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The Microstructure Evaluation of Single-Pass Cladding Process by Using Hot-Wire GMAW Process

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The single-pass cladding process by using hot-wire gas metal arc welding (GMAW) process has been developed for improving the cladding productivity. The stainless steel ER309LSi (as buttering layer and stainless steel ER308LSi (as the top-cladding layer) are clad on carbon steel A516 Gr 70 at one time. In this research has the objective to compare the microstructure revolution of single-pass cladding process by hot-wire GMAW with conventional cladding process by fluxed-core arc welding (FCAW). The infrared (IR) camera was used to monitor the weld metal cooling rate. Liquid tin quenching, was employed for freezing weld pool during welding. The result of single-pass cladding by hot-wire GMAW process shown the optimize microstructure (FN3) for service condition of the cladding process on top cladding surface. Therefore, the developing cladding process by single-pass hot-wire GMAW caused reduce cycle time 3.5 times by still contain service weldability.

Keywords: Single-pass cladding process / Hot-wire GMAW process / Microstructure / Infrared camera / Liquid tin quenching

Introduction

The single-pass cladding process was achieved by using gas metal arc welding (from here use as GMAW) with the addition of hot-wire technique for pressure vessel industrial. The carbon steel A516 Gr 70 was used to be base metal and clad by stainless steel ER309LSi and ER308LSI at the same time. This model cladding process could reduce 3.5 times of cycle time with 15% dilution compared to conventional cladding which used flux-core arc welding (FCAW) process as showed the cycle time comparison in Fig. 1. The hot-wire technique was applied to conventional welding processes such as gas tungsten arc weld (GTAW) and GMAW to improve the deposition rate [1]. The application of the hot-wire technique has the potential to control wire feeding speed and wire current separately. The filler wire was heated up to the melting point by Joule heating and uses heat energy from the weld pool to melt filler wire. Therefore, the addition of hot-wire has achieved high deposition rate with low heat input.

The microstructure evaluation of weld bead, the liquid tin quenching was employed during welding to freeze welding pool for studied microstructure of austenitic stainless steel [2]. The cooling rate of single-pass multi-layers GMAW was studied by using the infrared camera (after here using an IR camera). An advantage of IR camera is a more spatial resolution than a common thermocouple [3].

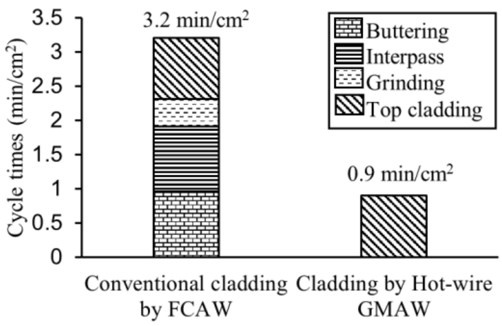

Figure 1 Comparison of cycle time between conventional cladding by FCAW to cladding by Hot-wire GMAW process

The purpose of this study is to evaluate the microstructure revolution of single pass cladding which performed by hot-wire GMAW with using liquid tin quenching during welding to investigate

Table 1. Chemical compositions of base metal and filler wires

Base metal					
Materials (% mass)	C	Mn	P	S	Si
Carbon steel A516 Gr 70	0.27	0.85-1.20	0.035	0.035	0.15-0.40

Filler wires									
Materials (% mass)	C	Cr	Ni	Mo	Mn	Si	P	S	Cu
SS ER309LSi	0.02	23.60	13.40	0.11	1.8	0.79	0.02	0.001	0.1
SS ER308LSi	0.02	19.79	10.24	0.014	2.25	0.78	0.03	0.03	0.75

fusion between base metal, buttering layer and the top cladding layer and compare with the microstructure of conventional cladding process by FCAW. Moreover, the real-time temperature of the weld bead was observed by using the IR camera to study the cooling rate of the weld bead.

Experimental

Materials and specimen

This developed process is mixing both of stainless steel wires. ER309LSi was used for GMAW to create bettering layer and ER308LSi was used for hot-wire to create the cladding layer in the conventional welding process by both of filler wires were used 1.2 mm. The carbon steel A516 Gr 70 with a thickness of 10 mm was used for base metal and was prepared as an illustrates in Fig. 2. Table 1 showed the chemical compositions of base metal and filler wires.

