Development of Ultra-low Spatter CO_2 Gas-shielded Arc Welding Process "J-STAR® Welding"†

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Abstract:

J-STAR® Welding is performed with an electrode negative polarity using a rare earth metal added wire in CO_2 gas shielded arc. In the welding current over 250 A, a conical arc plasma was formed from the wire tip, and the droplets that transfer to molten pool became fine and continuous, what is called "spray transfer," during J-STAR Welding. In the welding current under 200 A, application of waveform control of welding current realized periodic short circuit transfer. As a result, spatter generation was reduced to less than 10% in comparison with that of conventional CO_2 gas shielded arc welding method.

1. Introduction

Broadly speaking, there are three types of gas-shielded arc welding processes in application: MIG welding (Ar gas), MAG welding (a mixed gas of Ar and CO_2), and CO_2 gas-shielded arc welding (CO_2 gas). The type depends upon the shielding gas used during the welding. CO_2 gas-shielded arc welding, a process developed in the 1950s, has recently come into use as the mainstream through various improvements in welding power sources and welding materials. The drawback of this method is the abundant spattering during welding. Even with the cost benefits of CO_2 gas, the improvement of the welding work by arc stabilization is now regarded as an important task.

"J-STAR Welding," a method developed to meet the above-described requirement, has successfully reduced the amount of spatter to ultra-low levels by realizing a fine and continuous spray transfer[1-3]. The effect can only achieved, however, with the use of a relatively high current (250 A or more). A method for reducing spatter in low-current welding of steel sheets has not yet been developed.

In this research the authors examined a method for reducing spatter in the low current region by controlling the current by waveform control. Another attractive target is to obtain the uniform bead shape in the weld line direction, one of the beneficial properties attained by high-speed welding with a high current. Development toward high-speed, high-efficiency welding is therefore also expected. This paper describes the features of J-STAR Welding and various welding techniques based on the use of this welding process.

2. Ultra-low Spatter CO_2 Gas-shielded Arc Welding Process J-STAR Welding

J-STAR Welding is an abbreviation of JFE Spray Transfer Arc Welding. The conventional CO_2 gas-shielded arc welding process is performed with an electrode-positive (EP) polarity. J-STAR Welding, in contrast, requires the addition of an appropriate amount of rare earth element (REM) to the wire as an arc stabilizer and the adoption of an electrode negative (EN) mode reverse to the ordinary polarity.

2.1 Arc Phenomenon

One feature of the arc phenomenon in the free-transfer region of CO_2 gas-shielded arc welding is the increased arc concentration in the lower part of the droplet suspended from the leading end of the wire. This increased concentration leads to an irregular shaking of

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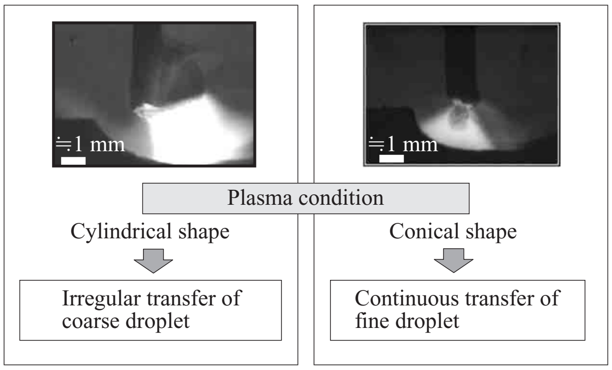
Table 1　Evaluation of effect of polarity/wire combinations on arc stability

Polarity	Welding wire	
	Si-Mn/Si-Mn-Ti	Si-Mn-Ti-REM
Electrode positive (EP)	Normal	Poor
Electrode negative (EN)	Poor	Excellent



(a) Electrode positive welding with Si-Mn-Ti wire　(b) Electrode negative welding with Si-Mn-Ti-REM wire

