Developments in Flux-cored Wire for Gas-shielded Arc Welding

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The use of flux-cored wires for gas-shielded, arc welding has increased dramatically over the past 25 years in Japan. Flux-cored wires occupy more than 30% of the total amount of arc welding materials consumed domestically. Flux-cored wires are used especially in the shipbuilding industry and their cost-effectiveness has expanded their use in other industries dramatically. This article outlines the development, production, and applications of flux-cored wires for mild steel, 490MPa class high strength steel and stainless steel.

Introduction

Arc welding technologies in Japan have developed dramatically since the time when an application of covered electrodes was first considered for shipbuilding about 90 years ago. The history of welding technology has always been the history of pursuits for higher "efficiency and speed" of welding processes. Welding materials, originally started as covered electrodes, have developed into more efficient submerged arc welding materials and gas-shielded arc welding materials to which automatic welding by robots is easier to apply.

The gas-shielded arc welding materials are mainly classified into solid wires and flux-cored wires (FCW), and above all, the use of the FCW is increasing year by year because of its workability and efficiency. **Figure 1** shows the result of a survey of the application ratio of welding materials in various fields.[1] The application ratio of FCW is highest in the vessels/marine structure and exceeds 30% in the average of all fields except for vehicles/automobiles.

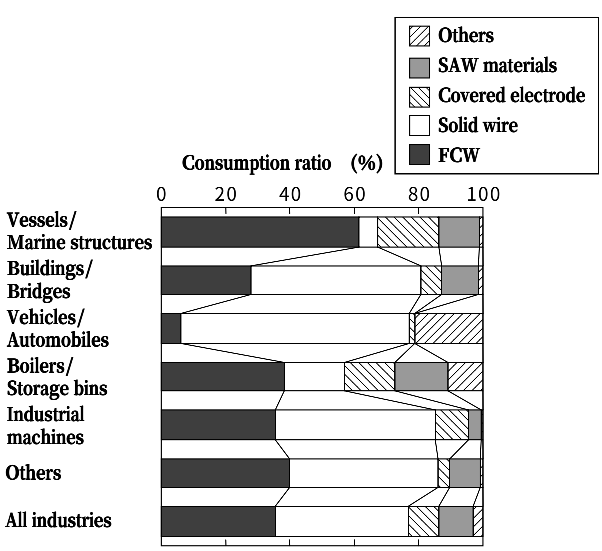


Fig. 1 Investigation results on application ratio of welding materials in various fields

This article describes the recent trend in the development of the FCW, which now holds the major position in the welding materials. A special focus is put on the FCW for carbon steels with some focus on the FCW for stainless steels.

1. History of the FCW for carbon steels

The history of the FCW to date roughly consists of 3 stages.[2] In the first stage, wires with large diameters (such as ϕ 3.2 mm) were mainly used, however, their application was limited to overlaying and others because of the limitation in weldability and adaptability.

The application has been expanded dramatically since the beginning of the second stage in 1979, and smaller diameter wires (such as ϕ 1.2 mm) were developed including the slag-type FCW for all-positions. The slag-type FCW for all-positions has contributed to the reduction of welding cost significantly, and is widely used for shipbuilding as the most versatile wire for semi- and full-automatic welding. **Photo 1** shows an example of the application of the slag-type FCW for all-positions.

The third stage, which started in 1985, has further expanded the applicability of FCW with the advent of the metal-type FCW. With the tide of automatization and robotization of the welding processes, the applications of the metal-type FCW have expanded not only in the shipbuilding area

Photo 1 Application of slag-type FCW to vessels (DW-100)

