

Development of Two-electrode Electrogas Arc Welding Process

Kiyohito SASAKI*¹
Ryu-ichi MOTOMATSU*¹
Shigeru OHKITA*²

Kazutoshi SUDA*¹
Yuji HASHIBA*²
Shiro IMAI*³

Abstract

Electrogas arc welding (EGW) is used for vertical position welding of sheer strakes and hatch side coamings of container ships because of its higher welding efficiency. However, in ordinary welding processes for ultra-thick steel plates, defects such as the lack of fusion are likely to occur. In order to solve this problem and others, a two-electrode VEGA[®] (Vibratory Electrogas Arc Welding) process was developed by the authors. This paper provides an outline thereto and describes the essential characteristics of this newly developed process for vertical position welding on extra-heavy-sectioned steel plates. It was demonstrated that the VEGA[®] process achieves a stabilized fusion-line profile for ultra-thick steel plates with higher welding efficiency. It was then confirmed that joint performance in this study satisfies regulations such as class NK KEW53 and KEW53Y40.

1. Introduction

In recent years, there has been a growing trend for ultra-thick, and higher strength steel plates. This trend is a result of the continuing race for ever larger steel structures. These have resulted in increased demand for higher efficiency of forming, higher quality and higher strengths of welding materials to handle these increased thicknesses of steel plates.

We have also witnessed a dramatic increase in the sizes of container ships. The increasing sizes are evidence of shipping companies' need for increased shipping efficiency. Larger container ships require thicker steel plates and a higher strength. Because vertical position welding is applied to the sheer strakes and hatch side coamings on the container ships when they are block-assembled in the dry dock, the most prevalent method for welding is the electrogas arc welding (hereinafter referred to simply as EGW) which is capable of a single pass, vertical position welding that is highly efficient.

However, because the steel plates that are used in a ship's side

(sheer strakes, see Fig. 1) are ultra-thick, it was extremely difficult to attain an integrity of weld joints and good properties of the welds using the conventional single pass EGW method. Hatch side coamings which also is a vertical position welding method (see Fig. 1 for the

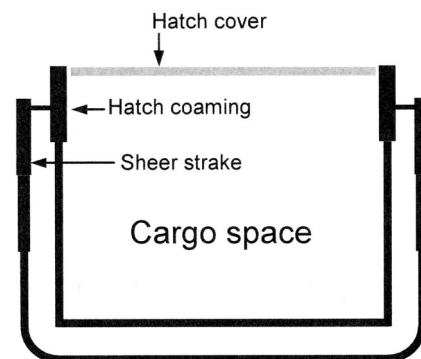


Fig. 1 Cross-section of container vessels

*¹ Nippon Steel Welding Products & Engineering Company Limited
*² Steel Research Laboratories

*³ Plate Sales Division

edge portion of the hatch) is generally used for even thicker steel plates. However, because of the application of a 2-pass welding process, worker-hour cost need to be applied has increased. In view of the conditions described above, a two-electrode VEGA® (Vibratory Electro-gas Arc Welding) process was developed based on the VEGA® process which is a simple electrogas arc welding method. The objective of this new process is to stabilize the fusion-line profile for ultra-thick steel plates and attain higher welding efficiency. This paper describes how this two-electrode VEGA® welding process was developed and outlines its features.

2. Conventional Technologies and Related Issues

Degradation of the conventional EGW method¹⁾ which was developed in the 1960's was a problem because of the low impact property of the welds. This was mainly caused because high heat input was apt to apply and because the wire diameter (2.4 to 3.2 mm) was thick so the sectional area of groove was wide. This caused the coarse microstructure of the heat affected zone (HAZ).

