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Development of a finite element simulation framework for the prediction of residual stresses in large welded structures

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ABSTRACT

In this study a framework for efficient prediction of residual stresses in large welded structure is proposed. For this purpose different finite element simulation approaches available in literature are implemented on a large bogie beam structure. Among all approaches rapid dumping approach used minimum computational time and also it showed qualitatively good agreement with X-ray diffraction measurements for welding residual stresses. Moreover, gradual weld bead deposition approach predicted more accurate results when compared with the experimental measurements and other approaches. Also, by using substructuring approach the computational time is significantly reduced with an acceptable accuracy of predicted welding residual stresses.

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1. Introduction

It is a known fact that welding residual stresses have significant effect on the structural integrity and fatigue performance of a structure/component. Their presence in the structure can either be beneficial or detrimental depending on magnitude, distribution and service loading conditions. In fatigue loaded structures compressive residual stresses are regarded as beneficial and usually desired in the structure while tensile residual stresses are detrimental and often of the magnitude of material's yield strength [1–3]. Therefore, it is essential to measure and predict welding residual stresses.

Finite element (FE) simulations for prediction of welding residual stresses is an effective tool and used quite often, but when it comes to a large and complex welded structure it is still very uncommon. The highly nonlinear and transient nature of the welding process makes the FE simulation computationally intensive; and a large and complex welded structure would make it even more complex and time expensive. Moreover, an accurate representation of welding residual stress in a structure demands three dimensional FE simulation [4] as well as incorporation of the entire structure surrounding the local weld zone [5]. Thus, most of the welding simulations found in literature focused on simple and small structures like butt jointed plates, T fillet joint etc.

Despite the advancements in modern day computing capabilities, efforts are still being made to reduce the computational time involved in the FE simulation for prediction of welding residual stresses in large structures. Ji et al. [6] utilized similitude principles and conduction theory to reduce the computational time involved in the FE simulations for welding residual stresses in large welded structures. Tian et al. [7] used parallel computing by setting up a cluster system of four computers to increase the simulation efficiency for a large complex electron beam welded aluminum alloy structure. Guirao et al. [8] implemented substructuring technique available in commercial FE software to reduce the analysis time for prediction of residual stresses and deformations. Kawaguchi et al. [9] significantly decreased the computational time by implementing iterative substructure method (ISM) in which the region close to local weld zone is considered as highly nonlinear and translates along with the heat source while the remaining region is considered as nearly linear elastic. Qingyu et al. [10] made use of adaptive meshing technique and Lindgren et al. [11] used automatic remeshing algorithm to reduce the calculation time in three dimensional FE simulation of welding process. Bhatti and Barsoum [12] developed an efficient three dimensional approach, rapid dumping, that makes use of moving heat source in thermal analysis and block dumping in mechanical simulation to reduce the computational time significantly. Other techniques like lumped pass or block dumping approach [13–15] in which moving heat source effects are not taken into account and the whole weld bead is deposited in a single load step, use of shell and solid shell

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elements [16,17] can also reduce the computational time significantly in welding simulation for large structures.

2. Investigated structure – bogie beam

Bogie beam is an important and critical component in many ground vehicles, e.g., in trains it is used to provide safe and comfortable ride on curved and irregular tracks, in construction equipments, e.g., in articulated haulers, it is used to transfer the loads from two rear axles to the main frame of the vehicle so that the rear axles can easily roll over in a remote terrain. In the present study a bogie beam structure used in articulated hauler is analyzed. It is a quite large structure and manufactured by several welding sequences. Hence, it is important to study the effects of welding process on its durability and especially distribution and magnitude of welding residual stresses in it. An illustration of bogie beam in an articulated hauler is shown in Fig. 1.

In previous work by Jonsson et al. [18] the weight optimization of bogie beam structure was carried out. The study focused on structural stability, environmental impact, production costs and fatigue life estimations but did not include 3D FE simulation for welding residual stresses. Moreover, in the earlier work by authors [12] an efficient FE approach, rapid dumping, for prediction of welding residual stresses was developed. This approach was only implemented on simple and small welded structures for prediction of residual stresses and the results were qualitatively in good agreement with experiments. In the present work, rapid dumping approach has been implemented on the bogie beam structure in order to validate the approach for large welded structures. Furthermore, the bogie beam structure is analyzed with other available approaches in literature in order to devise an efficient FE simulation framework for prediction of residual stresses in large welded structures.

