# Robot Welding Process for Medium and Heavy Plate

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*Welding processes are always required to have high-efficiency, quality stability, and reduced costs. The advanced controllability of the welding power sources has enabled the control of the output waveform, using an advanced control law, which has realized a new process with high added value for medium and heavy plates, the Ultra-High Current GMAW process, tandem arc welding and "REGARC™". The Ultra-High Current GMAW process is a highly-efficient welding process using single arc and offers large leg length, low-spatter and deep penetration, using special flux-cored wire and unique waveform control. Tandem arc welding reduces spatter generation by 70 percent compared with conventional equipment, thanks to its new waveform control. The advantage of this welding process is a high deposition rate and high speed welding. "REGARC™" reduces spatter generation by 90 percent compared with the conventional process using $CO_2$ gas-shielded arc welding.*

## Introduction

Semi-automatic welding has been used more frequently in the field of medium and heavy plate welding, which requires a more sophisticated level of technology than that required for the thin sheet welding used, for example, in the automotive field. Recently, however, robotic welding is being increasingly used to improve welding efficiency, to compensate for the lack of skilled workers and to stabilize the quality. In such circumstances, higher efficiency, faster welding, lower spatter and lower cost are always being pursued, increasing the desire for new welding processes.

In 2010, Kobe Steel began selling SENSARC TM, note 1) AB500 (hereinafter, AB500), a digitally controlled power source exclusively designed for welding robots (**Fig. 1**).

Fig. 1 Appearance of SENSARC AB500

Table 1 Summary of newly developed welding process

| | Welding wire | Shielding gas | Characteristics |
|---|---|---|---|
| Ultra high current GMAW Process | FAMILIARC™ MX-A100D φ 1.4mm | Ar+20%$CO_2$ | One electrode<br>High-deposition rate<br>Big leg length<br>Low spatter |
| Tandem arc Welding | FAMILIARC™ MG-50R φ 1.2mm | Ar+20%$CO_2$ | Two electrodes<br>High-deposition rate<br>High-speed welding |
| REGARC™ | FAMILIARC™ MG-50REG φ 1.1mm | 100%CO2 | Low spatter<br>Low gas cost |

This power source has improved control capability compared with the conventional machines, enabling the control of output waveform in accordance with high-level control laws. This has made it feasible to implement various welding modes that have been difficult when using the conventional machines and to develop welding processes with high added value.

This paper introduces three welding processes with high added value made possible by the improved functions of AB500 (**Table 1**). The first process is a type of gas metal arc welding (GMAW), named the "Ultra-High Current GMAW", which has enabled high current and high deposition with one electrode; the second is "tandem arc-welding", a high-deposition high-speed welding process using two electrodes, which has significantly reduced spatter compared with the conventional process; and the last is REGARC TM, note 2), which has enabled extremely low spatter despite being a $CO_2$ welding process.

## 1. Welding system for Ultra-High Current GMAW [1), 2)]

### 1.1 Background

Recently, in fields involving the use of medium to thick plates, as is the case, for example, with construction machinery, there has been a strong need to improve efficiency by increasing the deposition rate with one electrode and thus improving operability. In response to this need, Kobe Steel began selling a welding system for the Ultra-High Current GMAW in October 2012. This section describes the Ultra-High Current GMAW system and explains the effects of its introduction, giving examples of its installation.

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note 1) SENSARC (SENSARC™) is a trademark of Kobe Steel.

note 2) REGARC (REGARC™) is a trademark of Kobe Steel.

