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Welding Polarity Effects on Weld Spatters and Bead Geometry of Hyperbaric Dry GMAW

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Abstract: Welding polarity has influence on welding stability to some extent, but the specific relationship between welding polarity and weld quality has not been found, especially under the hyperbaric environment. Based on a hyperbaric dry welding experiment system, gas metal arc welding(GMAW) experiments with direct current electrode positive(DCEP) and direct current electrode negative(DCEN) operations are carried out under the ambient pressures of 0.1 MPa, 0.4 MPa, 0.7 MPa and 1.0 MPa to find the influence rule of different welding polarities on welding spatters and weld bead geometry. The effects of welding polarities on the weld bead geometry such as the reinforcement, the weld width and the penetration are discussed. The experimental results show that the welding spatters gradually grow in quantity and size for GMAW with DCEP, while GMAW with DCEN can produce fewer spatters comparatively with the increase of the ambient pressure. Compared with DCEP, the welding current and arc voltage waveforms for DCEN is more stable and the distribution of welding current probability density for DCEN is more concentrated under the hyperbaric environment. When the ambient pressure is increased from 0.1 MPa to 1.0 MPa, the effects of welding polarities on the reinforcement, the weld width and the penetration are as follows: an increase of 0.8 mm for the weld reinforcement is produced by GMAW with DCEN and 1.3 mm by GMAW with DCEP, a decrease of 7.2 mm for the weld width is produced by DCEN and 6.1 mm by DCEP; and an increase of 3.9 mm for the penetration is produced by DCEN and 1.9 mm by DCEP. The proposed research indicates that the desirable stability in the welding procedure can be achieved by GMAW with DCEN operation under the hyperbaric environment.

Keywords: welding polarity; hyperbaric welding; gas metal arc welding(GMAW); weld bead geometry; spatter.

1 Introduction

In recent years, a growing number of oil platforms, pipelines and other underwater components need to be assembled and repaired with the constantly development of marine resources[1–2], so the importance of underwater welding technology is increasingly prominent[3–6]. It is significant to research and develop the deep-sea underwater welding technology[7]. Underwater welding can be classified into three categories: wet welding, local dry welding and dry hyperbaric welding. For dry hyperbaric welding, water is discharged through the opening at the lower part of the gas chamber by high pressure gas, and the whole welding process is carried out in a dry gas phase environment, which is conductive to access good welding quality. It is more suitable for deep water environment compared with the other two categories.

As the ambient pressure is increased together with the growing depth of water, the arc shape in the hyperbaric environment has quite different characteristics from that of those at normal atmospheric pressure. LI, et al[8], investigated the arc behavior in dry hyperbaric GMAW process and confirmed that the arc length turned shorter, the arc column was contracted, the arc brightness increased, and the arc static characteristics were rising[9–11]. AZAR, et al[12], developed some mathematical approaches for predicting the hyperbaric GMAW process arc behavior and stability, and it was found that more energy was required to maintain the arc stability and the ambient pressure had great effects on bead geometry. WU, et al[13], studied the characteristics of bead geometry of GMAW with DCEP in the hyperbaric environment, and the experimental results showed that the welding spatters increased, the weld width decreased and the penetration increased with pressure. MIHOLCA, et al[14], studied the influence of pressure over the geometry of the layered beads, and it was found that the increase of the relative pressure inside the compartment results in the decrease of weld width, the increase of over height and an insignificant increase of penetration[15], irrespective of the layer ordinal number in the butt joints. Since the welding process becomes unstable and welding quality drops with the increase of the ambient pressure,

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many researchers have paid attention to the weldability of different materials under the hyperbaric environment. WANG, et al[16], studied the influence rule of the ambient pressure on welding quality of tungsten inert gas welding (TIG), the research results showed that the tensile strength and impact toughness of the welded joints were declined, while the hardness of the weld and the heat-affected zone was on the rise with the increase of the ambient pressure[17]. AKSELSEN, et al[18], assessed the weldability of duplex stainless steel under the hyperbaric conditions. The results showed that there was weld metal undermatch with respect to the yield strength, while the tensile strength was at the same level as that of the base plate. The notch toughness at –30℃ was excellent for all positions tested, which is far beyond current offshore requirements.

