

# Investigation of Microhardness and Microstructural properties of Friction Stir Welded Pure Titanium Joint-A Review

Shashank S. Shinde<sup>1</sup>, Niyati Raut<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, VIT, Mumbai University, Virar, India  
Email: shashankshinde06353@gmail.com

<sup>2</sup>Head of Department of Mechanical Engineering, VIT, Mumbai University, Virar, India  
Email: niyatinraut@gmail.com

**Abstract** Friction Stir Welding is a solid-state joining method implemented to join Titanium Alloys utilizing friction heat to join titanium sheets. Friction Stir welding avoids most of the solidification defects which are encountered in other types of fusion welding processes. Mostly Friction Stir Welding is carried out on materials having low melting points such as aluminium, magnesium. Nowadays Friction Stir welding is implemented in the joining of titanium and its alloys which has ever-increasing demand in aerospace, chemical, and nuclear industries. Since Titanium Alloys exhibits a high melting point, special types of tools are used made of tungsten. This paper presents a review of investigations by various authors in which pure titanium plates are welded by friction stir welding process using different tool material, carried at various welding and rotating speeds. The microstructural characteristics and microhardness are reported in the base metal and stir zone at various welding speeds.

**Keywords**—Friction Stir Welding, Microhardness, Microstructural Characteristics and Stir Zone.

## I. INTRODUCTION

Friction Stir Welding was invented in early 90's at TWI (The Welding Institute in Cambridge, UK). Friction Stir Welding is a novel process being getting popularized and adopted because it's a solid-state method of joining, utilizing friction between the material being joined, and a rotating non-consumable tool which generate the needed heat to plasticize and mix material. The problems encountered with traditional fusion welding processes are avoided by FSW, which produce defect-free welds having excellent properties, also in some materials with poor fusion-weldability. Therefore, most of the solidification defects usually encountered with other welding methods are avoided by FSW. Hence it is mainly performed on alloys having low melting point such as aluminium and magnesium. FSW is still rarely studied on titanium alloys because of requirement of more expensive experimental resources such as a cooling system or expensive welding tools. Since it has tremendous advantages, FSW has got attentions from various industrial fields. The most important parameters in FSW are the tool material and its configuration and dimensions especially in FSW of high temperature materials such as Ni and Ti. The tool plays three major roles in the formation of the joint: (1) heat the weld zone by friction and plastic deformation, (2) extrude the materials from the front to the rear portion of the pin, and (3) forge the plasticized materials by its shoulder.

Titanium and its alloys are largely used in aerospace, chemical and nuclear industry because of high specific strengths and good erosion resistance. With the demanding utilization of Titanium and Titanium alloys, its bonding became progressively essential. The implementation of traditional technique of fusion welding process to titanium, produced development of a brittle cast structure, distorted shape and higher residual stress value. Thus, the solid state bonding techniques are furthermore convenient for weaving the complications in relation with the welded materials melting.

## II. MATERIAL AND METHOD

### 2.1 Material

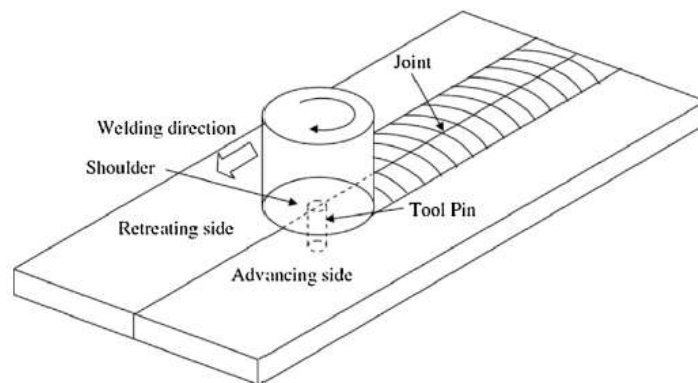
Won Bae Lee [1] examined that friction stir welding of pure titanium sheets of 5.6mm thickness using TiCtool and a cooling water system. Yu Zang [2] prepared study on pure titanium 3mm thick friction stir processed material with Polycrystalline cubic Boron Nitride (pcBN) tool having shoulder diameter of 15mm, plunge depth of 2mm, probe diameter of 5.1 mm, and length of 1.7 mm with rotational speed= 200 rpm, traverse speed= 50mm/min, Argon gas used as shielding agent. Hidetoshi Fujii [3] performed study on joining of pure titanium having 2mm thickness by FSW using tungsten carbide based alloy tool with specifications as shoulder diameter 15mm, probe diameter 6mm and probe length 1.8mm having rotational speed 200 rpm, welding speed 50 to 300 mm/min under the argon gas shield. S. Mironov [4] studied microstructural evolution of FSW'ed 3mm titanium with Molybdenum based alloy tool (shoulder diameter=15 mm and a pin, tapered from 5.1 mm at the shoulder to 3 mm at the pin tip, plunge depth=2 mm) at 400 rpm. S. Mironov [5] characterized friction stir welding of pure titanium 2mm thick joint by CW & HSS tool with tilt angle of 2.5° and tool size Pin Length-1.8mm, Pin Diameter- 4 to 6 mm, Shoulder Dia- 16mm with argon shielding gas. The chemical composition of pure titanium as follows in Table 1.

