“SE-A50FS” Arc Welding Wire for Thin Steel Sheet

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A new solid wire for Ar-CO_2 mixed gas welding has been developed for welding automobile part, such as frame assemblies and underbody parts, which are typically made of thin steel sheets 2-4mm thick. This new, innovative chemical composition wire design resulted in considerably improved molten pool properties. The most important advantages of this newly developed wire, compared to conventional solid welding wires, are as follows. 1) It has a wider and more stable bead shape; 2) It allows for higher welding speeds since undercut defects do not occur; 3) The welding condition settings are made easier for operators because the bead shape is immune to voltage changes; 4) The wire has very low slag generation and excellent paintability characteristics.

Introduction

Arc-welding robots are used in most welding processes of automotive manufacturing. The robots weld together steel sheets which have been press-formed into complicated three-dimensional shapes. In order to weld such sheets together, the press-formed sheets to be welded are required to have high dimensional accuracies. In reality, however, the accuracies of press-forming are limited, causing problems such as variations in root-gaps and in wire target-positions. The variations often cause welding defects such as misalignment of welding lines and burn-through, problematically increasing the man-hours involved in fixing such defects. A high-speed welding is desirable for efficiency, however, excessively high speed can cause problems such as undercuts, convexed beads and lack of bead-width, which again increase the man-hours for fixing.

Most of these problems are solved by reducing welding speed to secure bead-width, however, that solution is not feasible in terms of efficiency and cost. A means for solving the above problems in high-speed welding is to make bead-width wide by adjusting the shape of bead penetration. Wide bead-width secures high welding quality by reducing defects and is always pursued in the industry for welding thin steel-sheets. Another aspect in welding quality assurance is to further reduce slag which tends to peel paint-coatings off.

In response to such needs, Kobe Steel has developed an innovative welding wire, “SE-A50FS”, which provides wide bead-widths, which were difficult to be realized by conventional wires, and generates minimal amount of slag. This is a result of Kobe Steel’s study for controlling the properties of molten-pools during welding by designing the compositions of welding wires. The present paper introduces the features and performance of the “SE-A50 FS” welding wire.

1. Application of SE-A50FS

SE-A50FS produces excellent bead shapes and is featured by low slag generation. The wire is well suited for the corner welding of lap-joints and T-joints of thin (about 2 to 4 mm) steel sheets used for automobiles and electric appliances. The wire is also suitable for mixed gas (Ar-CO_2) welding and exerts its effect particularly in metal active gas (MAG) welding. The following describes the features of the developed welding wire.

2. The design concept of SE-A50FS wire

Wide bead-widths are effectively produced from molten-pools having low viscosities. Oxygen and sulfur are the elements known to significantly reduce the viscosities and surface tensions of molten metals[1]. However, these elements are also known to adversely affect the behaviors of welds. Although oxygen may be added purposely through shield gas, the element works to cool and shrink welding arcs and thus destabilize the arcs. In addition, oxygen reacts with steel elements having oxygen affinities, such as Si and Mn, and is discharged to the bead surfaces in large amounts as slag containing SiO_2 and MnO. The slag tends to remain on the bead surfaces and causes deterioration of the bead appearances and paintabilities. Furthermore, oxygen added in a practically acceptable amount does not exert any significant effect in improving the bead-shapes.

On the other hand, sulfur is known to increase the susceptibility to hot-cracking[2] and has been regarded as an impurity. Thus, its addition to welding wires has been avoided as much as possible. As a matter of fact, no conventional welding wire has purposeful addition of S. In an attempt to significantly reduce the viscosity and surface tension, Kobe Steel has carried out extensive studies of the purposeful addition of S and has developed a commercially feasible wire, "SE-A50FS", for the first time in the world.

The main feature of the SE-A50FS is that it contains S at about 0.06%, the content being several times higher than those in conventional wires. The addition of S advantageously reduces slag formation, unlike the case of O. The S addition serves not only to reduce the viscosity and surface tension, but also to improve the convections (Marangoni convections)[3] in welding pools, changing the pool's properties and yielding various merits.