To overcome those demerits, a single-electrode VEGA® welding process was developed in the 1970's by the Nippon Steel Welding Products & Engineering Company Limited. This new process enabled a welding with a narrower groove. To reduce the heat input with the single-electrode VEGA® welding process, a fine diameter wire was used to lower the welding current and to allow to use a narrow groove. Also, to attain a sound weld bead formation near the front and back surfaces of a joint, this welding apparatus is equipped with a mechanism to oscillate the wire (welding torch) in the plate thickness direction. Also, provided with a mechanism for holding of wire extension to a constant as a result that the rising speed of the carriage is controlled by detecting the welding current. To differentiate with the two-electrode VEGA® welding process which is described below, this single-electrode welding process will hereinafter referred to as the single-electrode VEGA® welding process. **Fig. 2**

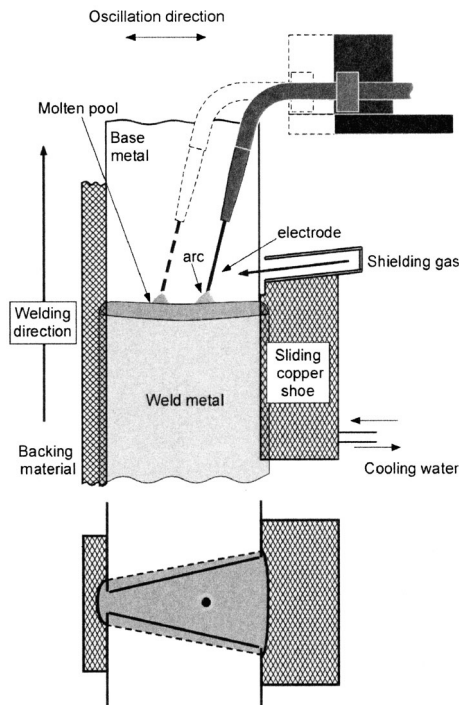


Fig. 2 Schematic illustration of single-electrode VEGA®

shows the general concept for the single-electrode VEGA® welding process.

The development of the single-electrode VEGA® welding process enabled easier formation of top surface beads and back surface beads. Also, because it was possible to reduce the welding heat input and the amount of weld metal, HAZ toughness and processing efficiency were dramatically increased. As can be seen in **Photo 1**, when the macrostructure of the weld cross-section was compared with the conventional EGW method and the single-electrode VEGA® welding process, the welds by VEGA® process showed narrow weld bead and heat affected zone, even on the same thickness of steel plate. Also, there was no lack of fusion even for 50 mm steel plates. Thus it was demonstrated that a sound weld could be attained.

Nevertheless, there is a trend for steel plate thicknesses to increase to 58 mm, and even to 65 mm and 70 mm thicknesses due to the growth in the size of container ships. Such steel thicknesses are used in the shear strakes and the hatch side coamings on the container ships. As can be seen in **Photo 2**, when the thickness of the steel plate exceeds 50 mm, welding defects (such as a lack of fusion) are generated even when using the conventional single-electrode VEGA® welding process. Thus, to handle these increased plate thicknesses, the necessary dwelling time for an arc to fully fuse a groove

Welding processes	Plate thickness	Cross-sections of welds	Heat input
Conventional EGW	19mm		227 kJ/cm
Single-electrode VEGA			72 kJ/cm
Single-electrode VEGA	50mm		258 kJ/cm

Photo 1 Comparison of cross-sections of welds by conventional EGW process and single-electrode VEGA®

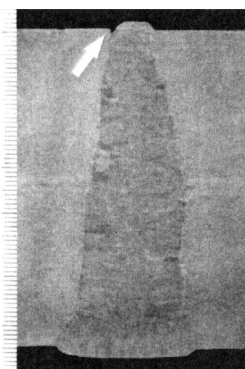


Photo 2 Example of "lack of fusion"(indicated by arrow) in weld by single-electrode VEGA® (plate thickness: 70mm)

face is insufficient when only using a single-electrode, even if arc oscillating width is increased. Therefore, welders required an extremely high level of technical skill to weld steel plates that exceeded thicknesses of 50 mm without the welding defects that are often associated with the single-electrode VEGA® welding process.

