Optimising residual stress measurements through the use of measurement simulation†

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1. Introduction

Mechanical strain relaxation (MSR) residual stress measurement techniques, and in particular deep hole drilling, are now being used to make accurate measurements of residual stress in environments that have previously caused problems. Conventional application of these techniques determines through-thickness residual stresses by analysing measured distortions with elasticity theory. In many welded components, however, the high magnitude and tri-axiality of the residual stress field can cause plasticity when a cut is introduced as part of the measurement. This plasticity can cause significant measurement errors. Deep hole drilling, one principal MSR technique, has been advanced in recent years to account for this plasticity. The research in this paper describes how deep hole drilling measurements may be optimised - in terms of reduced measurement errors and more efficient experimental parameters - by utilising measurement simulations prior to the actual measurement. Several cases

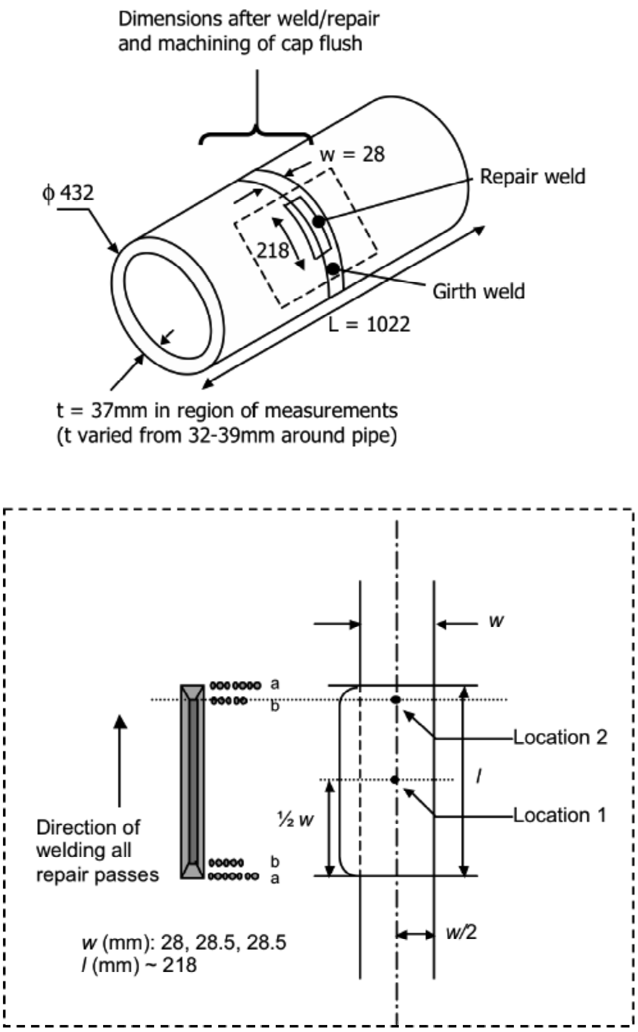

Fig. 1 316H offset repair

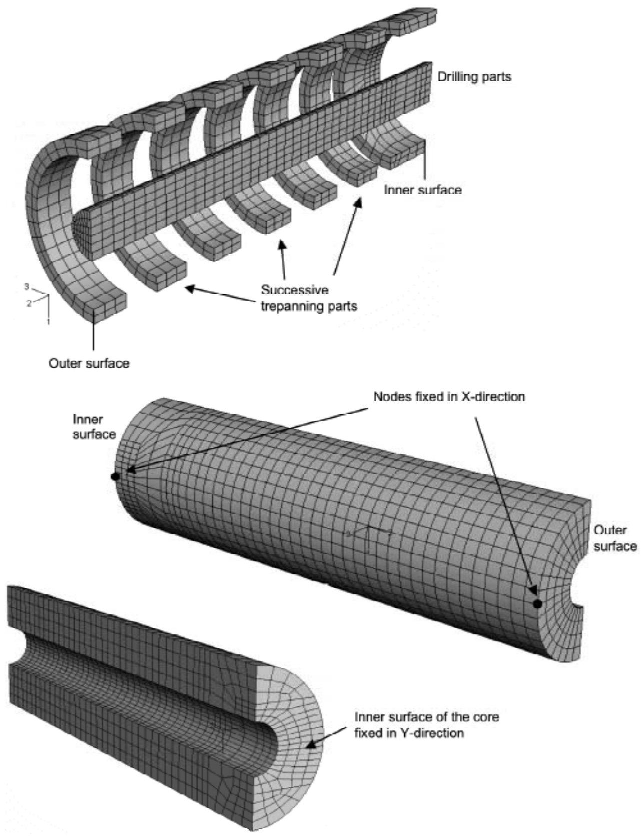

Fig. 2 Mesh illustrating the DHD drilling and trepanning sequence

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studies (all welded components) are considered where results of finite element predictions of weld residual stresses are mapped onto bespoke meshes and deep hole drilling simulations undertaken. These simulations permit the effects of several measurement parameters to be explored and optimised. Results are presented which demonstrate the significant experimental improvements obtained by utilising a combined measurement-simulation approach. This extended abstract describes two of the case studies, with more being considered in the presentation.

2. Case Study 1: 316H Stainless Steel Repair

A three dimensional (3D) finite element analysis (FEA) was carried out to investigate the influence of trepanning in the deep-hole drilling (DHD) residual stress measurement method on the initial residual stress present in a welded pipe containing a short repair, **Fig. 1**. Using a mapping procedure the initial residual stress and equivalent plastic strain fields from the repair weld simulation were mapped onto a 3D model with a mesh structure suitable to simulate the experimental deep hole drilling residual stress measurement technique, **Fig. 2**. Deep hole drilling measurements had been previously obtained.