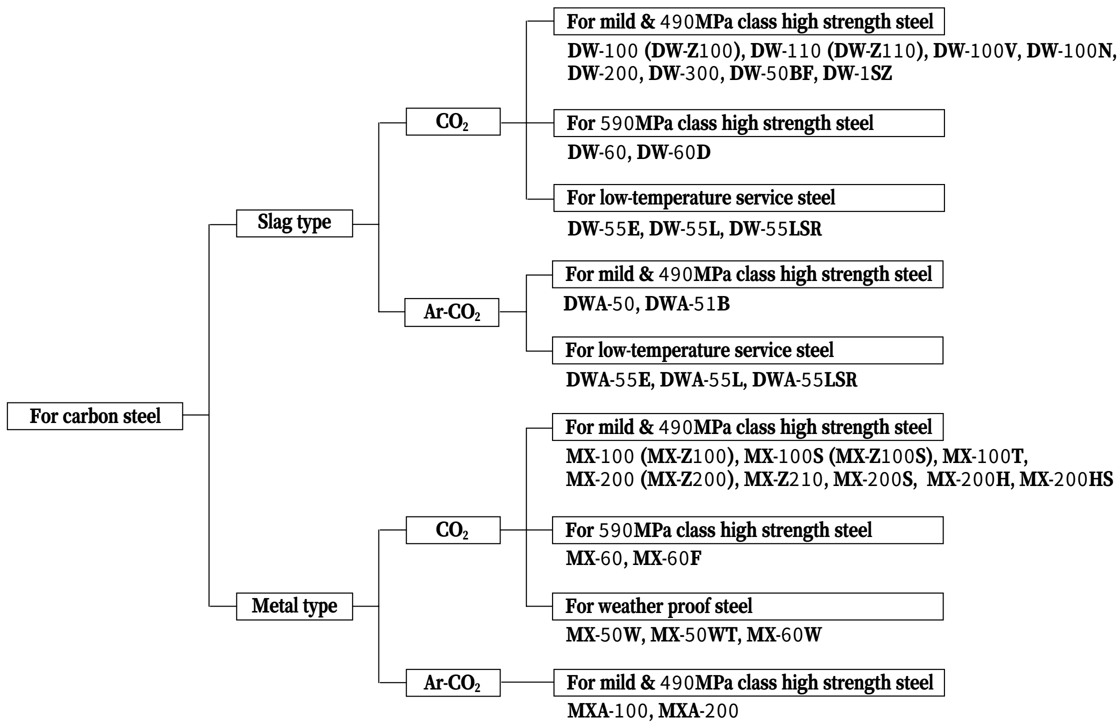


Fig. 2 Classification of FCW for carbon steel

but also into other areas, because of its high welding speed and less spatter generation along with the low slag characteristics inherent to the MAG welding solid wires. In 1989, the current technological base for the welding of mild and 480MPa class steels was established with the development of the metal-type FCW for primer-coated steel plates. The FCW causes less porosity in the fillet welding of primer-coated steel plates, which is often used in the shipbuilding and bridge construction. The technology has been developed for various kinds of steels including the 590MPa class high strength steels, steels for low temperature service, and stainless steels, and is applied to various FCW methods such as mixed-gas arc welding. **Figure 2** shows the classification of FCW for carbon steel.

2. Properties required of the FCW for carbon steel

As described previously, the history of welding technology has always been the history of pursuits for higher "efficiency and speed" of the welding processes, and it has been the major subject also for the FCW for carbon steel, to achieve the high deposition rate, high-speed welding and robotization. **Figure 3** shows the market need for the FCW.[3)] The needs for less-spatter, less-fume, less-porosity, wire-feedability, and high-speed rank high, with the less-fume being the only requirement from environmental stand point and

