Local Mechanical Behavior Measurements of Friction Stir Welded Titanium

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Introduction

Friction stir welding (FSW) is a solid state metal joining method that uses a traversing, non-consumable rotating tool as shown in figure 1, to join two materials along a joint line. The tool performs two primary functions: heating of the work piece, and movement of material to produce the joint.

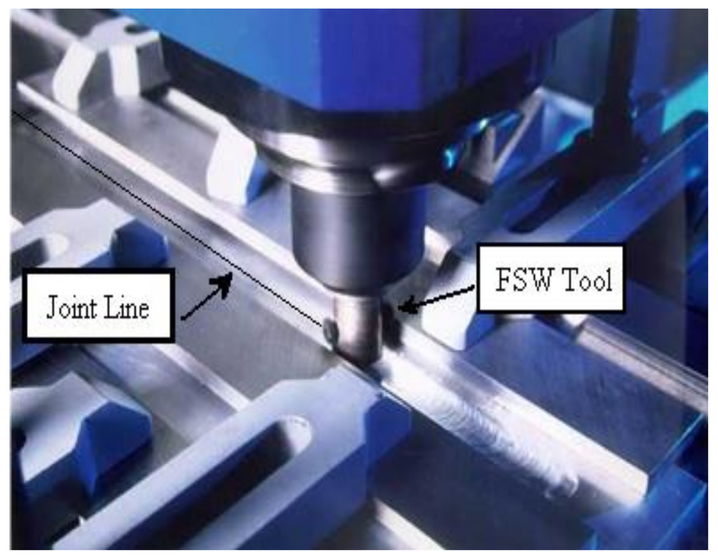


Figure 1: Photograph of friction stir welding and components [1]

- Process occurs under the materials melting point
- Reduction in grain size caused by plastic deformation at elevated temperatures
- Requires limited processing control parameters
- Environmentally friendly process

Motivation

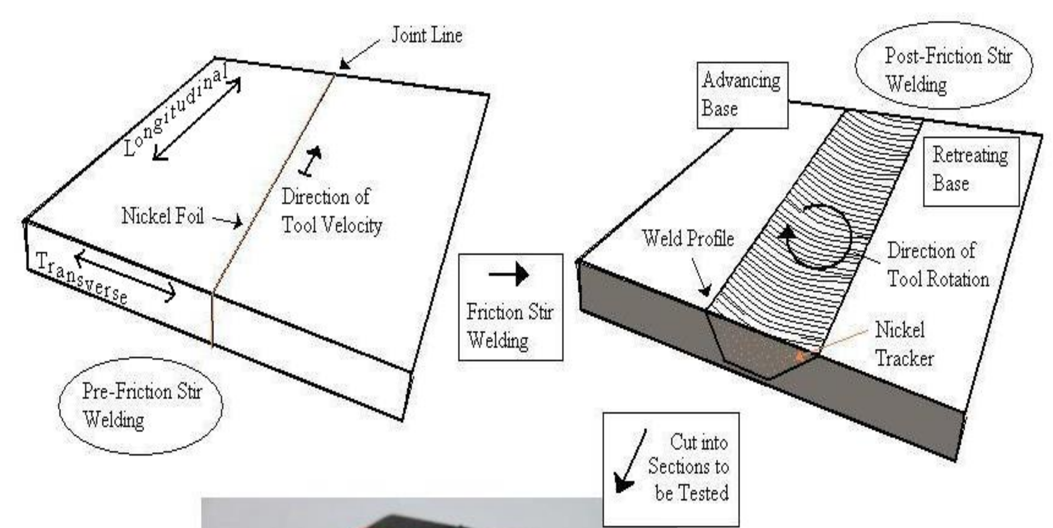
In this study commercially pure titanium is friction stir welded using a nickel foil along the joint line.