### 1.2 Exclusive flux-cored wire, FAMILIARC™, note 3) MX-A100D

The major issue with the conventional high-current welding using carbon steel solid wire is the spatter generation caused by rotating transfer.[3] This is due to the wire extension that is melted by resistance heat, loses its rigidity before it reaches the arc generation point and is rotated by the electromagnetic force to scatter the droplet.[4)-6)] We therefore focused on the possibility that the flux portion of a flux-cored wire (FCW) plays the role of a "column" that prevents this rotation. The inner flux of an FCW allows almost no welding current to flow through it, making the outer metal sheath, the outer portion of the wire, melt first even with an increased current density, while the flux portion maintains its columnar shape. This, as a result, enables spray transfer in which the molten portion of the wire tip does not rotate (**Fig. 2**).[4)-6)] In addition, the flux was designed for high current welding with optimized characteristics including resistance against nitrogen pick-up and slag formation. This has led to the development of FAMILIARC MX-A100D, an FCW exclusively designed for the Ultra-High Current GMAW. **Table 2** shows, as an example, the chemical composition and mechanical properties of a weld metal deposited by this wire.

### 1.3 Control of current, voltage and waveform by AB500

As described, the FCW wire configuration can prevent rotating transfer in the wire melting phenomenon and achieves stable spray transfer. However, when welded with a general constant voltage characteristic, the wire results in irregular variation of the arc voltage and arc length as shown in **Fig. 3**. It has been confirmed that this is caused by the fact that the outer metal sheath in the wire extension is melted by excessive arc heat and Joule heat before it reaches the arc generation point, making it difficult for the wire to maintain its shape and causing it to drop irregularly.[4)-6)]

In order to improve this phenomenon, waveform controls of the welding current and arc voltage have been adapted to stabilize the molten state of the wire extension. As a result, an exclusively designed waveform control incorporating low-current periods provided cyclically to suppress the heat input of the arc heat and Joule heat to the wire has enabled the stabilization of the arc length.

note 3) FAMILIARC (FAMILIARC™) is a trademark of Kobe Steel.

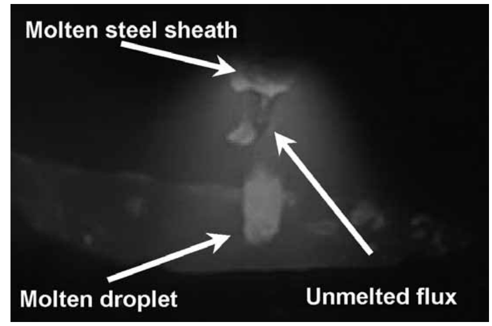


Fig. 2 Observation of droplet transfer using the developed process

Table 2 Chemical compositions and mechanical properties of weld metal

| C | Si | Mn | P | S | YS (MPa) | TS (MPa) | El. (%) |
|---|---|---|---|---|---|---|---|
| 0.06 | 0.81 | 1.61 | 0.01 | 0.007 | 482 | 604 | 25 |

Welding condition : 500A, 39V, 60cm/min, 4layers-8passes

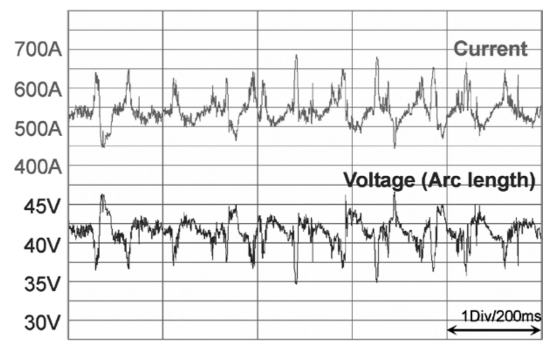


Fig. 3 Current and voltage waveforms in unstable welding arc with non-pulsed constant-voltage power source

### 1.4 Configuration of the welding system for implementing Ultra-High Current GMAW

**Fig. 4** is a schematic diagram showing the configuration of the system for the Ultra-High Current GMAW. The specifications of the system are shown in **Table 3**.

#### 1.4.1 AB500 parallel operation system

In order to weld with a current exceeding 500A, the welding power source must output more power than a conventional machine. Therefore, two AB500s, each capable of outputting 500A, have been connected in parallel so as to divide the total output current in half and achieve a high maximum output current of 700A with a utilization of 100%.