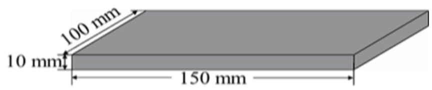

Figure 2 Specimen dimension of base metal

Experimental setup and welding condition

The conventional cladding by using the FCAW process was designed to weld buttering layer (stainless steel 309LSi) cladding (stainless steel 308LSi) layer separately. The welding parameters which used in actual industrial was fixed with arc current 150 amperes and arc voltage 28 volts with travel speed 30 cm/min. The 100% of CO2 gas was used for shielding weld bead at flow rate 20L/min by shown the schematic of setting torch in Fig. 3a and FCAW welding parameters in table 2.

The hot-wire GMAW cladding process was designed to weld stainless steel ER309LSi by GMAW as buttering layer and addition stainless steel ER308LSi by hot-wire for created cladding layer at the same time. The setting of torches was illustrated in Fig. 3b. The welding condition that used to evaluate the microstructure and temperature distribution as shown in table 2. The GMAW condition was fixed with arc current 290 amperes, arc voltage 29 volts, wire feeding speed 13 m/min, extension length 20 mm and torch angle 10 degrees. For hot-wire condition, wire feeding speed 9.1 m/min (ratio 0.7) was selected because of the FN prediction in the WRC-1992 diagram shown FN 3 by addition of hot-wire feeding ratio 0.7 with 15% of dilution. The wire current 175 amperes, wire feeding angle 30 degree and energy supply distance 70 mm were fixed. All of the experiment was used with mixing argon gas and 5 % CO2 with 20 L/min shielding gas and 60 cm/min of travel speed. By this parameter of hot-wire GMAW could get weld bead width 10 mm same as FCAW process.

Evaluation of weld bead microstructure

In this study, the liquid tin quenching was applied for freezing weld pool during welding to study evaluation of weld bead microstructure by poured a large amount of liquid tin from the back side of the arc to molting pool. After that, the electro etching was applied to etching specimen with 10% oxalic acid at 6 volts for 30 seconds. This solution was used for reveals austenite, austenite grain boundaries, carbides and sigma phase [4]. According to weldability and usability of austenitic stainless-steel weld [5], the top surface of the cladding layer should contain ferrite number (FN) in range 3-10 FN. The ferrite scope model Fischer MP-30 was applied to measure FN on the top surface of the cladding layer.

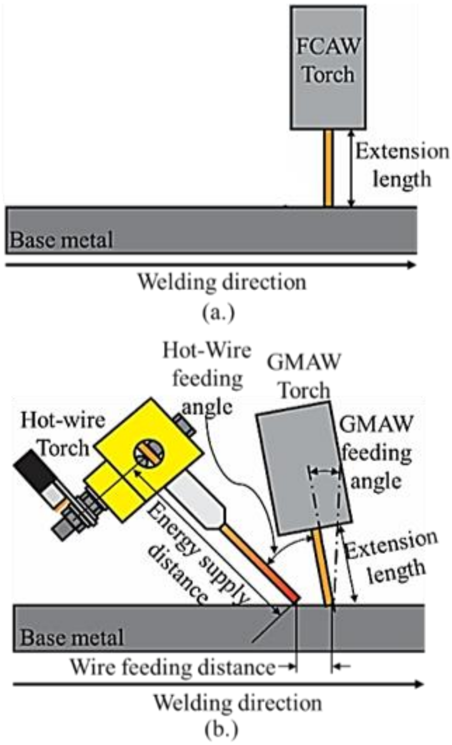

Figure 3 Schematic of adjustment parameter (a.) FCAW process (b.) Hot-wire GMAW process

Table 2 Cladding parameters.

Conventional cladding by FCAW parameter

Shielding gas (CO_2), [L/min]	20
Arc current, [Ampere]	150
Arc voltage, [Volt]	28
Wire feeding speed, [m/min]	8
Extension length, [mm]	20
Travel speed, [cm/min]	30

Hot-wire GMAW cladding parameter

GMAW process	
Shielding gas (Ar/5% CO_2), [L/min]	20
Arc current, [Ampere]	290
Arc voltage, [Volt]	31
Wire feeding speed, [m/min]	13
Extension length, [mm]	20
GMAW feeding angle, [deg]	10
Hot-wire process	
Wire feeding speed, [m/min]	9.1
Wire current, [A]	175
Wire feeding angle, [deg]	30
Wire feeding position, [mm]	0
Energy supply distance, [mm]	70
Travel speed, [cm/min]	60

