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Finite element analysis of butt welded joints under cyclic loading

S. Dineshkumar[1], Prof. S. Bradeesh Moorthy[2]
[1, 2] *Engineering Design, Government College of Technology, GCT Coimbatore, Tamilnadu*

Abstract: *Modern technological processes make it possible to produce high strength steel with up to 1200 MPa yield strength. This high yield strength gives potential for considerable improvements in performance and reduction in weight, which are of increasing importance in the industrial field. However, data found in literature showed that welded structural parts using these high and ultra-high strength steels have a fatigue resistance not very different in comparison with those obtained in conventional steels with a much lower yield stress. In this work a fatigue study was performed in high strength steel in order to evaluate the influence on fatigue strength. The material used in this study was a steel sheet called EN-8 with 5mm of thickness. This is a high strength steel with a yield stress of 465 N/mm2 and a hardness of about 201-255 (Brinell). Butt welded specimens using TIG welding process were submitted to cyclic loading. Two welding conditions of transverse butt joints and base material were investigated in this fatigue study: as welded; welds overfill removed by grinding; The overfill removing by grinding promotes a significant improvement of the fatigue resistance in comparison with the as welded condition.*
Index Terms: *High strength steel, fatigue, welded joints.*

I. Introduction

In the mechanical field materials can be joined using many processes like riveting, bolted joints or by using permanent joining techniques like welding, soldering or brazing. The welded joints are often used for structural applications due to the reason that they provide nearly the same strength of the parent material. But researches show that even though they provide good strength in tension , they fail much quicker when subjected to fatigue loading. This may be due to various reasons like improper welding sequence, improper welding parameters or improper preparation of the joint materials. The fatigue life may also get reduced due to stress concentration developed during the welding process. Fatigue failures often results in catastrophic failures. Many accidents have been reported to have occurred due to fatigue failures which resulted in heavy loss of human life and property. Materials with even higher tensile strength are found to fail at less number of cycles after welding.

II. Analytical work

In this work the fatigue analysis of a double V butt jointed specimen is conducted in a virtual environment. The analysis is conducted using Ansys 14.5 software. The material used for the analysis is EN-8 steel. This is one of the steel which is used for structural work.
Chemical composistion of EN-8 steel

Material	C	Si	Mn	S	P
Composition %	0.36-0.44	0.10-0.40	0.60-1.00	0.050 maximum	0.05 maximum

Physical properties of EN-8 steel

Density	Youngs modulus	Poisson ratio	Melting point	Thermal conductivity	Thermal expansion coefficient
7850 Kg/m^3	2×10^{11}Pa	0.3	Appr 2500ºC	60.5 W/m/C	1.2×10^5 1/C

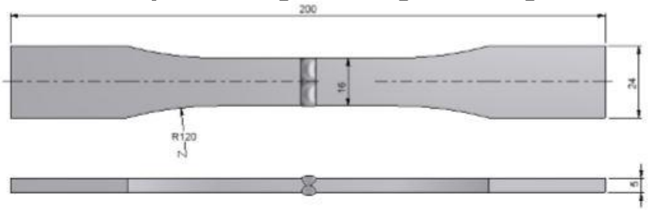
III. Modelling of the weld joint

The weld joint considered for analysis is a double V butt joint. The joints are modeled using Solid works modeling software. Then the model is imported in ANSYS14.5 software for analysis. . From the literature survey it is found that the fatigue life of the specimens tested with as welded conditions show a lesser fatigue life compared with those specimens whose over fill were removed by grinding. It is said that the removal of overfill reduced the stress concentration and thereby reducing the residual stresses. This reduced level of stress delayed the initiation of crack. This was said to be the reason for increase in the fatigue life of the specimens with over fill removed.

The analysis of as welded condition is conducted with two weld specimens one of 5mm thickness and 7mm thickness of the parent metal. The weldment is modeled using the modeling software and is imported to ANSYS 14.5 software. At first thermal analysis is done by giving a heat input which is equivalent to the heat generated by a TIG welding process.

The parameters used for giving heat input are selected from the recommended values of current and voltage for the particular thickness of weld. Then on the same specimen fatigue analysis is conducted by applying cyclic loading. The maximum stress is selected such that it is well within the yield value of the material to avoid plastic deformation. The same procedure is followed for material for thickness 5 mm and 7 mm. The results from the analysis are tabulated. Similarly analysis is done for specimens with 5 mm and 7 mm thickness whose overfill is removed. The results were also tabulated.

IV. Specimens Geometry For Fatigue Strength Testing With 5mm Thickness



The filler rod used is OK Autrod 13.13. It is usually welded Ar/CO_2 as the shielding gas. After stress relieving the mechanical properties decrease by about 30 MPa in the case of yield and tensile strength. A copper coated, low alloy Chromium-Nickel-Molybdenum with a minimum yield strength less than 610 MPa and a minimum tensile strength exceeding 710 MPa. Also suitable when welding steels where good impact strength at lower temperatures is required. After the welding the specimens were machined as shown in the above figure for fatigue testing. The repeated cyclic loading is given with force 10,000 N per cycle. From this the total deformation analysis and the fatigue strength improvement under two conditions i) As welded ii) Overfill removed has been analysed for 5mm and 7mm thickness plate.