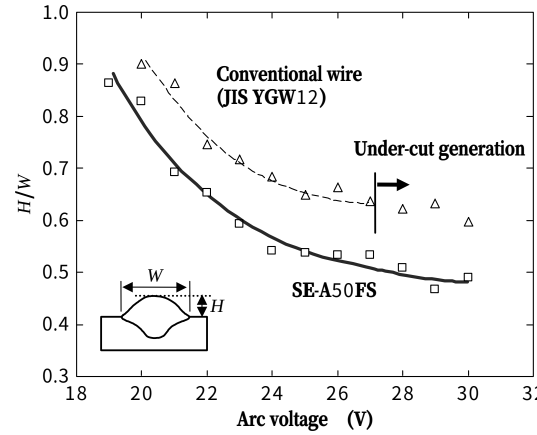
The susceptibility to high temperature cracking, which is regarded as a disadvantage of S addition and will be described more in detail in a later section, is considered to be affected by two factors; i.e., i) metallurgical factors such as the segregation and discharging of low melting-point compounds including S; and ii) morphological factors in macroscopic scale related to solidification. SE-A50FS was designed taking these factors into consideration. If the wire is used limitedly for the welding of thin steel sheets, the wire exhibits a resistance to hot-cracking comparable to those of conventional wires. The wire is epoch-making in that it provides a breakthrough to various problems associated with conventional welding wires.

3. The features and characteristics of SE-A50FS

3.1 Bead-shape

Photo 1 compares the appearances and cross-sectional shapes of lap-fillet joints welded by a conventional wire and SE-A50FS. As shown in the photos, SE-A50FS exhibits a stable, wide and flat bead shape. Such welding beads are formed consistently without excessive deposit and have merits such as reduction of subsequent machining steps. The smooth ends of the bead effectively reduce stress concentrations at these portions.

Fig. 1 depicts the relationship between the deposit height H divided by bead-width W (H/W) and arc-voltage. When compared to a conventional wire (JIS YGW12), SE-A50FS exhibits smaller H/W value through all the voltage range. A smaller H/W value indicates the formation of a wider bead with a lower deposit height. In addition, SE-A50FS allows formation of high quality beads without an undercut in the range higher than 28V in which the conventional wire exhibits undercuts. The result indicates that SE-A50FS effectively prevents undercuts which tend to be formed at high voltages. Thus, SE-A50FS allows formation of high-quality beads under a wide voltage range.



Welding method : Pulse GMAW, position : bead on plate, steel plates : SPCC 3.2t
Welding current : approximately 200A, welding speed : 80cm/min, wire dia. : 1.2mm

Fig. 1 Relationship between bead shape and arc voltage

When welding three dimensional works, such as press-formed automotive panels, the current and arc-length are subjected to changes all the time due to disturbances such as the change in projection-length and target position of the wire. SE-A50FS prevents formation of misaligned beads caused by such disturbances. The stable bead shapes also serve to facilitate the condition settings during robot teaching.

Fig. 2 depicts the relation between the welding current and bead-width at welding speeds from 70 to 130 cm/min for lap-fillet joints of steel sheets having 1.6 to 3.2 mm thickness. SE-A50FS produces wider beads compared to the conventional wire, regardless of sheet thickness, welding speed or welding current.