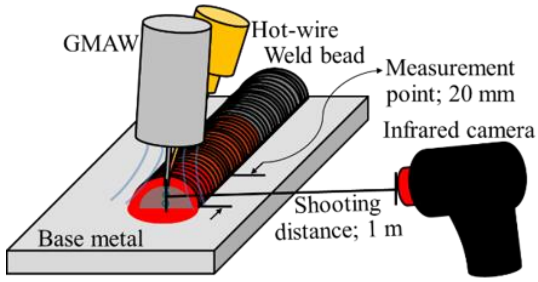

Figure 4 Schematic of IR camera setting

Temperature distribution of weld bead measurement

The IR camera model InfRec thermo gear G100EX was used for observing the temperature distribution of weld bead to study cooling rate. The schematics of the IR camera setting as illustrated in Fig. 4. The IR camera was set with the shooting distance was 1 m for weld bead to IR camera, and for measurement temperature point is 20 mm from GMAW filler wire. The IR camera parameters setting was 0.8 of emissivity calibration value [3] with 0 – 1400 °C of the temperature range for observed stainless steel melting temperature. The video resolution was fixed as 720 x 480 with frames rate 30 frames/sec.

Results and Discussion

The macrostructure of weld bead

The macrostructure of conventional cladding by FCAW and hot-wire GMAW were illustrated in Fig. 5. At same weld bead width as 10 mm, the hot-wire GMAW achieved single-pass cladding with high travel speed (increase 50%) with higher weld bead height (increase 40%) and lower dilution (decrease 50%) compared with FCAW that could weld just buttering layer.

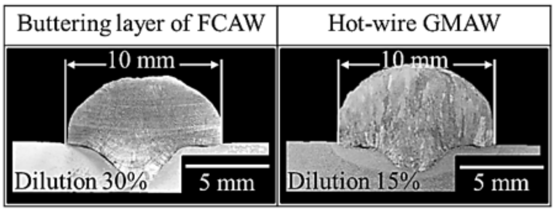

Figure 5 The macrostructure of FCAW buttering layer and hot-wire GMAW

Temperature distribution of weld bead result

In austenitic stainless steel 308 type, the temperature range was 1,300 °C to 800 °C was -

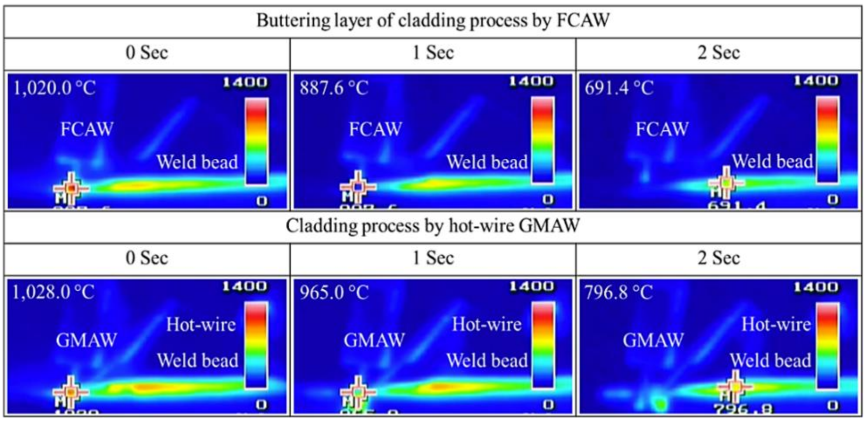

Figure 6 The result of IR camera in temperature range 1,300 °C to 800 °C

used to study the cooling rates because delta ferrite will be formed in this temperature range [6]. The cooling time of FCAW buttering layer and hot-wire GMAW which observed by IR camera as illustrated in Fig. 6 and shown the cooling time in the temperature range 1300 °C to 800 °C in Fig. 7. The result showed the temperature of FCAW was cool faster than hot-wire GMAW because of FCAW got small weld bead size when compare with hot-wire GMAW.

The cooling rate result of hot-wire GMAW

The cooling rate is the one factor that significantly affects to delta ferrite in stainless steel by low cooling rate cause low FN, but high FN will occur when the cooling rate is high [7]. The cooling rate of hot-wire GMAW was 105 °C/sec with FN 3. Vitek, J.M. and David, S.A., have studied the effect of cooling rate on ferrite in type-308 stainless-steel weld metal by at cooling rate 103 °C/sec got FN 4.7. It understood that at the same cooling rate, FN of hot-wire GMAW showed the result similar to previously studied at low FN.

