Reduction of shielding gas dosage in GMAW process

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Abstract. In order to reduce production cost, it is necessary to reduce the quantity of shielding gas under ensuring the quality of welding joints in gas metal arc welding (GMAW) process. Three nozzles, spiral nozzle, shrink nozzle and diverging nozzle, with different geometric structure were designed to compare with industrial normal nozzle. The influence of the shielding gas dosage on the protection radius for four types of nozzles were analysed through computational fluid dynamics (CFD) simulation, and the minimum dosage of shielding gas for different nozzles were obtained. The GMAW experiments were conducted with Q235 steel through the minimum dosage of mixture gas with four kinds of nozzles. After tensile tests of four kinds of standard welding samples, the fracture did not occur at the welding seam. So the shielding gas dosage in traditional GMAW process could be reduced greatly.

1. Introduction
In gas metal arc welding (GMAW) process, the shielding gases separate the arc and the welding molten pool from air to keep welding arc stable and protect the weld region [1]. Different components and concentrations of mixed gases are suitable for different metal materials and welding procedures [2]. A large amount of shielding gas consumption is consumed in GMAW process. In order to reduce production costs, it is necessary to reduce the quantity of shielding gas while maintaining the quality of welding joints.

Hu et al. analysed the effect of different kinds of inlet hole in the weld device and gas flowrate through comparing laminar flow lengths of shielding gas out of nozzle [3]. Fan et al. studied the relationship between diameters of welding nozzle and flowrate through CFD simulation [4]. Ramsey et al. used Fluent soft to investigate the effects of nozzle diameter and side draught on the shielding gas flow coverage during GMAW process [5]. Campbell et al. used CFD models and experimental trials to analyse the effects of geometry changes in the welding nozzle on the shielding gas flow coverage during GMWA process [6]. Kong et al. analysed the behaviors of droplet transfer and spatter in CO₂ gas shielded arc welding with high-speed photography system [7]. Yosuke et al. developed a unified model to investigate the influence of the shielding gas on the metal transfer [8]. Belinga et al. examined the effects of shielding gas mixtures and their components, and presented a cross-comparison of shielding effects in fusion welding [9]. Bitharaset al. undertook a systematic study to determine the effect of shielding gas flow rate, as well as changes in the nozzle stand-off and angle, on the weld quality by visualising the density gradients and flow characteristics of the shield gas during gas metal arc welding (GMAW) of DH36 with Schlieren imaging [10].

In literature, available studies dealt with the effect of shielding gas dosage on the welding area have appeared in less comparatively. So, this paper focuses on the minimum dosage of shielding gas needed in the certain GMAW process condition to reduce the cost and consumption of resources. This research has important guiding significance to the actual production.
2. CFD Simulation

2.1. Simulation Parameters

Figure 1 presents the 3D model of GMAW. The modeling area was rectangular (LxWxH, 120x120x63.5mm). The workpiece was located at 10mm below the nozzle. The mesh of the whole model was composed of 1.02x10^6 tetrahedral units. The mesh density in the nozzle, and between the nozzle and the workpiece, was larger than that of the lateral flow field [11].

The air pressure was 1.01325x10^5 Pa. The free boundary was the gas outlet, and the gas entered through the eight small holes uniformly distributed around the flow divider. A crosswind was added from one side in the whole flow field, and the allowed maximum speed of crosswind was 0.5m/s. The gas in all flow fields was set to be air at the beginning of welding. The unsteady pressure solver was used without considering the impact of the arc on the gas flow, and the shielding gas was incompressible.

![Figure 1. Configuration of the 3D model of GMAW.](image)

![Figure 2. Four kinds of nozzles.](image)

2.2. Nozzle Structure

Four kinds of nozzles models, normal nozzle, spiral nozzle, shrink nozzle and diverging nozzle, were used in CFD simulation as shown in Figure 2(a), (b), (c) and (d). The normal nozzle was commonly used in industry and the diameter of internal straight hole was 16mm. There were two spiral grooves in the spiral nozzle and the diameter at hole end was 16mm. The shrink nozzle end was an inner step and the diameter of inner step was 10mm. The tapered hole was in the diverging nozzle and the end diameter of the diverging nozzle was 12mm.