One major issue with welding thin steel sheets is

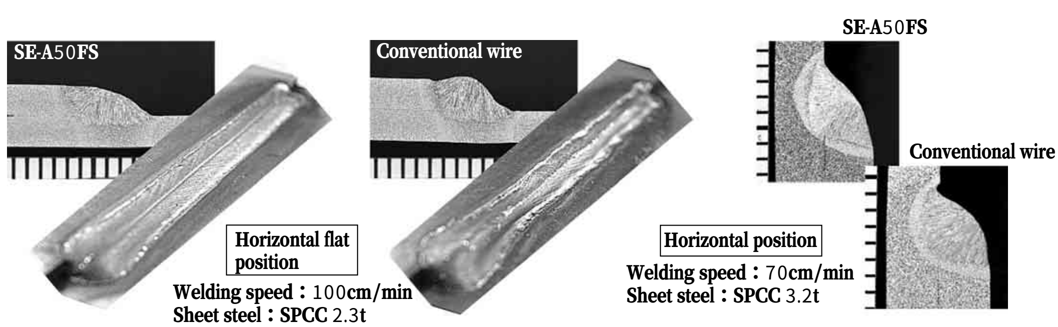
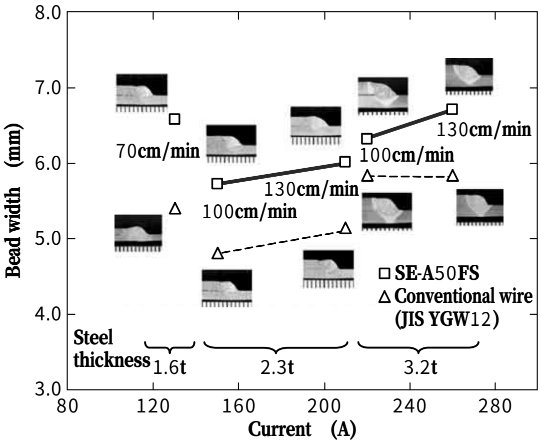


Photo 1 Comparison of cross-section shape with bead appearance along lap joint



Welding method : Pulse GMAW, steel plates : SPCC, wire dia : 1.2mm

Fig. 2 Relationship between current, bead width, steel thickness and welding speed along lap joint

burn-through defects caused by the increase in arc force. In other words, the defects are a result of current increased to compensate the lack of leg length due to increased welding speed. The current also needs to be increased to bridge inevitable root gaps and easily causes burn-through in thin sheets having thickness of only 1.6 mm or less. The wide beads formed by SE-A50FS prevent the lack of leg-length and bridging even at low currents with a small deposition amount and thus contributes in increasing welding speed and decreasing defect rates.

3.2 Bridging performance (Tolerability to root-gap and wire-target deviation)

Fig. 3 illustrates the relationship between bead-shapes, wire target-positions and root-gaps along lap joints. When compared to the conventional wire, SE-A50FS produces high-quality beads for wider root-gap range with high versatility. In other words, SE-A50FS allows welding of sheets with wider root gaps, even if the wire target position is somewhat offset. Such welding has been difficult for conventional wires.

Photo 2 demonstrates cross-sections of typical beads with wide root gaps. SE-A50FS exhibits a flat bead with a smooth end. An undercut, which appears on the conventional wire bead, is not observed on the bead of SE-A50FS.

3.3 Low slag generation

SE-A50FS has excellent slag characteristics which have not been obtained by conventional wires. The photographs in **Photo 3** are taken by a high-speed camera on molten pools of welding. The photos show the slag behaviors in the molten pools of SE-A50FS and a conventional wire. In the case of the conventional wire, the slag deposits in the rear end of the molten pool, disperses thinly and solidifies. In the case of SE-A50FS, on the other hand, the slag first agglomerates in spherical shapes in the vicinity of the arc and is dragged with the arc (Photo 3, #1) and then solidifies in the rear end of the molten pool when the agglomerates grow and coagulate (Photo 3, #2 & #3). Such slag formation is possible only when the surface tension of the molten pool is well controlled by

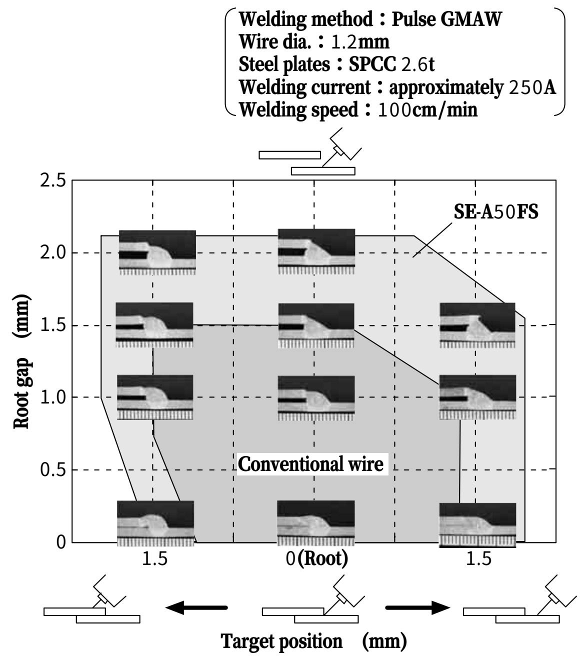
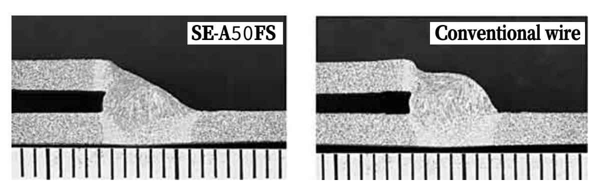


