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Finite element analysis of metallurgical phase transformations in AA 6056-T4 and their effects upon the residual stress and distortion states of a laser welded T-joint

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ABSTRACT

Aircraft industry makes extensive use of aluminium alloy AA 6056-T4 in the fabrication of fuselage panels using laser beam welding technique. Since high temperatures are involved in the manufacturing process, the precipitation/dissolution occurrences are expected as solid state phase transformations. These transformations are likely to affect the residual distortion and stress states of the component. The present work investigates the effect of metallurgical phase transformations upon the residual stresses and distortions induced by laser beam welding in a T-joint configuration using the finite element method. Two separate models were studied using different finite element codes, where the first one describes a thermo-mechanical analysis using Abaqus; while the second one discusses a thermo-metallo-mechanical analysis using Sysweld. A comparative analysis of experimentally validated finite element models has been performed and the residual stress states with and without the metallurgical phase transformations are predicted. The results show that the inclusion of phase transformations has a negligible effect on predicted distortions, which are in agreement with the experimental data, but an effect on predicted residual stresses, although the experimentally measured residual stresses are not available to support the analyses.

1. Introduction

Finite element (FE) analysis of welded structures has been a major concern of aerospace industry in recent years, mainly due to its potential to simulate the residual stress and distortion states. The present work addresses an industrial manufacturing process of an aircraft structure, where the fuselage panels made of an aluminium alloy AA 6056-T4 (Table 1) are joined with the stiffeners of the same material using laser beam welding (LBW) technique in a T-joint configuration. The emphasis is given to the FE simulation of LBW induced residual stresses and distortions taking care of the metallurgical phase transformations. It is believed that the knowledge of predicted stress state could help exercise better control over the untoward consequences of welding process like distorted shapes, assembly mismatch, buckling, stress concentration sites etc.

Numerical simulation of aluminium alloy welded structures has been the subject of various works produced recently. For instance, Josserand [1] studied LBW induced distortions using a commercial FE code Sysweld for an aeronautic aluminium alloy while working on thin test plates. Similarly, Darcourt [2] performed a thermo-mechanical simulation to predict LBW induced distortions in AA 6056-T4. She suggested that a correct thermal analysis is mandatory for a robust mechanical analysis. In a previous publication [3] of the related work, attempts were made to predict residual stress and distortion states in the test plates of AA 6056-T4 using the industrial boundary conditions. Other published works [4–8] focus upon factors affecting residual distortion in stiffened panels like loading and boundary conditions, geometry of the specimen, welding process parameters etc.

Metallurgical aspects have also been studied by some researchers. Gallais et al. [9], for example, studied the microstructural evolution in AA 6056 after friction stir welding from two initial conditions (T4 and T78) and suggested a physically based model for precipitation and hardening to account for the precipitation of quaternary (Q) phase and the existence of multiple nucleation sites. Olea et al. [10] performed sub-structural analysis of friction stir welded joints in AA 6056 alloy for T4 and T6 temper states and examined the evolution of microstructure in the weld zone. Cicala et al. [11] focussed upon hot cracking in laser beam welded butt

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