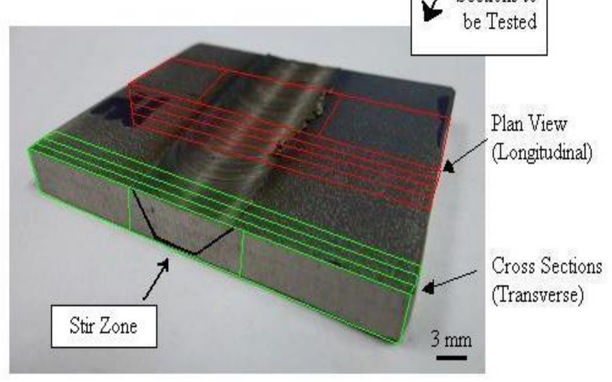
- Titanium is difficult to FSW
  Advantages: High strength, corrosion resistant, low density, no post weld heat treatment required.
- Nickel is introduced as a fast diffuser which:
  1. Decreases forging force, fatigue and wear on tool
  2. Increases tool speeds (higher production, lower costs)

The local mechanical properties of FSW titanium with nickel foil are determined using micro-tension tests

Methods

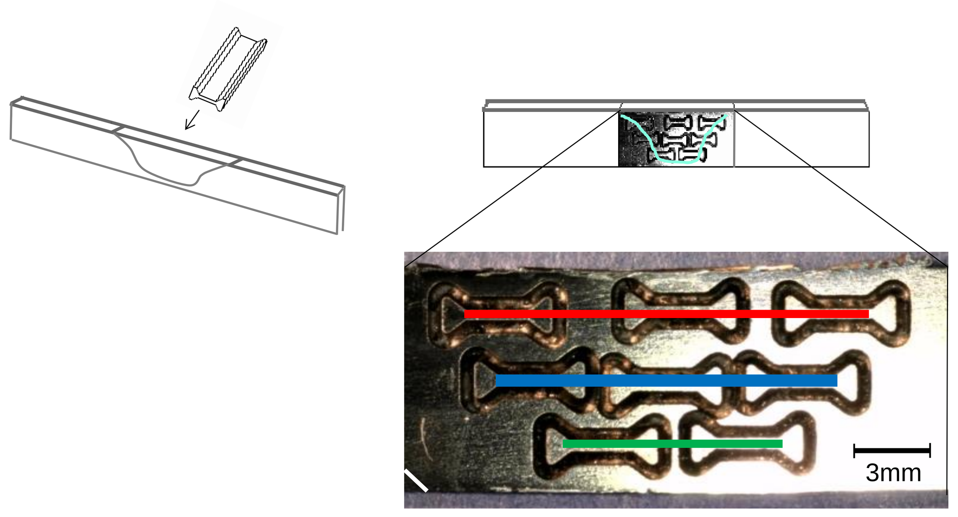
The evolution of micro-samples can be seen in figure 2.





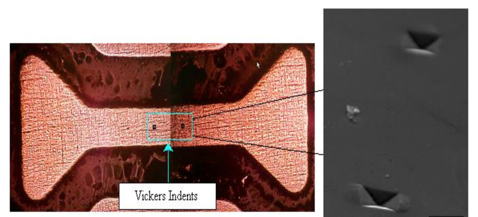
Slices are cut from the block and an electrode, set into an electron discharge machine, uses spark erosion to cut dog-bone shaped micro-samples.

Figure 2: Schematic of the FSW micro-sample development process



- Vickers indents, shown in figure 3 are used to measure the displacement of the gauge section.
- The testing configuration, shown in figure 4, has analogous components to a traditional load frame but has been modified to meet the challenges of small scale testing.

Figure 3: Vickers indents



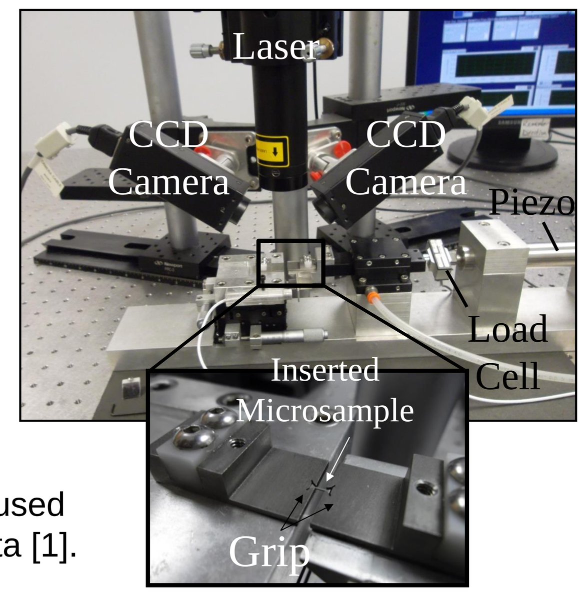


Figure 4: Configuration of tension testing apparatus used to retrieve stress strain data [1].