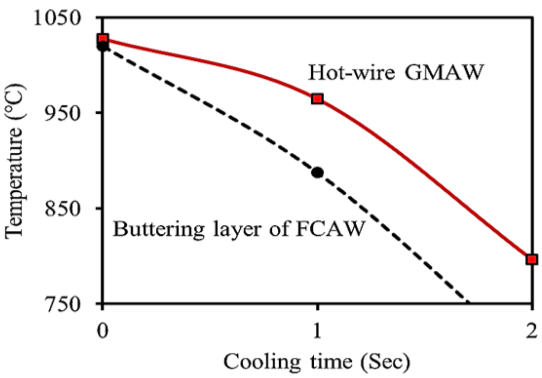

Figure 7 The cooling time result of FCAW and hot-wire GMAW

The microstructure evaluation of hot-wire GMAW

The microstructure evaluation of single-pass cladding was discussed in this section and compare with conventional cladding by FCAW which welded the buttering layer and cladding layer separately. The liquid tin quenching was applied for freezing weld pool during welding to evaluation weld bead microstructure by cutting along weld bead. The cross-section of hot-wire GMAW quenching in Fig. 8. The microstructure was evaluated by 4 regions as in illustrated schematic and microstructure in Fig. 9 followed by;

Region A; Mixing zone of carbon steel A516 Gr 70 with stainless steel ER309LSi. The high dilution as 30% occurred with conventional cladding process by FCAW. Retained delta ferrite (δ) as 9% in austenite (γ) structure. While The microstructure result of hot-wire GMAW with dilution 15% shown the microstructure solidification started with primary austenite and formed delta ferrite (8%) same as the conventional process. Therefore, both of process solidification as AF mode in region A.

Region B; Stainless steel ER309LSi. At final solidification microstructure, the conventional process solidified as primary delta ferrite with skeletal ferrite structure (17%) and occurred austenite after that (FA mode). While the microstructure of hot-wire GMAW showed the structure similar to the conventional process. The vermicular structure of ferrite dendrites in primary delta ferrite (11%) solidification (FA mode) occurred at hot-wire GMAW as well.

