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ORIGINAL PAPER

Failure assessment of armour grade tensile weld specimen: experimental, computational and analytical approach

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Abstract

Armour grade steel is high strength steel and it is used to build structures in defence applications. The weld zone of the armour weldment has lower tensile strength and deformation fracture in combat vehicles. In this study, experimental, computational, and analytical approaches are used to measure the failure assessment of tensile weld specimens. Tensile weld specimens are tested at strain rates of 0.1, 0.5, and 1 m/s and joint efficiencies of 56.2%, 61.2%, and 66.3%. Microstructures can be used to find a weld zone with different zones and ductile cracks in the fusion zone of tensile specimens. The computational approach of the Johnson Cook material model and the damaged material model is examined to assess the failure in the tensile test specimens with the help of different strain rates and temperatures. The analytical approach is used to calculate the stress, strain, and displacement values using safety applicable factors concerning tensile failure for armour grade steel, filler metal, and weld metal. According to MIL-STD-1185 standard, the different strain rates of tensile strength have been accepted within the range. The computational and analytical results are excellent methods for predicting tensile failure in armour weldments.

Keywords Weld joints · Tensile failure · Johnson cook · Simulation · Factor of safety

Abbreviations

C.E	Carbon equivalent
Q	Quenched
T	Tempered
W	Width
HAZ	Heat affected zone
OM	Optical microstructure
SEM	Scanning Electron Microscopy
FOS	Factor of safety
JC	Johnson cook
HIC	Hydrogen induced cracking
ASS	Austenetic stainless steel
HSLA	High strength low alloy
AISI	American iron and steel institute
ASTM	American Society for Testing and Materials
HIC	Hydroen induced cracking
FEA	Finite element analysis
SD	Standard deviation
CSD	Coefficient of standard deviation

List of symbols

ρ	Mass density
G	Shear modulus
E	Youngs modulus
v	Poisson ratio
K	Thermal conductivity
Cp	Specific heat capacity
α	Thermal expansion
A	Yield stress of the material
B	Strain hardening constant
ε	True strain

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n	Strain hardening coefficient
$\dot{\varepsilon}^*$	Strain rate
C	Strengthening coefficient of strain rate
T*	Homologous temperature
m	Thermal softening coefficient
T	Constant room temperature
εf	Equivalent failure strain
σ_m	Mean stress
σ_equ	Equivalent strain
σ^*	Triaxiality factor
σ_1, σ_2, σ_3	Triaxial stresses
I_1, I_2, I_3	Invariants
σ_x, σ_y, σ_z	Plane stresses
τ_{xy}, τ_{yz}, τ_{zx}	Shear plane stresses
$\dot{\varepsilon}_p^*$	Strain rate ratio
$\dot{\varepsilon}_p$	Plastic strain rate at different tensile tests
$\dot{\varepsilon}_0$	Reference strain rate
$\mathrm{T_r}$	Reference temperature
$\mathrm{T_m}$	Melting temperature

1 Introduction

The chemical composition of alloying elements, casting, and Quenched (Q) and Tempered (T) heat treatments transform ordinary grade metal into armour grade metal (Lenihan et al. 2019). Armour steels are used to resist projectiles from enemies in the combat environment (Pawlowski and Fras 2017). In recent years, high strength steel armour grade steel has beenused in defence vehicles and it has higher mechanical properties, namely tensile, toughness, and hardness properties. The fabrication process of Shield Metal Arc Welding (SMAW) is easy to handle inany combat zone, and Austenitic Stainless Steel (ASS) filler material is used to join the armour vehicle structures (Balaguru et al. 2021). Armour steels have higher carbon equivalent values, which is difficult to maintain a suitable heat input in the welding environment. This armour weldment is capable of producing a maximum Heat Affected Zone (HAZ) width and inducing a hydrogen-induced crack (Saxena et al. 2018; Grujicic et al. 2013; Saxena et al. 2020c). A low heat input by using welding parameters reduces the width of the HAZ in the weld joint, at which the strength of the weld zone is not equal to the armour steel strength. Reducing the width of the HAZ in the weld zone is a good solution to enhance the strength and ductility, but base material strength has a higher level as compared to the weld zone. A low heat input is increasing the cooling rate and enhance the ductility of the weld zone (Crouch et al. 2017; Singh et al. 2016; Cabrillo and Geric 2016).

The ASS filler material is commonly used for defence vehicles due to its sufficient mechanical properties in the weld joints. These mechanical properties of filler material in the weld zone are decreased due to weld thermal cycles (Krishna Murthy et al. 2014). Lower properties of the ASS filler material are recommended for arresting the hydrogen-induced cracking and joining armour plates in the weld zone (Suryo et al. 2021; Balaguru et al. 2020; Cabrillo and Geric 2018). Suitable welding parameters and groove design produce defect-free welds with ASS filler material that can enhance the tensile strength of the weld joint (Robledo et al. 2011). The ASS filler has good ductile properties in the armour weld joint. This filler determines the ballistic performance than tensile and hardness properties (Kumar et al. 2022; Naveen Kumar et al. 2022; Serrano et al. 2022). In the armour weldment, the tensile fracture is induced in the fusion zone at lower deformation and load carrying capacity. The different tensile strengths between the fusion zone and base metal (armour grade material) aredirectly related to the metallurgical limitation. These changes are obtained by chemical and microstructural changes in the filler material with thermal cycles involved in the welding environment (Banerjee et al. 2015; Saxena et al. 2020b; Wuertemberger and Palazotto 2016).

The structural weldments in the defence vehicle fail under ballistic impacts due to structural cracks formed under dynamic load conditions. These welding components are designed for higher strain rates, based on dynamic fracture tensile properties (Murugesan and Jung 2019). The computational (analytical) approach of the Johnson Cook (JC) material model and damage material model help predict the dynamic tensile fracture under dynamic load and different temperature conditions (Mehditabar et al. 2020; García-Castillo et al. 2020; Raj 2013). This method aids in the evaluation of real-time tensile failure in armour weldments, and failure causes are validated using metallurgical microstructure (Neuvonen et al. 2020; Vijaya Krishna Varma et al. 2020; Neuvonen et al. 2021). The applicable tensile strength of the armoured vehicle is measured using the factor of safety (FOS) and an analytical approach, and experimental tensile results are used to validate the results. This research is carried out with a static tensile fracture at different strain rates, fracture microstructure, and the influence of FOS on tensile failure are investigated in the armour grade materials.

In this study, a tensile test was carried out by different strain rates with 16 mm thickness of armour weldment. The weldment microstructure and metallurgical tensile fracture were investigated. In addition, the static tensile fracture was evaluated using the analytical approach of the JC material model and the damage material models. Further, the tensile failure in armour grade steel, filler metal, and weld metal was analysed by an applicable safety factor using an analytical method. The thermo-mechanical parameters and experimental tensile results were applied as inputs to the computational and analytical approaches, respectively.