- Tension tests are performed under uni-axial displacement
- A piezoelectric actuator produces a quasi-static strain rate
- A 25lb load cell is used.

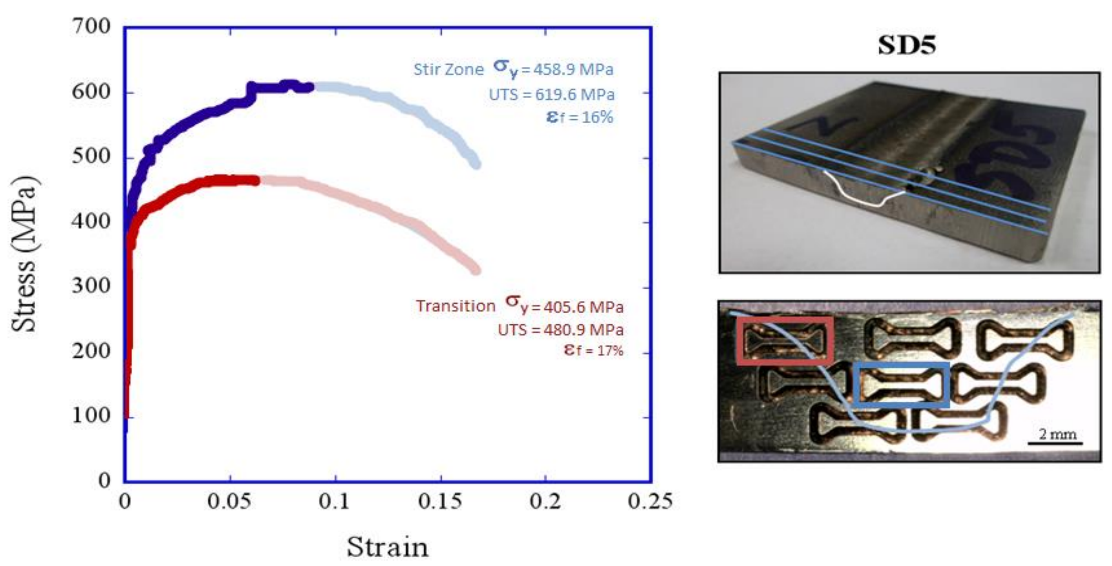


Figure 5: Stress v Strain plot (Left), Respective location in the weld (Right)

Figure 5 compares the stress v strain responses of two SD5 weld cross section micro-samples tested under the same conditions. Yield strength and ultimate tensile strength can be directly extrapolated from these graph.

- Similar elastic region
- Large deviation in the inelastic region

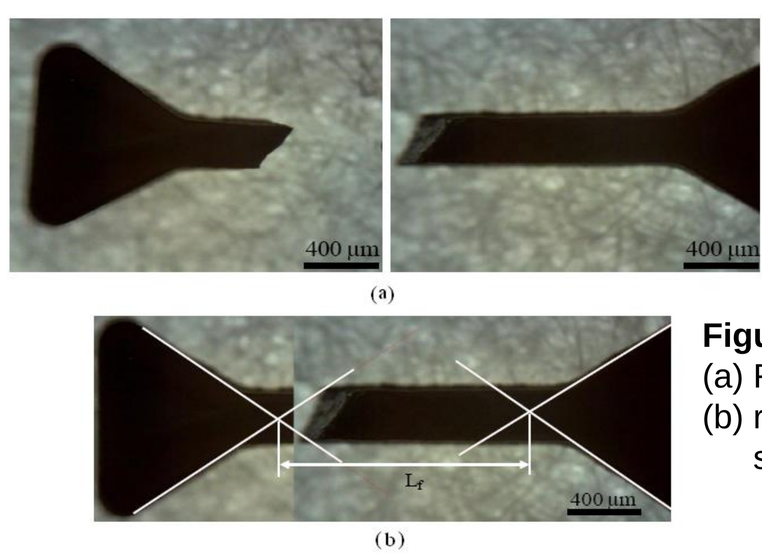


Figure 6:
(a) Fractured specimen
(b) reconstructed specimen [1]

Strain to failure is calculated using the initial and final lengths of the gauge section.