At one atmosphere and pressures of a few bar, GMAW is normally employed with electrode positive polarity(also known as DCEP), many studies at home and abroad showed that GMAW with DCEP could accelerate the melting of welding wire and ensure more stable welding procedure and better weld bead geometry compared with electrode negative polarity(also known as DCEN)[19–23]. However, in the hyperbaric environment, few studies about the welding polarity have been carried out since the hyperbaric environment for testing is hard to be constructed. With the increase of the ambient pressure, the welding arc contracts, the welding procedure becomes unstable and welding characteristics change a lot, so the effects of welding polarities on the welding procedure and the weld bead geometry are different from that of those at the normal atmospheric pressure. It is important to find the influence rule of welding polarities on the welding procedure and the weld bead geometry in order to ensure the welding quality in the hyperbaric environment. Therefore the experiments of GMAW with DCEP and DCEN operations were carried out under different environment pressures to find effects of welding polarity on the welding spatters and the weld bead geometry.

2　Experiments

A hyperbaric dry welding experiment system was constructed for GMAW experiments with different welding polarities in the hyperbaric environment. The system mainly included a hyperbaric chamber, a welding test platform, a welding process data collection and analysis equipment, a welding control system, a long-range control system and a power supply and so on, as shown in Fig. 1.

The design pressure of the hyperbaric welding test chamber was 5.0 MPa, equivalent to 500 m under sea level. The ambient pressure corresponding to a certain water depth was achieved by filling the test chamber with compressed air of a certain pressure using an air compressor. A welding platform was installed in the hyperbaric chamber for the welding experiments to be executed. The platform was comprised of three parts: a position-changing mechanism, a circular turntable and a wire feeding system. The position-changing mechanism could be used to fix the welding workpiece and make the welding workpiece move at a designed speed. The wire feeding system was fixed on the support of the welding platform in the chamber for the convenience of the welding experiments after the chamber was closed. The hyperbaric chamber and the welding platform are shown in Fig. 2 and Fig. 3, respectively.

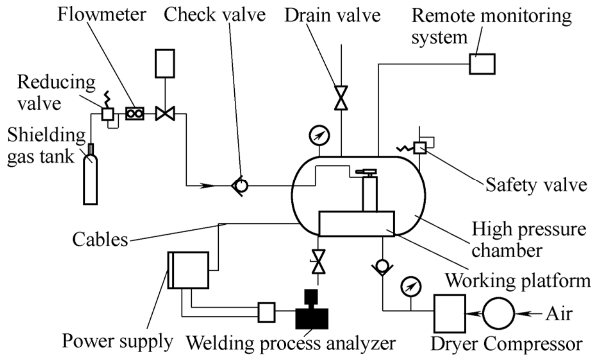


Fig. 1　Schematic diagram of the hyperbaric welding experiment system

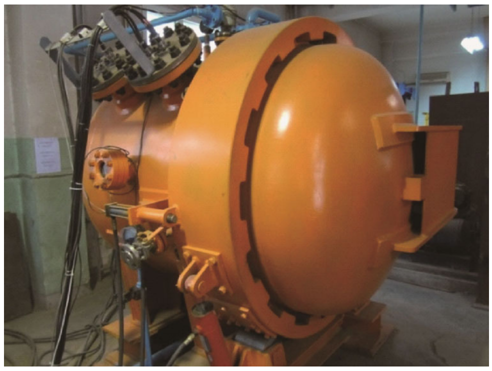


Fig. 2　Hyperbaric welding chamber

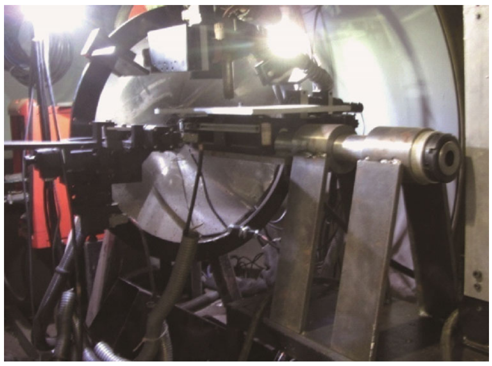


Fig. 3　Welding platform

The welding power source, the welding control system and the welding electrical signal acquisition system were placed outside of the hyperbaric chamber. The welding electrical signal acquisition system included a welding process analyzer, a welding current sensor and an arc voltage sensor. The system was used to get the welding current and voltage data in real time and execute fast data analysis.

