UTM Faculty of Mechanical Engineering UNIVERSITI TEKNOLOGI MALAYSIA THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 8, 2024, 9-14

PREDICTING THERMAL BEHAVIOUR OF WELDED Cr-Mo STEEL FLAT BAR: A SENSITIVITY ANALYSIS

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ABSTRACT

This research delves into the thermal behaviour of welded Cr-Mo flat steel bars by employing modelling techniques, with a particular focus on heat flux sensitivity. The TIG arc welding method (ASTM A304) was employed, utilizing a double-sided half V-groove welding process with a movable heat source. Various welding parameters, including material thickness, number of passes, electrode types, and electric current, were systematically adjusted during the welding process. Transient heat transfer profiles were generated and analyzed using Autodesk CFD 2018 software, integrating welding parameters as inputs. This software facilitated the development of 3-D model weld heat profiles, illustrating temperature distribution within the welded metal, extending from the welding point through the heat-affected zone to the parent metal. Heat intensity was visually represented through coloured gradients, with the welding zone depicted in red and the parent metal in light blue. A comparison between the modelled temperature fields and experimentally obtained values revealed close correspondence, albeit with slightly higher values in the model. This study highlights the reliability of predictive modelling of welding heat flux, underscoring its significance in optimizing the welding process for Cr-Mo flat steel bars.

KEYWORD

Thermal behaviour, welded Cr-Mo flat steel bars, sensitivity analysis, TIG arc welding method, heat flux modelling

INTRODUCTION

Welding processes stand as pivotal techniques in the fabrication industry, crucial for joining various materials to create sturdy and reliable structures. Among these materials, Chromium-Molybdenum (Cr-Mo) steel emerges as a prominent choice due to its exceptional mechanical properties and corrosion resistance, particularly under high-temperature conditions. Understanding the thermal behaviour of welded Cr-Mo flat steel bars is imperative for ensuring the integrity and performance of welded components in diverse applications (Adewuyi *et al.*, 2023).

This study delves into the intricate thermal dynamics governing the welding of Cr-Mo flat steel bars, with a specific emphasis on elucidating the sensitivity of heat flux. Employing advanced modelling techniques, the research scrutinizes the multifaceted interplay between welding parameters and heat transfer phenomena. Central to this investigation is the application of the TIG (Tungsten Inert Gas) arc welding method, conforming to ASTM A304 standards, which offers precision and versatility in welding operations.

Utilizing a double-sided half V-groove welding process with a mobile heat source further enriches the complexity of heat transfer dynamics, necessitating a comprehensive exploration of heat flux sensitivity (Trupiano *et al.*, 2022). Various welding parameters, including material thickness, number of passes, electrode types, and electric current, are systematically varied to discern their impact on thermal behaviour during welding operations.

To facilitate the analysis, transient heat transfer profiles are generated using Autodesk CFD 2018 software. This computational tool integrates welding parameters as inputs, enabling the development of detailed 3-D model weld heat profiles. These profiles vividly illustrate the temperature distribution within the welded metal, encompassing the welding point, the heat-affected zone, and extending to the parent metal. The visualization of temperature gradients, with the welding zone depicted in vibrant red hues and the parent metal in contrasting light blue shades, offers valuable insights into heat distribution patterns.

Crucially, the reliability of predictive modelling of welding heat flux is validated through a comparison between modelled temperature fields and experimentally obtained values. Despite minor discrepancies, this study underscores the efficacy of predictive modelling in anticipating welding heat flux, thereby optimizing the welding process for Cr-Mo flat steel bars.

In essence, this research contributes to advancing the understanding of thermal behaviour in welded Cr-Mo steel flat bars, offering valuable insights into heat flux sensitivity and its implications for welding processes (Reda *et al.,* 2022). By leveraging advanced modelling techniques, the study aims to enhance the precision and efficiency of welding operations, ensuring the robustness and reliability of welded structures in diverse industrial applications.