V. Calculations

The calculations were made for giving an equivalent heat input of the welding process. The calculations are as follows

For 5mm thickness,
Current- 125A
Voltage- 70V
Tungsten size- 2.4mm
Filler rod size- 3.2mm
Travel speed- 12in/min = 307.2 mm/60 =5.12mm/s
Weld time= 4.68 secs
Weld length= 24 mm

Heat input is calculated by using the formula,

$$Q = \frac{\text{Current} \times \text{Voltage} \times 60}{1000 \times S(\text{Travel Speed})}$$

$$Q = \frac{125 \times 70 \times 60}{1000 \times 307.2}$$

$$Q = 1710 \text{ J/mm}$$

For 7mm thickness,
Current- 130A,
Voltage- 72 V
Tungsten size- 3.2 mm,
Filler rod size- 4.8 mm
Travel speed = 10in/min = 256mm/60 = 4.266mm/s
Weld time = 5.62 secs
Weld length= 24 mm

Heat input is calculated by using the formula,

$$Q = \frac{\text{Current} \times \text{Voltage} \times 60}{1000 \times S(\text{Travel speed})}$$

$$Q = \frac{130 \times 72 \times 60}{1000 \times 256}$$

Q = 2190 J/mm

The values thus calculated from the calculations are fed as the input parameters for the analysis of the specimens. The analysis were done and the results are tabulated.

VI. Results and Discussion

The results of the thermal analysis and structural analysis conducted on specimens are shown by the coloured graph.

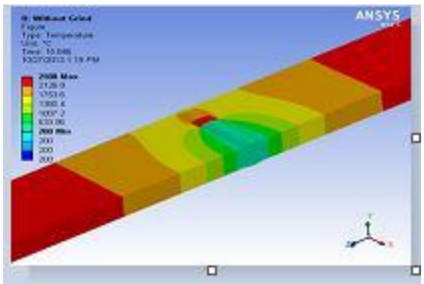


Fig 6.1 Thermal analysis of 7mm as welded specimen

The fig 6.1 shows the thermal analysis of 7mm as welded specimen. The results show a clear picture of the temperature distribution of the specimen.

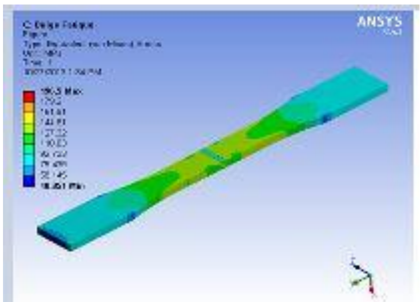


Fig 6.2 Equivalent von-mises stress analysis of 7mm as welded specimen The Von – mises stress analysis of the 7mm as welded specimen in Fig 5.2 shows the stress after the welding process.

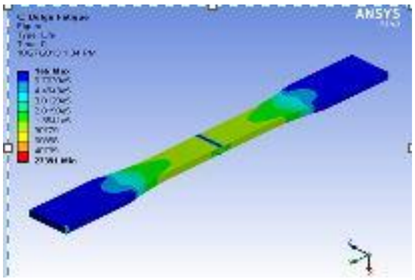


Fig 6.3 Fatigue analysis of as welded 7mm specimen

The fatigue analysis of the 7mm plate specimen is analysed for fatigue life and the result is shown in the figure 6. 3.

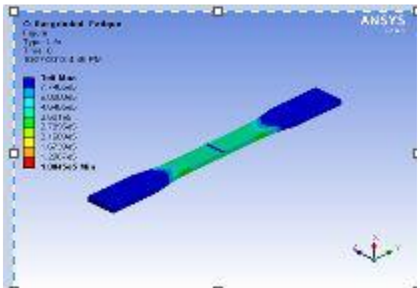


Fig 6.4 Fatigue analysis of overfill removed 7mm specimen

The Fig 6.4 shows the fatigue life of the 7mm specimen whose overfill is removed which shows a better life than the as welded specimen.

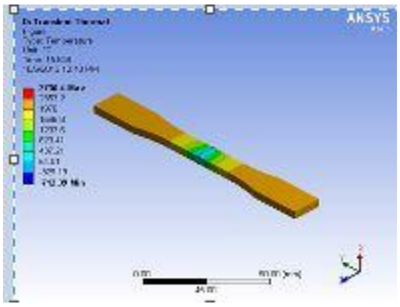


Fig 6.5 Thermal analysis of 5mm as welded specimen

The fig 6.5 shows the thermal analysis of 7mm as welded specimen. The results show a clear picture of the temperature distribution of the specimen.

