.

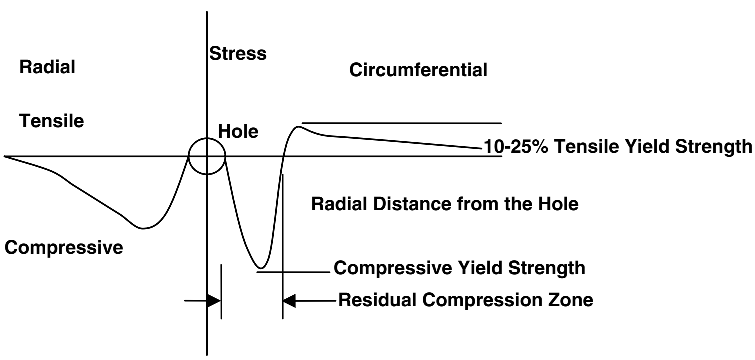

Fig. 2. Typical residual stress distribution at a cold expanded hole.