Fig. 3 Relationship between bead shape, wire target position and root gap along lap joint



Target position : 0mm(root), root gap : 1.5mm

Photo 2 Comparison of bead shape at wide root gap

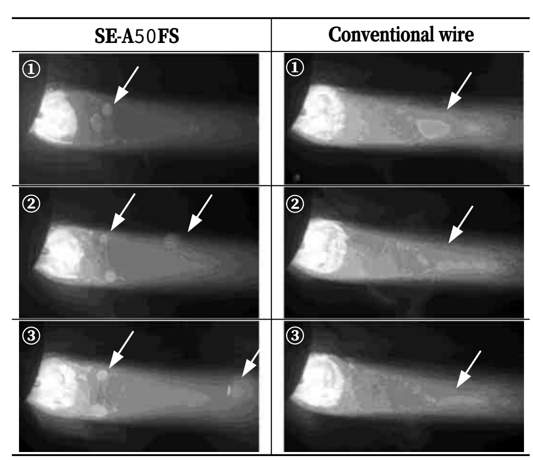


Photo 3 Observation of slag movement on molten pool by the high speed camera (Current : 220A, welding speed : 100cm/min)

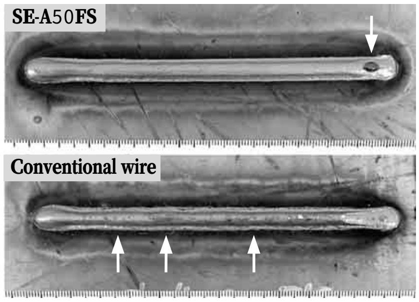


Photo 4 Comparison of slag distribution after welding

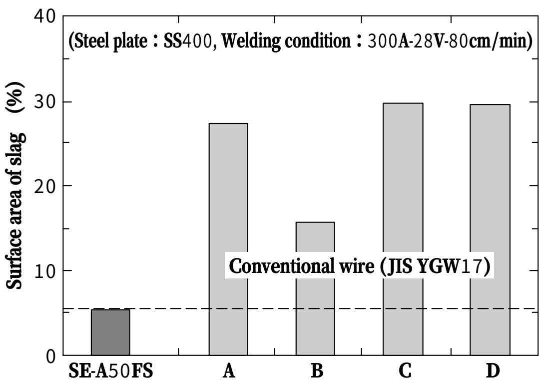


Fig. 4 Comparison of slag area

adjusting the surface tension at the interface between the pool and slag.

Photo 4 shows the slag appearances after solidification. In the case of conventional wire, the slag is formed thinly along the surface of the bead and its distribution is inhomogeneous. In contrast, in the case of SE-A50FS, slag concentrates in the crater and is rarely formed in other areas. The slag generated with SE-A50FS is likely to clump together, forming a small area with preferable bead appearance. **Fig. 4** compares the slag area ratios (slag surface area / total bead surface area) of conventional wires for MAG welding (JIS YGW17) and of SE-A50FS. The area ratio for SE-A50FS is only 1/3 to 1/5 of those for other wires and is significantly lower. The slag formed by SE-A50FS can easily be removed, in most cases naturally, or by light tapping. Residual slag on welding beads can cause rusting of steel sheets which are welded and subsequently subjected to electrodeposition coating. The coating is applied to prevent corrosion of the welds, however, the slag tends to peel the coating off, causing the rusting. The slag characteristics of SE-A50FS advantageously prevent rusting due to the peeling of the electrodeposition coating and thus contribute to cost reductions and quality improvements.