3. Development of Two-electrode VEGA® Welding Process

3.1 Development targets

In order to resolve the issues described above, the authors embarked on efforts to develop the two-electrode VEGA® welding process with the presumption of employing a narrow groove to reduce heat input during welding. To attain their objective, the number of electrodes was increased to uniformly distribute welding heat input in a stable manner in the plate thickness direction. It was supposed that it would be effective to reduce the width of oscillation for each of the two electrodes. The following three points were the targets for the development of the two-electrode VEGA® welding process. The authors also maintained a view to the need to overcome any arc interference that could be caused by the application of a second electrode, the overall simplicity of the structure of the apparatus and the need to optimize welding conditions.

- (1) Welding must be possible on steel plates having thicknesses anywhere from 50 mm to 70 mm. There must be no welding defects and joints must be sound.
- (2) There must be good mechanical properties of welds.
- (3) Good welding workability must be attained and it must contribute to improved efficiency of welding work.

3.2 The two-electrode VEGA® welding process apparatus

In the same way as the conventional single-electrode VEGA® welding process, the apparatus which is a vertical position single-pass welding method is arranged with a water cooled copper shoe that automatically rises along with the carriage on the front surface side of the groove, and a light weight ceramic backing material to touch the backside of the groove. This was configured to prevent fusing slag and weld metal from flowing out. Fig. 3 shows the configuration of the 2-electrode VEGA® welding process apparatus; Fig. 4 shows a model thereof.

The two-electrode VEGA® welding process is a simple structure that applies one more electrode to the single-electrode VEGA® welding process. Mounting and dismantling the welding torch of the second electrode is simple. Furthermore it is easy to change the structure into a single or two-electrode apparatus according to the thickness of the steel plate targeted for welding.

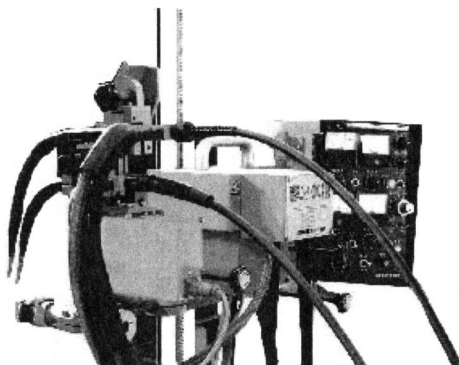


Fig. 3 Two-electrode VEGA® apparatus

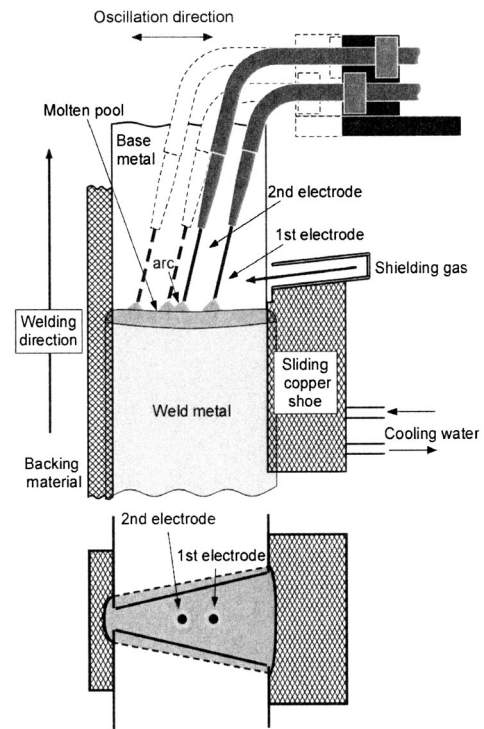


Fig. 4 Schematic illustration of two-electrode VEGA®

The power source for welding was a direct current. This was selected because of the stability of the arc. If both electrodes have the same polarity, specifically, if they are both positive or negative, the arc becomes highly unstable. Accordingly this produces great amounts of spatter. For this reason, the polarity of the two electrodes was made opposites. Also, normally if the electrode is positive, the beads are wider, and the fusing is shallow. Conversely, if the electrode is negative the beads are narrow and fusing is deep²⁾. From these facts, to weld a wide single V groove, the positive electrode was arranged on the grooved surface side because of its ability for a wide fusing, and the negative electrode was arranged on the narrow backside of the groove.

