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Multi-objective optimization of gas metal arc welding parameters and sequences for low-carbon steel (Q345D) T-joints

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ABSTRACT

Q345D high-quality low-carbon steel has been extensively employed in structures with stringent welding quality requirements. A multi-objective optimization of welding stress and deformation was presented to design reasonable values of gas metal arc welding parameters and sequences of Q345D T-joints. The optimized factors included continuous variables (welding current (I), welding voltage (U) and welding speed (v)) and discrete variables (welding sequence (S) and welding direction (D)). The concepts of the pointer and stack in Visual Basic (VB) and the interpolation method were introduced to optimize the variables. The optimization objectives included the different combinations of the angular distortion and transverse welding stress along the transverse and longitudinal distributions. Based on the design of experiments (DOE) and the polynomial regression (PR) model, the finite element (FE) results of the T-joint were used to establish the mathematical models. The Pareto front and the compromise solutions were obtained by using a multi-objective particle swarm optimization (MOPSO) algorithm. The optimal results were validated by the corresponding results of the FE method, and the error between the FE results and the two-objective results as well as that between the FE results and the three-objective optimization results were less than 17.2% and 21.5%, respectively. The influence and setting regularity of different factors were discussed according to the compromise solutions.

1. Introduction

The welding material Q345D is a high-quality low-carbon steel that has a relatively high research value in enterprises[1] and has been extensively employed in structures with stringent welding quality requirements for the manufacture of railway vehicles[2,3]. Many different models of Q345D have been applied to study the phenomena and problems in the welding process[4-6]. Among these models, the T-joint model is extensively applied due to its simple composition, distinct deformation mode and abundant experimental resources[7,8].

The welding residual stress and deformation are the most important concerns of a weldment among many different research objectives in the gas metal arc welding process[9]. To control the residual stress and deformation at a reasonable level, pre-weld treatment, post-weld treatment and treatment during the welding process were proposed[10]. The pre-weld treatment and treatment during the welding process enable a better control effect and a more extensive application. Studies have investigated the pre-weld treatment. Jindal et al.[11] attempted to optimize the following weld bead parameters, weld bead form factor, dilution, microhardness and diffusible hydrogen content, for the welding of structural pipe. Moradpour et al.[12] optimized the welding parameters in the submerged arc welding of API X65 steel plates. Studies have also investigated various treatments during the welding process. Jeong-Ung and Gyu[13] investigated the effect of welding sequence on fillet welding distortion and proposed a new model of the joint rigidity method to determine the welding sequence for minimum welding distortion. Ji et al.[14] investigated the influence of different welding sequences on welding quality and presented a suitable sequence. These investigations provided available welding parameters or sequences to enhance the process of welded structures. However, few studies have combined the pre-weld treatment and treatment during the welding process to investigate

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their influences on welding stress and deformation.

Unexpected welding deformation and stress can be controlled by the optimization of above-mentioned factors. The most frequently used optimization methods include the single-objective optimization design, analysis of variance, and sensitivity analysis[15,16]. Asadi and Goldak[17] used a surrogate model to obtain the minimum distortion in a pipe girth weld with six subpasses. Voutchkov et al.[18] proposed a surrogate model to reduce the computational expense of sequential combinatorial finite element problems in a weld path planning problem. Kadivar et al.[19] utilized a genetic algorithm with a thermomechanical model to determine the optimum welding sequence to reduce the residual stress in thin plates. However, the welding deformation and stress always have the opposite variation tendency. Therefore, a multi-objective mathematical model must be established to address this problem. Shojaeefard et al.[20] used an artificial neural network model to understand the correlation between the welding parameters and peak temperature. Ajith et al.[21] presented a multi-objective optimization of continuous drive friction welding process parameters using a response surface methodology with an intelligent optimization algorithm. However, the discrete and continuous parameters were rarely combined as the optimization variables.

In this study, a finite element (FE) model of T-joint with the material Q345D was established to investigate the control method of the residual welding stress and deformation with reasonable selection of welding factors. The FE analyses of the T-joint models were conducted according to the order of the design of experiments (DOE). The optimization mathematical models were established based on the production specification of the gas metal arc welding process, and the influencing factors are the continuous variables (welding current (I), welding voltage (U) and welding speed (v)) and the discrete variables (welding sequence (S) and welding direction (D)). The multi-objective optimization method was used based on a polynomial regression (PR) model and a multi-objective particle swarm optimization (MOPSO) algorithm to obtain the Pareto front and the optimal compromise solutions.

2. Materials and Methods

2.1. Material model

Material of the T-joint is Q345D, a high-quality low-carbon steel that is prevalent in the manufacture of railway vehicles. This material has a strong representation and a relatively high reference value for enterprises. The chemical composition of Q345D is shown in Table 1. The temperature-dependent thermal and mechanical properties of Q345D are gained by the Springer Materials database and shown in Fig. 1. The thermal and mechanical properties of the welding seam are equivalent to the thermal and mechanical properties of the region far from the welding seam.

Table 1
Chemical composition of Q345D (wt. %)

C	Mn	Si	P	S	Ni	Cr	Mo	Fe
0.050	1.470	0.230	0.018	0.004	0.030	0.030	0.004	Balance

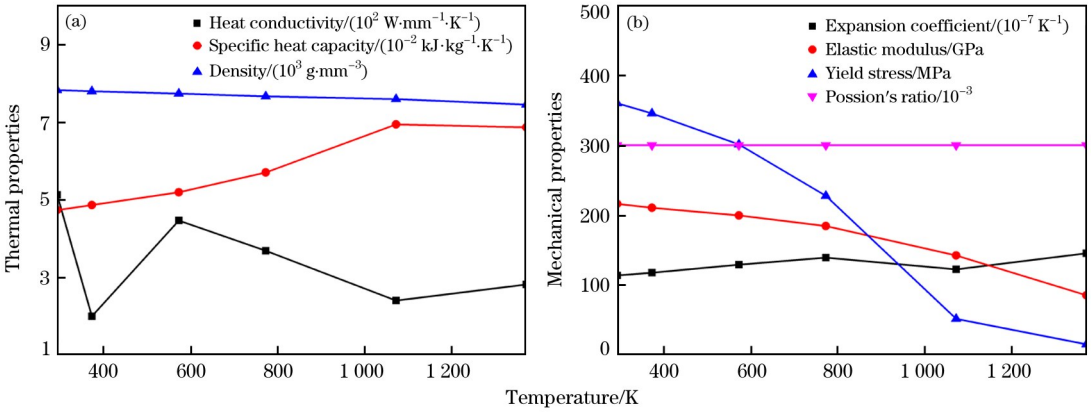

Fig. 1. Temperature-dependent thermal (a) and mechanical (b) properties of Q345D.

2.2. Finite element modeling

2.2.1. Finite element modeling method

A T-joint model is composed of a web plate, a flange plate and two welding seams. The FE model of the T-joint is established for multi-objective optimization of residual welding stress and deformation in this study, which is shown in Fig. 2. The dimensions of the web plate and flange plate are 100 mm×150 mm×4 mm and 50 mm×150 mm×4 mm, respectively. The region of the welding seam is composed of a quarter circle with a radius of 4 mm. Many