ELSEVIER

Materials Science and Engineering A280 (2000) 177–181

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Electron beam welding, laser beam welding and gas tungsten arc welding of titanium sheet

Qi Yunlian *, Deng Ju, Hong Quan, Zeng Liying

Northwest Institute for Nonferrous Metal Research, Xi'an 710016, People's Republic of China

Abstract

Microstructures, properties and technical parameters of welding specimen of 0.5 mm thick sheets of commercial purity titanium (C.P. Ti) have been studied via high vacuum electron beam welding (EBW-HV), CO_2 laser beam welding (LBW) and gas tungsten arc welding (TIG), as well as optical microscope (OM) observation and microhardness measuring. The results indicate that the EBW is more suitable for C.P. Ti sheets welding, and the welding seam without defects can be obtained. The tensile strength and microhardness of joints are corresponding to matrix structure. The full-penetration butt welds are obtained by TIG, but they have many defects such as wide weld-seam, big deformation and coarse grains. The LBW has many advantages such as the narrowest weld-seam, the least deformation and the finest grains. The fine grains are good for properties of weld seam, but the LBW should be studied again for the reasons of unstable welding technologies and strict condition. Published by Elsevier Science S.A.

Keywords: Ti; EBW-HV; LBW; TIG

1. Introduction

Titanium alloys have been successfully applied for aerospace, ship and chemical industries etc. because they possess of many good characteristics such as high strength to weight ratio, corrosion resistance and excellent weldability [1–3]. With the development of titanium industries, many welding methods such as gas tungsten arc welding (TIG), beam welding, resistance welding and diffusion welding have already been developed. Because of their high chemical activity, titanium alloys are easy to absorb harmful gas (oxygen, hydrogen and nitrogen) and many problems such as low mechanical properties and unstable structures would appear [3–5]. TIG is a usually welding method. The laser beam welding (LBW) with high energy density and welding speed is a new welding technology.

High vacuum electron beam welding (EBW-HV) can protect joints from gaseous contamination.

The welding experiments of titanium sheet with 0.5 mm thickness are tested by using the above methods. The welding technology, the structures and properties are analyzed for titanium sheets.

* Corresponding author. Tel.: +86-296-231-078; fax: +86-296-250-729.

0921-5093/00/$ - see front matter Published by Elsevier Science S.A.
PII: S0921-5093(99)00662-0

2. Experimental procedures

The sample of $100 \times 80 \times 0.5$ mm where the rolling direction is parallel to the width direction is used in this study. After certain machining and cleaning, with the gaseous protection of helium and argon are used during CO_2-LBW (ROFIN-SINAR-850) and TIG. The square-groove butt joints without filler metal are adopted in base metal up to 0.5 mm thick. Then the standard tensile and bending samples are prepared. Table 1 shows the parameters of welding technology.

The structure analysis of joints by OM observation, hardness measurement by HX-100 method, X-ray detection and evaluation of tensile and bending properties are done in this study.

3. Results and discussion

3.1. Weld-seam quality

Table 2 shows the quality of welded seam using several welding methods. The welded joints by EBW-HV method are bright sliver, smooth and show little deformation. However, the backs of welded joints by TIG method are light blue and show large deformation.

Although the precautions are used during welding processing, the back of welded joints would also be oxygenated because the samples are thin and easy to deform. The width of weldment by CO_2-LBW method is the narrowest and the deformation is the smallest among three welding methods. The width of the welding joints is 2.0 mm at observation side and 1.8 mm at the back by EBW method, while they are 3.6 and 3.4 mm for TIG method. The difference between observation side and reverse side of CO_2-LBW method is more than that by EBW and TIG method. The X-ray detection shows that full-penetration are obtained and no porous and no defects exit in EBW and TIG, but black lines are appeared by LBW because LBW is a high

Table 1
Welding technology parameters

Welding type	Welding parameters				
	Voltage (kV)	Current (mA)	Power (W)	Travel speed (mm s^{-1})	Vacuum (Pa)
EBW-HV	150	2.3	–	30	9.5×10^{-3}
TIG	0.018	25000	–	8	–
CO_2 LBW	–	–	2000	50	–

Table 2
Quality of welded seam

Welding type	Welded seam quality					
	Color		Width (mm)		The biggest distance between welding sample and platform (mm)	Defect (X-ray flaw detection)
	Observed side	Reverse side	Observed side	Reverse side		
EBW-HV	Silvery white	Silvery white	2.0	1.8	0.3	Nothing
TIG	Silvery white	Blue	3.6	3.4	0.8	Nothing
CO_2-LBW	Silvery white	Light straw	1.5	0.5	0.15	Black line in some areas