TPS4000 welding machine produced by Fronius Co. was adopted in the welding experiments. Q235 steel was used as the test workpiece which was cut in the size of 300 mm×150 mm×10 mm. The welding current was set as 280 A; the welding voltage was 35.7 V; the welding wire type was JM-56 and its diameter was 1.0 mm. The welding speed was 50 cm/min. The shielding gas was Ar80%+ $CO_2$20%, and the flow rate of the shielding gas was 20 L/min. GMAW with DCEP or DCEN operations were used in the experiments with other welding conditions unchanged.

3 Results

3.1 Welding spatters

Fig. 4 shows the distribution of the welding spatters corresponding to GMAW with different polarities and under different ambient pressures. At the atmospheric pressure, there are few welding spatters and the seam appearance is of high quality for GMAW with DCEP operation. However, as the ambient pressure was increased gradually, the welding spatters gradually grew in quantity and size.

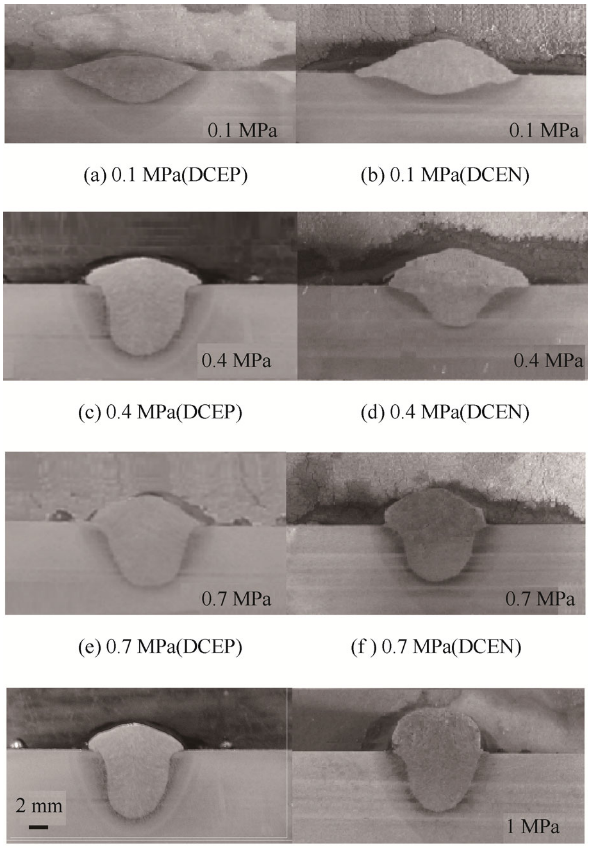
(a) 0.1 MPa(DCEP) (b) 0.1 MPa(DCEN)
(c) 0.4 MPa(DCEP) (d) 0.4 MPa(DCEN)
(e) 0.7 MPa(DCEP) (f) 0.7 MPa(DCEN)
(g) 1.0 MPa(DCEP) (h) 1.0 MPa(DCEN)

Fig. 4 Weld surface appearance with different polarities

When GMAW with DCEN operation is employed at the atmospheric pressure, there are a lot of welding spatters and the weld seam appearance is of low quality. However, with the increase of the ambient pressure, the welding spatters were reduced and the weld seam appearance gradually improved. When the ambient pressure was greater than 0.7 MPa, the spatters became noticeably fewer.

3.2 Weld bead geometry

Fig. 5 shows the weld bead geometries of GMAW with different polarities at ambient pressures of 0.1 MPa, 0.4 MPa, 0.7 MPa, and 1.0 MPa. Shape sizes of the weld bead geometries including the weld width, the penetration and the weld reinforcement are listed in Table 1.



(a) 0.1 MPa(DCEP) (b) 0.1 MPa(DCEN)
(c) 0.4 MPa(DCEP) (d) 0.4 MPa(DCEN)
(e) 0.7 MPa(DCEP) (f) 0.7 MPa(DCEN)
(g) 1.0 MPa(DCEP) (h) 1.0 MPa(DCEN)

Fig. 5 Weld cross-section shapes with different polarities

Table 1. Sizes of weld bead geometries for GMAW with DCEP and DCEN in hyperbaric environment

Pressure p/MPa	Reinforcement a/mm		Weld width B/mm		Penetration H/mm	
	DCEP	DCEN	DCEP	DCEN	DCEP	DCEN
0.1	1.9	3.7	10.6	15.3	4.6	2.3
0.4	2.8	3.5	9.4	13.2	6.1	4.1
0.7	3.2	4.3	7.2	10.2	6.2	5.9
1.0	3.2	4.5	6.5	8.1	6.5	6.2

The influence rules of welding polarities on the weld bead geometry under different ambient pressures are shown in Fig. 6. Together with the increase of the ambient pressure, the weld reinforcement increases accordingly for GMAW with both polarities, as shown in Fig. 6(a). When GMAW is set in DCEN, the weld reinforcement is higher than that in DCEP. Since the welding wire is taken as a cathode of higher heat production for GMAW with DCEN operation, it is good for melting of the filler wire and the droplet transfer.

