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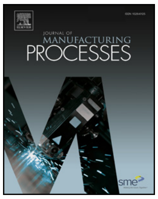

Advanced numerical modelling of friction stir welded low alloy steel

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ABSTRACT

The development of advanced joining processes such as friction stir welding (FSW) is necessary to maintain manufacturing competitiveness in any industrial nation. Substantial research that has been carried out on FSW of aluminium alloys has demonstrated considerable benefits; this has led to greater interest in FSW of steel and other high melting temperature alloys. In this context, numerical modelling can provide cost-effective development of steel FSW. Due to the limitations associated with the Johnson Cook model when employed in high melting temperature metals, a three-dimensional thermo-mechanical simulation of FSW featuring low alloy steel with previously generated experimental temperature dependant properties has been successfully solved in Abaqus/Explicit. Unlike any previous research in which either the workpiece is assumed as a high viscous body or the tool is modelled as a moving heating source, the Coupled Eulerian Lagrangian approach has been innovatively applied to model the FSW process on steel. All stages of FSW (plunge, dwell and traverse) have been modelled for slow and fast process parameters and their results compared with previous experimental work on the same grade of steel. In each model, the weld shape and weld surface flash were found to be in exceptionally close alignment with previous experimental results.

1. Introduction

Friction stir welding (FSW) is considered to be a remarkable advancement in material joining in the previous years [1]. It is a solid state joining process that plasticises the material during welding. Heat is generated by the plastic deformation and the frictional contact between the tool and the workpiece, which in turns, softens the material around the tool [2]. Several studies show that significant reduction in porosity [3], cracking [1], distortion and reinforcement dissolution [4] can be achieved with the FSW process. It provides exceptional surface finish, low maintenance and energy costs along with enhanced fatigue strength of welded components compared to other welding techniques like electric or gas arc welding [5].

To date, FSW has been successfully applied for the welding of aluminium and other low melting point alloys [3]. There has been recent research carried out on FSW of steel and high strength alloys [6,7]. The factors affecting the quality of friction stir welds are normally rotational and traverse speed of the tool, plunging force of the tool on the workpiece, and the angle of the contact between the tool and workpiece [8]. FSW process parameters such as tool rotational and traverse speed greatly influence the heat input, cooling rate and the quality of the welds produced [9]. The main issues behind the particularly limited application of FSW of steel are the short life and high cost of FSW tools [10]. The design of the FSW tool is primarily influenced by material selection, geometry and production cost. The tool technology for welding steel is comparatively underdeveloped and more research needs to be conducted to ensure that the whole welding process becomes entirely independent from the tool's life [11]. Polycrystalline boron nitride (pcBN) is mainly being used as the tool material for steel welding with the maximum welding length as 40 m per tool [12]. The pcBN material is considered expensive and has also been shown to exhibit cracks and significant wear, both of which are detrimental to the weld characteristics [3].

Numerical simulation is a cost-effective means of investigating and predicting different physical phenomena during FSW [13]. From a modelling perspective, it is important to capture the numerical results of the process as close to the experimentally generated data as possible such as the temperature gradient, surface features and material flow in the workpiece. This allows an evaluation of the diverse process parameters, for instance tool geometry and process parameters [8].

Numerous researchers [13–21] have considered various types of FSW numerical models. Simulation techniques in the literature mainly assume either the rotating tool as a moving heating source or the workpiece as a viscous fluid body. Camilleri et al. [14] developed a FSW numerical model for DH36 workpiece by replacing the solid tool with a heat source. They calculated thermal stresses in the workpiece and found that fast welding conditions result in lower peak temperatures [14]. A computational fluid dynamic (CFD) model was developed by Al-

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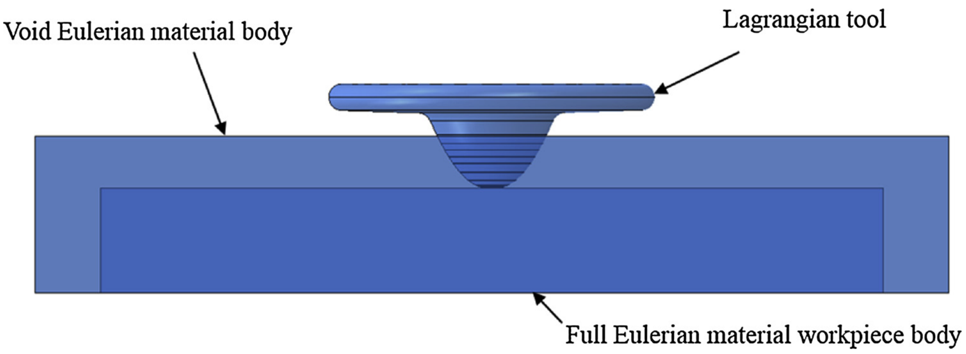

Fig. 1. Illustration of the CEL approach with material assignment.