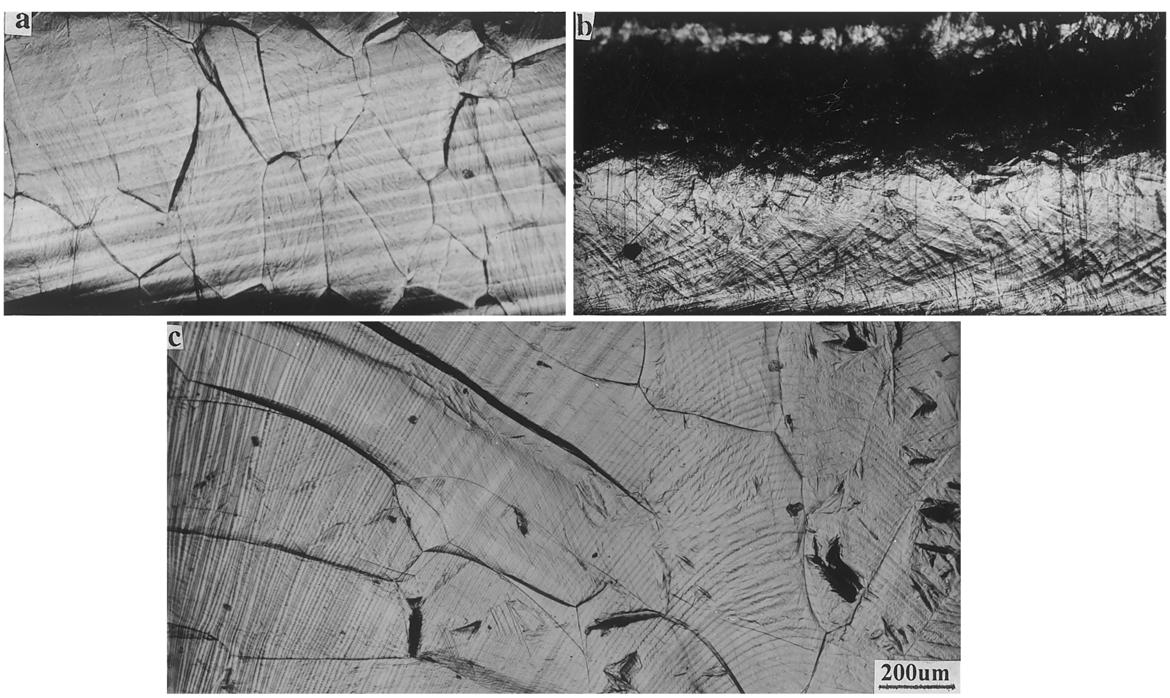

Fig. 1. Joint surface of Ti welding samples (a) EBW; (b) LBW; (c) TIG.

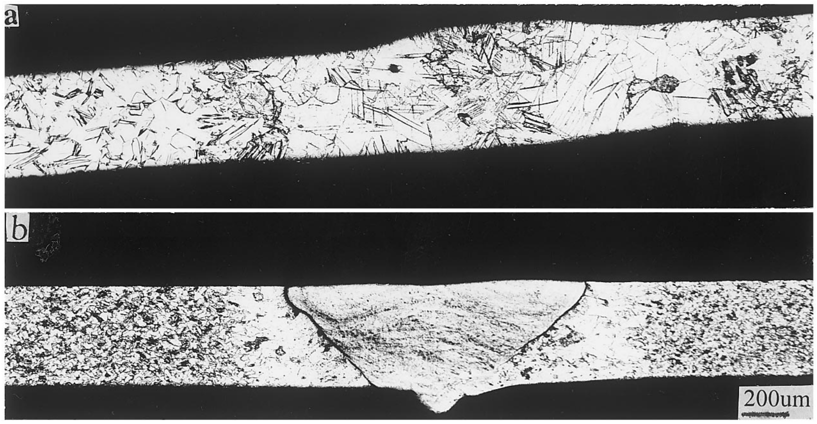

Fig. 2. Welded joint low-powered microstructure of Ti welding samples (a) EBW; (b) LBW.