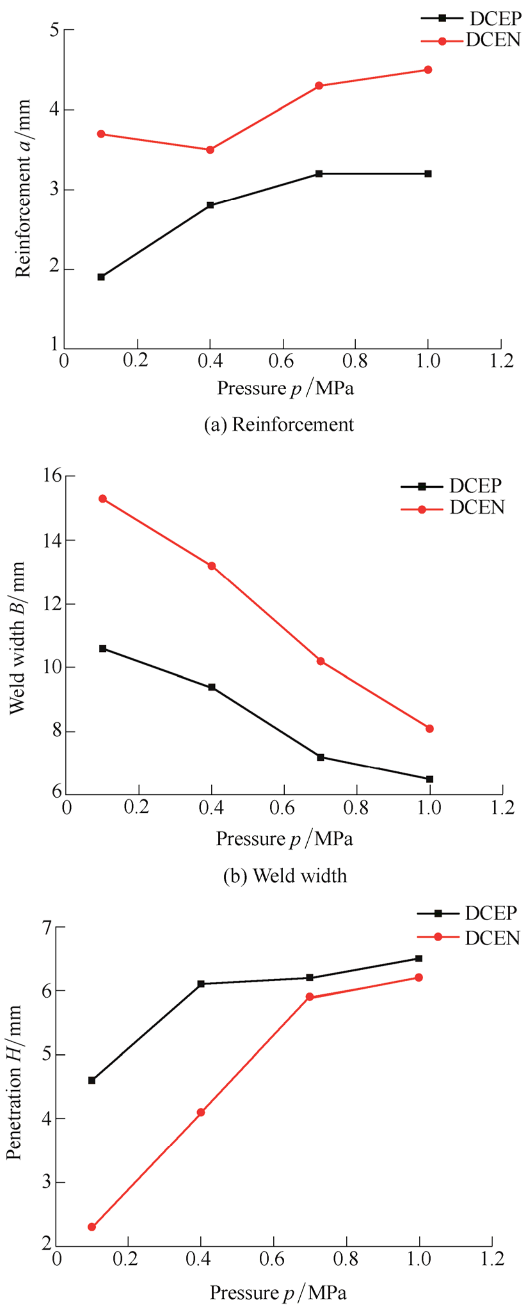


Fig. 6　Shape sizes of weld bead geometries as a function of the ambient pressure for GMAW operated in different polarities

Along with the increase of the ambient pressure, the weld width reduces for GMAW with both polarities, as shown in Fig. 6(b), which is due to the contraction of the welding arc that occurs in the hyperbaric environment.

Fig. 6(c) shows that the penetration is greater for GMAW with DCEP than with DCEN at the atmospheric pressure. When GMAW is applied with DCEP, the change of the penetration slows down after the ambient pressure exceeds 0.4 MPa. However, when GMAW is applied with DCEN, the penetration change is rapid before the ambient pressure reaches 0.7 MPa. When the ambient pressure exceeds 0.7 MPa, the penetrations for GMAW with both polarities approach the same value almost and change little.

4　Discussion

The results of above experiments indicate that a large amount of welding spatters are produced when GMAW is employed with DCEP operation in the hyperbaric environment. However, GMAW with DCEN operation is clearly an effective way to reduce welding spatters when the ambient pressure is greater than 0.7 MPa.

For GMAW with DCEP operation, the anode plasma jet is the dominant mass transport force in the arc at the normal atmospheric pressure. With the increase of the ambient pressure, the arc contracts, and the cathode mode changes from diffuse to spot mode and a number of discrete, and highly mobile emission sites are formed. A relatively strong plasma jet emanates from each of these sites. As the ambient pressure further increases, the number of emission sites tends to reduce, eventually forming a single spot with a very strong plasma jet. The force of this jet is found to be increased with the pressure and blocks the droplet transfer, so that more welding spatters are formed.

