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# Effects of cutting and specimen size on neutron measurement of residual stresses

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**Abstract.** To perform neutron residual stress measurements it is often necessary to cut samples to a manageable size. The effects of cutting a girth welded pipe were investigated with analytical methods and finite element analysis. The effect of cutting on measured stresses was calculated. A simplified method of modelling residual stresses in welds, “chill modelling”, is introduced.

In ring slitting a cut is made in the axial direction and the deformation is measured. The change in elastic stress can be calculated and added to neutron diffraction measurements made on a cut ring to calculate the original stresses. Residual stress measurements were performed to validate the ring slitting correction using ANSTO’s residual stress diffractometer Kowari.

## 1. Introduction

Many samples need to be reduced in size before making neutron measurements. The effect of cutting on residual stresses is explored in this paper, the cutting and analysis is performed on a number of welds in pipes.

There are 2 types of macroscopic residual stresses acting on the girth weld, “self-equilibrating” and “bending” [1]. Typical “self-equilibrating” stresses are in the weld direction; these are equilibrated by lower compressive stresses across a large area of parent material. Bending stresses may be caused by a “tourniquet” of shrunk weld metal around the weld. Cutting and drilling changes the local stress field. These effects reduce with distance in accordance with Saint-Venant’s principle [2], a qualitative description of the observation that localised stresses do not extend beyond a certain distance from that area. This distance is considered to be a few “characteristic lengths” of the sample itself, a function not only of the plate thickness but also weld width.

Three cutting operations were analysed (figure 1):-“Length reduction” of the length of pipe containing the girth weld (cut 1). “Ring-slitting” cuts this ring axially, which may cause ring opening or ring closing (cut 2). “Coupon cutting” is making another axial cut to reduce the sample to a quarter segment approximately (cut 3).

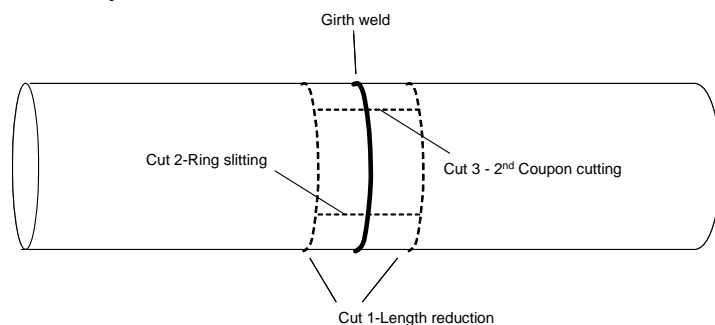


Figure 1 Length reduction to pipe containing a girth weld

Modelling was carried out by analytical and finite element methods at 3 common diameter to thickness ratios ( $D/t$ , where  $D$  is the diameter and  $t$  is the thickness) of 20, 40, and 100.

The sample size requirement may come from table size, slit configuration, weight considerations, or the size sample that be conveniently shipped.

## 2. Length Reduction

As the pipe length containing the weld is reduced, the tensile stresses along the girth weld will cause increasing inwards deflection at the weld. The deflection may be calculated [3] for a radial line loading at the cut end of the pipe (figure 2). The deflection is calculated at the cut end; it will be greater than a pipe where the load is in the centre, as rotation is possible in the cut end case. Using this conservative analytical approach, the deflections become constant (figure 2) where the length from the weld to the cut is greater than  $3.5\sqrt{Dt}$ . This is measured from the weld to the cut surface, and is doubled when cut either side of a weld.

