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METALLURGICAL CHARACTERISTICS OF WELDED TITANIUM ALLOYS

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ABSTRACT

Titanium and Aluminium alloys are commonly used in various applications. Welding of the above-mentioned materials is of utmost importance in the engineering industry. A lot of studies have been made to understand the mechanical properties of the materials. During welding, titanium alloys absorb oxygen and nitrogen from the atmosphere easily. It has become necessary to develop unique welding procedures and techniques to control the alpha/beta phase transformations and precipitation reactions responsible for the deleterious weld properties in these materials. This article brings out the salient points concerning the metallurgical characteristics of the welded materials.

Keywords: Titanium alloys, pulsed current GTA welding, TIG welding, microstructure analysis

I. INTRODUCTION

Earlier work by Becker and Adams showed that the use of the pulsed current in GTA welding of titanium alloys did not result in any measurable grain refinement; nor did it affect tensile properties. Pulsing of the welding current results in grain refinement of the weld zone. Significant refinement of the solidification structure and a transition from columnar to equiaxed growth has been reported in aluminum alloys and austenitic stainless steels [1].

The effect of microstructures on fatigue crack growth rates in Ti-6Al-4V plates and laser welds have been investigated by Tsay and Rsay[2]. The metallograph of the as-welded fusion zone reveals the microstructure of coarse beta grain with internally acicular morphology. TEM micrograph revealed that FZ consists of mainly alpha prime martensite as compared to granular alpha and refined lamellar alpha-beta in the BM. The acicular alpha prime in the FZ of laser welds is attributed to the rapid cooling of the molten weld pool during solidification. In addition, the microstructure in HAZ would also depend on the thermal history of welding. The microstructure of the heat-affected zone(HAZ) near the fusion boundary ithe s same as FZ; while regions far away are heated to relatively low temperatures and had a microstructure similar to that of BM.

The effect of annealing treatments on welded α-β Ti Al Mn alloy was investigated by Keshava Murthy and Sundaresan [3]. The weld energy input is least for the EB weld and the highest for the MGTA weld. As a result, the prior beta grain size was least in the EB weld (about 100-150 μm) and highest in the MGTA weld (about 400-600 μm). In GTA welds the high-temperature beta phase has decomposed to a lamellar alpha-beta structure entirely by diffusion. During post-weld heat treatment, any martensite in the as-welded condition gets decomposed by the formation of the beta phase, with the composition of the martensite approaching the equilibrium composition of the alpha phase at the heat treatment temperature. Heat treatment resulted in a coarse alpha-beta structure. However, the prior beta grain size is not changed during any of the heat treatments, since these are all performed below the beta transus temperatures. Two α+β titanium alloys under a variety of conditions including direct current pulsing and alternating current pulsing were studied by Sundaresan et al [4]. Current pulsing responsible for refining the solidification structure is much stronger in a.c pulsing than in d.c pulsing. Macrostructure examination showed that grain size is the least in the welds made at a pulse frequency of 6 Hz. At the optimum frequency of 6 Hz, the reduction in grain size amounts to 36% in Ti-6Al-4V.

In the optimum set of parameters of current pulsing and magnetic arc oscillation, the fusion zone of various alloys exhibited fine equiaxed grains [5]. The columnar grains in the fusion zone almost vanished. Combining current pulsing and magnetic arc oscillation techniques in AC-TIG welding of various alloys resulted in much more refined equiaxed grains than those obtained with current pulsing and arc oscillation techniques individually.

Alternating current pulsing resulted in better grain refinement in the fusion zone compared to direct current pulsing in the TIG welded alloys. Equiaxed grains observed near the fusion boundary of continuous current welds were found to be part of the fusion zone and not part of the unmixed zone in titanium welds. Equiaxed grains observed near the fusion boundary of continuous current welds were found to be swept into the entire fusion zone by current pulsing and arc oscillation techniques.