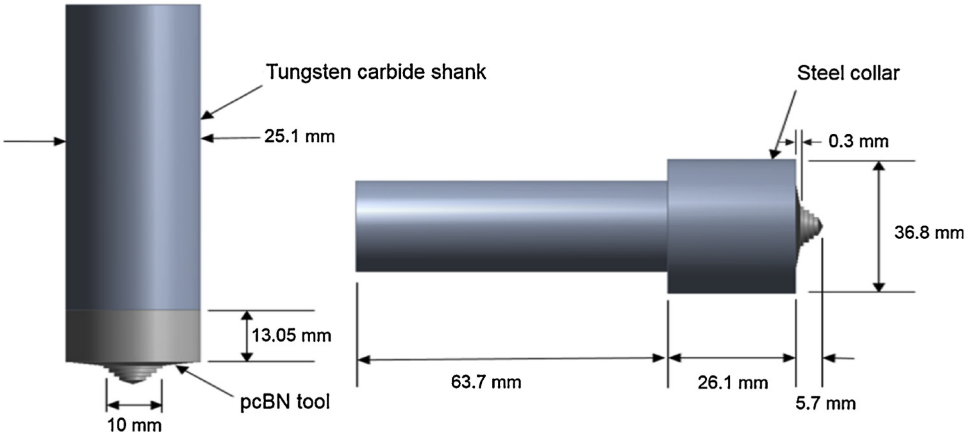

Fig. 2. FSW tool geometrical dimensions [6,31].

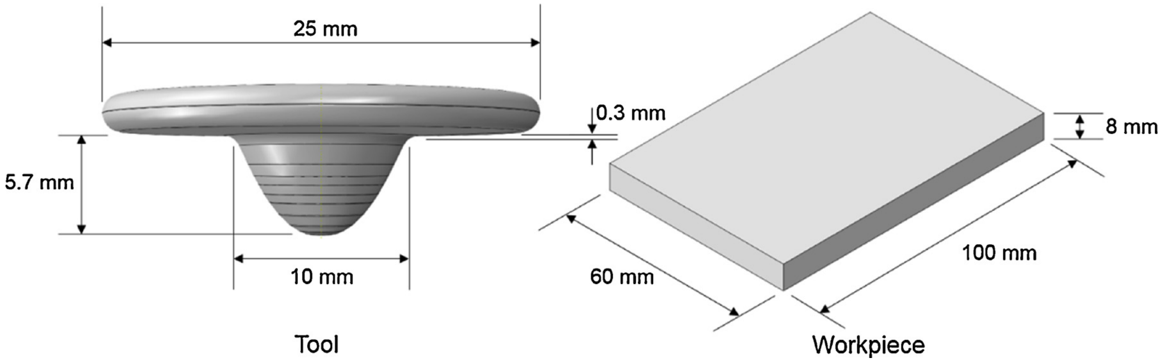

Fig. 3. Simplified tool and workpiece geometrical dimensions.

Table 1
Percentage chemical composition of DH36 with respect to weight.

C	Mn	Si	P	S	Al	Nb	N
0.11	1.48	0.37	0.014	0.004	0.02	0.02	0.002

Moussawi et al. [18], where the material flow in the workpiece was analysed by considering the solid workpiece as a highly viscous fluid body. It was concluded that for the slow welding conditions, the maximum temperature lied under the tool shoulder whereas for fast welding conditions, it existed in the shear layer just out the tool shoulder periphery [18]. In addition, the minimum temperature was located in the probe end, and the cooling rate was increased by increasing the traversing speed [18]. To make a fully developed model with realistic boundary conditions, the Arbitrary Lagrangian Eulerian (ALE) approach has been used, in which the viscoplastic flow and the

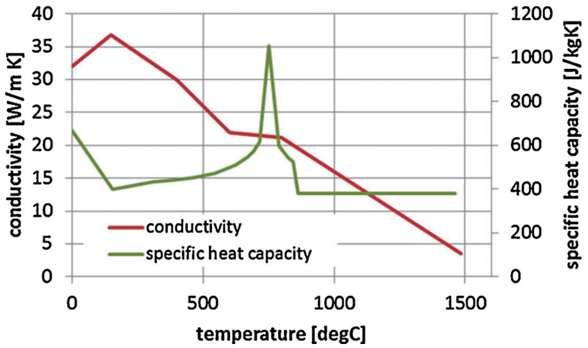

Fig. 4. Temperature dependent thermal conductivity and specific heat capacity of DH36 steel [28].