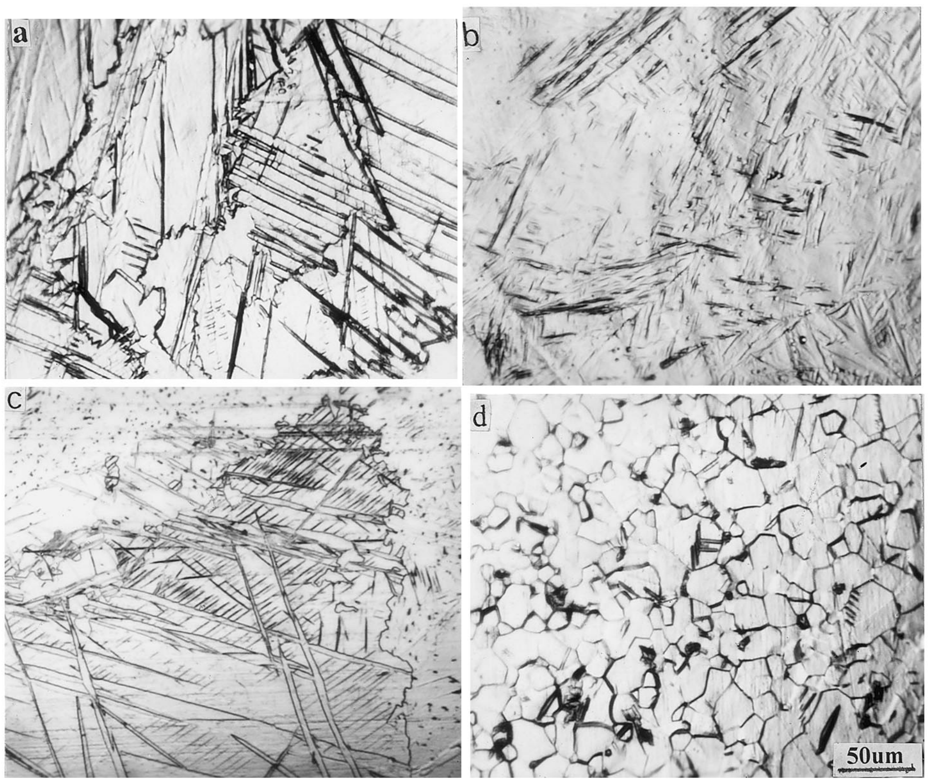

Fig. 3. Welded seam microstructures of Ti welding sample (a) EBW; (b) LBE; (c) TIG; (d) base metal.

energy density welding process. This technology cannot be used because of the limitation of the test condition and the sample precision.

3.2. Structure of welding joints

Fig. 1 shows the joint surface photographs by various welding methods. The surfaces of the welded joints indicate typical casting structures composed of equiaxed grains in the center and the dendritic grains in the outside of welded seam. The size of grains by TIG is the largest, while the size by LBW is the smallest. The fine acicular α structures are observed. The grain size by EBW is intermediate. The center of welded joint is clean. The differences of the grain size in center and outside of welded seam are two and a half times greater in TIG than that in EBW, and four times greater in TIG than in LBW. Due to the high temperature and low welding speed of TIG, and the grains would grow from outside to inside, otherwise the speed by LBW is the fastest and the grain is fine.

Fig. 2 shows the low magnified structures of titanium sheets by LBW and EBW methods. The reverse triangle shape and clear fusion line are appeared by LBW and