For GMAW with DCEN operation at the normal atmospheric pressure, there are multiple cathode emission sites, which root both on the molten droplet and on the sides of the wire. These sites are highly mobile and exist over a relatively large wire area. Therefore the welding procedure and the droplet transfer are highly unstable. However, as the ambient pressure is increased and the roots contract, the arc concentrates on the wire tip, thereby the force that promotes the droplet transfer is increased. So the spatters are reduced and the welding stability is improved.

The welding arc voltage and current data are sampled by the welding process analyzer, and their waveforms are shown in Fig. 7. At one atmosphere, the welding current and the arc voltage are stable for GMAW with DCEP or with DCEN. As the ambient pressure is increased, fluctuations arise in the welding current and the arc voltage of DCEP and DCEN. While fluctuations by DCEN are fewer than that by DCEP, indicating that the droplet transfer occurs more smoothly. Fig. 8 shows the welding current probability density distribution with different polarities. At the normal atmospheric pressure, the welding current is concentrated at the set current for DCEN or DCEP, indicating that the corresponding welding process is stable. As the ambient pressure is increased, the current distribution becomes diffused. By comparison, the instant value of 0 A in welding current waveforms has a higher probability of occurrence for GMAW with DCEP operation than that with DCEN operation, which indicates that arc extinction occurs more frequently in the welding process of DCEP. The probability of the maximum welding current for DCEP is almost equal to that for DCEN, indicating that short circuiting transfer in the welding process of DCEP is in the same frequency with that of DCEN. In addition, the current distribution near the set current is more concentrated for DCEN, which indicates that current fluctuations in the welding process of DCEN occur in a relatively small probability and the welding process is comparatively stable. The above data analysis shows that GMAW with DCEN operation results in a more stable droplet transfer procedure in the hyperbaric environment, and the welding spatters can be reduced.