3. Experimental setup

The bogie beam structure is manufactured with steel plates of grade S355 having thickness of 8 mm and 15 mm at webs and flanges respectively. It is a triangular section with a maximum width of 2 m and height of 1.5 m at the middle section. A sketch of bogie beam is shown in the Fig. 2.

3.1. Welding process

The bogie beam structure is fabricated with robotic MAG welding. Before mounting it on the fixture the center sleeve, flanges and internal supporting plates are manually tack welded to the webs as shown in Fig. 3.

The two sides of the bogie beam are named as side A and side B depending on which side is welded first. The welding is started at 12 o'clock position around the center sleeve on side A and then

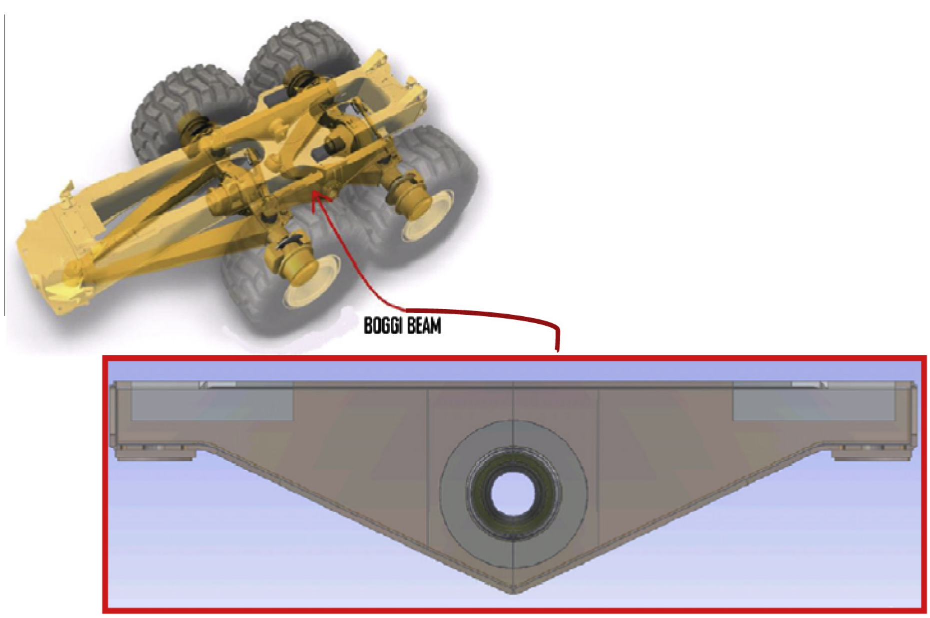

Fig. 1. Illustration of bogie beam in an articulated hauler [18].

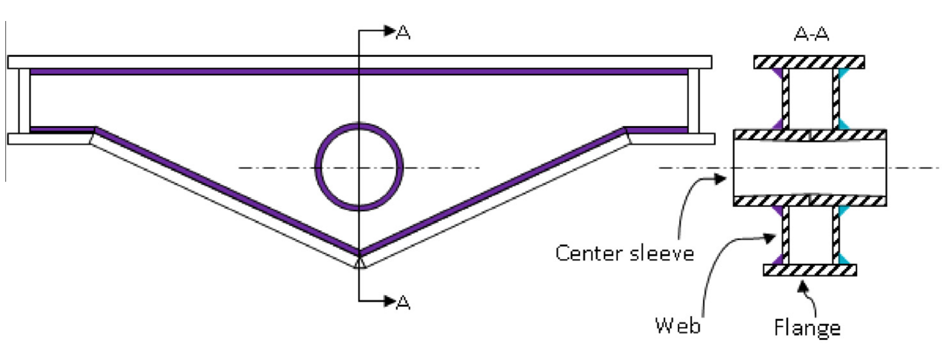

Fig. 2. Sketch of bogie beam structure.

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