**TABLE 1**  
**CHEMICAL COMPOSITION OF PURE-TI**

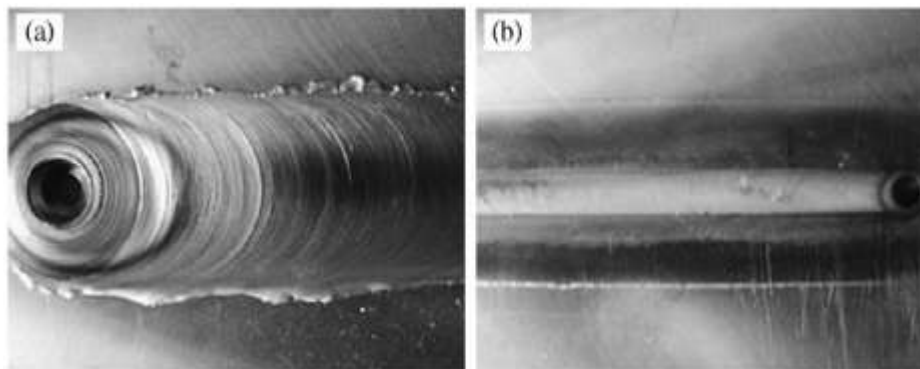
Chemical Composition	C	B	O	N	Fe
Weight in Percentage (%)	0.007	0.0013	0.08	0.004	0.05

### 2.2 Method

Figure 1 shows the representation of Friction Stir welding process. According to Won Bae Lee [1] the microstructures observed by OM (Optical Microscopy) and TEM (Transmission Electron Microscopy). The polished cross-sectional weld specimens were chemically etched using a mixture of HF (5 ml), HNO<sub>3</sub> (5 ml) and H<sub>2</sub>O (70 ml), figure 2 shows upper and bottom surface of friction stir welded pure Ti. In the study by Yu Zang [2] FSW of titanium was carried out under Argon gas shielding with use of optical microscopy (OM) under polarized light and SEM (scanning electron microscopy) for microstructure characterization. The specimen is cut at 90° with welding direction and ground mechanically using water abrasive paper, polished with size 6, 3 and 1 μm diamond paste. The investigation by Hidetoshi Fujii [3] used optical microscopy (OM), electronic backscattering diffraction (EBSD) and TEM (transmission electron microscopy) to observe microstructure. The Vickers microhardness measured with a load of 0.98N for a dwell time of 15 s along the centerlines of the cross-section with an interval of 0.5mm. As per S. Mironov [4] the OM studies were carried out using a Nikon Optiphot-100 optical microscope. EBSD analysis with high resolution was carried with a Hitachi S-4300SE FE-SEM (equipped with TSL OIM™ EBSD system). According to S. Mironov [5] before friction stir processing the plates were ground on surface, the microstructures of friction stir processed samples & untreated pure Ti were noted using a JEOL JSM-840A SEM (scanning electron microscope) and Mott-Schottky analysis were conducted in a phosphate buffer solution and the Vickers microhardness test was conducted with a load of 250 kgf having dwell time of 15s.