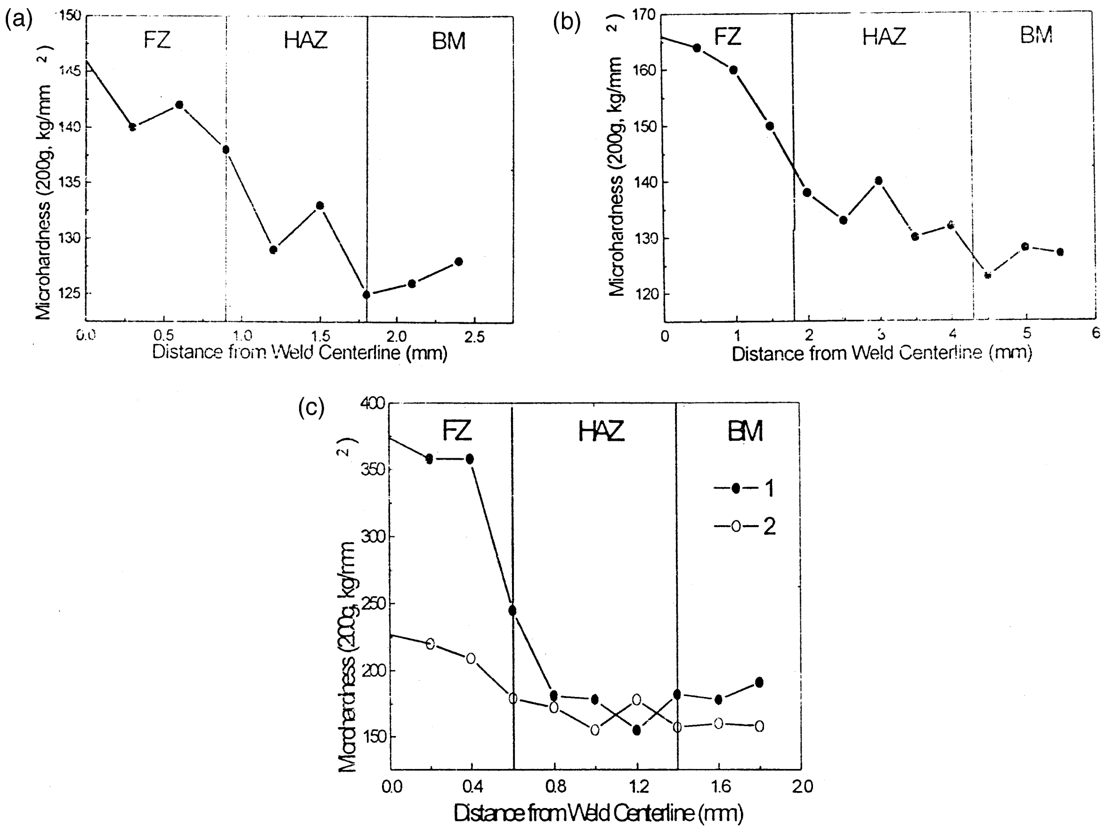

Fig. 4. Microhardness of Ti sheet welded joints (a) EBW (TAI); (b) TIG (TAI); (c) CO_2-LBW (TA2, 1, cold-rolled and welded state; 2, welded and then annealing state).

not appeared by EBW. Fig. 3 shows that the serrate and regular plate-shaped a structures are appeared by EBW while fine acicular a structure is appeared by LBW method, and the coarse serrate and acicular α structures are appeared by TIG method. The equiaxed grains are appeared at the matrix. The structures are related with the cooling speed. The formation of the acicular grains is due to the fast cooling speed by LBW method and the plate-like α is due to the low cooling speed by EBW. The excellent structure by LBW has little influence on ductility, but the reverse triangle shape is harmful for welded seam formation, maybe the coarse structure by TIG method has a certain influence on ductility.

3.3. Mechanical properties

Fig. 4 shows the microhardness of weldment. The microhardness decreases from center of welded joint to matrix for EBW and TIG methods while the microhardness of fusion zone (FZ) is 1.1 times greater than that of matrix by EBW and 1.26 times greater than that of based metal (BM) by TIG. The curve 1 in Fig. 4c shows that the smallest microhardness by LBW is in the heat affected zone (AHZ) and the highest hardness of fusion zone is 1.5 times greater than that of matrix (cold-rolled and welded state). After annealing the microhardness is decreases and the microhardness of fusion zone is 1.28 times greater than that of matrix. However, the smallest hardness is not appeared in heat effected zone. The reason is perhaps aging treatment where the temperature is high and the cooling speed is fast and a little β phase is exist. The reasons why that the microhardness by EBW is smaller than that by LBW and TIG is that the harmful gas by EBW is the least comparing with others and the joint would be contaminated.

The fracture locations of TIG and EBW specimens are base metals as also shown in Table 3. UTS and

Table 3
Properties of welded joint of Ti sheet

Welding type	UST σb (MPa)	Bend angle (γ^0)	Fracture location
EBW	328	>140	
Base metal	330	>140	Base metal
TIG	352	>140	
Base metal	330	>140	Base metal
CO_2-LBW	576	524	HAZ
Base metal	410	265	Base metal (annealed state)

bending strength are corresponding to matrix. The fracture location of LBW specimen is in heat affected zone, and after annealing the location is changed to base metal with corresponding to the change of the hardness.

4. Conclusions

1. The size of grains is the finest by CO_2-EBW, and largest by TIG. The structures are serrate and regular plate shaped a structures by EBW-HV, coarse serrate and a little acicular α structures by TIG, and fine acicular a structures by LBW.
2. The tensile strength and microhardness of joints by EBW-HV and TIG are corresponding to matrix.
3. The EBW-HV method is more suitable for C.P. Ti sheets welding, and the welded seam without defects can be obtained.

References

[1] Deng Ju, Rare Metal Mater. Eng. 1 (1997) 7.
[2] Luo Guozhen, Zhou Lian, Deng Ju, Rare Metal Mater. Eng. 5 (1997) 1.
[3] G. Disheng, Nonferrous Metal Welding, Mechanical Industry Press, Beijing, 1987, p. 206.
[4] Li Yuru, Development Titanium Industry 3 (1998) 11.
[5] Bys Chiang, C.E. Albright, Welding J. 3 (1993) 118s.