A comparison of EBW, LBW, and GTAW welding of CP Ti sheets revealed that the size of grains is the finest by EBW and largest by TIG. The structures are serrate and regular plate-shaped α structures by EBW, coarse serrate and little acicular α structures by TIG, and fine acicular α structures by LBW. The structures are serrate and regular plate alpha structures by EBW-HV. The formation of plate-like alpha is due to the low cooling speed in EBW and the formation of acicular grains is due to the fast cooling by LBW [6]. Laser beam welding revealed that the weld microstructure consists primarily of retained ordered β phase and is independent of the laser welding parameters. The microstructure examination results suggested that the structures of the weld metal made with laser beam under the welding condition employed in this work are predominantly metastable beta. The welding parameter does not affect the phase constitution but the microstructure and orientation. The microstructure becomes coarser with the heat input increasing. The solidification crystal of the weld metal made with heat input up to 600J/cm exhibited distinct orientation [7].

A reduced amount of primary α grains in the HAZ and weld metal may account for improved impact toughness. Weld has essentially acicular α and β microstructure with large prior β grains. A metallographic study showed that the weld is the most brittle part in the welded joint with the coarsest grains and highest micro-hardness. The base metal contains primary alpha grains and some alternate alpha and beta platelets. The HAZ has primary alpha grains in a matrix of acicular alpha and beta. The microstructure of the fusion zone reveals a needle-like martensitic prime alpha structure formed from transformed beta. The microstructure of the HAZ is a mixture of acicular alpha and primary alpha. The micro-hardness profile across the weldment indicates that the hardness of the fusion zone is higher than both the HAZ and parent metal [8].
A study of the metallurgical properties of gas tungsten arc weldments of Ti-6Al-4V and CP titanium alloys shows that the top of the welds have relatively larger columnar grains and the bottoms of the same welds exhibit equiaxed fine grains The fusion zone microstructures consist of acicular α and needle-like martensite α', and the fusion zone is the region of maximum hardness in the CP Titanium and Ti-6Al-4V welds. The columnar grains at the tops of the welds for CP Ti, Ti-64, and Ti-153 are about 400-450, 450-500, and 350-400 μm respectively. The equiaxed grains at the weld bottoms for CP Ti, Ti-64, and Ti-153 have sizes of about 50-80, 50-80, and 80-100 μm respectively. The FZ of Ti-153 alloy exhibits coarse beta grains. This coarse grain structure would degrade the mechanical properties of the weldment [9-10].

The fusion zone geometry and grain structure in the HAZ of titanium alloy GTA welds have been studied experimentally and theoretically. The grain growth in the HAZ of titanium alloy is compared with that in the commercially pure titanium. It is concluded that both the calculated results and the experimental data showed that for identical welding conditions, the grain size in the HAZ of the alloy is significantly smaller than that in the commercially pure titanium. Average grain size near the fusion region is about 4 to 12 times larger than that in the base plate depending on the heat input used. The extent of grain growth in the HAZ is strongly dependent on the heat input. The grain size distributions were found to be identical for different locations in the HAZ [11].

An experimental study on CO_2 laser welding of Ti-6Al-4V alloy was done by Caiazzo et al [12]. Examination showed hardness increase towards the HAZ and to the melted zone. This is due to the very high cooling rates during the laser welding process. The grains appear very fine, as they have not had either the time or temperature gradient necessary to increase their size. Microstructures of laser deposited Ti-6Al-4V revealed directional growth of the grains counter to the cooling direction, and subsequently to the formation of columnar grains. The fact that columnar grains grow to greater than 20mm in length shows that continued epitaxial growth of these columnar grains occurs during the deposition of the following layers. It appears that the top of the grains in the previous layer is partially re-melted and then serves as nuclei and grows again epitaxially counter to the cooling direction. When a layer of metal is added to the pre-existing layer, the region which remains solid at the top of the pre-existing layer is re-heated; therefore grain growth can take place in this region, where coarser alpha and beta are visible in these bands [13]. Friction stir welding was found to be an important process in the fabrication of non-ferrous materials [14-16]. Titanium alloys were greatly influenced by the pulsing of current in the gas tungsten arc welding process [17-18].

