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Diffusion Bonding of Stainless ASTM A240 Grade 304 in Double Side Flux Cored Arc Welding

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Abstract

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Double side flux cored arc welding (DS-FCAW) has been developed from conventional flux cored arc welding (FCAW). DS-FCAW, dual torches are used by placing an opposite to each other and welding on both sides simultaneously. The objective of this research paper is to investigate diffusion bonding effect due to DS-FCAW. Stainless steel ASTM A240 Grade 304 was studied. Other welding parameters were set constant except welding current and voltage. Diffusion bonding was observed even though weld profiles from macro inspection showed lack of penetration by weld metal in all experiments. It can be concluded that, at certain conditions, the welds can pass both mechanical test and microstructure examination because diffusion bonding process was completely developed due to high contraction stress and high temperature. The advantage of DS-FCAW is that the required joint mechanical properties can be achieved in single welding which results in reduction of welding time and cost.

Key Words : Double side flux cored arc welding (DS-FCAW), Diffusion

Introduction

Conventional flux cored arc welding (FCAW) is the most widely used welding process in the construction work, for example ship building, pressure vessel, high land construction and site construction. The advantages of this process are higher deposition rate and lower heat input resulting in a lower distortion than the other semi-automatic welding process. FCAW can be used either self shielding or external shielding gas. However, in the conventional FCAW welding method the material has been welded with one torch from one side. This required gouging or grinding process on the other side including non destructive testing (NDT) such as a dry penetrant test before complete welding. All of these steps cause considerable amount of time and money.

Stainless steels can be diffusion welded using the suitable condition. These steels are normally covered by a thin adherent oxide (chromium oxide) that must be broken up and/or dissolved during the welding process. This is possible when higher temperature and/or higher pressure are used.(1) Diffusion bounding is a process that produces solid-state coalescence between two materials under the following condition: First, joining occurs at a temperature below the melting point, Tm of the material to be joined (usually > 0.5 Tm). Second, coalescence of contacting surface is produced with loads below those that would cause macroscopic deformation to the parts.(2) Figure1. shows the joining surfaces which are separated to three parts. The first one is called "Base metal", the second "Cold work layer", the last "Surface oxide and Contaminant film".(3) For diffusion welding, a three stage mechanistic model, shown in Figure 2. adequately describes weld formation. In the first stage, deformation of the contacting asperities occurs primarily by yielding and by creep deformation mechanism to produce intimate contact over a large fraction of the interfacial area. At the end of this stage, the joint is essentially a grain boundary at the area of contact with voids between these areas. During the second stage, diffusion becomes more important than deformation and many voids disappear as grain boundary diffusion of atoms continues. Simultaneously, the interfacial grain boundary migrates to an equilibrium configuration away from the original weld interface, leaving many remaining voids within the grain. In the third stage, the remaining voids are eliminated by volume diffusion of atoms to the void surface (equivalent to diffusion of vacancies away from the void).(4-5)

The purpose of this study was to evaluate the diffusion bonding of stainless steel using the Double side flux cored arc welding (DS-FCAW). The information obtained in this study should also improve and create new welding techniques in order to save time and cost for the welding fabrications and manufacturing industries.