Fig. 1　Arc phenomena in CO_2 gas shielded arc welding

the droplet, which in turn causes spattering. Concretely, the spatter can be attributed to the scattering of the molten metal during the re-arcing after the droplet and molten pool are short-circuited, or after the droplet itself is scattered under the arc force. The coarsening of the droplets compounds the spattering effect. **Table 1** shows an evaluation of the stability of CO_2 gas-shielded arc welding when applying different combinations of polarity and wire. **Figure 1** shows arc phenomena during two processes: first, in the conventional welding process in EP mode; second, in the JFE-developed welding process in EN mode. In each case, the welding is performed at a welding current of 300 A with or without a REM-added wire. In the conventional EP welding, CO_2 gas-shielded arc welding with an Si-Mn/Si-Mn-Ti-based wire is less stable when no REM is added to the wire, compared to the case when REM is added. In the EN welding plus the use of REM-added wire, the arc generation point is substantially displaced and a coarser droplet is formed, resulting in an unstable arc and increased spatter. In EN welding, an ideal conical arc terminating in the wire tip is formed with the use of an Si-Mn/Si-Mn-Ti-based wire treated with an appropriate amount of REM, and the micro-droplets in the spray are smoothly transferred onto the base-metal sheet side without shaking from the tip.

2.2 J-STAR Welding Wire "KC-500"

Table 2 shows the chemical composition of the KC-500 wire for J-STAR Welding. KC-500, the same

Table 2　Chemical composition of steel welding wire

(mass%)

Type	C	Si	Mn	P	S	Ti	Other
Si-Mn-Ti-REM KC-500	0.05	0.7	1.6	0.01	0.01	0.2	REM

JIS Z 3312, YGW11

Table 3　Chemical composition and mechanical properties of deposited metal

Chemical composition (mass%)					Mechanical properties			
C	Si	Mn	P	S	0.2% proof stress (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Absorbed energy at 0°C (J)
0.06	0.40	0.96	0.01	0.01	470	560	32	160

material as YGW11 in JIS Z 3312, contains a trace amount of added REM.

Table 3 shows the results of a total deposited metal test of CO_2 gas-shielded arc welding with KC-500. The deposited metal obtained from KC-500 as a welding wire for 490 N/mm^2 class steels has sufficient strength and toughness. Tests have confirmed that the addition of a trace amount of REM into the welding wire leads to good welding characteristics with J-STAR Welding Wire regardless of the strength level, and the ready development of welding wires for application to 540 N/mm^2 class and 590 N/mm^2 steels.

2.3 Welding Characteristics of J-STAR Welding

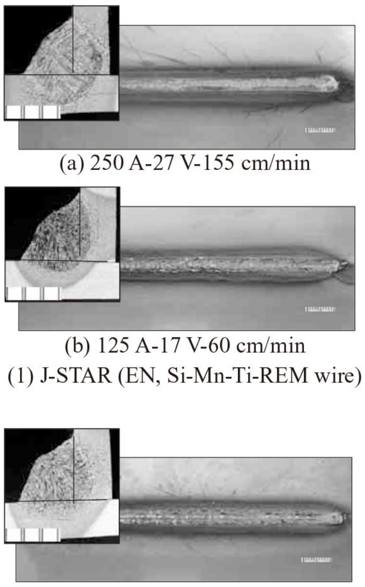
Tests have confirmed for the very first time that J-STAR Welding, a technique characterized by the formation of a stable conical arc terminating with the wire tip at its apex, realized a fine spray transfer optimal for droplet transfer in CO_2 gas-shielded arc welding. The advantages of this technique over conventional CO_2 gas-shielded arc welding are enumerated below.

(1) The generated spatter is reduced to 1/10 that generated by the conventional technique.
(2) No spatter adheres near the weld bead.
(3) The generated fumes are reduced to 1/2 the level generated by the conventional technique.
(4) The sound of the Arc is soft, with sound pressure reduced to 1/2 that of the conventional technique.

These advantages of J-STAR Welding are expected to improve working environments for welding lines and beautify the appearance of welded structures.