3.3 Improved welding workability

The amount of slag generated when welding greatly affects welding workability when using the EGW method. The welding workability described in this report was evaluated according to the amount of spatter generated, and the external appearance of the beads.

Initially, flux-cored wire which is dedicated to the single-electrode VEGA® welding process was used in both poles for the 2-electrode VEGA® welding process and for the backing material, a product that is supported by the single-electrode VEGA® welding process was used. It was learned that there was a great amount of spatter generated and that long-term welding would be difficult. A great amount of fusing slag was built up on the molten pool near the back side of the groove. On the other hand, the backing material for the single-electrode VEGA® welding process was provided arc shaped grooves as shown in Fig. 5 (a) to attain the same kind of excess weld metal as for general welding. However, this is not a shape that is appropriate for promoting the discharge of fusing slag that is excessively produced. Two types of backing material were manufactured with depths of gap to promote discharge of slag (see Fig. 5 (b) and (c)) with the objective of discharging fused slag that is retained in

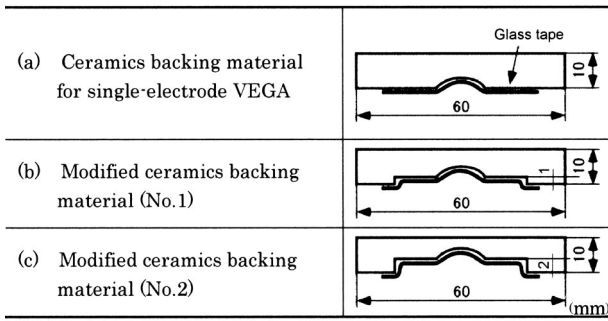


Fig. 5 Backing materials with various shapes

excess, to the backing material side. Then the welding workability was evaluated. The welding conditions used are shown in **Table 1**; The groove face configuration is shown in **Fig. 6**; and the results of the test are shown in **photo 3**.

The amount of spatter (spattered slag) generated was lower in the order of the No. 1 configuration then the No. 2 configuration (for the single-electrode VEGA® welding process) of the backing materials (see Fig. 5 (b) and (c)). A thorough reduction in the amount of spatter was observed in the process using the shape No. 2. However, undercuts were generated at the toe of back bead. Because this is thought to be a cause of fatigue failure, the backing material having the shape No. 1 was employed.

It is insufficient to reduce the amount of spatter generated for the markets and the actual process simply by changing the shape of the backing material. Next, by adjusting the amount of flux of the welded wire, the amount of slag that is generated from the welding material

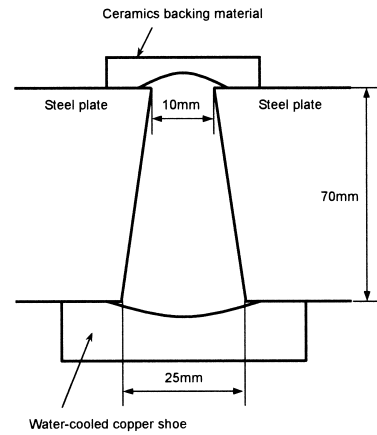


Fig. 6 Groove configuration

was reduced. This was used in an attempt to suppress the amount of slag spatter that is generated. **Table 2** shows the welding wire used in the test, the steel plate and the welding conditions. Note that the groove face configuration is the same as that depicted in Fig. 6. **Table 3** shows the results of evaluations on the welding when using they flux-cored wire that has half the amount of flux as the wire used with the single-electrode VEGA® welding process, and a solid wire that conforms to JIS Z 3325 TGL1-4G (AP). Because it was learned that the solid wire possesses characteristics having lower slag generating amounts in comparison to the flux-cored wire, it can be expected to affect the production of the amount of slag generated on the back side of the groove where slag retention is high. The study was un-