Results

Base values for ultimate tensile strength, yield strength and strain to failure (elongation) are compared to values found in literature, shown in table 1.

Table 1: Theoretical (T.) and Experimental (E.) Mechanical Properties of Commercially Pure Titanium

Material	Ultimate Tensile Strength (MPa)	Yield Strength Range (MPa)	Elongation (%)
T. CP Ti	344 - 430	275 - 450	20
E. CP Ti	483	406	19

Small variations in the forging of the metal can cause shifts in the mechanical properties seen in table 1.

The graphs (below) show the results for 24 micro-samples, cut from the weld that were tested, analyzed and compared to 8 base specimens.

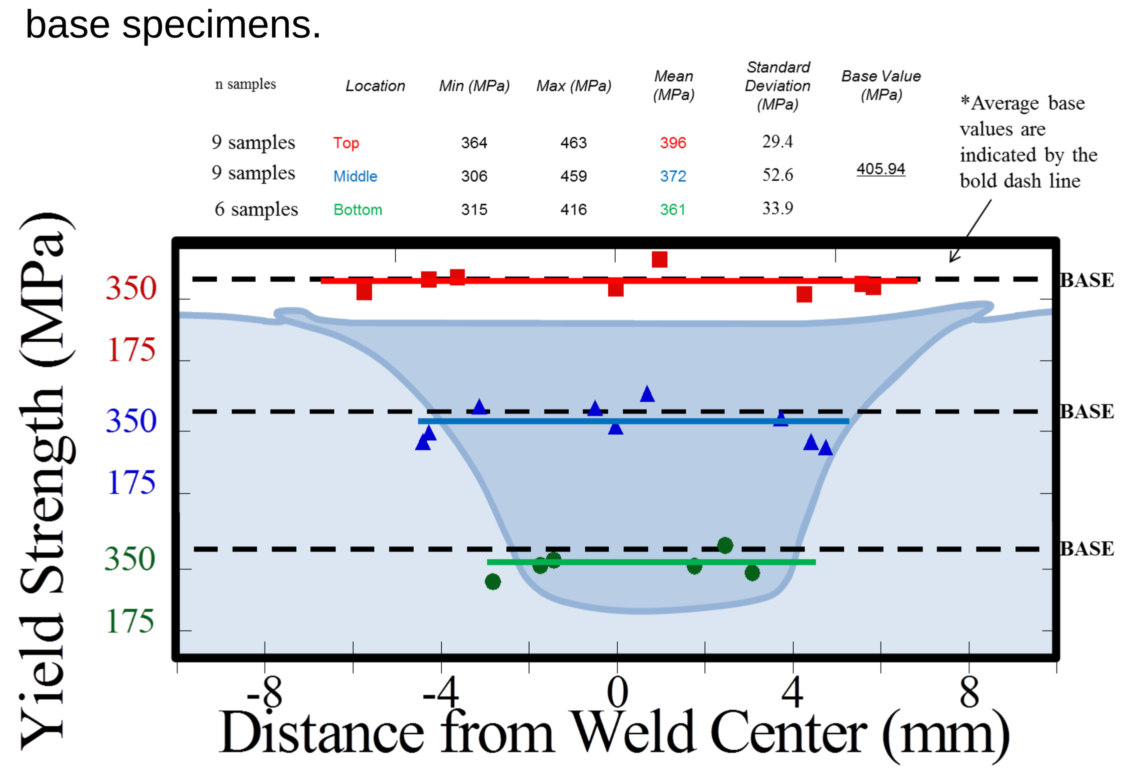


Figure 7: Transverse Yield Strength along Weld

The yield strengths of the top and middle sections are within one standard deviation of the base values. The yield strength at the bottom of the weld showed an 11% decrease than that of the base value.