**FIGURE 1: Schematic of Friction Stir Welding Process [6]**



**FIGURE 2: Friction Stir Welded Pure Ti (a) Upper Surface and (b) Lower Surface [1]**

### III. RESULT

Won Bae Lee [1] concluded that microstructure of the weld nugget was described by the presence of coarsened grains and mechanical properties of the FSW Ti joints found close to those of the base metal. From Yu Zang [2] we come to result that the microstructure and hardness in a 3- mm thick cp-Ti friction stirred examination the stir zone characterised by fine grain size structure with highest hardness. As per Hidetoshi Fujii [3] the experimental hardness noted higher than the calculated one with microstructure in stir zone less than 6.4  $\mu\text{m}$ .S. Mironov [4] stated that this study examined the grain structure evolution during FSW of commercial purity titanium, where in the stir zone formation of strong structure took place and the grain structure produced was close to the texture evolution. By S. Mironov [5] it was stated that microstructure was characterized by the effects of multi-pass FSP on the electrochemical response and behaviour of pure ti in presence of phosphate buffer solution. Multipass FSP reduced the grain size remarkably down to submicron range due to dynamic recrystallization phenomena which resulted in increase in great potential of corrosion resistance with favourable values. Also difference found in hardness of base metal and stir zone, in which hardness in stir zone found to be higher than base metal. Figure 3 (A)-(C) represents Vickers hardness which resulted in higher hardness in stir zone than base metal. Figure 4 shows the microstructural changes in which as welding speed increases the grain size goes on becoming finer in stir zone. Table 2 represents the hardness and microstructure of different experiments held on pure titanium.

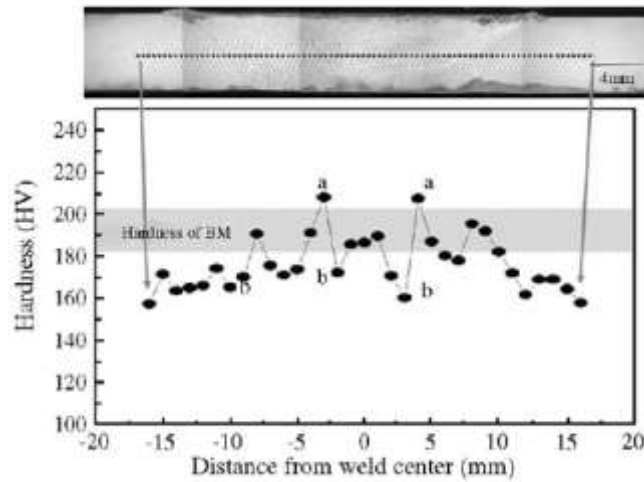


FIGURE 3(A)[1]

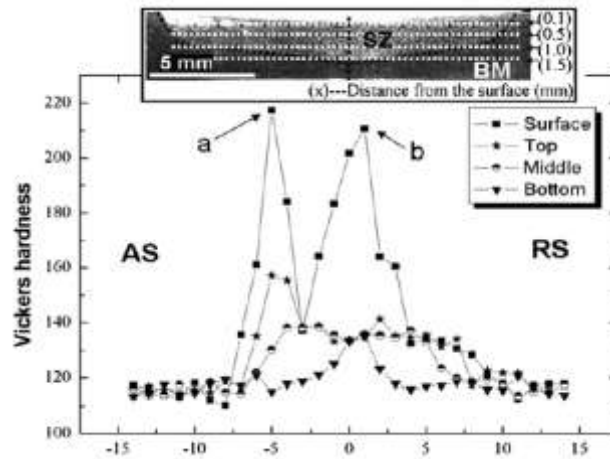


FIGURE 3(B)[2]

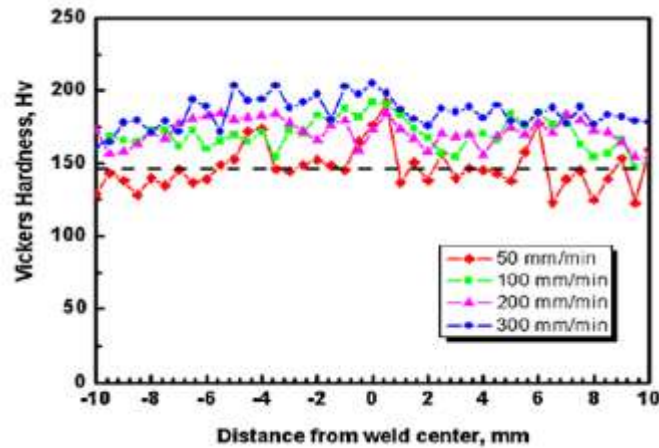
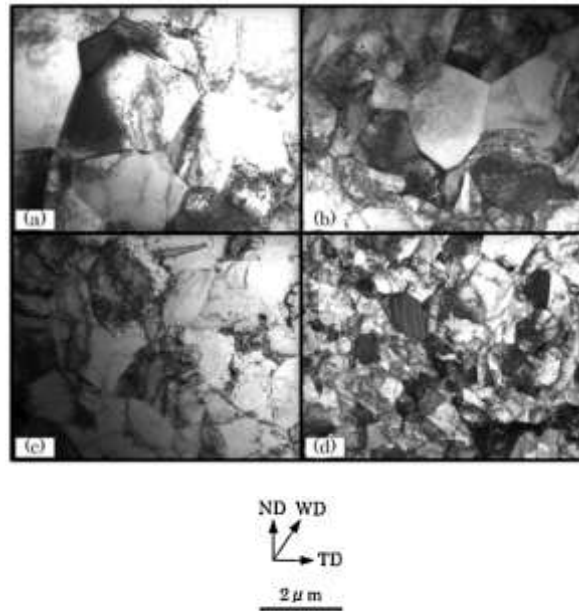