MATERIALS AND METHODOLOGY

The study utilized Cr-Mo steel flat bars of varying thicknesses (5mm, 10mm, and 15mm), which were welded via a double-sided half V-groove joint using Tungsten Inert Gas (TIG) welding. Each pair of materials was machined to dimensions of 100mm by 50mm, resulting in a total of 18 samples. Before welding, a 6.00mm hole was drilled and tapped near the weld centreline of each pair to attach a K-type thermocouple with a 20000C capacity. This thermocouple was connected to a data logger equipped with type K thermocouples (3 channel – LU-MTM-380SD) to measure temperature distribution between the base metal and welded bead, which varied with time during welding operations (Adewuyi *et al.,* 2023). The arc welding temperature (1350 - 1450°C) was measured using a Digital Infrared Thermometer. Welding was performed at currents of 90A, 100A, and 150A, with a constant voltage of 24V and a welding rate of

(a) (b)

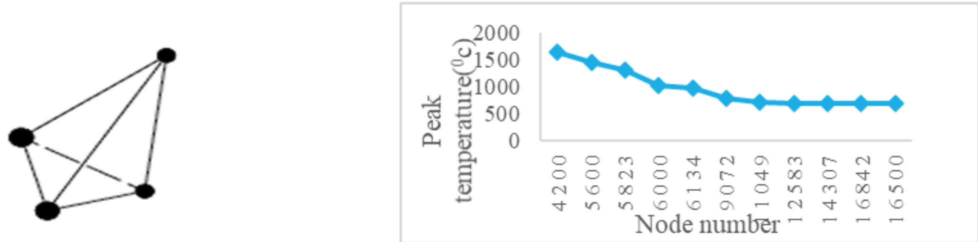
Figure 1: (a) Weld samples and (b) Experimental setup with data logger.

FINITE ELEMENT MODELING

The transient state of the TIG weldment was modelled using numerical and analytical methods. A Double-Sided Half V-Groove weld joint was simulated, with dimensions of 50mm by 100mm and thicknesses of 5mm, 10mm, and 15mm. The welding procedure was modelled as a single pass on both sides of the bar. Finite Element (FE) modelling of the TIG welding process was conducted in two steps using Autodesk Inventor 2018 and Autodesk CFD 2018 for physical and thermal analyses, respectively. Nodal discretization and Grid Independence test of nodes on peak temperature were adopted for validation as presented in Figure 2. Non-uniform volumetric temperature distribution during the weld thermal cycle was considered, leading to welding-induced thermal stresses and distortion of grains, critical in welded joint and structure design. Goldak's double ellipsoidal heat source model with transient temperature distribution was used (Antonino *et al.,* 2018). Assumptions and boundary conditions included transient heat transfer, a voltage of 24V, a weld length of 100mm, and a welding time of 370s. Nodes and elements underwent grid independence tests, resulting in meshes with 13,549 nodes and 6,989 elements (5mm thick), 14,565 nodes and 7,537 elements (10mm thick), and 16,254 nodes and 9,946 elements

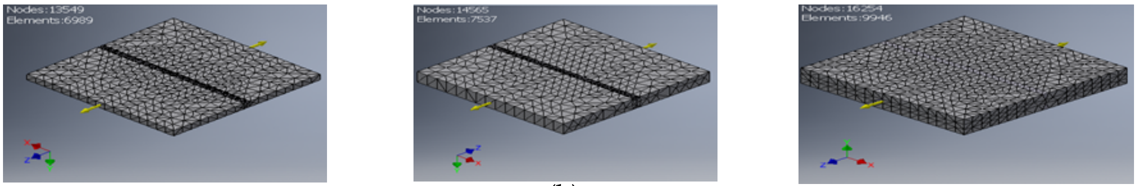
(15mm thick) see Figure 3(a-c). Degrees of freedom at each node included temperature (T) for thermal analysis and displacements (Ux, Uy, Uz) for structural analysis.

The analysis at each node had four degrees of freedom, including thermal expansion effects. This comprehensive approach aimed to optimize the design and performance of welded joints and structures. The analysis at each node has four degrees of freedom - Ux, Uy, Uz, and T (due to thermal expansion effects).



(a) (b)

Figure 2: (a) 3-D Solid element, Tetrahedral with four sides and (b) Grid Independence Test



(a) (b) (c)

Figure 3: Geometry and mesh distribution in a 3D model for (a) 5 mm, (b) 10 mm and (c) 15 mm thick steel flat bars.