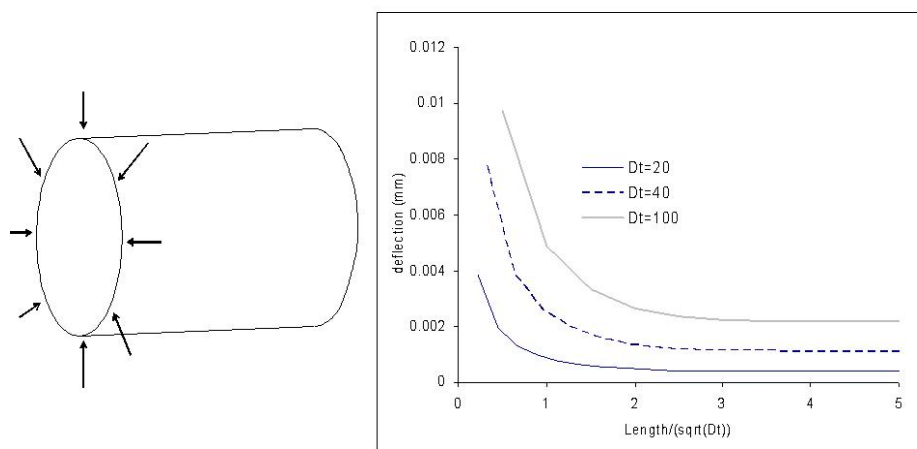


Figure 2 Pipe with line loading on free end and analytical results, from [2].

Rather than attempting full thermo-mechanical weld modelling, a complex procedure which is only now becoming feasible, a simplified method known as chill modelling is employed. Residual stresses were simulated with by cooling a weld section by  $500^{\circ}\text{C}$ , producing hoop stresses which were above yield. This procedure generates local-scale residual stress distributions typical, but not identical to, real welds but is considered representative of the global stresses and sufficient for this study. The stresses were normalised against the maximum tensile stress in each case (as each case had a different  $D/t$  ratio and slightly different weld profile, the maximum stresses are different), and against  $\sqrt{Dt}$ . It was assumed that the weld is in the centre. The maximum stress obtained is within 5% of the global stress value at lengths of  $> 3.5\sqrt{Dt}$  (figure 4).

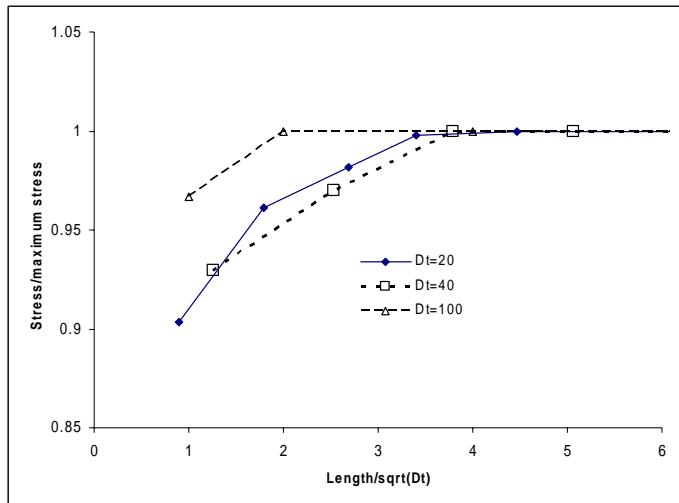


Figure 3 Normalized hoop stress vs. normalized distance from weld.

### 3 Ring Slitting

In ring slitting a cut is made in the axial direction and the change in circumference is measured and the elastic stress can be calculated and added to neutron diffraction results. The technique can only assess hoop stresses, and assumes that the hoop residual stresses are uniform in the ring. Ring openings of 35 mm or more have been seen in the field, and one case of a ring closing of 8mm has been characterised by neutron methods [4].

The bending stress is given by  $\sigma = Et (1/D_o - 1/D_f)$  where  $D_o$ ,  $D_f$  are the original and final mid-wall diameters,  $t$  is the wall thickness, and  $E$  is the Young's Modulus [5]. Results from the ring slitting and neutron methods give different information; the ring slitting method shows any imbalance in the total hoop direction bending moment, while neutron diffraction derived stresses are direct measurements in any direction at discrete locations.