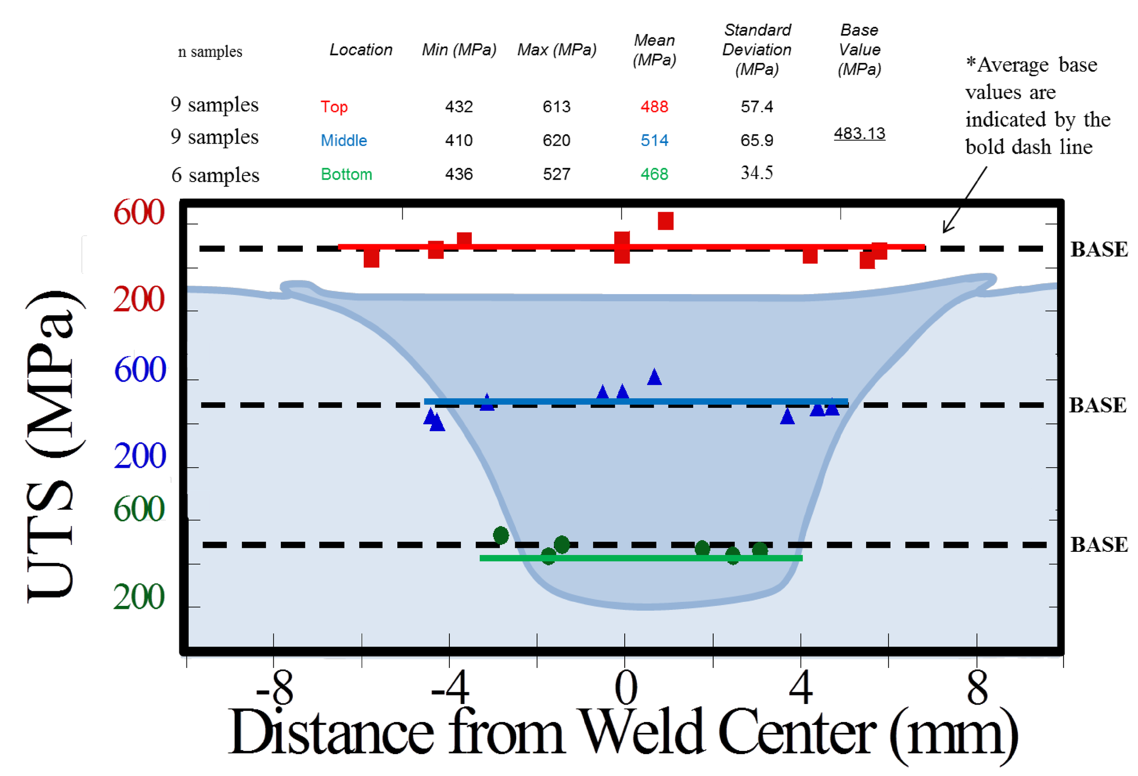


Figure 8: Transverse Ultimate Tensile Strength along Weld

The ultimate tensile strengths (UTS) at the top, middle, and bottom of the weld also showed consistent results to that of the base value, being within one standard deviation at each depth location.