The welding power sources have been allocated to a master and a slave such that the master, receiving a command from the robot control panel, sends the command to the slave in order to control it. Thus, like the conventional panel, the robot control panel still controls only one welding power source. Therefore

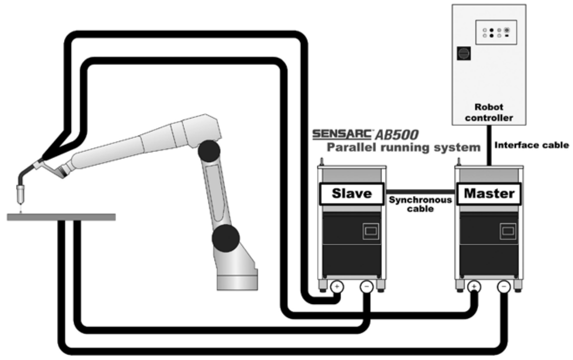


Fig. 4 Configuration sketch of Ultra-High current GMAW Process welding system

Table 3 Specifications of Ultra-High current GMAW Process welding system

| | | |
|---|---|---|
| Manipulator | | ARCMAN MP,XL |
| Welding power source SENSARC$^{TM}$ AB500 Parallel system | Rated output current | 700(A) |
| | Usage rate | 100(%) |
| | Load voltage | 55(V) |
| Maximum wire feed rate | | 30.0(m/min) |
| Welding torch for Ultra high current welding RTW601 | Rated current | 600(A) |
| | Usage rate | 100%(Ar+20%$CO_2$) |
| | Application of wire diameter | 1.4(mm) |
| | Cooling method | Water-cooling |
| Welding wire | Brand | FAMILIARC MX-A100D |
| | Wire diameter | 1.4(mm) |
| | Maximum deposition rate | Approximately (300g/min) |
| Shielding gas | | Ar+20%$CO_2$ |

the users need not concern themselves about the fact that two power sources are running, but can operate the system in the same manner as they would operate a single welding power source.

### 1.4.2 Welding torch, RTW601, for high current

Major problems arising in a welding torch with increased current include the heat generated by the electrical resistance of the power cable and increased radiant heat of the arc. In response, Kobe Steel has developed a new welding torch for high current, RTW601 (**Fig. 5**).

As a measure against resistance heat generation in the power cable, the two welding power sources are connected by conventionally used power cables to a power supply port of the torch, in which the cables from each power source take separate paths to suppress heat generation as well as to facilitate heat release (Fig. 4).

Increased current enhances the heat radiated from the arc, making the peripheral temperature of the contact tip higher than that hitherto achieved in an arc atmosphere of 600A. Once the temperature of the contact tip becomes too high, the wear of the tip itself is accelerated, which destabilizes the power supply to the wire, increasing the scattering of spatter, and spoiling the appearance of the bead. Therefore, in order to maximize the effect of the improved efficiency of the Ultra-High Current GMAW, while minimizing the frequency and times of the contact tip changes, it is essential to suppress the temperature rise of the contact tip. To increase its heat releasing efficiency, the RTW601 has increased contact area between its water-cooled tip body and contact tip, as well as an enlarged tip shape and increased inner diameter to increase the surface area. This has achieved wear resistance, in terms of the amount of molten metal, comparable with or better than that achieved by the conventional process.

Fig. 5 Appearance of RTW601

## 1.5 Effect of Ultra-High Current GMAW

### 1.5.1 Reduction in spatter generation rate

**Fig. 6** shows the amounts of spatter generated by the conventional process using a solid wire and by the Ultra-High Current GMAW. In the conventional process, a wire melting rate exceeding 150g/min (welding current 450A) triggers rotating transfer, which abruptly increases the spatter generation. In contrast, the Ultra-High Current GMAW maintains stable spray transfer regardless of the welding current, enabling low spatter in the high-current region.