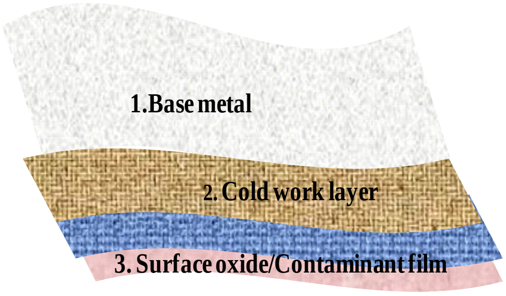

Figure 1. Joining Surface

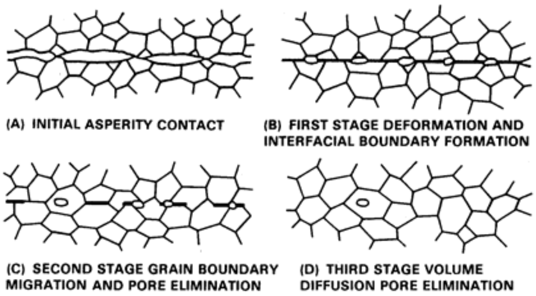

Figure 2. Diffusion Mechanism

Experimental Procedure

Stainless steel ASTM A240 Grade 304 was selected in this experiment since it is one of the most widely used in fabrication industries. The samples were prepared for square butt weld and were welded by using the Double side flux cored arc welding technique. Four welding conditions were designed in order to investigate diffusion bonding effect at the joining interface. The sample size was 0.6 cm thick, 12 cm wide, and 20 cm in length. The butting surface was created by the milling machine to obtain a surface roughness in the range of $R_a = 0.4\text{-}0.8\ \mu m$ as shown in Figure 3. Then the samples were tack welded to form square butt joint and obtain intimate contact. The gap variation is within 0-0.01 cm. The samples were fixed at the fixture and moved during welding at travel speed of 26.4±1cm/min. The welds were made in 2G position (Horizontal position) with fixed travel angle of 20^0 and working angle of 75^0. The flux cored wire electrode was E308LT-1 with a diameter of 0.12 cm. CO_2 shielding gas was used to match with the welding electrode used. The electrode extension was kept constant at 1.5 ± 0.2cm for all tests. Four welding conditions are shown in Table 1 and also Figure 3 showed the comparison between butt surface preparation and standard gauges. This figure showed careful weld preparation to obtain required surface roughness. It is crucial to get intimate contact or minimize surface asperities at the joining interface. Experimental setup is shown in Figure 4 and 5.

Table 1. Welding Parameters

Weld parameters No.	Welding Current and Voltage (Amp/Volt)		Electrode Extension (cm)	Welding Speed (cm/min)	Lap-Distance (cm)
	Leader torch	Follower torch			
1	180/23	210/23.5	1.5±0.2	26±1	1±0.1
2	190/23	200/23.5	1.5±0.2	26±1	1±0.1
3	200/23.5	190/23	1.5±0.2	26±1	1±0.1
4	210/23.5	180/23	1.5±0.2	26±1	1±0.1

Figure 3. Surface preparation compared with standard gauge

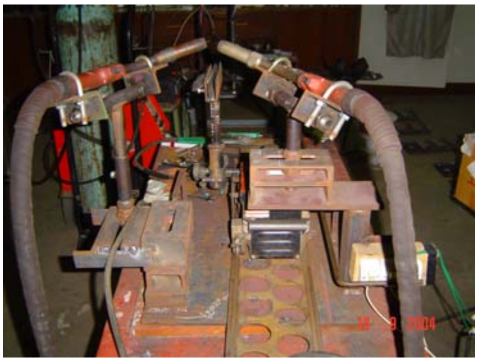

Figure 4. Welding jig and fixture

Figure 5. Test pieces with welding apparatus

All tested pieces were investigated for diffusion bonding by microscopic examination at joining interface where full penetration can not be achieved. The mechanical tests were also done by using side bend test according to ASME Section IX.

Experimental Results and Discussions

In this investigation, test pieces were cut by band saw to avoid heat effecting welded samples. Metallographies were prepared using standard metallographic techniques with final polishing with a 0.05-micron silica aqueous solution. A Vilella's etch was used to reveal the microstructural features and then the micrographs were recorded at position "A", "B", and "C" as shown in Figure 6. It can be clearly seen that the diffusion bonding was observed as shown in Figure 7 for welding parameters 1 and 2 and in Figure 8 for welding parameters number 3 and 4. The joining interfaces of the samples were pressed by high contraction stress as can be observed from highly deformed cold work layer.