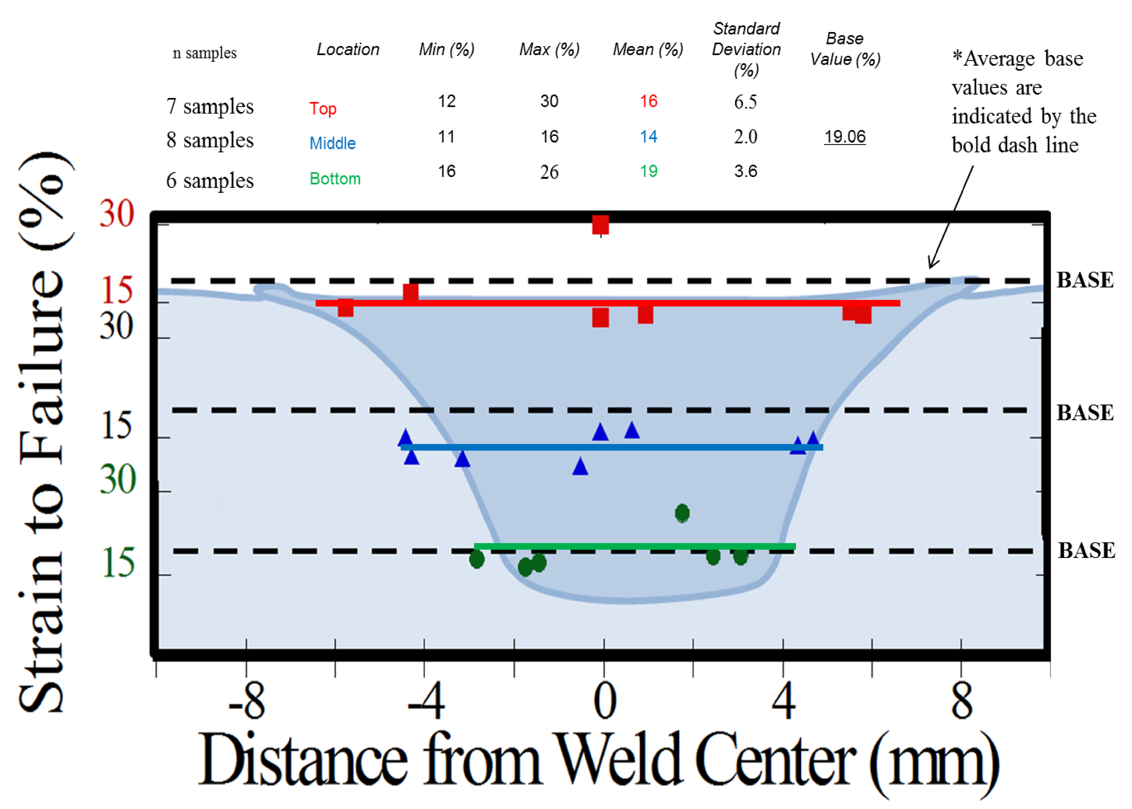


Figure 9: Transverse Strain to Failure along Weld

The top and middle of the weld showed a decrease in strain to failure compared to the base values. A 26.5% decrease in strain to failure occurred at the middle of the weld. The bottom of the weld showed consistency with the base values.

Scanning electron microscope images are used to visually inspect the fracture surface.