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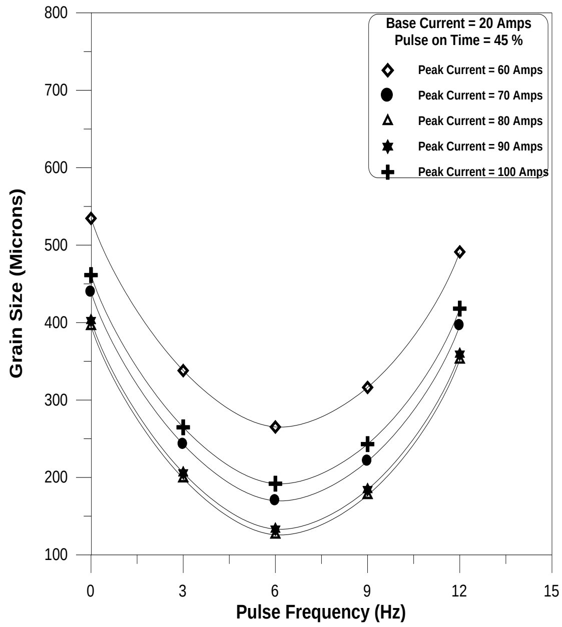
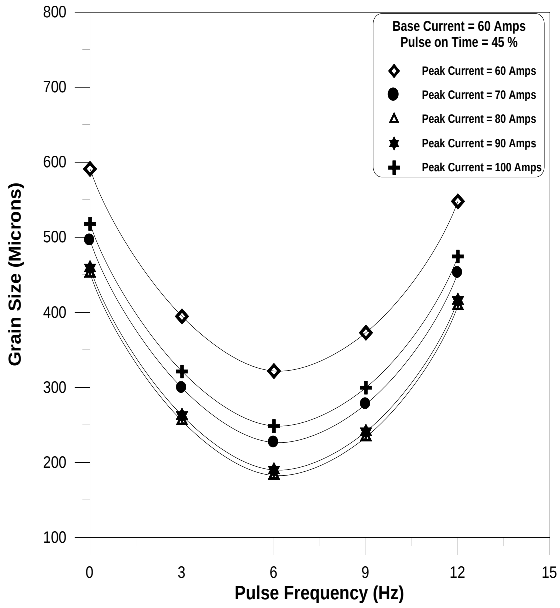
II.METHODOLOGY

The welded joints were sliced and then machined using wire-cut electric discharge machining (EDM) to the required dimensions for preparing tensile, impact, and corrosion specimens. The specimens were prepared following metallographic procedures. The microstructural examination has been carried out using a light optical microscope (VERSAMET-3) incorporated with an image analyzing software (Clemex-Vision). The specimens for metallographic examination were sectioned to the required sizes from the joint comprising weld metal, HAZ, and base metal regions and were polished using different grades of emery papers. Final polishing was done using the diamond compound (1μm particle size) in the disc polishing machine. Specimens were etched with Kroll's etchant to reveal the microstructure. The average diameter of the fusion zone grains is measured by applying the Heyn line intercept method.

III.RESULT AND DISCUSSION

It is well established that grain boundaries affect the strength of metal at low temperatures. Since slip cannot go directly from one grain another ,grain boundaries act as barriers during dislocation. Once a slip or a crack propagates at the grain boundaries, it has to be nucleated and continue in the new direction in the adjacent grain. This means that the energy required for a slip or a crack to propagate in metal with finer grains is higher compared to that in metal with coarser grains. Grain size decreases when the pulse frequency values are increased from 0 to 6Hz. The grain size is observed to increase when pulse frequency values raise from 6 to 12Hz as shown in Figure 1. The microstructure of the specimen is shown in Figure 2. The grain size increases by 45% for an increase of base current by 200%, measured at a constant pulse on time of 45%. The grain size value shoots by 38.92% for an increase of pulse on time by 57%, observed at a constant base current of 40 amps. A tendency of decrease in grain size is witnessed for an increase of peak current from 60 to 80amps and found to have an increasing trend for values of peak current ranging from 80 to 100 amps with whatsoever changes observed in base current and pulse on time.