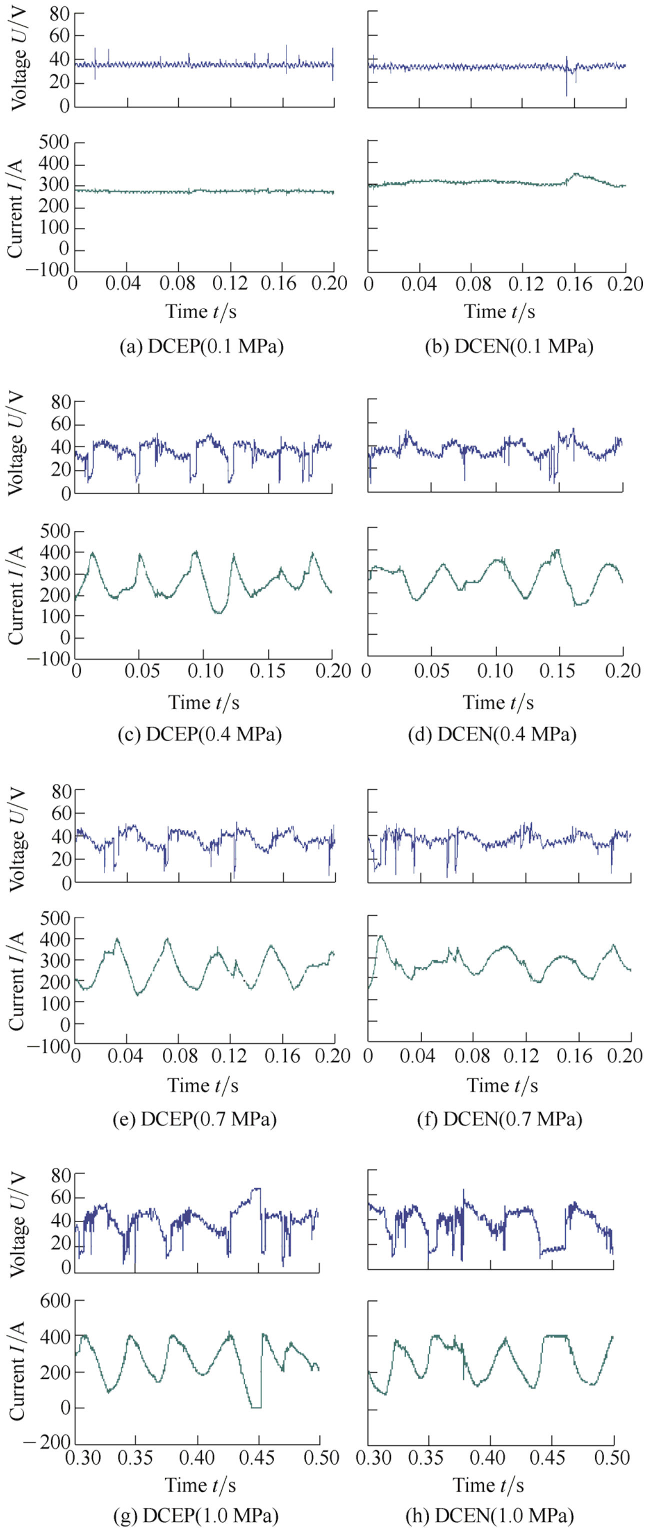


Fig. 7 Waveforms of the welding current and arc voltage for GMAW with different polarities

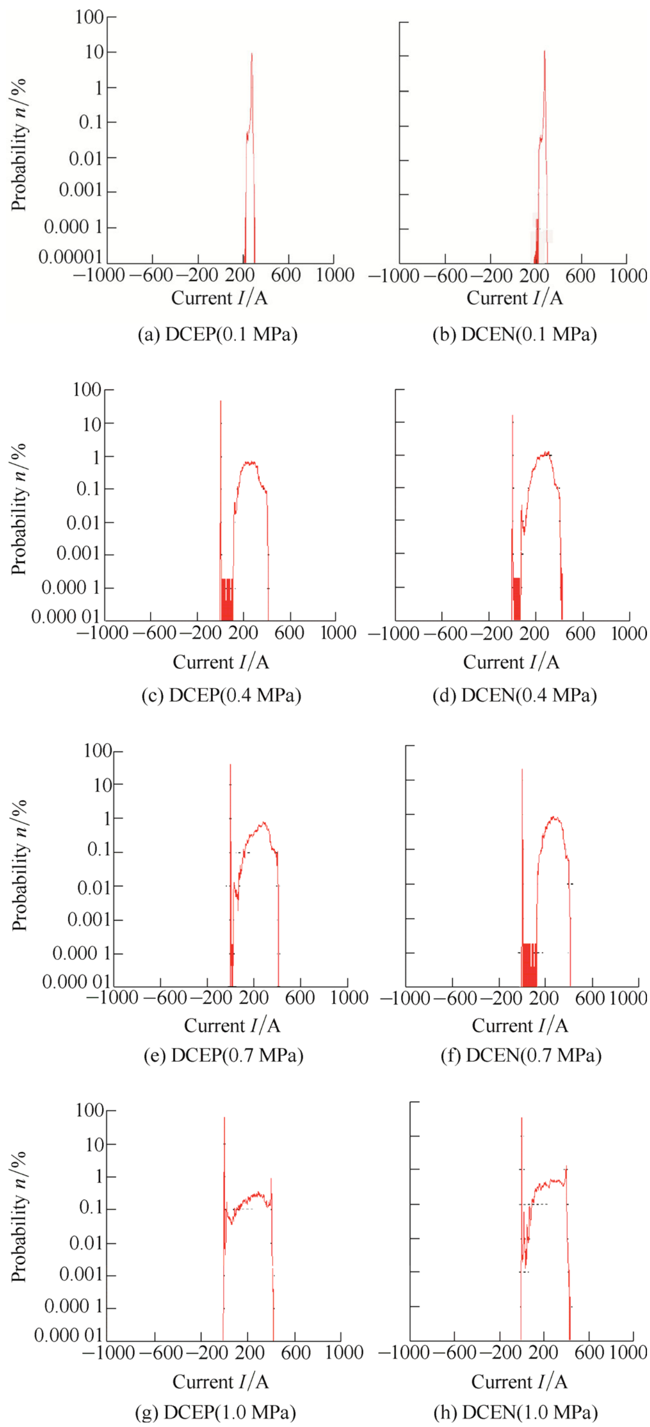


Fig. 8 Welding current probability density distribution for GMAW with different polarities

5 Conclusions

(1) With the increased ambient pressure, welding spatters grow both in quantity and size during the GMAW procedure with DCEP polarity, while spatters are reduced for GMAW with DCEN polarity.

(2) When the ambient pressure is higher than 0.7 MPa, all the weld appearance, the waveforms of the welding current and arc voltage, and the welding current probability density show that the GMAW procedures with DCEN polarity have a desirable stability.

(3) Also with the increasing ambient pressure, the sizes of the weld bead geometry change a lot for the GMAW process with both polarities. The weld reinforcement and the penetration are increased, while the weld bead width is decreased.

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