RESULT AND DISCUSSION

The effect of weld heat input on welded metal was modelled with a coupled temperature-displacement analysis, each node in the weld model has three degrees of freedom Ux, Uy, Uz, and T (due to thermal expansion effects) in three planes (YZ, XZ, and XY). Thermal model (temperature fields) on Cr-Mo steel using Autodesk (CFD) 2018 revealed how temperature fields change over the length of the welded specimen. The reddish area of the weld zone changed towards the bar's edges. This colour change was used to investigate thermal stresses that occurred within the grains that led to failure. The thermal simulation of the heat-affected zone and weld pool on Cr-Mo steel bar showing the three planes (YZ, XZ, XY) aids in understanding how differential heating and cooling in different zones of a weld joint cause non-uniform volumetric changes, which lead to residual stresses. This type of data was useful for the determination of thermal stresses which normally lead to failure in machine parts. Figure 4 presents the model result of weld heat input.

Thermal analysis of weld metal

The temperature profile of the xz-plane heat-affected zone away from the weld zone differs significantly from the bar's edges. Figure 4 shows non-uniform temperature distribution within the weldment away from the weld zone which altered the mechanical properties of the weldment leading to failure while in service.

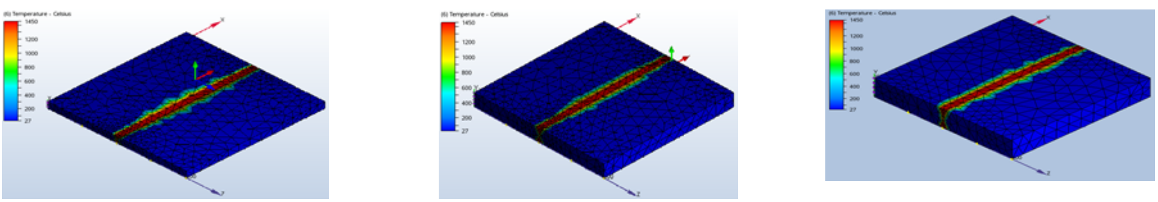


Figure 4: 3-D Model generated for 5 mm, 10 mm and 15 mm thick Steel flat bars

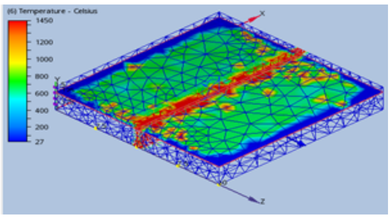


Figure 5: Effect of weld heat input on HAZ across the welded XZ-Plane along Y axis 3 mm depth.

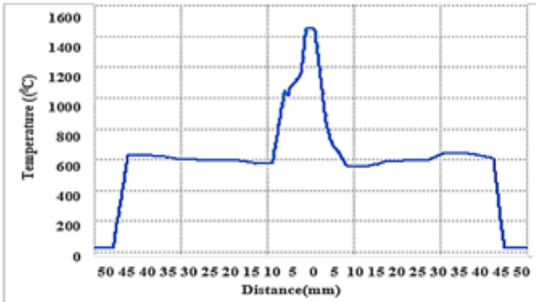


Figure 6: Temperature field against distances away from weld zone 3 mm depth.

Figures 5 and 7 illustrate non-uniform volumetric changes in temperature at 3 mm depth caused by cracks or slide lines, a material behaviour that causes the temperature to rise at some nodes/elements that form the mesh.

Tracing the nodes/elements that form the mesh on XZ-Plane across the weld zone revealed non-uniform volumetric changes in the temperature profile presented in Figures 6 and 8. There is a decrease in temperature as it moves away from the weld zone

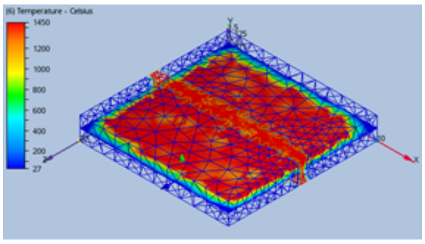


Figure 7: Effect of weld heat input on weldment XZ-Plane align to Y axis at 7 mm depth.

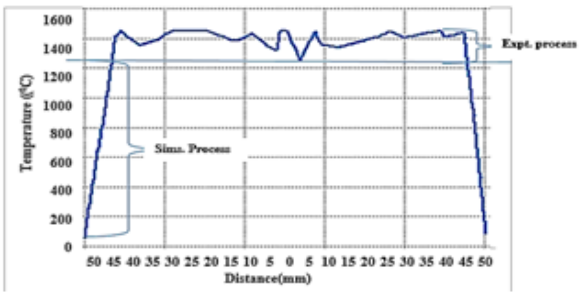


Figure 8: Temperature field against distances away from weld zone 7.5 mm depth.