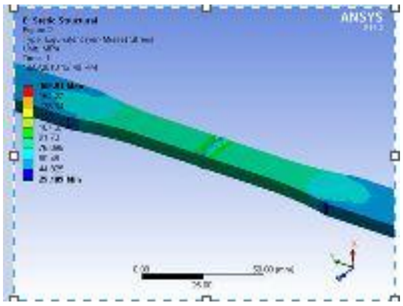


Fig 6.6 Equivalent von-mises stress analysis of 5mm as welded specimen

The Von – mises stress analysis of the 7mm as welded specimen in Fig 6.6 shows the stress after the welding process.

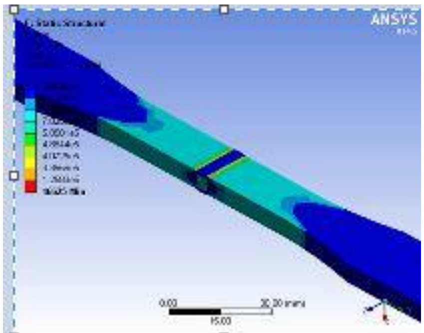


Fig 6.7 Fatigue analysis of as welded 5mm specimen

The fatigue analysis of the 7mm plate specimen is analysed for fatigue life and the result is shown in the figure 6.7

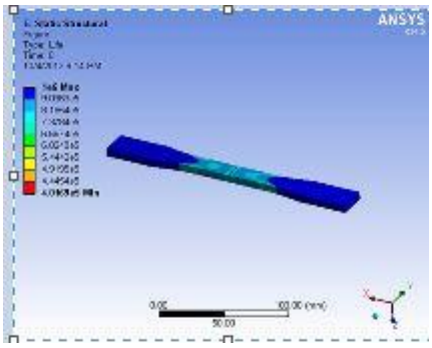


Fig 6.8 Fatigue analysis of overfill removed 5mm specimen

The Fig 6.8 shows the fatigue life of the 5mm specimen whose overfill is removed which shows a better life than the as welded specimen.

<table>
<tr><th>Plate thickness</th><th>Conditions</th><th>Von- mises stress(N/mm^2)</th><th>Fatigue Life</th><th>Stress in weld toe region</th></tr>
<tr><td rowspan="4">5mm</td><td rowspan="2">As welded</td><td>Max-169.91</td><td>Max-1×10^6</td><td rowspan="2">91.73</td></tr>
<tr><td>Min -28.189</td><td>Min- 46625</td></tr>
<tr><td rowspan="2">Over fill removed</td><td>Max- 101</td><td>Max- 1×10^6</td><td rowspan="2">76.998</td></tr>
<tr><td>Min– 29.003</td><td>Min- 4.016×10^5</td></tr>
<tr><td rowspan="4">7mm</td><td rowspan="2">As welded</td><td>Max-196.5</td><td>Max-1×106</td><td rowspan="2">92.733</td></tr>
<tr><td>Min-40.851</td><td>Min-27351</td></tr>
<tr><td rowspan="2">Over fill removed</td><td>Max-172.07</td><td>Max-1×106</td><td rowspan="2">84.916</td></tr>
<tr><td>Min-41.338</td><td>Min- 1.0045×105</td></tr>
</table>

The various results obtained from the thermal and the fatigue analysis of the welded specimens are tabulated in the Table 6.1

VII. Discussion of Results

From the table 6.1 the results suggest that in 5mm and 7mm plates the Von – mises stress and the stress at the weld toe is reduced when the overfill is removed. This caused an increase in the fatigue life of the specimen.

In the 5mm specimen the effect of over fill removing caused a decrease in the stress at the weld toe to about 16%. This reduction in the stress values caused the fatigue life to be increase about 7.61 times of the as welded specimen.

But in case of the 7mm specimen the effect of over fill removing caused a decrease in the stress at the weld toe to about 8%. This reduction in the stress values caused the fatigue life to be increase about 2.61 times of the as welded specimen.

From this results it is clear that overfill removed specimen has a better fatigue life due to the fact that the stress at the weld toe is reduced. This reduction in the stress level is much prominent in the lesser thickness specimen (5mm) than the higher thickness specimen in this case. This is may be due to the fact that lesser thickness material are more prone to stress concentration than the higher thickness material. This stress concentration is relieved by removing the over fill thus contributing to the increase in fatigue life.

VIII. Conclusion

Two welding conditions of transverse butt joints and the base material of a high strength steel were investigated in this fatigue study: 1) as welded 2) welds overfill removed. The analysis is conducted in a virtual environment using the analysis software ANSYS 14.5. The removal of the overfill from the weldment caused the fatigue life to improve. This improvement in fatigue life is more pronounced in the lesser thickness material.

From this virtual analysis of the welded specimens it is found that the overfill removal of the welded specimens will give good results to specimens with low thickness than that of higher thickness.

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