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Improvement of welding heat source models for TIG-MIG hybrid welding process

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ABSTRACT

Tungsten inert gas-metal inert gas (TIG-MIG) hybrid welding process is an effective way to improve welding productivity and quality due to advantages of the two processes. Mathematical analysis is crucial to fundamentally understand this synergetic welding process. In this study, based on experimental visualization of arc behaviors, some assumptions are proposed to deduce adaptive plane and volumetric heat source models separately for each involved welding method first. The influence of torch angles on distribution of temperature and geometry of weld bead are calculated and compared with experimental results. It shows that this developed algorithm of heat source can be employed to accurately predict welding process whether the electrode gun is slanted backward or forward to the direction of welding. Then TIG-MIG hybrid welding process is simulated and analyzed without considering the attractive or repulsive force of two arcs. The characteristic of TIG-MIG welding process is discussed compared to single MIG. It lays the foundation for the further research on the interaction of the two arcs during TIG-MIG hybrid welding.

1. Introduction

With the unceasing intensification of the manufacturing competition, the traditional arc welding processes, such as tungsten inert gas welding (TIG) and metal inert gas welding (MIG), have been improved to satisfy enterprise's requirements for welding technology with high quantity and high quality. TIG-MIG hybrid welding process is one of the effective ways to develop welding productivity and quality due to advantages of the two processes, which is similar to DE-GMAW (double-electrode gas metal arc welding) [1–4]. The major differences between TIG-MIG and DE-GMAW hybrid welding processes are as follows: (1) The mechanism of TIG-MIG is that an appropriate distribution of arc energy is simply liberated on the workpiece by a tailing TIG arc to improve traditional GMAW process directly. However, during DE-GMAW, the adding TIG arc is used as part of galvanic circle to make sure that the bypass current can flow back to the power source through the bypass TIG torch without going through the workpiece [1]. (2) The major effects of additional TIG arcs are different from each other. During TIG-MIG hybrid welding, the additional TIG arc is used to reheat the workpiece and to improve the weld bead deformation. And during DE-GMAW, the purpose of adding tailing TIG arc is to increase the depositing rate of filler metal without imposing excessive heat on the workpiece, thus the tailing TIG arc is not directly liberated on the workpiece. And compared to tandem or T.I.M.E. welding [5–7], TIG-MIG hybrid welding is an easy way to utilize the advantages of TIG and MIG welding with low cost, since neither special shielding gas nor complex synergic powers are needed. It shows that MIG arc can be stable by simple hybridization of TIG even though pure argon shielding gas is used, which means the weld metal toughness is improved and welding quality is developed [4]. The further study indicates that it also has great potentiality to increase welding speed with high quality because of the quite stable cathode spots appearing in this hybrid welding [8].

However, it is still lack of comprehensive and profound research on physical mechanism of TIG-MIG hybrid welding, which hinders the development of this new welding method. In recent decades, many researches have been done on heat source models to reveal various welding process, such as gauss or elliptical heat source model for TIG in low welding current [9,10], double ellipsoid heat source model for MIG [11,12], double-ellipsoidal + EHGC (exponentially-tapered peak value of heat flux in Gaussian cylinder) heat source model for plasma arc welding [13], self-adaptable heat source models for laser beam welding and plasma arc welding separately by considering dynamic energy distribution during above welding processes [14]. However, all the heat

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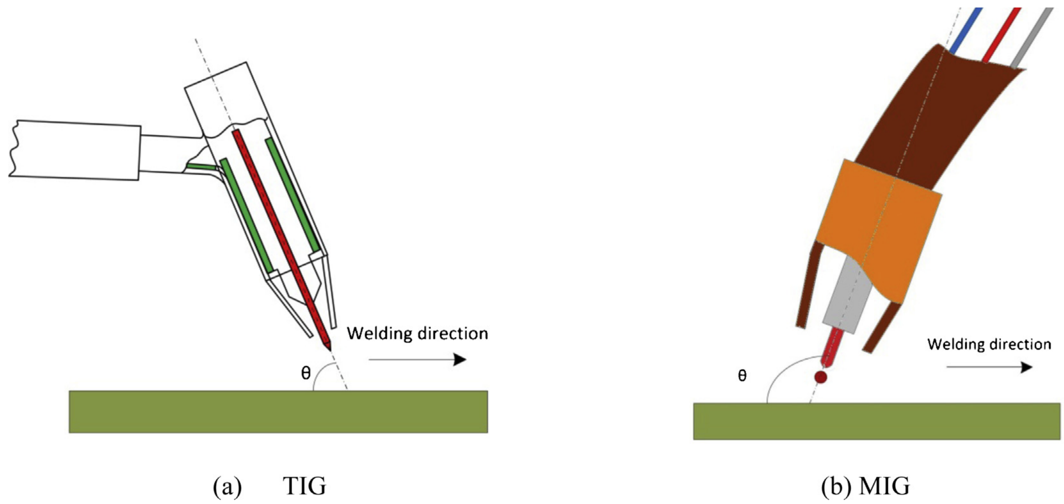