FIGURE 3(C)[3]

FIGURE 3: vicker's hardness in stir zone and base metal of titanium (a) won-bae lee [1], (b) yu zang [2], (c) hidetoshi fujii [3]



ND = NORMAL DIRECTION

WD = WELDING DIRECTION

TD = TRANSVERSE DIRECTION

**FIGURE 4:** microstructure of the stir zone sown by transmission electron microscopy at different welding speeds (a) 50mm/min, (b) 100mm/min, (c) 200mm/min, (d) 300mm/min [3]

**TABLE 2**  
**HARDNESS AND MICROSTRUCTURE OF PURE TITANIUM**

Sr. No.	Paper Name	Hardness	Microstructure
01.	Microstructural investigation of friction stir welded pure titanium	-	BM- 25 μm
02.	Stir zone microstructure of commercial purity titanium friction stir welded using pcBN tool	BM-115 HV, SZ-140 HV	BM- 30μm , SZ- 13μm
03.	Investigation of welding parameter dependent microstructure and mechanical properties in friction stir welded pure Ti joints	BM- 146 HV, SZ- 150 to 190 HV	BM- 10 μm, SZ- 3.5 to 6.3 μm
04.	Development of grain structure during friction stir welding of pure titanium	-	BM- 8.9μm to 24 μm, SZ- 4.6 μm to 8.6μm
05.	Passive and electrochemical response of friction stir processed pure titanium	BM= 150HV, SZ= 240 to 375 HV	SZ= 25 μm

---

#### IV. CONCLUSION

From this review study it can be concluded that application of friction stir welding of pure titanium with high strength tool material is always superior as compared to conventional fusion welding processes as FSW gives defect free product. The friction stir processing of titanium leads to enhanced hardness in stir zone than base metal and also provides fine grain structure in stir zone.

#### REFERENCES

- [1] Won-Bae-Lee, Chang-Young Lee, Woong-Seong Chang, Yun-Mo Yeon, Seung-Boo Jung, "Microstructural investigation of friction stir welded pure titanium," *Materials Letters* 59 (2005) 3315 – 3318
- [2] Yu Zang, Yukata S. Sato, Hiroyuki Kokawa, Seung Hwan C. Park, Satoshi Hirano, "Stir zone microstructure of commercial purity titanium friction stir welded using pcBN tool," *Materials Science and Engineering A* 488 (2008) 25–30
- [3] Hidetoshi Fujii, Yufeng Sun, Hideaki Kato, Kazuhiro Nakata, "Investigation of welding parameter dependent microstructure and mechanical properties in friction stir welded pure Ti joints," *Materials Science and Engineering A* 527 (2010) 3386–3391
- [4] S. Mironov, Y.S. Sato, H. Kokawa, "Development of grain structure during friction stir welding of pure titanium," *Acta Materialia* 57 (2009) 4519–4528
- [5] Arash Fattah-alhosseini, Mojtaba Vakili-Azghandi, Mohsen Sheikhi, Mohsen K. Keshavarz, "Passive and electrochemical response of friction stir processed pure titanium," *Journal of Alloys and Compounds* (2017)
- [6] S. Mironov, Y. S. Sato, H. Kokawa, "Friction stir welding and processing of Ti-6Al-4V titanium alloy: A review," *Journal of Materials Science & Technology* 34 (2018) 58–72
- [7] D. G. Sanders, P. Edwards, A. M. Cantrell, K. Gangwar and M. Ramulu, "Friction stir welded titanium alloy: Microstructure, mechanical and fracture properties," *Journal of Materials* (2015)