### 4 Neutron residual stress measurements

Residual stress measurements were performed to validate the ring slitting correction detailed above using ANSTO's residual stress diffractometer Kowari [6]. Stresses in a ring of pipe were measured before and after slitting. Because the basic principles of this technique are well known [7, 8, 9] only details specific to this measurement will be reported. A monochromatic beam with  $\lambda = 1.666 \text{ \AA}$  and diffraction from Si{400} planes were used in this analysis. A nominal gauge volume of  $2 \times 2 \times 2 \text{ mm}^3$  was used to perform through-thickness scans at 5 depths. A section of the pipe was cut into a 6 mm thick plate to derive a d-zero values (the unstressed inter-atomic spacing). Stresses were calculated with this d-zero value.

### 5 Neutron measurement results

The neutron results for the ring before and after slitting are shown in figure 6, along with linear fits to the data. These fits provide a simple method of stress linearization, which is separating the membrane stress (intercept with the midpoint) and the bending stress (which is the slope times the distance from the centre). At the outer surface the bending stresses are -6.9 MPa for the original ring, and 27.4 MPa for the cut sample. Thus a stress change of -34.3 MPa occurs at the outer surface during cutting.

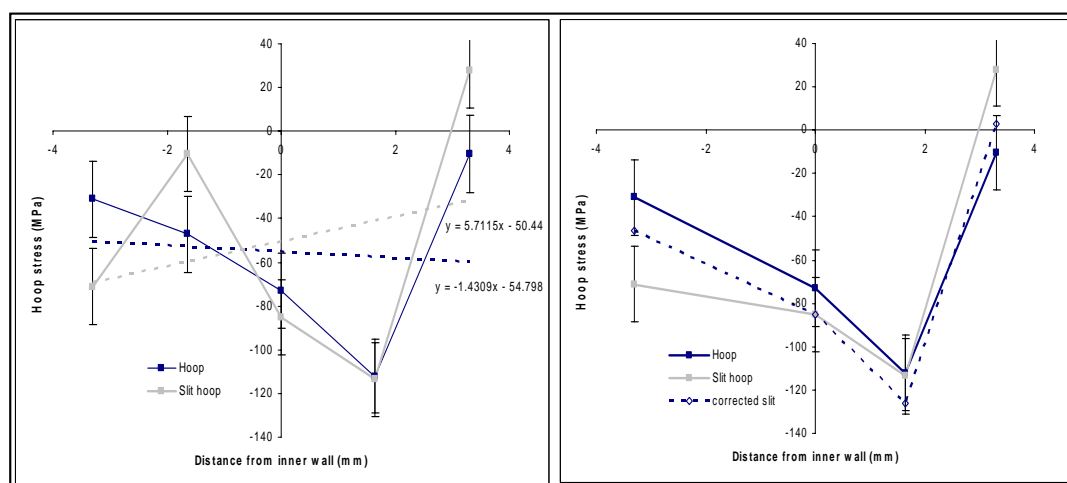


Figure 6a Original and cut residual stresses. Figure 6b Original, cut, and corrected residual stresses. For clarity, data at 3.15 mm has been removed error bars are only shown on original measurements, the cut and corrected error bars are similar in magnitude.

After slitting an average ring opening of 7.97 mm was measured, equivalent to a stress change of 23.4 MPa. The corrected stresses are shown in figure 6b. The calculated average stress change is less than that seen in the neutron results. The most likely reason for the difference is a localised region showing strong ring-closing behaviour, such as the seam weld. Another issue is the small magnitude of the bending stresses in this sample, approximately the same as the error bars in the neutron measurements. Cases of residual stresses calculated from ring opening have been seen of up to 200 MPa.

## 6 Conclusions

Analytical methods may exist to assess stress change on cutting for simple geometry and global stress distributions, more complex geometries and localised stress fields (such as welds) may require finite element methods. A method of calculating any stress relaxation that occurs during ring-slitting is described; these stresses can be added to neutron diffraction residual stress measurements made on a cut ring to calculate the stresses before cutting. This assumes that uniform stresses exist in the sample, a condition that is often not met.

“Bending” type residual stresses may show large changes on cutting, while the “self-equilibrating” residual stresses are often little affected on cutting (except at the cut face).

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