3.4 High-speed weldability

Fig. 5 compares the applicable ranges of welding speed and arc-voltage between SE-A50FS and a conventional wire. Each range in the figure is defined for the respective wire by the welding conditions, in which number of expulsions due to short circuiting is acceptable (less than 100 times/sec) and no irregular bead is formed, such as undercut and hump-formation. SE-A50FS enables welding under high-speed conditions in which conventional wires fail due to hump-formation or excessive short circuiting.

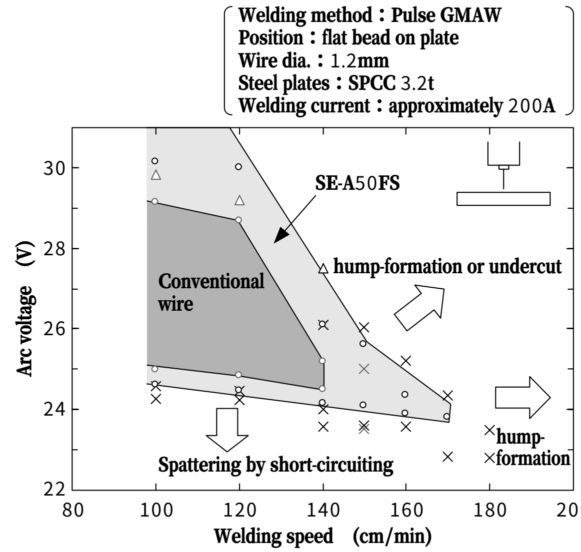


Fig. 5 Applicable range of welding speed and arc voltage

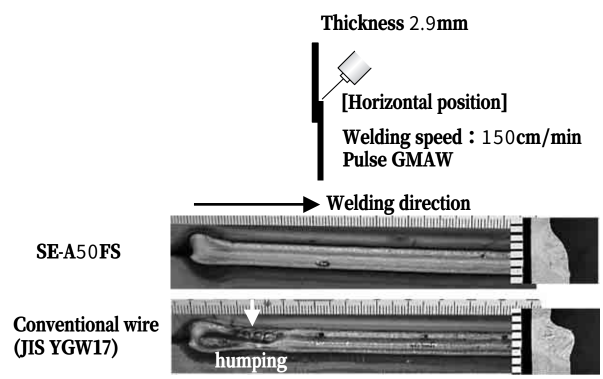


Photo 5 Comparison of start bead appearance at high speed welding

Meanwhile, SE-A50FS has a wider applicable range of voltage for lower welding speeds. The wire is effective in preventing undercut and hump-formation particularly at high voltages. The result indicates that a well-conditioned bead is formed even with a long arc length. In other words, SE-A50FS prevents the short-circuiting of molten drops and reduces the amount of expulsion to an extremely low level.

Photo 5 compares the bead-shapes of joints respectively welded by SE-A50FS and a conventional wire at a high speed (150 cm/min). A hump is formed at the starting point of the bead of the conventional wire, while SE-A50FS exhibits a stable bead without hump-formation. The hump is considered to have been caused by a disturbed flow of molten metal at the arc-start and is enhanced in high-speed welding. Conventionally the hump-formation has been prevented by applying an advancing angle to the torch angle only at the time of arc-start. Since no hump is formed when SE-A50FS is used, the wire eliminates the needs for otherwise complicated robot teaching and detailed condition setting, and thus facilitates the control. Furthermore, SE-A50FS has an advantage in its bead shape since the wire prevents defective shapes, such as convexed-shapes, lack of width and constrictions, as well as undercut and hump, all of which tend to occur in high-speed welding. The advantage arises from the wire's intrinsic characteristics of producing wide beads with smaller deposits.

