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The dissymmetry of friction stir welding joints and variable polarity plasma arc welding joints study†

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KEY WORDS: (FSW) (VPPAW) (nano-indentation experiment) (Half-leaf'zone), (dissymmetry)

1. Introduction

Recently, because of aluminum's light weight, it has been considered an energy-saving structural material in advanced applications. In addition, aluminum is an easily saved resource because it can be recycled, and thus can be expected to be an environmental friendly metallic material. One such application would be its use in automobiles, which would facilitate transportation, numerous similar examples could be cited in support of employing aluminum as a structural material[1]. In addition, because aluminum has large thermal conductivity, large specific heat, quick thermal conductivity and large linear expansion coefficient, it easy to form an air hole during the welding[2]. So, welding Aluminum welding is a difficult problem. Two kinds of mature approach are Friction Stir Welding(FSW) and Variable Polarity Plasma Arc Welding(VPPAW). Therefore, it is important to compare the microstructure and micro-hardness of the Friction stir welding joints and Variable polarity plasma arc welding joints.

Therefore, the friction stir welding and the variable polarity plasma welding are compared, and the study is based on differences of the microstructure and mechanical properties of these two methods. A nano-indentation experiment is used to test the hardness in some narrow and small zones, such as the "Half-leaf" zone . The nano-indentation method is flexible and accurate and provides a powerful tool to test the hardness of weld joints. It is the basic work for the hybrid welding has laid a solid foundation.

2. Experimental procedures

Specimens of the FSW and VPPAW joints are obtained from 6mm 2219 aluminum alloy plate. By using an optical microscope, the microstructure of welding joint is observed. The procedures are sampling, polishing, corrosion and observation. The cross sections of metallographic specimens are polished, etched with Keller's reagent (1 ml hydrochloric acid,1.5 ml nitric acid, 2.5 ml hydrofluoric acid and 95 ml water) and washed by 4% of the nitrate acid. At last specimens are observed by optical microscopy. What's more, aqua regia is used. By using SEM, microstructure is very clearly seen. After these experiments, a Nano-indentation test is done. All the tests were conducted on a Nano Indenter G200.

3. Results

At first Keller reagent is used to corrode the specimens, second the specimens are washed by the 4% of the nitrate acid, at last, the specimens are observed by optical microscope. FSW joint can be divided into the following several zones(see **Fig. 1**) : A:"Half-leaf" zone, B:zone above WNZ, C:TMAZ, D:WNZ, E:boundary of AS, F:boundary of RS, G:HAZ, H:Base metal.

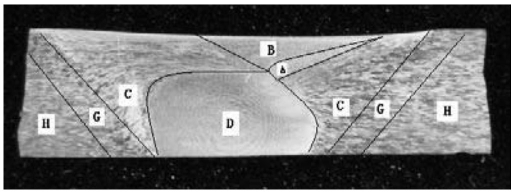
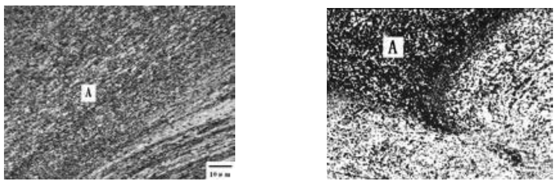


Fig. 1 Macro Map of FSW joint

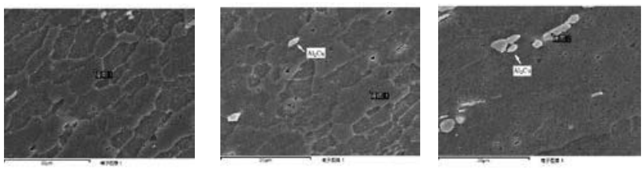
The regions are observed under the microscope. And the regions show different characteristics, and asymmetry features of the FSW joints.



(a) "Half-leaf" zone corroded by Kellar acid (b) "Half-leaf" zone corroded by aqua regia

Fig. 2 microstructure of "Half-leaf" zone

Figure 2(a) shows the "Half-leaf" zone, the zone is under strong pressure. "Half-leaf" zone can be shown clearly by use of aqua regia, and this area can be corroded easier than other zone(see. Fig. **2**(b)).



(a) "Half-leaf" zone (b) bound of "Half-leaf" zone (c) near the "Half-leaf" zone(TMAZ)

Fig. 3 result of "Half-leaf" zone by Scanning electron microscopy

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Scanning electron microscope tests are done on "Half-leaf" zone, θ-phase grown up and gathered together from "Half-leaf" zone to TMAZ by observing. 2219 aluminum alloy used in solid solution strengthening. With the precipitation of θ-phase, the effect of solid solution strengthening can be weak. So the hardness of TMAZ is lower than "Half-leaf" zone. See, **Fig. 3**.

According to the microstructure observed by optical microscope, the indentation experiments are arranged. Test points of Nano-indentation test for the FSW joints as shown in **Fig. 4**.

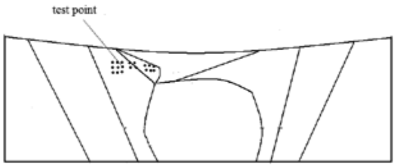


Fig. 4 distribution of Nano-indentation test point on FSW joint

The hardness of "Half-leaf" zone has been greatly improved and increased the 21.5% of hardness. This is the severely corroded area which is used aqua regia. The grains of "Half-leaf" zone are slightly larger than the grains of WNZ, and less than the surrounding. The smaller grains are brought about the higher hardness.