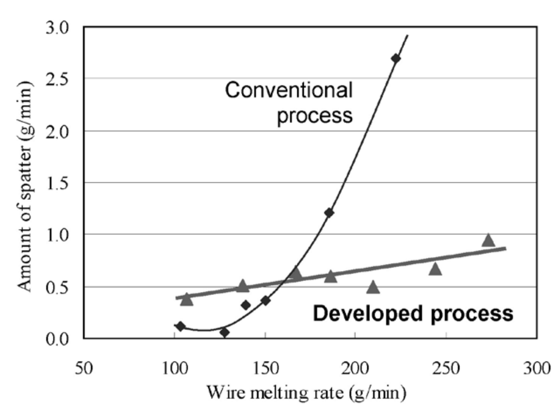


Fig. 6 Comparison of spatter generation rate (Bead on plate) (Welding condition: 1.4mm dia., Ext: 28mm; Ar+20%$CO_2$; 60cm/min)

### 1.5.2 Improvement in porosity resistance

**Fig. 7** compares the nitrogen content in the welding metal prepared by the conventional process using solid wires with that prepared by the Ultra-High Current GMAW. As described above, the conventional process results in rotating transfer in the high-current region. The softened wire tip is rotated by the magnetic force, which also rotates the arc. Together with this, the shielding gas atmosphere is also agitated and picks up the surrounding air more easily. This is considered to be the cause of the significantly increased nitrogen content in the welding metal. This as a result increases the risk for blowholes at wire melting rates of 200g/min or higher.

Meanwhile, in the case of the Ultra-High Current GMAW, stable spray transfer is achieved even in the high-current region, which minimizes the amount of surrounding air picked up and thus suppresses the nitrogen content of the welding metal. Furthermore, the flux composition of the newly developed wire is designed for resistance against nitrogen pick-up, which prevents porosity defects at a wire melting rate of 300g/min.

### 1.6 Application examples

The following describes examples of the application of the Ultra-High Current GMAW: namely, flat fillet welding and V groove welding. The steel materials used were SS400, and the tip to base-material distance was 28mm.

### 1.6.1 Flat fillet welding; leg length 15mm; single-pass welding

**Table 4** shows the welding conditions for the conventional process and the Ultra-High Current GMAW, **Fig. 8** shows their cross-sectional macrographs, and **Fig. 9** shows the appearance of their beads. In order to obtain a leg length of 15mm by the conventional single welding, two-pass welding must be performed. On the other hand, the high deposition rate of the Ultra-High Current GMAW achieves the same leg length with only one pass, the welding efficiency being increased by a factor of 2.4. Despite its high current of 600A, the newly developed process exhibits a clean bead appearance with almost no spatter adhesion. It should be noted that this process has achieved a deep penetration depth of 5.0mm, a depth difficult to achieve using the conventional high deposition process of tandem welding.

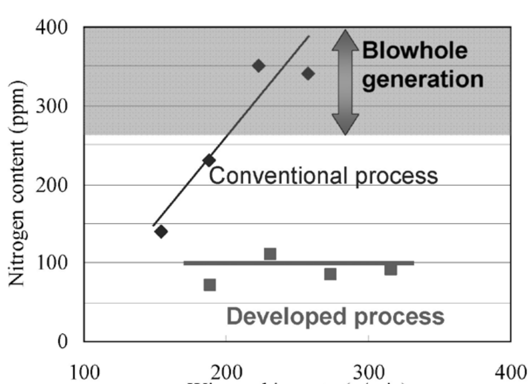


Fig. 7 Comparison of nitrogen content in fillet weld metal (1.4mm dia., Ext: 28mm, Ar+20%$CO_2$; 60cm/min)

### 1.6.2 50 degree V groove; plate thickness, 16mm; root opening, 5mm

**Table 5** shows the welding conditions for the conventional process and the Ultra-High Current GMAW, **Fig.10** is a schematic diagram of the welding pass sequence, and **Fig.11** shows a cross-sectional

Table 4 Comparison of welding conditions in flat fillet welding

| | Conventional process* | | Developed process |
|---|---|---|---|
| Layers | 1 | 2 | 1 |
| Welding current(A) | 420 | 420 | 600 |
| Deposition rate(g/min) | 125 | 125 | 268 |
| Welding Speed(cm/min) | 34.0 | 23.0 | 33.0 |
| Ratio of weld efficiency | 1 | | 2.4 |