3.5 Hot-cracking resistance

As describes previously, SE-A50FS is featured by its purposeful addition of sulfur. Generally, S is known to increase the susceptibility to hot-cracking. Because of this, the addition of S is limited to 0,030% at maximum in the JIS standard for solid welding-wires used in the welding of mild steels and high tensile-strength steels of 490 MPa grade. The major cause of hot-cracking is considered to be caused by a low melting-point phase being discharged from the metal during the solidification process, forming a final solidification line in liquid phase which is unable to withstand the tensile stress induced by thermal distortion. As mentioned previously, two types of factors affect the susceptibility to hot-cracking, i.e., i) metallurgical factors and ii) morphological factors. The metallurgical factors include a) impurity elements having low melting-points, such as P, S and B, which form liquid phases at grain boundaries in the final stage of solidification; and b) elements such as C added in large amounts which increase the formation of γ-phase (**Fig. 6**) in which the low melting-point elements have very low solubilities. As for the morphological factors, a bead having an excessive shape factor (P/W) is known to be more susceptible to hot-cracking, where P is the throat thickness and W is the bead width[4].

Thin steel sheets are less susceptible to hot-cracking compared to thick steel plates, considering their binding forces and shape factors. Now, a thick plate is used for an accelerated test to clarify the effect of sulfur on hot-cracking susceptibility. As shown in **Fig. 7**, hot-cracking was induced on purpose in bead-ends having a large shape factor (P/W). The bead was formed by continuously welding layers with no interruption in the narrow groove of the thick plates. **Fig. 8** shows the relationship

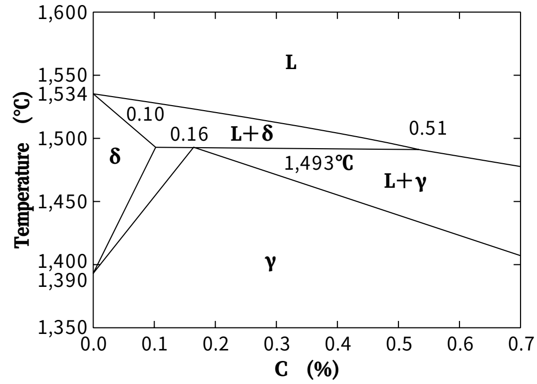


Fig. 6 Fe-C binary alloy phase diagrams

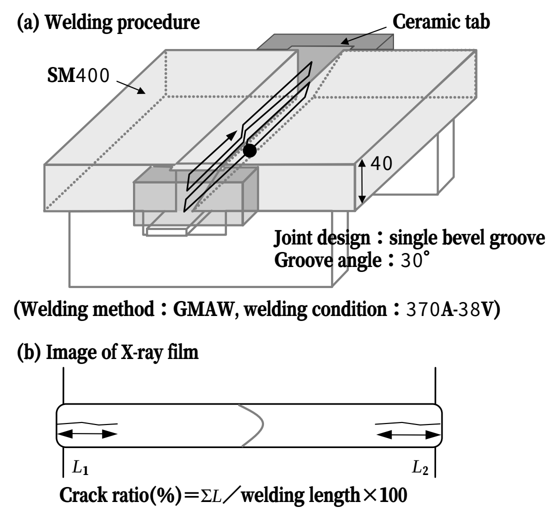


Fig. 7 (a)Welding procedure and (b)image of X-ray film of hot cracking test

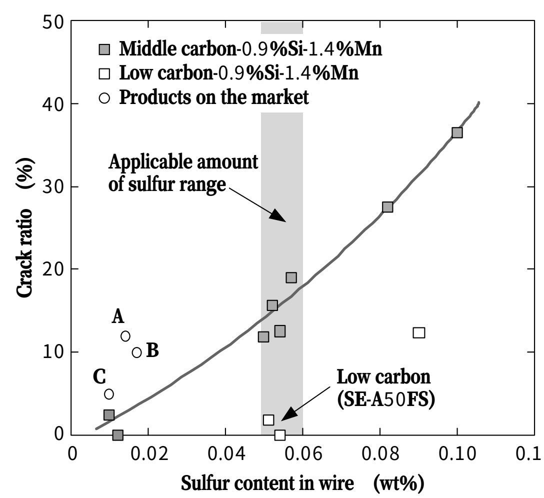


Fig. 8 Relationship between crack ratio and sulfur content in wire

between the crack ratio (crack length / total bead length) and sulfur content in wires. The results indicate that higher sulfur content in wires increases the crack ratio. The minimum S content to achieve the various properties described above has been found to be 0.05%. Such sulfur content, if applied to