Table 1 Welding conditions

Electrodes	Welding wire	Current (A)	Voltage (V)	Travel speed (cm/min)	Heat input (kJ/cm)	Electrode spacing (mm)	Oscillation width (mm)	Shielding gas	
								Composition	Flow rate (ℓ/min)
1st	Flux-cored wire ^{*1}	420	42	5.0-5.5	366-404	15	35	100% CO ₂	30
2nd	Flux-cored wire ^{*1}	400	40						

^{*1}: For single-electrode VEGA®

Base plate: EH40 (plate thickness: 70mm)

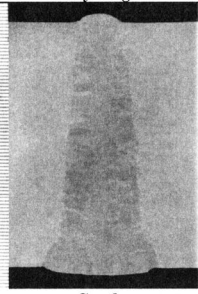
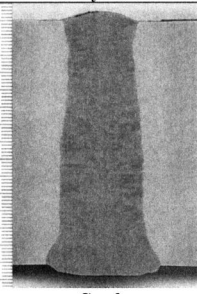
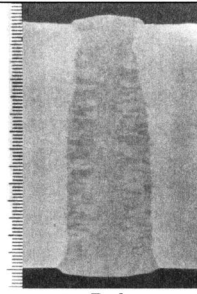
	With ceramics backing for single-electrode VEGA	With No. 1 ceramics backing	With No. 2 ceramics backing
Amount of spatter	Very large	Fairly small	Small
Cross-sections of welds	 Good	 Good	 Bad
Comprehensive evaluation for actual application	Not suitable	Not suitable	Not suitable

Photo 3 Weld test results by various backing materials

Table 2 Welding conditions

Test No.	Electrodes	Welding wire	Current (A)	Voltage (V)	Travel speed (cm/min)	Heat input (kJ/cm)	Electrode spacing (mm)	Oscillation width (mm)	Shielding gas	
									Composition	Flow rate (ℓ/min)
1	1st	Flux-cored wire ^{*1}	420	42	5.0-5.5	366-404	15	35	100% CO ₂	30
	2nd	Flux-cored wire ^{*1}	400	40						
2	1st	Flux-cored wire ^{*1}	420	42	5.0-5.5	366-404	15	35	100% CO ₂	30
	2nd	Solid wire ^{*2}	400	40						
3	1st	Solid wire ^{*2}	420	42	5.0-5.5	366-404	15	35	100% CO ₂	30
	2nd	Solid wire ^{*2}	400	40						
4	1st	Flux-cored wire ^{*3}	420	42	5.0-5.5	366-404	15	35	100% CO ₂	30
	2nd	Solid wire ^{*2}	400	40						

*1: For single-electrode VEGA®

*2: JIS Z 3325 TGL1-4G (AP)

*3: For two-electrode VEGA® (contains one-half the flux compared with the wire for single-electrode VEGA®)

Base plate: EH40 (plate thickness: 70mm)

Table 3 Test results with various welding wires

Test No.	Electrodes	Welding wire	Test results		
			Amount of spatter	Bead appearance	Comprehensive evaluation for actual constructions
A	1st	Flux-cored wire ^{*1}	Very large	Good	Not suitable
	2nd	Flux-cored wire ^{*1}			
B	1st	Flux-cored wire ^{*1}	Large	Good	Not suitable
	2nd	Solid wire ^{*2}			
C	1st	Solid wire ^{*2}	Very small	No good	Not suitable
	2nd	Solid wire ^{*2}			
D	1st	Flux-cored wire ^{*3}	Small	Good	Suitable
	2nd	Solid wire ^{*2}			

*1: For single-electrode VEGA®

*2: JIS Z 3325 TGL1-4G (AP)

*3: For two-electrode VEGA® (contains one-half the flux compared with the wire for single-electrode VEGA®)

Base plate: EH40 (plate thickness: 70mm)

dertaken with regard to the application of this solid wire to the second electrode which arranged on the narrow backside of the groove.

Case A which employed the flux-cored wire for the single-electrode VEGA® welding process on both electrodes, had the greatest amount of spatter generated. In the order of B, C, and D, cases C and D showed that spatter had reduced to an acceptable amount. As a result, it is suggested that the amount of slag generated from the welding wire greatly affects the amount of spatter.