*Solid, 1.4mm dia., MAG, Ext 25mm

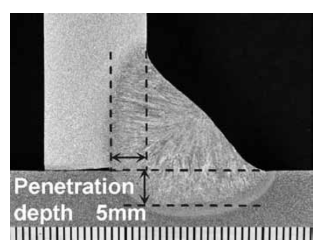


Fig. 8 Macrostructure of cross section

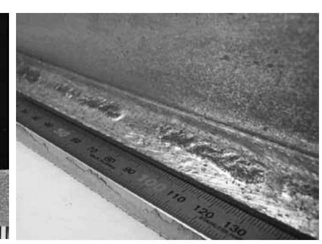

Fig. 9 Bead appearance

Table 5 Comparison of welding conditions in single V groove welding

| | Conventional process* | | | | Developed process | | |
|---|---|---|---|---|---|---|---|
| Layers | 1 | 2 | 3 | 4 | 1 | 2 | 3 |
| Welding current(A) | 320 | 360 | 360 | 360 | 530 | 530 | 390 |
| Deposition rate(g/min) | 88 | 101 | 101 | 101 | 255 | 255 | 153 |
| Welding speed (cm/min) | 32.0 | 28.0 | 24.0 | 19.0 | 48.0 | 37.0 | 25.0 |
| Ratio of weld efficiency | 1 | | | | 1.8 | | |

*Solid, 1.4mm dia., Ext 25mm

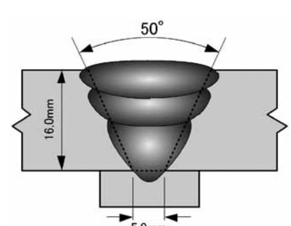


Fig.10 Welding pass sequence

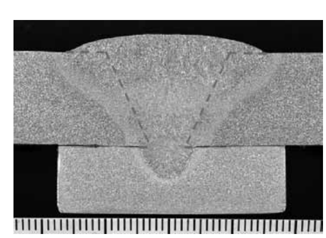

Fig.11 Macrostructure of cross section

macrograph. The conventional single welding requires four passes of welding, while the new process reduces the number of passes to three with increased welding speed thanks to its high deposition rate, increasing the welding efficiency by a factor of 1.8.

## 2. Tandem arc welding

### 2.1 Background

In 2001, Kobe Steel started selling a robot system adapting tandem arc welding having two electrodes with one pool to achieve increased welding speed and sound welding bead at the same time. The company continued to develop new technologies with new functions and has achieved improved welding operability by improving the functions of AB500. This section focuses on the newly developed waveform control technology and its effect.

### 2.2 New arc-length control of AB500

#### 2.2.1 Synchronous amplitude modulation control

Tandem arc welding, using two electrodes for generating arcs, adapts pulse welding to reduce spatter; in pulse welding the arc length of the leading electrode is controlled by frequency modulation. In order to suppress arc interference between the two electrodes and improve welding stability, the pulse frequencies of the two electrodes must be synchronized. For this purpose, a conventional machine controls the arc length of its trailing electrode by amplitude modulation of the peak current, rather than by frequency modulation. However, if amplitude modulation based solely on the peak current is adapted, the newly developed process lacks the current required for controlling the arc voltage. This may also cause an inability to maintain the pulse waveform to realize low spatter, a feature of pulse welding, causing difficulty in keeping the desired arc length, increasing spatter.

To deal with this issue, AB500 is equipped with a "synchronous amplitude modulation control", a new way of controlling the arc length of the trailing electrode. The new method controls the arc length by modulating not only the peak current but also the base current (**Fig.12**). As a result, both the leading and trailing electrodes have greater tolerance for outer disturbance and can maintain their arc lengths within a wider range of conditions. In the case of conventional machines, a change in the welding condition of the leading electrode often causes changes in the welding current and arc length of the trailing electrode. The

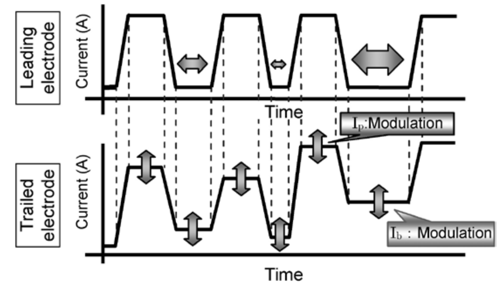


Fig.12 Image of synchronous amplitude modulation control

newly developed control has resolved this issue, facilitating the adjustment of welding conditions.