Table 1 Mechanical properties of deposited metal of SE-A50FS

Steel plates and groove	Shielding gas	YP (N/mm^2)	TS (N/mm^2)	El. (%)	Adsorbed energy (J) 0℃
SM490A 20mm thickness 45°V GAP12mm	80%Ar-20%CO_2 Gas flow rate : 25L/min	434	527	29	87 87 78 Avg. 84

(Welding conditions : 200A-22V, heat input : 10kJ/cm, interpass temp. : 150℃)

conventional wires, causes cracks to occur at a ratio from 11 to 20%. The authors have also found through a research conducted separately on hot cracking that C has more significant influence on hot cracking sensitivity when compared with S, P and B in a practical composition range[5]. Thus, SE-A50FS has a reduced carbon content to compensate the deterioration of hot-cracking resistance. The reduction in carbon content narrows the range of solid-liquid coexisting zone and increases the volume fraction of δ phase which has high solubility of sulfur. As a result, SE-A50FS exhibits a very small crack ratio of 0 to 2 % despite its high sulfur content. Commercially available wires were tested in the same manner and their results are depicted in the figure as plots A, B and C (crack ratios 4 to 11 %). As shown in the figure, SE-A50FS has a lower crack ratio even in comparison with commercially available wires.

Generally, the shape factor (P / W) becomes smaller for thin steel sheets compared with thick steel plates. Another test was also conducted on samples purposely having a large (P / W) to evaluate the hot-cracking susceptibilities. In this test, pipes are disposed in a manner as shown in **Fig. 9**. The flare portions were welded and the bead cross-sections were visually inspected for any cracks. **Photo 6** shows a typical cross-sectional macro structure of the joint welded at 100 cm / min. Neither the conventional wire nor SE-A50FS exhibited any crack under any of the testing conditions.

As described SE-A50FS takes appropriate measures to prevent hot-cracking. From a metallurgical aspect, the increase in hot-cracking susceptibility caused by the addition of S is compensated by the reduction of C content. From a morphological aspect, the shape factor (P / W) is kept small enough by limiting the application of the wire to single-pass welding of thin steel sheets.

3.6 The mechanical properties of welded metals

Table 1 summarizes the mechanical properties of the all deposited metal. The deposit has sufficient strength that falls in the range of 490 MPa grade. It should be noted that thin steel sheets up to 590 MPa grade can be welded with sufficient joint strength using the developed wire.

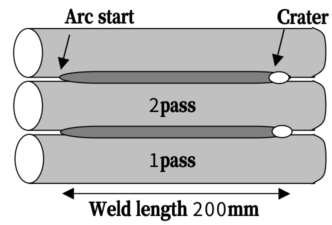
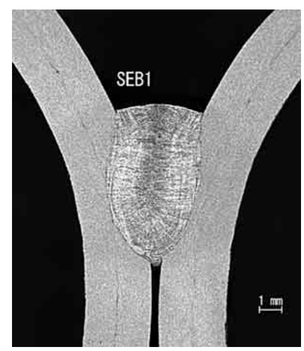


Fig. 9 Schematic diagram of pipe welding crack examination



Welding condition : 350A-26V-100cm/min
Distance from arc start : 10mm

Photo 6 Typical photograph of cross section

Conclusions

The design concept and basic properties of SE-A50FS have been introduced. The wire exhibits unprecedented excellence in bead-shapes and provides high-quality welding of thin steel-sheets frequently used in automotive industries. The wire is promised to improve production efficiencies and lowers defect rates.

Tough competitions among automotive industry will make SE-A50FS more feasible. The wire will be increasingly used as the requirements for technologies, efficiencies and qualities of welding become more stringent.

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