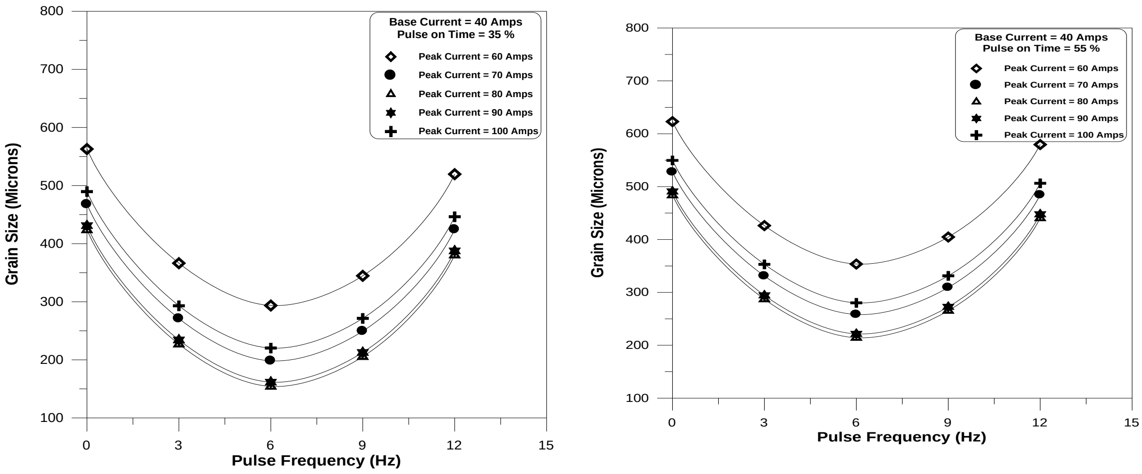
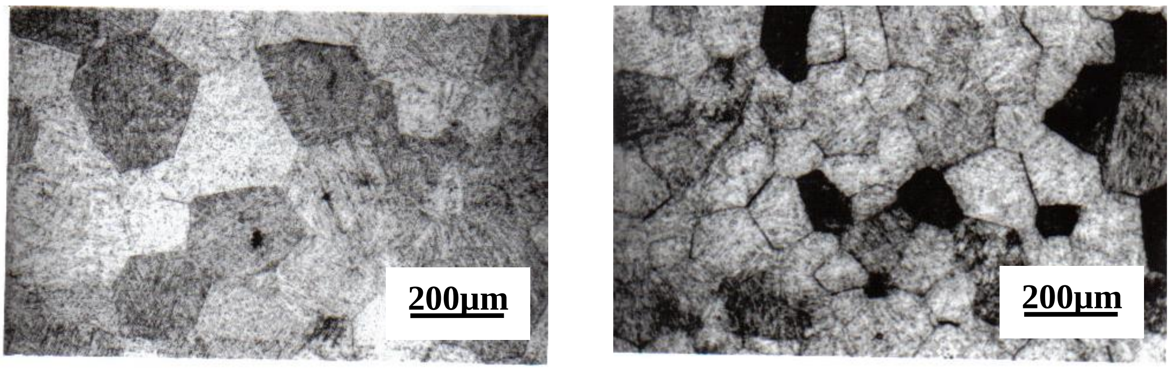


Fig.1 Effect of pulse current parameters on fusion zone grain size



Pulse Frequency at 0 Hz

Pulse Frequency at 6Hz

Fig.2 Microstructure of the specimen at different pulse frequency.

IV.CONCLUSION

1. The minimum grain size obtained by this optimization procedure is 72.7µm. The optimized pulsed current parameters to obtain the above values are: peak current is 83.6amps, the base current is 43.9amps, the pulse frequency is 6.26Hz, and pulse on time is 43.5%

2. Current pulsing lead to a relatively finer and more equiaxed grain structure in GTA welds. Grain refinement is accompanied by an increase in hardness, tensile strength, tensile ductility, and corrosion resistance. Of the four pulsed current parameters, peak current is having a predominant effect on properties.

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