#### 2.2.2 Advanced load characteristics control (arc length control of the trailing electrode)

In tandem arc welding, it is important that a bulge of molten metal formed between the two arcs be maintained so as to realize arc stability and sound bead shapes (**Fig.13**).[7)]

In the case of conventional machines, when the state of the molten pool is changed by the arc-length control working against the outer disturbance of the leading electrode, the arc length of the trailing electrode must be fine-tuned for the change. This often causes a further change in the molten pool, which disturbs the bulge of molten metal and destabilizes the arc.

For this reason, Kobe Steel has developed a new "advanced load characteristics control," a type of arc-length control for the trailing electrode. This new control alleviates the effect of outer disturbance on the basis of the moving average of the feedback current, used as a determinant factor for the control target of the arc length, and suppresses the effect of the arc-length control on the molten pool (**Fig.14**).

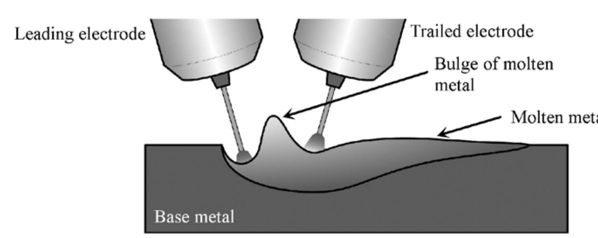


Fig.13 Welding arc and molten metal in tandem arc welding

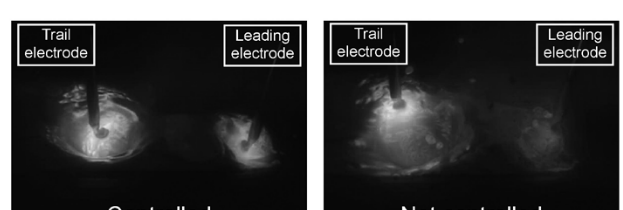


Fig.14 Example of advanced load characteristics control

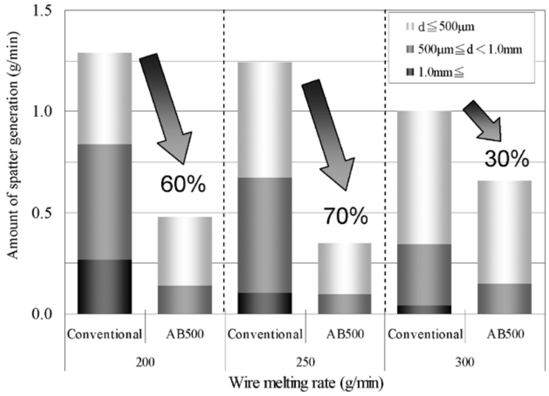


Fig.15 Comparison of spatter generation rate in flat fillet welding

### 2.3 Effects of introducing tandem arc welding (reduced spatter generation rate)

Tandem arc welding using AB500 has remarkably improved the arc stability and welding workability thanks to the two newly developed waveform controls described in section 2.2. It has also significantly reduced the formation of spatter (up to 70% reduction) and decreased the size of the spatter (**Fig.15**).

## 3. REGARC [8)]

### 3.1 Background

Carbon dioxide and argon are mainly used as shielding gas for arc welding, the former having the merit of costing much less than the latter. Conventional carbon dioxide arc welding, however, is inevitably accompanied by large grain spatter. Against this background, Kobe Steel focused on a new droplet transfer control using a special pulse current waveform and has succeeded in the development of a welding system, REGARC, for achieving low spatter by regular droplet formation and detachment.

This section explains the features of the REGARC welding system and the effects of its introduction.