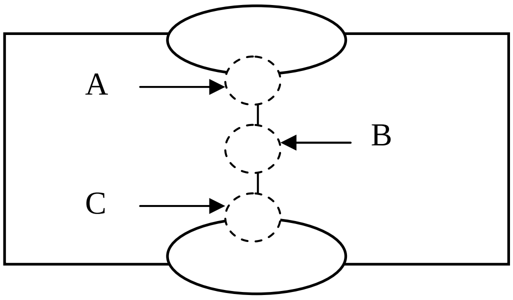

Figure 6. Micrograph recorded Position

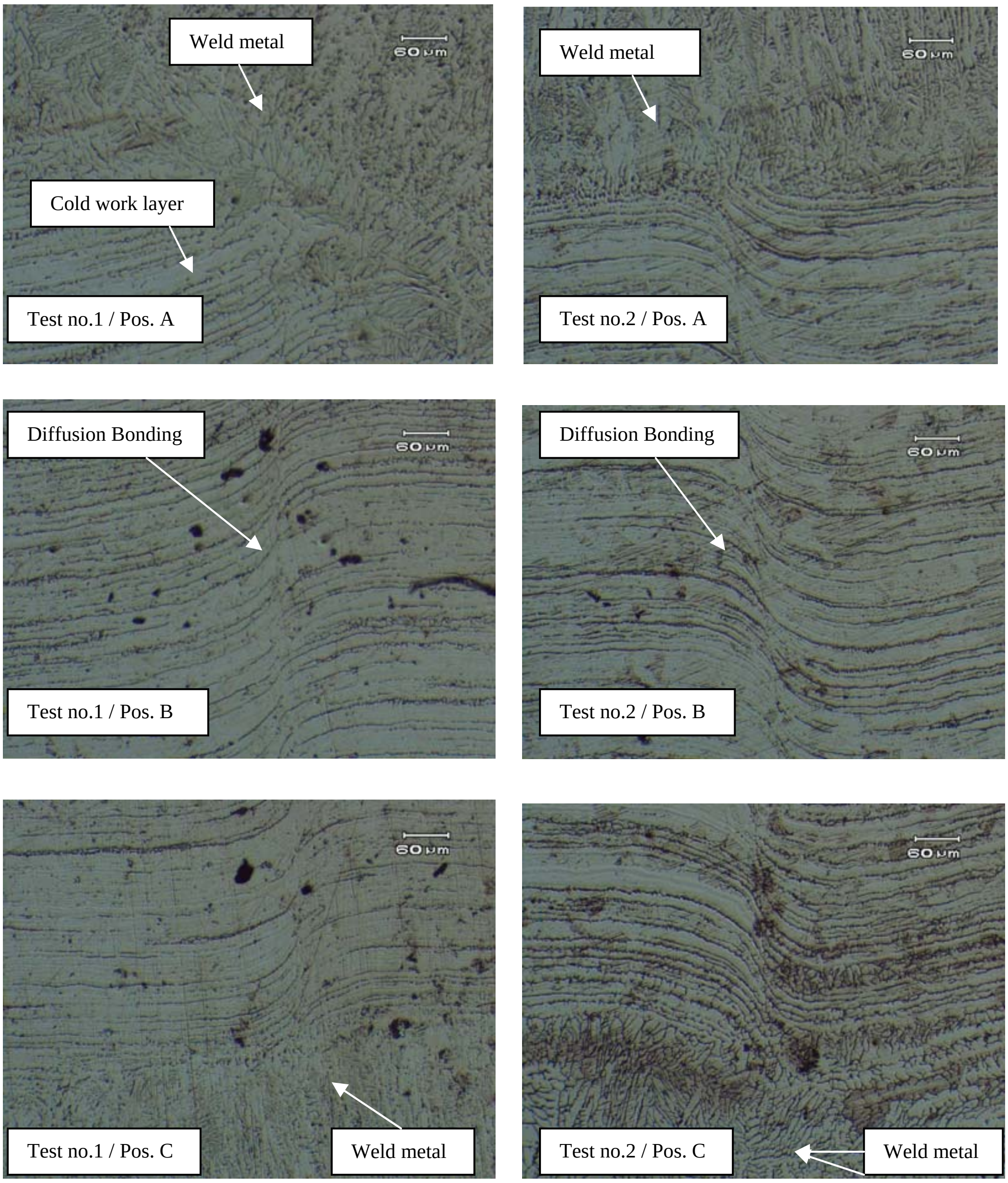

Figure 7. Diffusion bonding at test pieces No. 1, 2

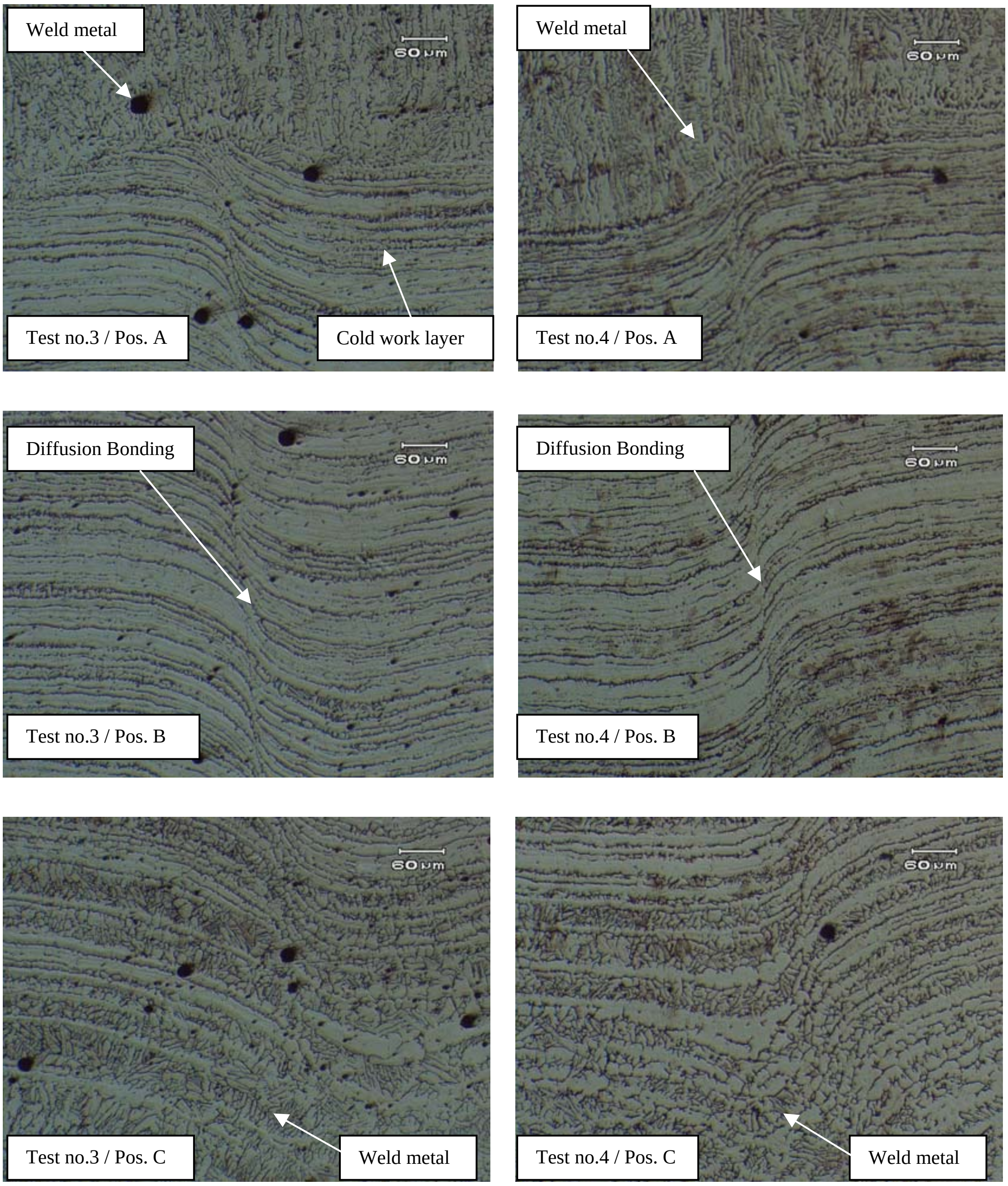

Figure 8. Diffusion bonding at test pieces No. 3, 4

Positions A and C in Figures 7 and 8 clearly show the weld metal area where the joining interface was melted as well as incompleted penetration area where the joint interface was not melted. In the base metal area, the microstructure shows deformed austenitic grains in rolling direction. At joining interface as shown in position B of Figures 7 and 8, the direction of rolled austenitic grains was changed due to high compressive force related to high contraction stress from weld metal on both sides and high temperature from welding heat. Diffusion bonding was also clearly observed since the grain boundary migration and welding heat. Diffusion bonding was also clearly observed since the grain boundary migration and pore elimination as compared with Figures 2c and 2d was also observed here. The side bend test (mechanical test) as shown in Figure 9 was carried out according to ASME Section IX (QW-141.2). The result shows that tested samples were accepted according to the acceptance criteria. Even though incompleted joint penetration was observed, diffusion bonding was developed at an unpenetrated area and has sufficient bonding strength resisting tensile stress on convex surface. Therefore it can be proved that the diffusion process can be completed within a short period of time.