The microstructure of VPPAW joint, which is used 2219 aluminum alloy as base material and 2319 aluminum alloy as filling material, is observed. VPPAW joint can be divided into the following several zones (see **Fig. 5**); A:weld, B:HAZ, C:FL, D:BM. There are two methods for forming VPPAW joints: keyhole-mode variable polarity plasma arc welding (see Fig. 5) and melting-keyhole variable polarity plasma arc welding (see **Fig. 6**).

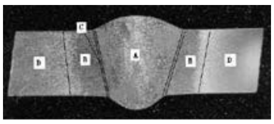


Fig. 5 keyhole-mode VPPAW joint

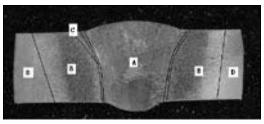
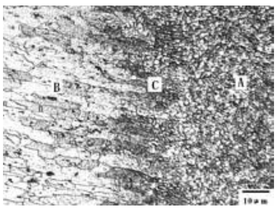
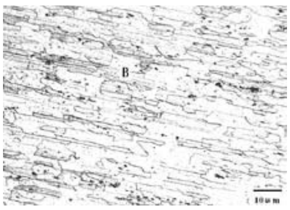


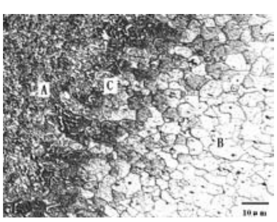
Fig. 6 melting- keyhole VPPAW joint



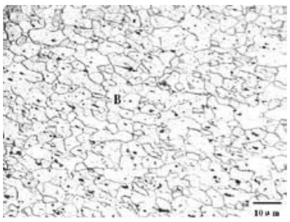
(a)FL



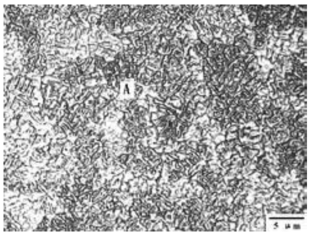
(b)HAZ



(c)HL



(d)HAZ

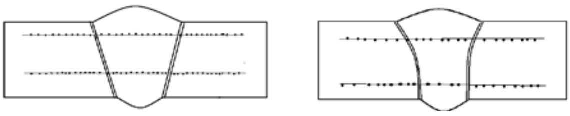


(e)100X weld

Fig. 7 microstructure of keyhole-mode welding joint

Figure 7(a-d) are shown HL and HAZ by Metallographic microscope at 40 times. It is worth noting that keyhole-mode welding joint is asymmetric. The grains in two HAZ grow up differently. The grains in left HAZ(see Figure 7(a)) grow up obviously. But Figure 7(d) shows that right grains don't change obviously after thermal cycling, and these grains still retains the rolling direction of the base material. Dissymmetric microstructure is decided by dissymmetric heat input in this area. Because VPPAW uses vertical position, and it has strong power of arc, so the heat input is dissymmetric.

Test points of Nano-indentation test for the VPPAW joints as shown in **Fig. 8**.



(a)keyhole (b)melting-keyhole

Fig. 8 distribution of nano-indentation test point on VPPAW joint

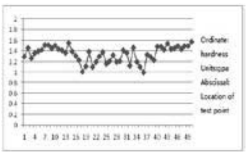


Fig. 9 result of nano-indentation test on melting-keyhole VPPAW joint

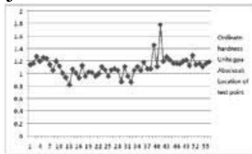


Fig. 10 result of nano-indentation test on keyhole VPPAW joint

As shown in **Fig. 9**, reasonable welding process makes the performance of VPPA obvious symmetry. Hardness of weld is slightly lower than the base metal. Weld nugget has a part of dendrites, rather than completely composed of equiaxed grains. There are satisfactory aluminum welded joints, but not all VPPAW processes can achieve satisfactory results. For VPPAW includes keyhole VPPAW and melting-keyhole VPPAW. The peak hardness is found in HL, so the property of the weld is asymmetry in the whole joint (see **Fig. 10**). It has not only relationship with the high mobility of melt metal, because keyhole VPPAW uses large energy, but also VPPAW is generally vertical position welding.

4. Conclusions

In this paper, two welding methods which are FSW and VPPAW are used to weld 2219 aluminum alloy. Finally both the FSW and VPPAW will appear non-symmetrical welded joints, such non-symmetry is reflected in the microstructure morphology and performance.

(1)In the FSW joints, defects in onion rings, the different of forward side and backward side microstructure and "Half-leaf" zone have made FSW joints have a strong dissymmetry. The dissymmetry in welded joints is brought about the dissymmetry in joint performance. The dissymmetry in FSW joint can not be suppressed due to the nature of the mixing head and the process of FSW, it is difficult to over come.

(2)The problems about dissymmetry are also present in the VPPAW joint. However by changing the form of VPPAW, VPPAW joint can be adjusted to symmetry and results of satisfactory welding. Not only symmetrical microstructure is obtained, but also good properties of welded joints are obtained by using the right filling material.

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