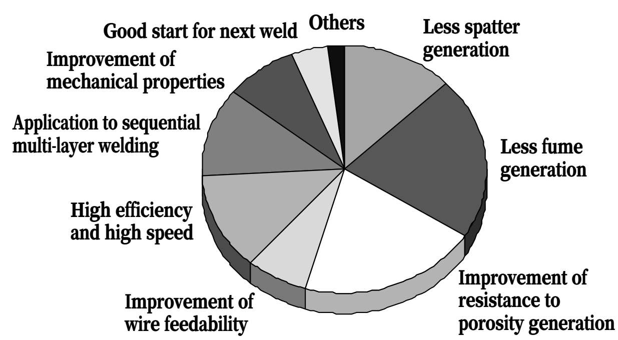


Fig. 3 Market needs for welding materials

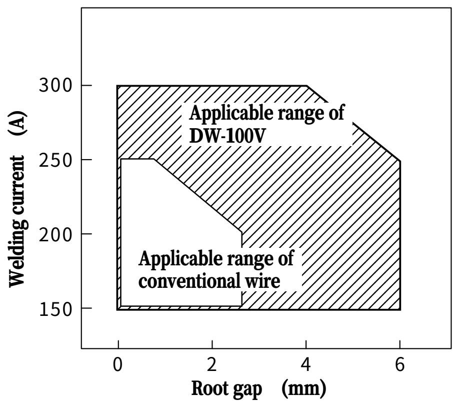
the rest being the requirements from the need for higher efficiency and higher speed.

The development of new FCWs has become a major subject. This includes the development of new welding processes, for even higher efficiency, and the development of a new FCW for applications including "metal working", to which the conventional FCW is not applicable. More specifically, the subject includes development of FCW processes for the multiple electrodes welding and for the post weld heat treatment (PWHT) which was not possible for the conventional FCW.

3. Developmental trends of the carbon steel FCW

3.1 Pursuits for higher efficiency and higher speed

The slag-type FCW is featured by its good



Wire dia. : ϕ1.2 mm, Shielding gas : 100% CO_2,
Vertical-up fillet welding

Fig. 4 Applicable range of DW-100V

workability in all directions, and is widely used in shipbuilding, which requires a lot of vertical and overhead welding postures. Recently, a new FCW developed for robot welding has wider range of applicable welding conditions for the vertical welding because its molten crater is more resistant against dropping as shown in **Figure 4**.[4)] The developed wire (DW-100V) holds molten metal better because the viscosities of the molten metal and slag are higher and melting point of the slag is also high. This increases the efficiency of the vertical-up robot welding.

The common welding practice in the shipbuilding is the "one-side gas-shielded welding" using ceramic backing plates placed behind the welding grooves for ease of the process. However, the FCW for all directions tends to have higher susceptibility to the hot-crack compared to the solid wires, and tends to result in the "solidification crack" as shown in **Photo 2**, especially in the first layer of the one-side welding at a high current. Because of this, only limited amount of current can be applied to the process, lowing the efficiency and quality. In order to solve this problem, the FCW with higher hot-crack resistance has been developed lately.[5)] The developed wire (DW-100N) has an optimized chemical composition in the first welded layer to achieve a high hot-crack resistance. **Table 1** shows the hot crack resistance of the DW-100N in the first layer of a one-side welding on a flat position. The DW-100N with groove angle of 40 degree allows a high current, high efficiency welding at the maximum current of 260 A (ϕ 1.2 mm) for the first layer.

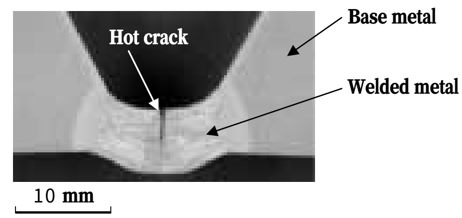
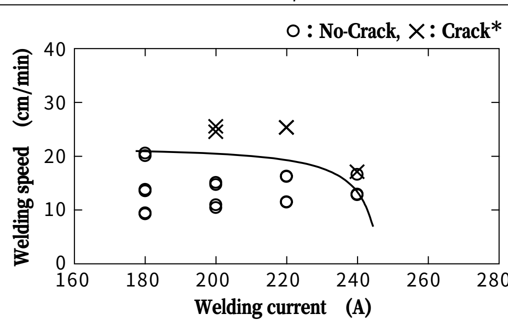
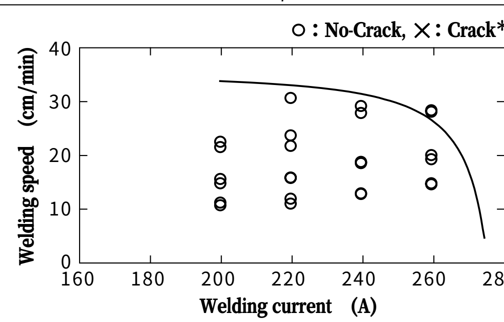
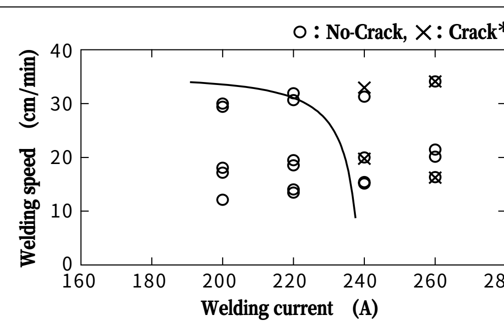