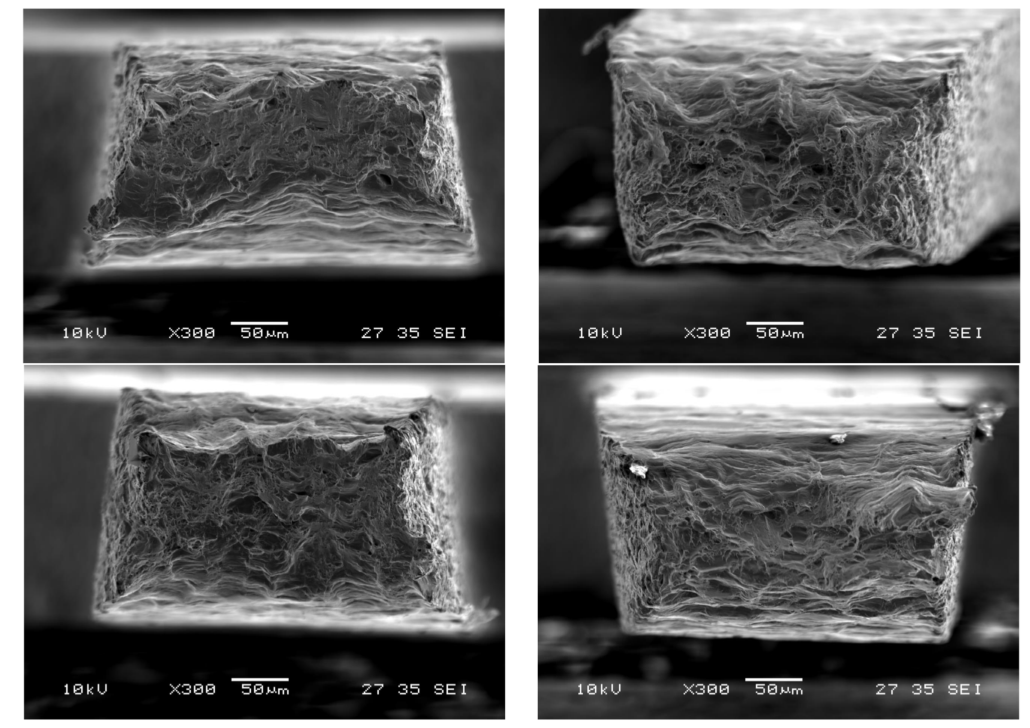


Figure 10: Scanning electron microscope images of fracture surface of the base micro-samples

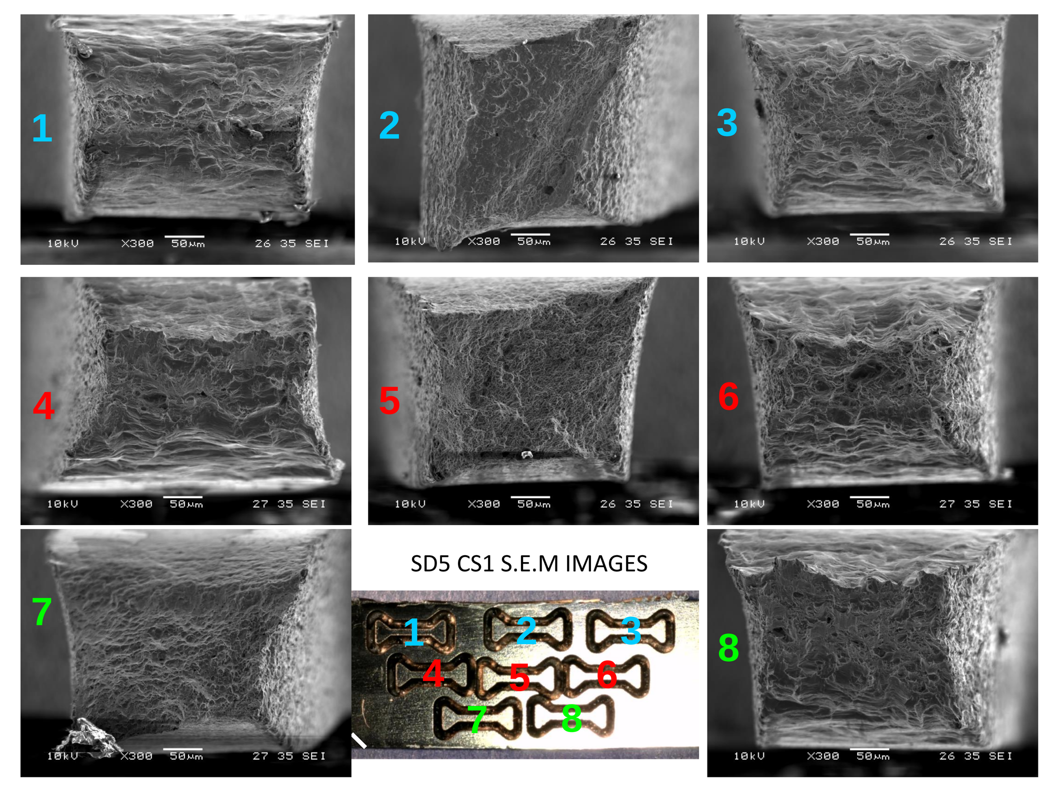


Figure 11: Scanning electron microscope images of the fracture surface of the transverse micro-samples

Conclusions

-The use of a nickel foil at the joint to improve process parameters showed no reduction in mechanical strength.
-The FSW process generated fine and equiaxed recrystallized grains resulting in refined metallurgical properties in the joint area.
-A decrease in strain to failure was observed in the middle of the weld and can be attributed to reduced grain size, high fatigue, and variations in processing parameters

References

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