Figure 9. Side Bend Test, No Crack was found at all test pieces

Temperature profiles which are created by Double side flux cored arc welding (DS-FCAW) at the test pieces would be simulated by conventional Finite Element Analysis Software, ANSYS 8.1, by using the same welding parameter as used in experiments (parameter 3) to calculate the heat flux pass through to the unpenetrated weld metal.

Figure 10 shows the finite element analysis results for temperature distribution developed at joining interface of an unpenetrated area. The results show the minimum temperature of 966°C at the middle thickness. The contraction stress can be calculated by using the classical method of stress, stain and modulus of elasticity at the given temperature.

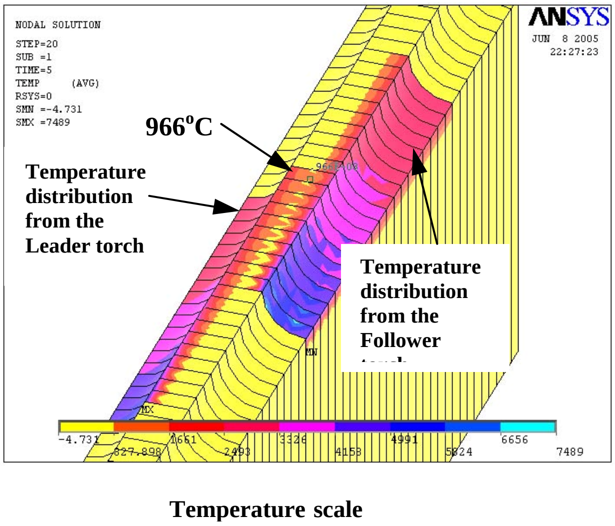

Figure 10. Temperature Distribution Simulation

By this method the modulus of elasticity of stainless steel at a given temperature of 815.55°C (using the minimum value at the maximum temperature used) was 125,089.1 MPa.(6) and the test pieces strain was calculated to be 0.00416 by rechecking the total width of test pieces before and after welding. Therefore, the contraction stress averaged along the surface was 520.37 MPa. According to the value of stress and temperature even the welding time was so short (about 45-55 sec), diffusion bonding could be achieved. Compared with previous research papers, diffusion bonding can occur in stainless steel by stress ranging from 2.1-7 MPa and temperature ranging from 880-970°C with a welding time of 60 min.(7, 8) However, in this analysis diffusion bonding can be achieved in a short period of time with a relatively high contraction stress of 520.37 MPa.

Conclusions

DS-FCAW of Stainless Steel ASTM 240 Grade 304 was studied to investigate the diffusion effect. Four welding conditions were used in this experiment. The butting surface roughness was carefully controlled in the range of R_a = 0.4-0.8 μm to obtain intimate contact at joining interface. The results showed complete diffusion bonding on all tested conditions. The microscopic examination showed a highly deformed area where diffusion bonding was developed. This results from high contraction stress and temperature at joining interface. Mechanical testing was also performed by using side bend test according to ASME Section IX (QW-141.2) to determine the degree of welded soundness at diffusion bonding area. Convex surface of bended samples experience high tensile stress, if the diffusion bonding is not achieved, open defects on the convex surface will be observed. As shown in the experiment results, no defect was observed on the convex surface. It can be concluded that diffusion bonding strength can resist high tensile stress obtained by side bend test. Therefore, DS-FCAW can weld the sample on both sides simultaneously and the work can be completely welded by single operational welding. Grindings or gouging process was eliminated by using this technique. Even though weld metals from both torches cannot give full penetration, the diffusion bonding process was developed at the unpenetration area resulting in high bonding strength in this region. DS-FCAW is a relatively new welding technique to be used in the fabrication field, and it may prove to save considerable amount of time and money.

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