Photo 2 Typical hot crack in one side welding

For bridge construction fewer main beams are used, for the purpose of cost reduction. As a result, the framework members are becoming larger, the

Table 1 Comparison of resistance to hot crack in one side welding between conventional FCW and DW-100N

	Conventional ϕ1.2 mm	DW-100N ϕ1.2 mm
Groove 40° (Typical)		
Groove 30° (Narrow)	Impractical combination	

*) Checked by radiography (X-ray) except crater

plates becoming thicker, and the leg length of welding fillet becoming larger. An FCW for fillet welding with larger welding fillet length has been developed as shown in **Figure 5**.[5] In the conventional FCW, the maximum leg length is limited to approx. 8 mm to prevent the under-cut at the upper side and overlap at the lower side of the leg. The developed wire (DW-50BF) allows the one-pass welding up to 10 mm leg length with its higher viscosity and larger quantity of slag.

3.2 Improvement of working environment

In response to the recent environmental requirements in the industries, new FCWs with lower fume and spatter generation have been developed.[4] **Figure 6** shows the properties of the developed wires (Z series). The new wires reduce the amounts of fume and spatter generation by more than 30% compared to the conventional wires. This is due to the lower carbon content in the wire and addition of alkali metals, which stabilize the metal transfer and arc. The Z series contributes not only to the improvement of work environment with its low fume feature, but also to the reduction of post-welding process with its low spatter feature.

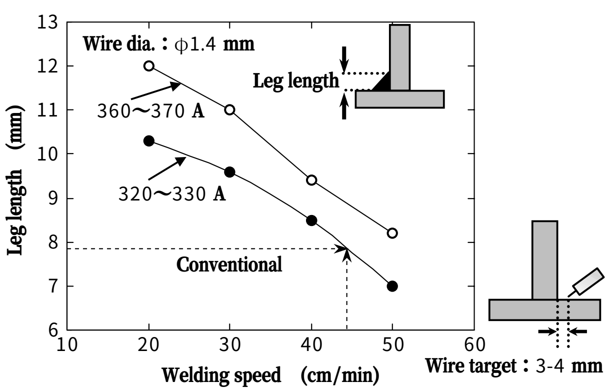


Fig. 5 Relationship between welding parameters (welding current, welding speed) and leg length in horizontal fillet welding by DW-50BF (φ 1.4 mm)

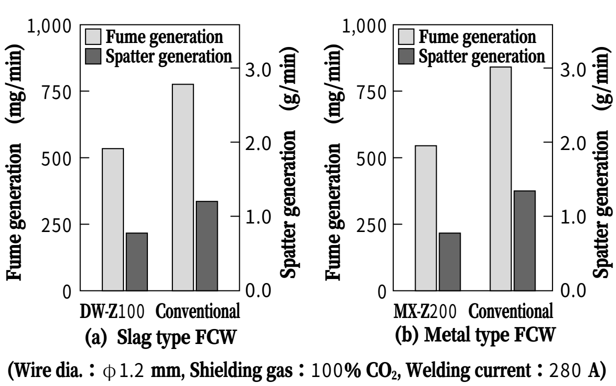


Fig. 6 Characteristics of low fume and low spatter type FCW (DW-Z100, MX-Z200)

3.3 Response to post-weld working process and new welding method

Vital welding applications using low temperature service steels, such as offshore structures and LPG vessels, employ mainly the covered electrodes with lower efficiencies. In case of the conventional slag-type FCWs, when a PWHT, such as stress relief (SR), is applied, the toughness of the welded joint becomes lower after the treatment. The development of a slag-type SR treatable FCW for low temperature service steels has vastly increased the welding efficiency of SR-required parts as shown in **Figure 7**.[6] The developed wire (DW-55LSR) has improved toughness over the SR with its reduced impurities (Nb, V, etc.) and its additional deoxidizer in the flux, which purifies the weld metal.