### 3.2 Specifications of REGARC welding system

**Table 6** shows the specifications of the REGARC welding system. The FAMILIARC MG-50REG is a new welding wire developed exclusively for REGARC. This wire features excellent feedability with an optimized wire composition and wire diameter, which has enabled the enlarged range of welding conditions for achieving regular droplet transfer. REGARC has been made possible also by the advanced current voltage waveform control law using the welding power source AB500.

Table 6 Specifications of REGARC welding system

| | |
|---|---|
| Welding power source | SENSARC AB500 |
| Shielding gas | 100%$CO_2$ |
| Welding wire | FAMILIARC MG-50REG $\phi$ 1.1mm |
| Maximum wire melting rate | 145(g/min) |
| CTWD | 25(mm) |
| Applicable welding position | Flat fillet, Horizontal fillet |

### 3.3 Droplet transfer control in REGARC

In the case of conventional carbon dioxide arc welding, a number of large grains of spatter are generated. This occurs in two ways. In the first case, a droplet becomes short-circuited with the molten pool, causing the arc to be extinguished; and as soon as the short circuit is released and the arc is re-ignited, parts of the droplet and molten pool are blown off (**Fig.16** (A)). In the second, the arc is generated in a focused manner at the lower portion of a droplet, which pushes the droplet up in the opposite direction from the arc, making the droplet difficult to detach, and it grows larger. This droplet is further pushed up by the reaction force of the arc and detaches as a spatter of large grains. This phenomenon is generally referred to as globule transfer (Fig. 16 (B)).

To deal with this issue, REGARC prevents the droplet from being pushed up, thanks to its welding current with a special pulsed waveform, at each step of droplet formation and detachment in the process of carbon dioxide arc welding. This has enabled the regular transfer of the droplet into the molten pool before the droplet grows too large, suppressing the short-circuit and scattering of large granular spatter (**Fig.17**).[9)]

### 3.4 Effect of introducing REGARC

#### 3.4.1 Low spatter

**Fig.18** compares the spatter generation rate of conventional carbon dioxide arc welding and REGARC. REGARC resulted in a significantly

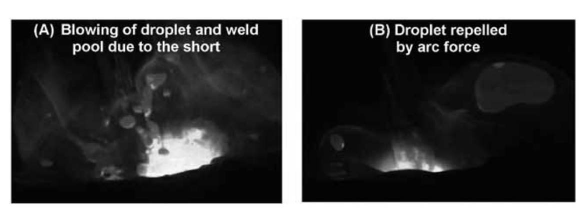


Fig.16 Spatter generation with conventional $CO_2$ arc welding

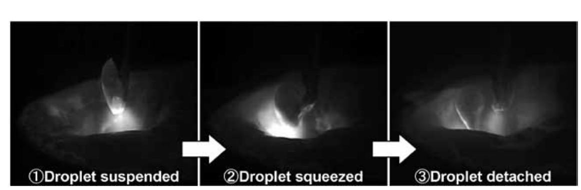


Fig.17 Droplet transfer of REGARC

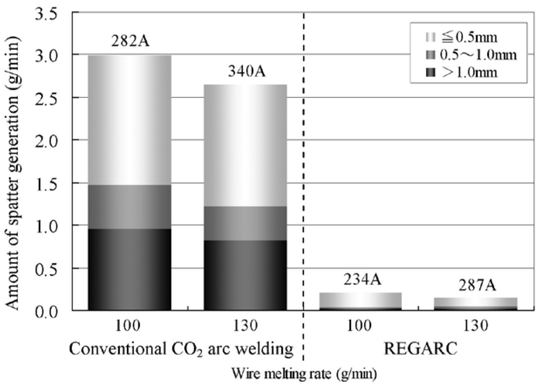


Fig.18 Comparison of spatter generation rate in flat fillet welding

reduced rate of spatter generation, one-tenth of the rate for conventional carbon dioxide arc welding. In addition, the spatter, having a much smaller grain size, is cooled and solidified in the air before it reaches the base material, making it less likely to adhere to the surface of the base material (**Fig.19**). Hence, users of carbon dioxide arc welding can expect a shortened backend process and improved work environment as benefits of the reduced spatter. Furthermore, those using mixed gas welding to reduce spatter can realize a reduction in cost by switching to the less expensive carbon dioxide.