Thus, as described above, research was conducted into the backing material configuration and the composition of the welding wire. Overall evaluations were also conducted on the welding workability. As a result, a decision was made to use the backing material of the shape No. 1, and to apply the flux-cored wire that halves the amount of flux as the wire used with the single-electrode VEGA® welding process on the first electrode and the solid wire on the second electrode. These realized superior welding workability that also could withstand actual welding work.

4. Results of Application of the Two-electrode VEGA® Welding Process

By applying a variety of improvements to welding workability, it has become possible for a highly efficient single pass welding of steel plates that have thicknesses anywhere from 50 mm to 70 mm using the 2-electrode VEGA® welding process. The following outlines the effects of this method of welding.

4.1 Stabilized penetration of weld metal

With the development of the 2-electrode VEGA® welding process, it has become possible to easily attain front side beads that have

good shape, and to form beads on the backside. This development means that now welders can perform their duties without much worry with regard to welding defects such as poor penetration or lack of fusion when changing the oscillating conditions (width of oscillation and stopping time of both ends when oscillating, and position of aim of the wire) or the gap. Therefore, it can be said that this newly developed method of welding is highly applicable because it does not require welders to have high levels of technical training or skill to weld steel plates that exceed 50 mm in thickness. See **photo 4**. This shows sectional views of sample microstructures of welds on steel plates having 50, 60 and 70 mm thicknesses. Furthermore, the penetration of weld metal near the front surface, backside surface of the plate and to the groove face was stabilized allowing for good quality welding without the defects often associated with welding such as poor penetration or lack of fusion.

4.2 Improved welding efficiency

Because the 2-electrode VEGA® welding process is substantially twice the welding speed of the single-electrode welding process, deposition rate for a single electrode when using the same groove shape is approximately doubled, as shown in the **Fig. 7**, thereby demonstrating that this method of applying two electrodes to be highly efficient. Furthermore, the amount of time required for setup of the apparatus is substantially the same as that for the single-electrode VEGA® welding process so efficiency, considering the entire process of welding from set up to actual welding, is substantially twice that of the single-electrode VEGA® welding process. Still further, when using the single-electrode, or the 2-electrode VEGA® welding process, almost all of the welding wire used is contained on single-