Fig. 1. Schematic diagram of welding process with a slanted gun: (a) TIG and (b) MIG.

models mentioned above are focused on single welding process, which could not be used in hybrid welding directly. Though many improved heat source models have been deduced for laser + GMAW hybrid welding or laser + TIG hybrid welding, the influence of torch angles is not studied comprehensively as most of the researches are focused on the synergetic heat effects of two sources [15,16]. A new hybrid heat-source model is developed to simulate DE-GMAW process, which is similar to TIG-MIG. However, their physical mechanisms are different. For example, during DE-GMAW process, the tailing TIG arc is only the conductive path of current without directly acting on the weld pool [17]. And the parameters of all above heat or arc force models need to be verified by experiments each time if the torch angle changes. To solve this problem, Cho et al. develop a complex heat source model for submerged tandem arc welding process [18]. Two different effective radii of arc plasma are introduced to reflect the influence of torch angles on heat flux and arc pressure distribution. Considering Lorentz force due to the magnetic field induced by leading and trailing arc, the interaction of these two arcs is partially dominated by leading arc displacement. The nine different model parameters in leading and trailing arc models make it to be utilized intricately. Tanaka et al. analyze arc phenomena in TIG-MIG hybrid welding process with different torch angles using three-dimensional numerical models [19]. It is found that the convergence of heat flux will get maximum value under certain torch angles of TIG and MIG, which can be explained by the balance between the stiffness of arc and the repulsion of both arcs. However, the complex current conservation equation and Maxwell–Ampere equation needs to be solved to study the influence of torch angles and interaction of arcs [19]. So a simple and effective way is needed to evaluate the influence of torch angles on welding process first.

Based on several simple assumptions, the adaptive plane and volumetric heat source models are deduced respectively by considering the influence of torch angles and arc length in this paper. The heat transfer mechanism is investigated by solving three-dimensional numerical equations for TIG and MIG welding separately. The influence of torch angles on temperature profiles and the weld bead geometry is numerically analyzed. Good agreement is shown between the predicted and experimentally determined weld bead cross-section as well as welding thermal cycles. Then the influence of tailing TIG arc on heat transfer and formation of weld bead is calculated and analyzed compared to single MIG. It lays foundation to study the interaction of these two arcs further.

2. Formulation

In arc welding process, the additional filler metal not only produce weld bead but also influences the heat conduction process. The complicated surface condition makes it difficult to solve the boundary conditions of weld bead and arc crater areas in the Cartesian coordinate system. Thus the body-fitted coordinated system is adopted in this study by the transformation of the rectangular

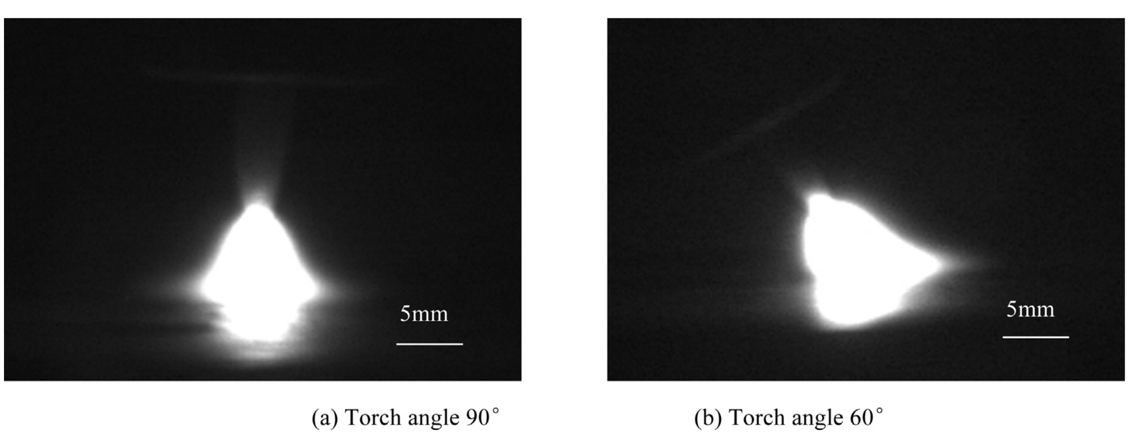

Fig. 2. Photo of TIG welding arc for different torch angles (90 A): (a) torch angle 90° and (b) torch angle 60°.