2.3. Evaluation Criteria for Flow Field of Shielding Gas

In the simulation analysis of the protective gas flow, the evaluation standard of qualified field of protective gas was stipulated. The standard was that the protection radius (L) from the nozzle center to the side wind extrusion boundary must cover the pool area and the fusion zone, and the gas concentration in the area of protective radius was greater than or equal to 95% when crosswind speed was 0.5m/s, as shown in Figure 3. In the following simulation, the setting thickness of workpiece was 4mm, the width of welding pool width was 8mm, the width of fusion zone was 1mm, the transient residence time at some point during welding was 0.2s. So the protection radius L should be greater than 4.5mm (width of weld pool 4mm + fusion zone 0.5mm).
2.4. Simulation Results and Analysis

2.4.1. Influence of flowrate with industrial normal nozzle on the protection radius L. In industry, for a normal nozzle with a 16mm hole diameter used in GMAW process [12], commonly considered flowrate for shielding gas is 16~20L/min. In the simulation, the mixing gas (80% Ar + 20% CO₂) was used in the normal nozzle, and the flow rate was 16 L/min, 14 L/min and 11 L/min. The mass concentration distribution of shielding gas for flow rate of 16 L/min, 14 L/min and 11 L/min was shown in Figure 4 (a), (b) and (c), respectively. The corresponding protection radius L was 9.68 mm, 5.69 mm and 4.35 mm. According to the above comparison, when flowrate was 16 L/min, lots of shielding gases were wasted. The welding pool and fusion zone were not completely covered when the flow rate of shielding gas was 13 L/min. Therefore, according to the simulation analysis, the best flow rate for normal nozzle was 14 L/min.

2.4.2. Distribution of mass concentration of shielding gas in different nozzles. Figure 5 (a) and (b) present the concentration distributions of shielding gas with different flow rates on workpiece under windless and windy (0.5 m/s) condition for normal nozzle (12 L/min), spiral nozzle (12 L/min), shrink nozzle (9 L/min) and diverging nozzle (9 L/min). According to Figure 5, the concentration of the shielding gas on the workpiece was the highest at the center of the welding seam, and gradually decreased to both sides. Under the same flow rate, the anti-crosswind capability for the diverging nozzle was weaker than that for the shrink nozzle; However, the coverage area of diverging nozzle was larger than that of the shrink nozzle. So the shrink nozzle was suitable for the great crosswinds, on the contrary, the diverging nozzle was suitable for little or weak crosswinds. The coverage area of shielding gas for normal nozzle and spiral nozzle were both large under windless conditions, and the anti-crosswind capability for the normal nozzle was better than that for spiral nozzle.
3. Experiment

3.1. Experimental System
The type 2003 gas distributor and CO₂ GMAW machine were used to form a welding system shown in figure 6. The welding was conducted in indoor and butt welding was employed[13]. Welding wire type was Ehr506, welding current was 180A and mixture ratio was 80%Ar+20%CO₂.

The workpiece material was Q235A steel and the plate thickness was 4mm. After being welded, the plate samples were processed into standard shape through electrical discharge machining (EDM) according to GB/T228-2002 and GB/T2651-2008 [14] as shown in figure 7.

3.2. Experimental Results and Analysis
The samples were stretched with the electronic universal testing machine and the test results were shown in table 1. The fracture locations were at the sample shrinkage of parent material for normal nozzle, spiral nozzle, shrink nozzle and diverging nozzle, and at the heat affected zone for diverging nozzle. The tensile strengths were 432.34, 404.23, 427.15 and 421.56 MPa, respectively, and all were in the tensile strength range of Q235A steel (375-460 MPa). The results showed that the welding effect of reducing the amount of shielding gas was satisfied with the mechanical properties.
Table 1. Tension experiments of welded joint.

| Item               | Nominal diameter of nozzle (mm) | Flowrate of shielding gas (L/min) | Maximum load (N) | Tensile strength (Mpa) | Fracture location |
|--------------------|--------------------------------|----------------------------------|------------------|------------------------|-------------------|
| Normal nozzle      | 16                             | 16                               | 17293.6          | 432.34                 |                   |
| Spiral nozzle      | 16                             | 14                               | 16169.2          | 404.23                 |                   |
| Shrink nozzle      | 12                             | 9                                | 17080            | 427.15                 |                   |
| Diverging nozzle   | 12                             | 9                                | 16862.4          | 421.56                 |                   |

4. Conclusions
(1) Without reducing the protection scope, the special structure nozzles could significantly reduce the dosage of protective gas.
(2) Under the windless and weak crosswind conditions, the protective coverage of the common nozzle was smaller than that of spiral nozzle, and the protective coverage of diverging nozzle was larger than that of shrink nozzle.
(3) Under larger crosswind conditions, the anti-crosswind capacity of the normal nozzle was higher than that of the spiral nozzles, and the anti-crosswind capacity of the shrink nozzle was higher than that of the diverging nozzle.
(4) Under the condition of the qualified protection scope, the dosages of protection gas of the shrink nozzle and diverging nozzle were less than those of the normal nozzle and the spiral nozzle.

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