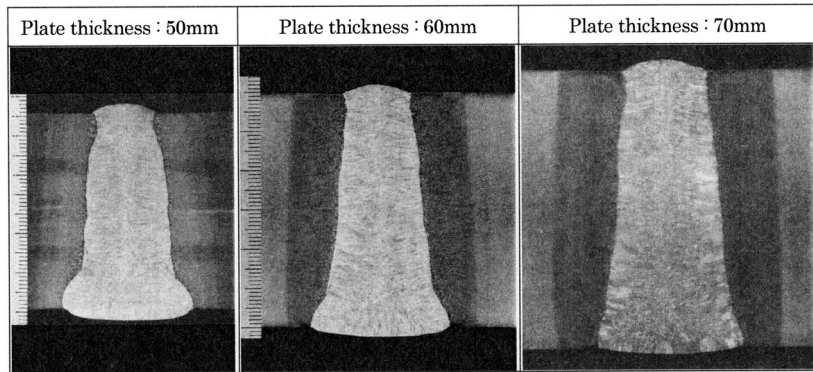


Photo 4 Cross-sections of welds by two-electrode VEGA®

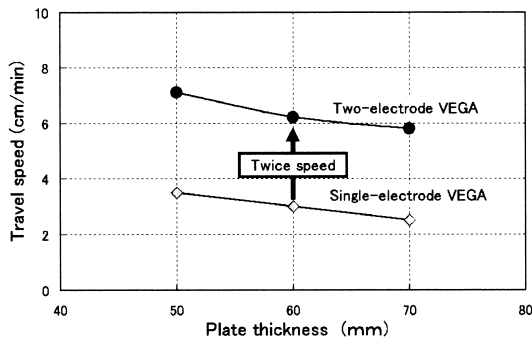


Fig. 7 Comparison of travel speed with single- and two-electrode VEGA®

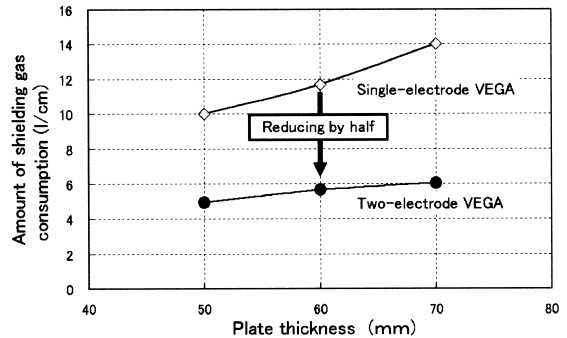


Fig. 8 Comparison of amount of shielding gas consumption with single- and two-electrode VEGA®

reel, 20 kg spools, so it is necessary to replace the welding wire and 20 kg units. Therefore, the possible welding length without interruption on the 2-electrode VEGA® welding process is approximately two times that of the single-electrode VEGA® welding process. When welding is terminated, gouging occurs in that position. It is necessary to repair that using a shielded metal arc welding or a gas-shielded metal arc welding. This translates into a greatly shortened amount of processing time through the application of the 2-electrode VEGA® welding process.

4.3 Reduction in the amount of shielding gas

Because the welding speed with this newly developed method is substantially doubled, the amount of shielding gas consumed per single welding length is approximately halved that for a single electrode. This again allows for a highly economical method of welding

(see Fig. 8).

4.4 Welding performance and application to ship building

The Mo-Ti-B type weld metal³⁻⁷⁾, which is an alloy designed to attain low temperature toughness that is essential in high heat input welding, was also applied to the 2-electrode VEGA® welding process. Table 4 shows the materials and welding conditions used in the test; Fig. 9 shows the groove face configuration; Fig. 10 shows the locations of the test specimen. As can be seen in Table 5, performance was attained that met the standards of KEW53 and KEW53Y40 as prescribed by the Nippon Kaiji Kyokai (Class NK). See Photo 5 for a view of the microstructure of the weld metal (central location) on the steel plates. An extremely fine microstructure was attained under high heat input welding. Also, mechanical performance was attained that had thorough mechanical property of HAZ

Table 4 Welding conditions

Plate thickness (mm)	Electrodes	Welding wire	Current (A)	Voltage (V)	Travel speed (cm/min)	Heat input (kJ/cm)	Electrode spacing (mm)	Oscillation width (mm)	Shielding gas	
									Composition	Flow rate (ℓ/min)
50	1st	Flux-cored wire ^{*1}	410	41	7.1	281	15	5	100% CO ₂	30
	2nd	Solid wire ^{*2}	400	40						
60	1st	Flux-cored wire ^{*1}	410	41	6.2	321	15	17	100% CO ₂	30
	2nd	Solid wire ^{*2}	400	40						
70	1st	Flux-cored wire ^{*1}	420	42	5.8	382	15	35	100% CO ₂	30
	2nd	Solid wire ^{*2}	460	42						

*1: For two-electrode VEGA® (contains one-half the flux compared with the wire for single-electrode VEGA®)

*2: JIS Z 3325 TGL1-4G (AP)

Base plate: EH40 (plate thickness: 70mm)

of the applied EH40 steel.

In 2001, the 2-electrode VEGA® welding process was applied to the welding of sheer strakes and hatch side coamings (plate thickness: 58 mm) of large sized container ships at Mitsubishi Heavy Industries Limited Kobe shipyard & Machinery Works (see **Photo 6**). Also, in 2002, this method of welding was applied to hatch side coamings of steel plates having thicknesses of 65 mm.

As described above, success was achieved in the development of the 2-electrode VEGA® welding process which is a single-pass, and highly efficient automatic welding method that attains stable penetration of weld metal even when vertically welding steel plates having thicknesses between 50 mm and 70 mm. This method was successfully applied the building of ultra large-sized container ships.