3. Welding of Steel Sheets

J-STAR Welding is capable of ultra-low-spatter welding through a process of fine spray transfer. A relatively


(a) 250 A-27 V-155 cm/min

(b) 125 A-17 V-60 cm/min

(1) J-STAR (EN, Si-Mn-Ti-REM wire)

(c) 160 A-18 V-60 cm/min

(2) Conventional (EN, Si-Mn wire)

Fig. 2 Welding bead appearance and cross-sectional macroscopic organization

high current (250 A or more) is required to obtain this effect. **Figure 2** (a) shows the weld appearance and cross-sectional macrostructure of a T fillet welded joint with a plate thickness of 2.0 mm. In spite of favorable performance features (a smooth weld bead shape with no spatter adherence) during high-speed welding at 155 cm/min, the penetration exceeds 80% of the thickness and there appears to be a risk of burning with thicknesses of 1.6 mm or less. Arc stabilization in a lower current region is required for the stable welding of steel sheets of lower thicknesses.

3.1 Spatter Reduction by Waveform Control of the Welding Current

Figure 3 shows the waveform control of current in low-current welding. In welding power sources designed to maintain constant-voltage characteristics, the welding current suppresses voltage variations by adjusting the output characteristics in direct opposition to the voltage variations. In addition to this basic function, waveform control detects a short circuit from an abrupt decrease in voltage and controls current output, thereby realizing stable droplet transfer and re-arcing. This is control technique is indispensable for low-current welding, where short-circuiting between the droplet and molten pools cannot be avoided.

The droplet in J-STAR Welding is coarser than the droplet in conventional CO_2 gas-shielded arc welding under low-current welding conditions, and the number of transfers in J-STAR Welding is decreased to only several transfers per minute. According to an investigation into waveform control parameters suitable for this coarse droplet peculiar to J-STAR Welding, the optimal parameters were a short-circuit transfer period (Ta) of 10 ms and a re-arc current (Ib) of 400 A[4]. The number of transfers was approximately doubled, as the current decreased gradually in the arc period.

Figure 4 shows variations in the waveform of current and voltage and the short-circuit transfer cycle. In conventional EP welding, no great difference is observed in the variations in the short-circuit transfer cycle ascribable to the difference in welding wire composition. In EN welding, however, the use of a wire with a trace amount of added REM reduced the variations in the short-circuit transfer cycle twofold and the application of optimum waveform control reduced the variations six-fold.

Figure 5 shows the relationship between welding current and the amount of generated spatter. The

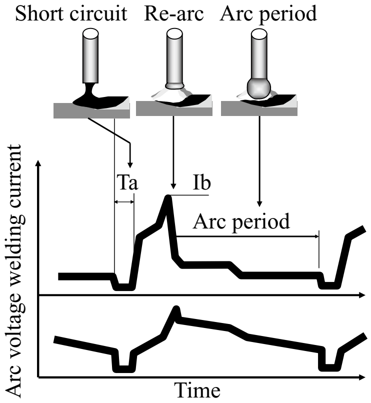
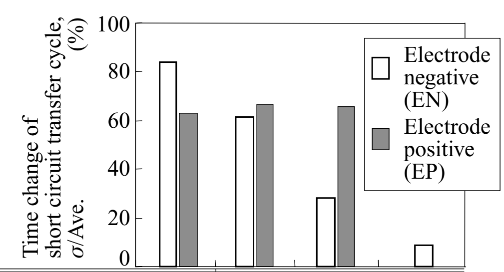
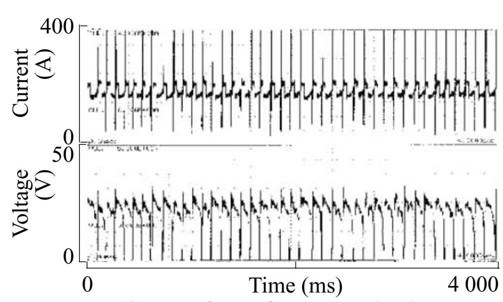


Fig. 3 Waveform control of welding current



Welding wire type	Si-Mn	Si-Mn-Ti		
	REM non addition		REM addition	
Waveform control	Non-control			Control