The initial results obtained from the weld residual stress model and the DHD measurement simulation both utilised a mixed hardening material model. The direction of the DHD simulation through the thickness of the repair weld was from the outer surface towards the inner surface. This correctly mirrored the experimentally applied measurement direction.

The study showed, in general, a minimal effect of trepanning in the DHD measurement method on the redistribution of the original residual stress present in the component and verified the applicability of the method on this particular component. A degree of redistribution was, however, noticeable close to the outer surface of the component. In particular, the redistribution effect was more pronounced in the longitudinal residual stress component.

3. Case Study 2: 3-pass Slot Weld (NeT TG4)

The TG4 specimen is a 3-pass slot weld in AISI 316LN austenitic stainless steel, made using the tungsten-inert-gas (or TIG) welding process. The dimensions of the plate are 194 x 150 x 18 mm, while the slot is 80 mm long and 6 mm deep, and is filled with three superimposed weld passes. This specimen provides a natural increase in complexity over the NeT-TG1 specimen [1]: the weld is made with three passes rather than one, and the volume of weld metal is much greater, extending over about 1/3 of the depth of the plate. The overall specimen geometry is illustrated in **Fig. 3**.

In order to systematically study a suite of potential measurement options, with a view to improving accuracy and better understanding the influence of potential plasticity issues, the results of a finite element weld simulation [2] of the TG4 specimen were used as initial state conditions in a simulation of the measurement, **Fig. 4**.

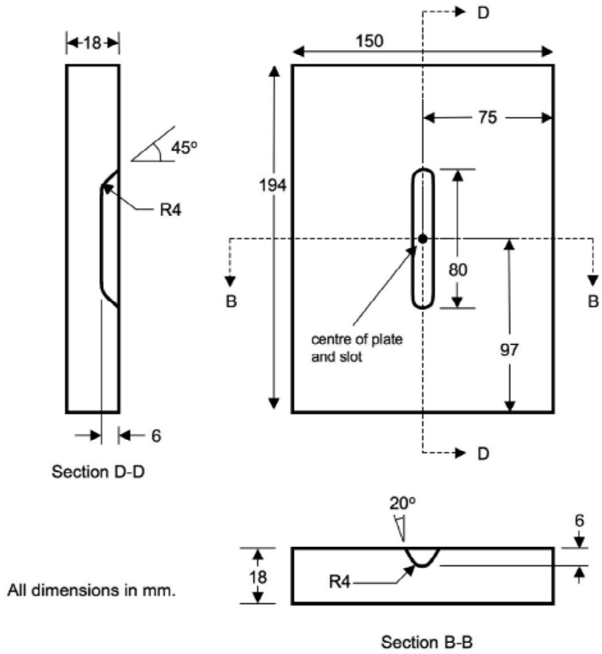

Fig. 3 General arrangement of NeT TG4 specimen

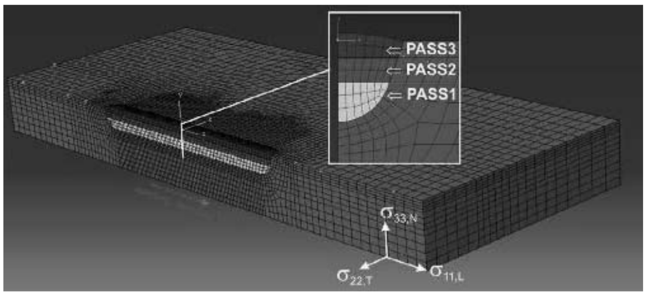

Fig. 4 Weld residual stress model results, used as initial state for measurement simulations

4. Conclusions

Deep hole simulations on the girth-butt welded component revealed that the deep-hole method worked well for practical components with some degree of redistribution effect in the reconstructed DHD simulated residual stress components close to the outer surface. The redistribution was more apparent in the case of longitudinal stress component. The study illustrated the influence of the DHD procedure on the initial residual stress distribution present in a component. The reconstructed residual stress distribution did not reveal the initial peak tensile residual stress near the outer surface of the butt-girth welded pipe component. Both the initial and the reconstructed residual stress distributions were sensitive to the material hardening behaviour.

Results of measurement simulations in the TG4 specimen, some of which are displayed in **Fig. 5**, highlighted the necessity of devising an optimized measurement strategy prior to experiment. The specimen contained very high magnitude residual stresses, a high degree of tri-axiality and substantial regions of plastically yielded material.

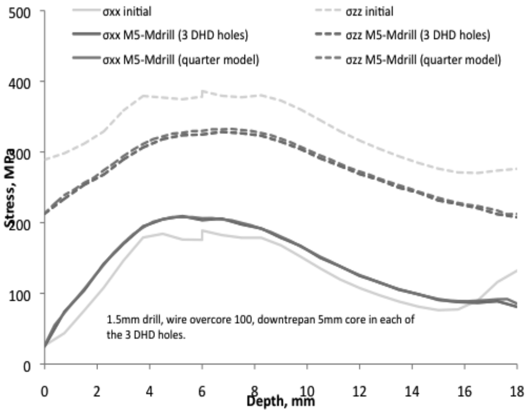

Fig.5 "Overcoring" results for DHD simulation in TG4 specimen

References

[1] C. E. Truman and M. C. Smith: Int. J. Pres. Ves. Pip., 86(1) (2009), pp 1-2

[2] O. Muránsky et al: ASME Pres. Ves. Pip. Conf. (2010), PVP2010-25