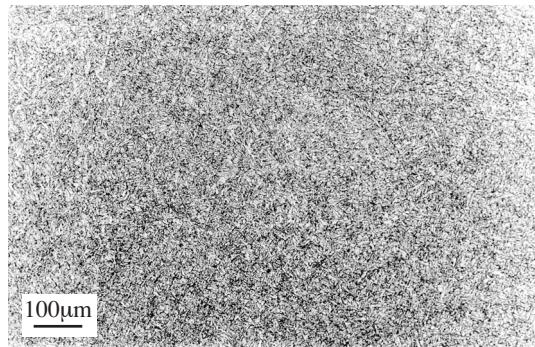


Photo 5 Microstructure of weld metal welded by two-electrode VEGA® (center)

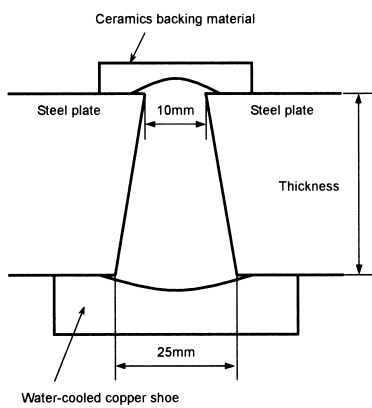


Fig. 9 Groove configuration



Photo 6 An example of construction site where two-electrode VEGA® operated

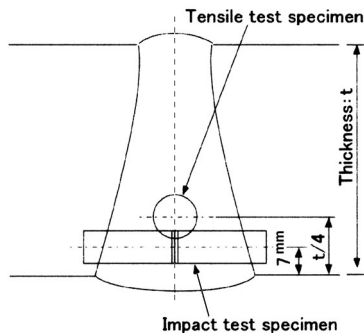


Fig. 10 Sampling locations of test specimens

5. Conclusions

According to the processes described above, success was attained in the development of the 2-electrode VEGA® welding process as a highly efficient automatic welding method for vertical position when welding steel plates having thicknesses of 50 mm to 70 mm. The 2-electrode VEGA® welding process realizes stable weld metal penetration and high efficiency in single-pass, vertical position welding of steel plates having thicknesses between 50 mm and 70 mm, and has obtained valuable tried and tested data through its applications in actual container ship building. The scope of application to steel plate thicknesses will expand in the future and can be expected to become more widely applied because of its superior applicability as a welding method.

Table 5 Mechanical test results of weld metal with two-electrode VEGA®

Plate thickness (mm)	Classification	Tensile test			Charpy impact test
		0.2% proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	Absorbed energy at -20°C (J)
50	EH36	473	610	25	89
60	EH40	471	611	23	86
70	EH40	506	656	24	79
ClassNK KEW53		≥375	490-660	≥22	≥34
ClassNK KEW53Y40		≥400	510-690	≥22	≥41

Acknowledgements

The authors wish to express their deep gratitude to the Mitsubishi Heavy Industries Limited Kobe Shipyard & Machinery Works for their cooperation in the development of the 2-electrode VEGA® welding process.

Note that the VEGA® welding process is a registered trademark of Nippon Steel Welding Products & Engineering Company Limited.

References

- 1) Inagaki, M. et al.: Automatic Vertical Position Welding – Electroslag Welding/Electrogas Welding. First edition. Tokyo, THE NIKKAN KOGYO SHIMBUN Limited, 1966, p.151
- 2) Japan Welding Society: Welding and Joining Technology. First edition. Tokyo, SANPO PUBLICATIONS Incorporated, 1993, p.388
- 3) Mori, N. et al.: Seitetsu Kenkyu. (307), 104(1982)
- 4) Mori, N. et al.: J. Jpn. Weld. Soc. 50(2), 174(1981)
- 5) Mori, N. et al.: J. Jpn. Weld. Soc. 50(8), 786(1981)
- 6) Ohkita, S. et al.: Australian Weld. J. 29(3), 29(1984)
- 7) Ohkita, S. et al.: ISIJ Int. 35(10), 1170(1995)