(a) Time change of short-circuiting-transfer cycle



(b) Waveform of current and voltage

Fig. 4 Short circuit transfer cycle

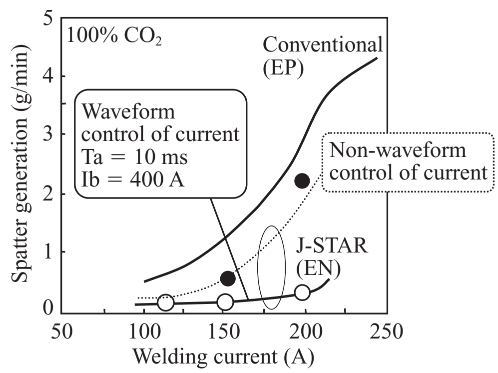


Fig. 5 Relationship between welding current and spatter generation

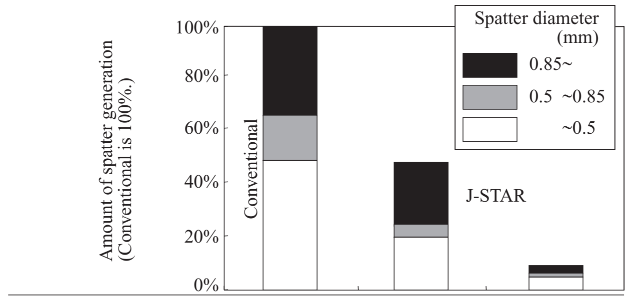
application of waveform control substantially reduced the amount of generated spatter in the welding current region of 200 A or less[4].

3.2 Applicability of New Waveform-Control Power Source

The high-speed inverter circuits and digital control techniques have led to dramatic improvements in the characteristics of recent welding power sources and the development of a power source suitable for the arc characteristics of EN welding. This new waveform-control power source accurately predicts the generation of a re-arc by detecting the bridging constriction of the short-circuit transfer, enabling rapid-decrease control of the arc current, and adopting the controlled bridge transfer (CBT) method for controlling the arc current after the generation of a re-arc[5]. The adaptability of this new power source to J-STAR Welding was investigated.

Figure 6 shows the amount of generated spatter and the particle diameter distribution of the spatter. Tee joints of 2.0 mm thick sheets were fillet-welded with a weld torch angle of 45°, forehand welding of 10°, and a wire extension of 12 mm. In J-STAR Welding under high-current, high-speed welding conditions (250 A, 27 V, 155 cm/min) with an REM-added wire, the amount of generated spatter was dramatically reduced to 49% of the level measured in standard welding conditions (160 A, 18 V, 60 cm/min). In J-STAR Welding under low-current, low-speed conditions (125 A, 17 V, 60 cm/min) with the use of the new power source, the amount of spatter was reduced to only 10%.

Figure 2(b) shows the weld bead appearance and cross-sectional macrostructure obtained under the low-current, low-speed conditions. The penetration is suppressed to approximately 20% of the plate thickness, and J-STAR welding is adequately applicable to the welding of thinner-gauge steel sheets. No spatter adheres to the test specimen. The reductions in spattering with J-STAR welding are expected to reduce the man-hours required



Welding wire type		Si-Mn	Si-Mn-Ti	
		REM non addition	REM addition	
Welding conditions	Polarity	Electrode positive	Electrode negative	
	Welding current	160 A	260 A	125 A
	Arc voltage	18 V	27 V	17 V
	Welding Speed	60 cm/min	155 cm/min	60 cm/min
	Waveform control	Non-control	Non-control	Control

Fig. 6 Particle diameter and amount of emergence of spatter

for spatter removal and to improve the appearance and paintability of automobile underbody parts that require welding.

4. Conclusions

Thanks to its fine spray transfer in a high-current region and adoption of a new waveform-control power source in a low-current region, J-STAR Welding permits ultra-low spatter welding in a wide current range. As an added benefit, J-STAR welding reduces the man-hours required for the removal of adhered spatter after welding, an unavoidable task after conventional CO_2 gas-shielded arc welding. It may be that the continuous transfer of fine droplets, a phenomenon that stabilizes arc current values, is also effective in stabilizing the quality of the welded metals and shape of weld beads. J-STAR Welding is expected to be applied for the assembly of steel sheets in the future.

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