Effects of electrode diameters and weld passes on heat flux

Figure 9 shows the effect of electrode diameter on Heat flux generated in the welded metal**.** The heat flux distribution obtained gradually decreases with an increase in metal thickness and electrode diameter. Figure 10 shows the effect of weld passes on Heat flux generated in the welded metal**.** The heat flux distribution obtained gradually decreases with an increase in metal thickness and the number of weld passes

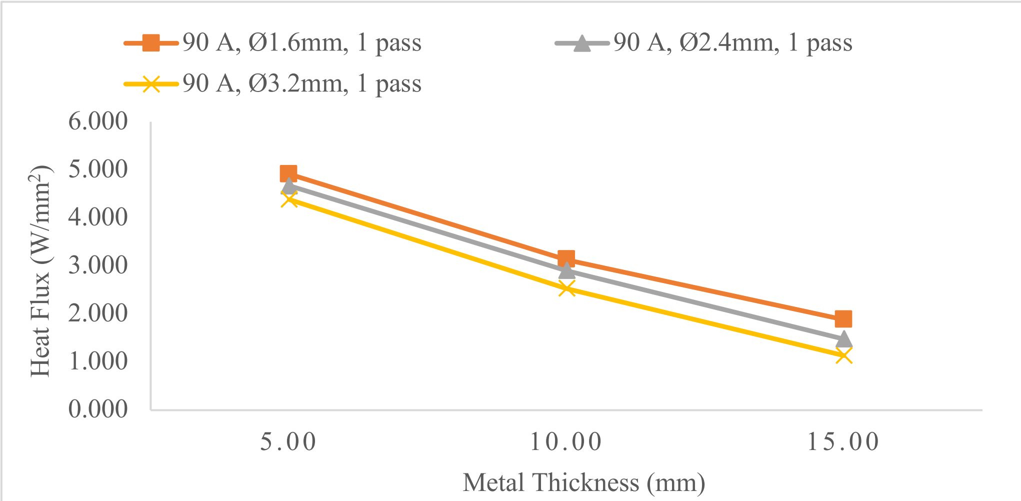


Figure 9: Effect of Electrode diameter on Heat flux.

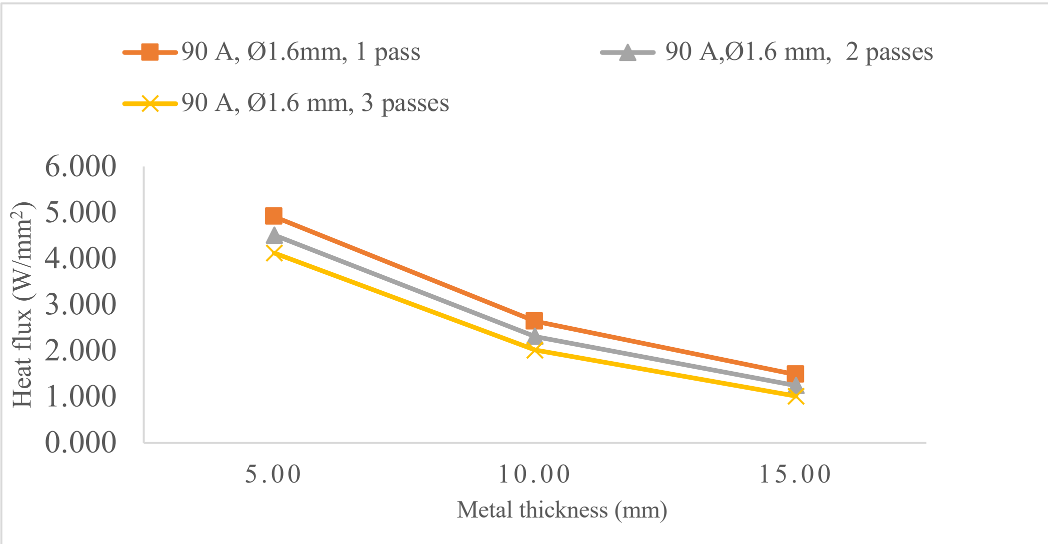


Figure 10: Effect of weld pass on Heat flux.

CONCLUSION

The material thickness has a great influence on the Heat flux generated in weld metal. An increase in the value of this parameter leads to a decrease in heat flux generated between 12.07 to 20.14%. The thickness of the material significantly impacts heat flux in weld metal. This phenomenon arises from thicker materials' greater heat absorption and dissipation capacity, altering welding parameters and emphasizing the need for process adjustments across varying material thicknesses.

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