The Effect of Welding on Brittle Fracture: A Statistical Investigation

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The fracture toughness of a weldment is a function of many complex geometrical, metallurgical and environmental factors. Variation in any of these factors causes scatter in fracture toughness data. This is true for variations both within individual welded structures and between welded structures that are otherwise similar \cite{1}.

In practice, these variations can be divided into 2 categories: material inhomogeneity from welding heat or chemical inputs \cite{2, 3} and inhomogeneity in locked-in, residual stresses caused by mechanical misfitting or material phase transformations \cite{4, 5}. Both categories have yet to be fully characterised because they are governed by a multitude of interconnected factors. These factors include: welding heat input, non-uniform cooling rates and pollution of the fusion zone during welding.

The aim of this research is to quantify the contribution of welding residual stress and microstructural embrittlement to the fracture toughness variation of a set of submerged arc weldments. To determine these relative contributions, the fracture toughness of several ferritic steel plate butt-weldments was measured as well as their welding residual stresses and microstructure.

Welding residual stress was mapped using the contour method at several locations in the transverse-perpendicular plane to the weld longitudinal direction. These data are shown in Figure 1. Spatial variation in microstructure in the weld longitudinal direction was evaluated by testing sub-standard sized Charpy impact fracture energy specimens. The data from these tests are shown in Figure 2.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure1.png}
\caption{Plot of welding residual stress distributions in plates 1-9 obtained using the contour method. Distributions measured along the mid-thickness of each plate. Stress components are in the non-through-thickness, transverse direction perpendicular to the weld longitudinal direction.}
\end{figure}

Figure 2 Plot of variation in relative embrittlement index, the ratio of each weld Charpy impact fracture energy measurement to the mean parent reference value (1.57 J), with a) position N = i, ii, iii through the thickness of the weld of plate sections 7A and 5A and b) position Y = 1, 2, 3, 4, 5, 6 along the weld longitudinal direction of plate sections 7A and 5A

Analysis suggests no correlations exist between Charpy impact fracture energy, welding residual stress or spatial position in the weld longitudinal direction. Further, Charpy impact fracture energy and welding residual stress are individually inadequate estimators of weld fracture toughness variability. Investigating the joint responsibility of either inhomogeneity using Principal Component Analysis (PCA) suggests that microstructural embrittlement (evaluated via Charpy impact fracture energy) accounts for the vast majority of the variability in weld fracture toughness data with the contribution from welding residual stress remaining non-negligible. Table 1 summarises the variance contributions from the principal axes derived during PCA analysis. Principal axes 1 and 2 are representative of the variability in microstructural embrittlement and welding residual stress, respectively.

<table>
<thead>
<tr>
<th>Principal Axis</th>
<th>Variance (-)</th>
<th>Proportion of total variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.168</td>
<td>88.16</td>
</tr>
<tr>
<td>2</td>
<td>0.023</td>
<td>11.84</td>
</tr>
</tbody>
</table>

Table 1 Summary of principal axis variances and their relative contribution to the total variance in the PCA-transformed Charpy impact fracture energy and welding residual stress data modelled

References