### 3.4.2 High melting rate / reduced heat input

For any given average current, the wire melting rate of REGARC is 20 to 25% higher than that of conventional carbon dioxide arc welding (**Fig.20**). This is because REGARC uses a pulse current that has a high effective current and an exclusive wire

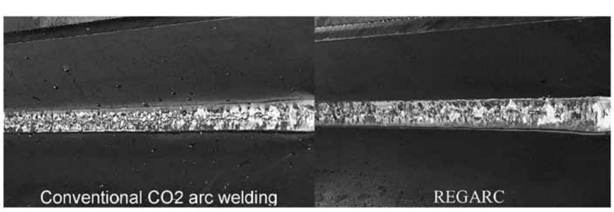


Fig.19 Comparison of adhered spatter in fillet welding

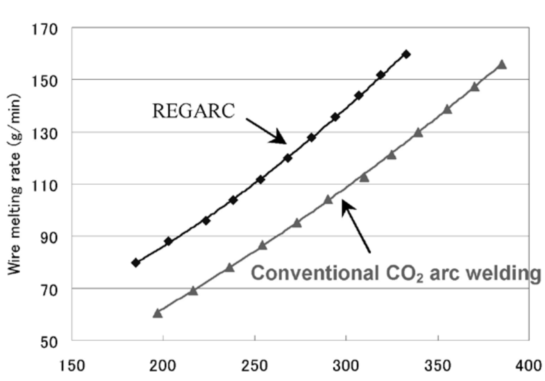


Fig.20 Comparison of wire melting rate

"FAMILIARC MG-50REG". Conversely, the welding current becomes smaller for a given melting rate, which prevents welding deformation due to heat input.

## Conclusions

Three welding processes with high added value for medium to thick plates have been explained. Kobe Steel has lined up tandem arc welding and the Ultra-High Current GMAW for high deposition welding to expand the company's menu of welding processes. These processes have their respective strengths, tandem welding having superior maximum welding speed and the Ultra-High Current GMAW having superior penetration depth with fewer welding deficiencies, enabling their application in accordance with the user's needs. In addition, REGARC has achieved extremely low spatter, something hitherto considered difficult to achieve with general carbon dioxide arc welding. These welding processes are strongly expected to improve the efficiency of welding work for users and their work environment, which eventually leads to cost reduction.

We will strive to provide new welding solutions through various approaches combining welding consumables, application technologies and robot systems.

## References


1) K. Tsuji et al. Welding Technology. Sanpo Publications Inc., 2012-11, Vol.60, p.112-117.
2) K. Tsuji. Kobe Steel Homepage. Yousetsu-dayori Gijutsu-guide, Gijutsu-report (in Japanese). (Welding News, Technical Guidance, Technical Report) 2012-11, Vol. 52.
3) S. Izutani et al. International Institute of Welding 2006. XII Doc. 212-1090-06.
4) Y. Yuan et al. Preprints of the National Meeting of JWS 2010-9-7. Japan Welding Society, 2011, p.146-147.
5) Y. Yuan et al. "Development of High Current GMAW Process Preventing Rotating Transfer". 214th Technical Commission on Welding Processes, 2011, No. SW-3374-11.
6) R. Suzuki. "State of the Arc of Process Control of Molten Droplet and Pool in Gas Metal Arc Welding". Journal of the Japan Welding Society, 2010, Vol.79, No.6, p. 27-33.
7) M. Yokota et al. R&D Kobe Steel Engineering Report. 2004, Vol.54, No.2, p.81.
8) A. Ogawa. Kobe Steel Homepage. Yousetsu-dayori Gijutsu-guide, Gijutsu-report (in Japanese). (Welding News, Technical Guidance, Technical Report), 2011-12, Vol.51.
9) K. Yamazaki et al. Preprints of the National Meeting of JWS 2010-3-29. Japan Welding Society, 2010, p.138-139.