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SUB CRUCE LUMEN

Breakdown of Residual Stress in Highly Restrained Thick Section Steel Welds

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Abstract

Residual stress is the stress that remains stored within a structure as a result of its manufacturing history. Often called a locked in stress, it remains when there is no applied load, influences the applied load and changes the structure's expected response to stress. An example of this is that a tensile residual stress will add to an applied tensile load, increasing the maximum tensile stress. Conversely when a compressive load is applied, a tensile residual stress reduces the maximum compressive stress. Residual stress develops in a part during all stages of manufacturing through the action of plastic deformation and thermal inhomogeneities. The final residual stress within a structure can be a combination of the residual stresses created through these stages.

Processes that produce significant residual stress in steels include quenching and tempering, rolling, bending and welding. Due to the highly localised thermal input at the weld point, welding produces the largest short range variation in residual stress field. In the immediate region of a weld, the residual stress is dominated by the residual stress from the welding processes: tensile stress in the weld region, becoming compressive further from the weld. Prior residual stress fields can influence the expansion and contraction and thus the final welded residual stress profile.

Because residual stress acts on a scale that interacts with applied stresses, it becomes important to know what residual stress is present within a component in order to know the final load acting on the structure. In many situations it is not possible to determine the residual stress within a component directly and an approximation, or best practice, residual stress profile must be used. This can be simple, for example considering the residual stress produced by bending, but the residual stress profile produced in welding is a great deal more complex, depending on weld thickness, geometry, restraint, heat input and is difficult to accurately predict. It is important to have a highly accurate prediction of the residual stress when carrying out processes such as an Engineering Critical Assessment (ECA) since this will determine the integrity of a welded joint in its environment.

An ECA uses a combination of the applied stress and the residual stress profiles in order to determine the likelihood of growth of a flaw at a particular point in the structure. The residual stress profiles used to make these assessments are conservative and in the case of steel T-butt welds are based on a very narrow range of heat inputs and welding processes. The typical residual stress profile is assumed to be highly tensile which means that an ECA on any flaws in the weld region will indicate potential failure of the welded joint and repair is necessary.

One of the factors that may affect the conservatism of these residual stress profiles is the lack of consideration of the overall interaction of the residual stress fields prior to welding. This work experimentally measures the residual stress fields in thick steel plate before and after welding, in

both restrained and unrestrained plate, and uses this to consider whether the residual stresses are a result of welding or pre-welding processes and examines how these influence the final residual stress field. The work allows a new consideration of what residual stress fields around highly restrained, thick section welds are: creating a basis for pre-existing residual stress fields to be considered in conjunction with the welding residual stress in ECAs.

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Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Abbreviations and Symbols

ANSTO - Australian Nuclear Science and Technology Organisation

AINSE - Australian Institute of Nuclear Science and Engineering

FEA - Finite Element Analysis

HSLA - High Strength Low Alloy

ECA - Engineering Critical Assessment

MMA - Manual Metal Arc

SMAW - Shielded Metal Arc Welding

SAW - Submerged Arc Welding

TASS - The Australian Strain Scanner

TOF - Time of Flight

RS - Residual Stress

$\mu strain$ - microstrain (μm/μm)

σ - stress (MPa)

$\sigma_{y,w}$ - Yield strength of weld metal

$\sigma_{y,p}$ - Yield strength of parent metal

E - modulus of elasticity (GPa)

ε_i - strain in i direction (mm/mm)

r_a - outer measuring grid radius (mm), hole drilling

r_i - inner measuring gauge radius (mm), hole drilling

υ - Poisson's ratio

ε_{ps}=pseudo-strain

d - lattice spacing

d_{av} - average lattice spacing of an unstressed sample

θ_{av} - average Bragg diffraction angle of an unstressed sample

a- lattice parameter