In the shipbuilding and bridge construction area, many steel plates have primer coatings (rust preventing primer) on the surfaces, which decompose, generate gases (H_2, CO, etc.) and fumes (Zn, etc.), and cause porosity defects in the welded joints. This tendency is enhanced at a higher welding speed, prohibiting the speeding-up of the process. In practical applications, the method of twin-tandem one pool (TOP) and metal-type FCW for primer-coated steel plates are combined in response to the requirements of higher efficiency and higher quality for the horizontal fillet welding.

The TOP method, which is superior in porosity resistance and high-speed welding, uses 4 electrodes for one vertical plate with each two of the electrodes forming one pool, as shown in **Figure 8**. Compared to the conventional twin-single method and twin-tandem two-pool method (the two electrodes form two separate pools), the

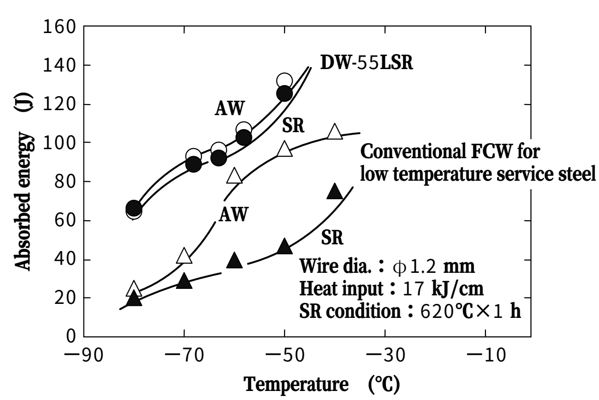


Fig. 7 Charpy energy of DW-55LSR after SR

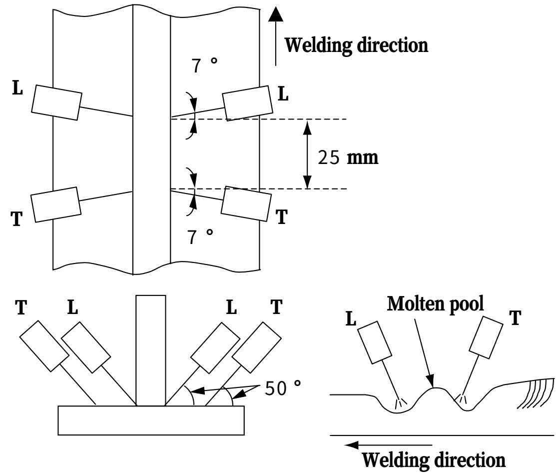


Fig. 8 Twin-tandem one pool method

TOP method increases the crater length, promotes floating and releasing of gas, and thus results in less porosity. Currently, a high-speed welding of approx. 150 cm/min (leg length 5 mm) is made possible by the TOP method, and further speed-up is pursued by new metal-type FCWs.[7] The conventional metal-type FCW tend to result in porosities, and in defective shapes and appearances of the weld bead, when the current is increased for higher speed. On the other hand, the developed wire (MX-200HS) shows good porosity-resistance, weld bead shape and appearance even in a super-high-speed welding at 200 cm/min as shown in **Figure 9** and **Photo 3**. This is due to an arc-stabilizer added to the flux, and improved cross-sectional shape of the wire.