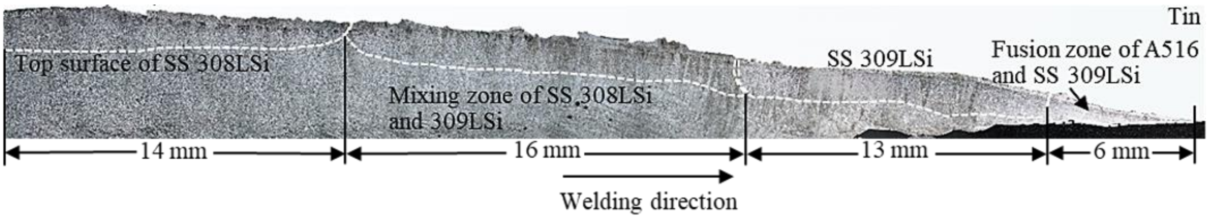

Figure 8 The cross-section of hot-wire GMAW quenching

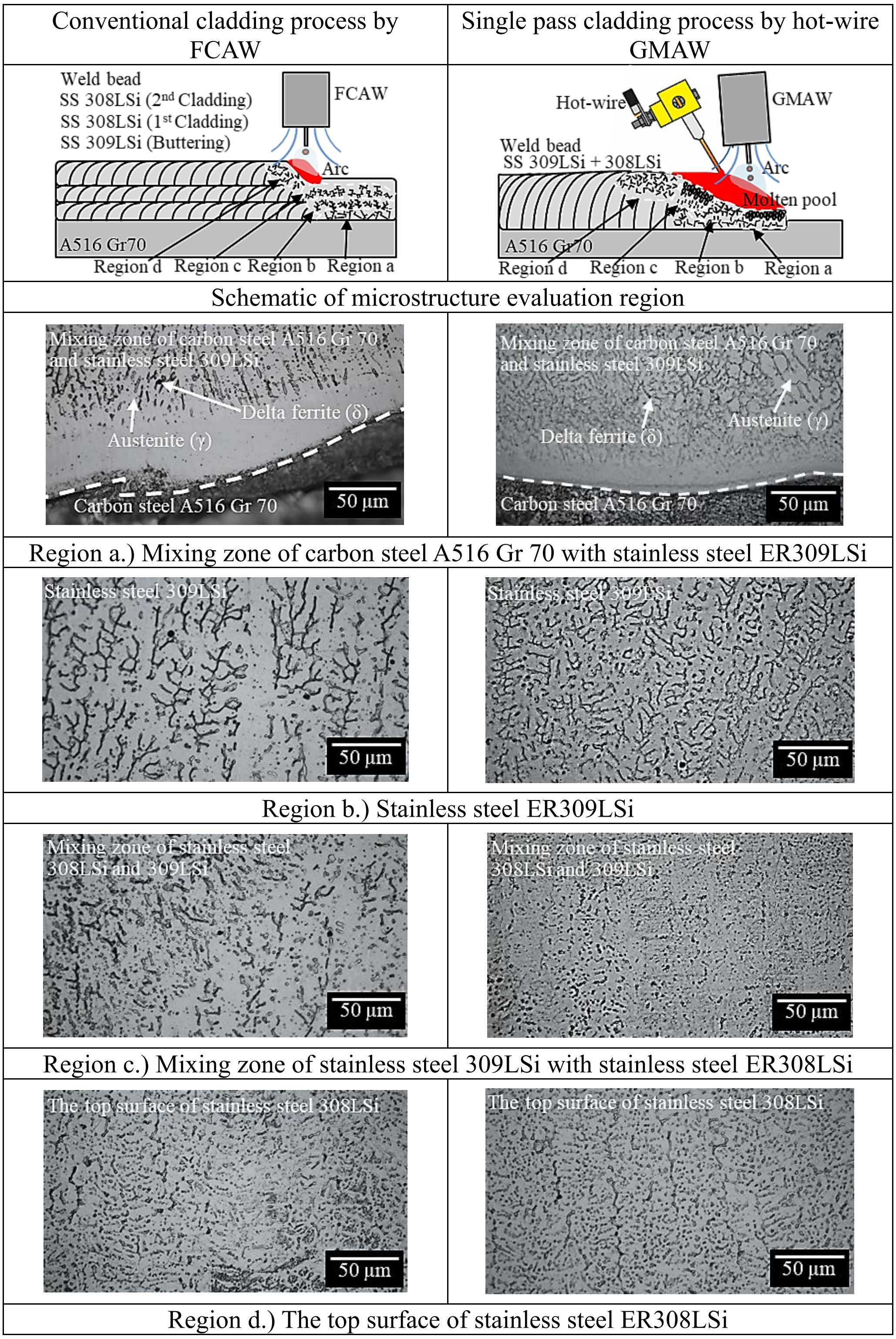

Figure 9 The schematic of microstructure evaluation and microstructure result of each region

Region C; Mixing zone of stainless steel ER309LSi with stainless steel ER308LSi. According to the high percentage of delta ferrite of FCAW buttering layer, it occurred vermicular ferrite structure (20%) as FA mode solidification. Consequently, cladding by FCAW is necessary to weld one more cladding layer to get optimal microstructure. On the other hand, the primary austenite with a small amount of delta ferrite (2%) as AF mode solidification occurred in hot-wire GMAW process.

Region D; The top surface of stainless steel ER308LSi. Both of cladding processes by hot-wire GMAW and FCAW showed evidence delta ferrite in austenite structure as AF mode solidification without crack defect. The conventional cladding process by FCAW is necessary multi-layers to get an optimal microstructure on the top surface (delta ferrite 5% and FN 3.5). On the other hand, the cladding process by hot-wire GMAW can obtain the optimize microstructure (delta ferrite 4% and FN 3) within single pass by high deposition rate and welding speed.

The microstructure evaluation of hot-wire GMAW cladding process was illustrated the phase evaluation of each region in table 3.

Table 3. The hot-wire GMAW phase evaluation of each region.

Region	Description	Phase evaluation
A	516+309LSi	L→ γ→ γ + δ (8%); AF mode
B	309LSi	L→ δ→ δ (11%) + γ; FA mode
C	309LSi+308LSi	L→ γ→ γ + δ (2%); AF mode
D	308LSi	L→ γ→ γ + δ (4%, FN 3); AF mode

Conclusions

In this research, microstructure evaluation of single pass cladding by hot-wire GMAW was studied. It can be concluded that:

(1) On the top surface of hot-wire GMAW showed an evidence delta ferrite in austenite structure (FN 3) same as the conventional process, but it could reduce 3.5 times of cycle time.

(2) The microstructure evaluation of hot-wire GMAW cladding process is similar to conventional cladding process by FCAW in mixing zone of carbon steel A516 Gr70 with stainless steel ER309LSi and the buttering layer. On the other hand, in the mixing zone of stainless steel ER309LSi with stainless steel ER308LSi of hot-wire GMAW showed a small amount of delta ferrite in austenite structure deference with the conventional process. Therefore, it caused hot-wire GMAW could achieve cladding within single-pass.

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