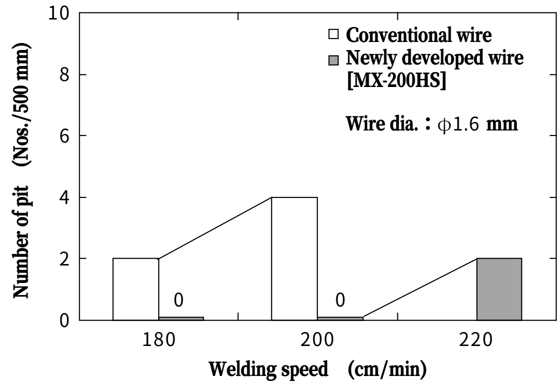


Fig. 9 Porosity generation in high speed horizontal fillet weld

4. Developmental trends of the stainless steel FCW

Stainless steel is widely used in various industries because of its high corrosion resistance, and its usage is increasing year by year. As in the case of carbon steel, the welding of stainless steel employs shielded metal arc welding, TIG welding, submerged arc welding and gas-shielded arc welding. Use of FCW is characteristically high, and occupies close to 50% of all the welding materials used for stainless steels. There are 3 types of our FCWs for stainless steel. Those are the FCWs for flat and horizontal fillet positions (low fume, low spatter type), the FCWs for all-positions (LP series) and the very fine-diameter FCWs (0.9 mm series). Our FCWs are widely used in many industries for various applications and purposes. In addition, we have developed new FCWs such as the FCWs for thin sheets (DW-T series), the FCWs for high temperature applications (Bi free type) and high-toughness dual-phase FCWs.[8]

Figure 10 shows the characteristics of DW-T series wire. The conventional practice of welding

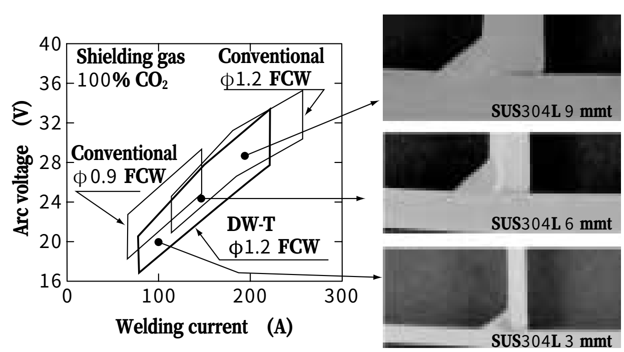
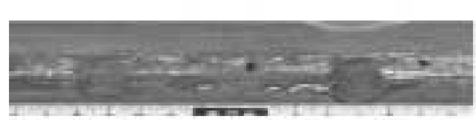
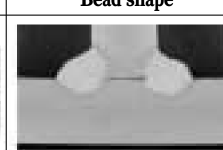
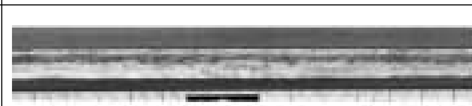


Fig.10 Applicable welding parameters and cross sectional macro structures of DW-T FCW in horizontal fillet weld

Wire	Bead appearance	Bead shape
Conventional wire		
Newly developed wire [MX-200HS]		

(L : 540 A, T : 470 A, Wire dia. : φ1.6 mm, Welding speed : 200 cm/min)

Photo 3 Bead appearance and shape in high speed horizontal fillet weld thin stainless sheets uses super-fine-diameter FCWs of ϕ 0.9 mm. The DW-T allows the use of ϕ 1.2 mm wire because it generates low spatter, and yields good bead shape even below 130 A, which used to be the current range for 0.9 mm wires. This is made possible by the higher flux ratio and the optimized slag composition of the wire. This ϕ 1.2 mm wire, which can be handled easier than ϕ 0.9 mm wires, covers most of the area where the ϕ 0.9 mm wires were used to be applied.

Conclusions

Technical trends of the flux-cored wires (FCW) for gas-shielded arc welding have been reviewed with the focus on the current developments. The basic idea of the FCW development is to achieve the speed-up of the welding process by replacing the shielded metal arc welding, which lacks deposition rate despite its versatility and ease of use, compared with MAG welding. The MAG welding is suitable for mechanization and robotization, improves productivity and compensates the lack of welding technicians.

On the other hand, the progress of FCW technology has always been driven by strong demands of customers. The market needs shown in Figure 3 such as "high-efficiency and high-speed", "reduction of spatter and fume" and "porosity resistance" have to be satisfied at even higher levels, and to override the higher hurdle and achieve the goal, it is necessary to approach the arc phenomena and the properties of molten metal and slag more closely.

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