FACULDADE DE CIÊNCIAS E TECNOLOGIA
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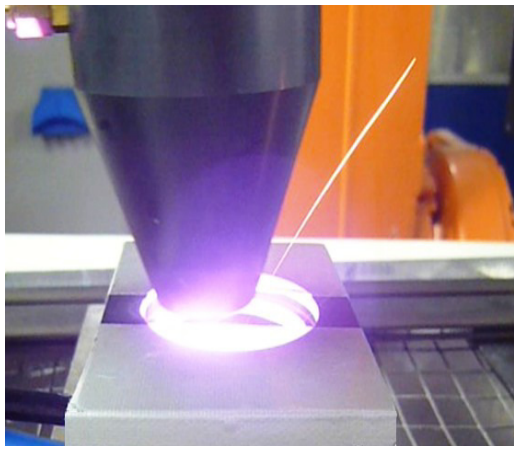
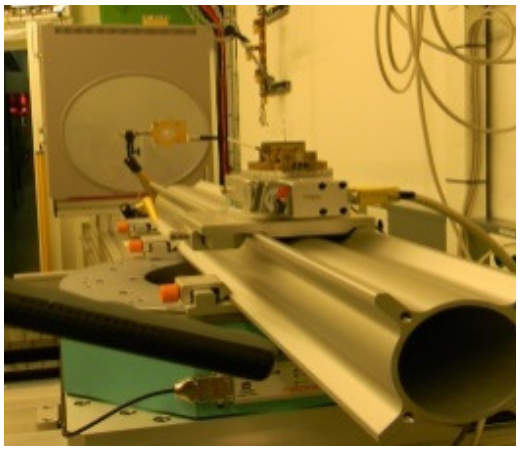
Workshop
Processing, Characterization and Applications of Shape Memory Alloys

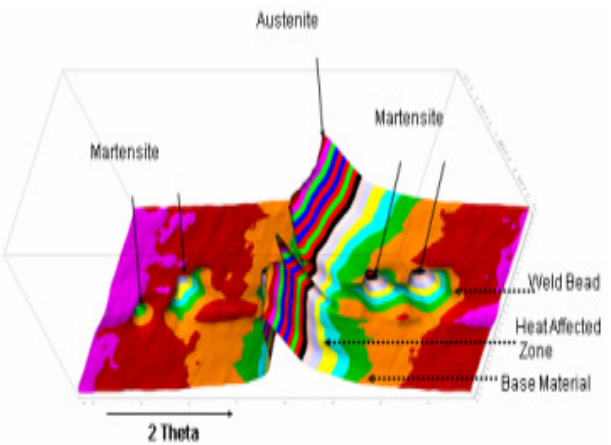
Dissimilar Laser welding of NiTi to Stainless Steel and Ti alloys

Rosa M. Miranda

UNIDEMI, Universidade Nova de Lisboa, Portugal







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Outline

- Background
- Experimental Procedure
- Results and Discussion
- Conclusions

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Background

Shape memory alloys (SMAs) have been investigated in different engineering applications specially for:

- damping

- active vibration control

- pre-stressing or post-tensioning of structures with fibers and tendons.

- in medical instruments, aeronautics and automotive industries

For which dissimilar joining is a technological challenge.

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Experimental

NiTi /SS

Table 1 Nominal chemical composition of the base materials (wt%)

	C	Si	Ti	Cr	Mn	Ni	Mo
NiTi			43.6			56.4	
Stainless steel	0.03	1.0		17.0	2.0	12.0	2.5

NiTi 0.34 mm thick

AISI 316L 0.47 mm thick

Lap welds performed with the laser beam impinging directly NiTi foil positioned on top of the stainless steel and inversely,

Ni Interlayers 0.025 and 0.125 mm thick between NiTi and steel foils.

Welding equipment and parameters

PW Nd/YAG Laser SWMP 6002 from Carl Basel Lasertechnik.

Equipped with a camera that allows positioning precision of about 0.01 mm.
Special box built for gas protection

Argon= 22 1/min opened before welding and shut down after welding

Dedicated clamping system to guarantee full contact between foils

Table 2 Laser weld parameters tested

Flash lamp voltage	190 to 400 V
Wavelength	1.06 µm
Average rated output	50 W
Max. pulse energy	80 J
Max. pulse peak power	6.0 kW
Pulse duration	0.5–50 ms
Max. connecting power	1.7 kW
Pulse shape	Rectangular
Beam spot diameter	1 mm

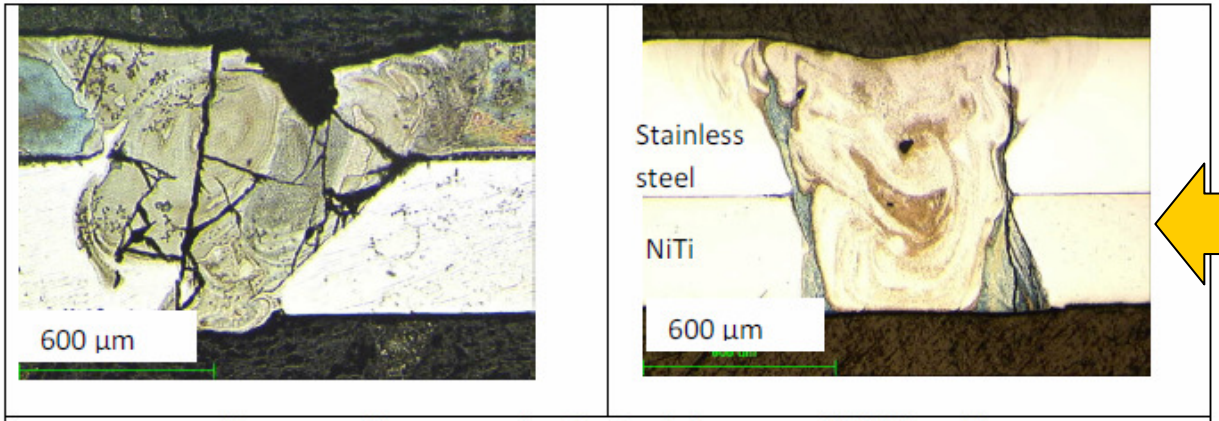


Figure 3: Macrograph of a Stainless steel/ NiTi weld.
Flash lamp: 250 V; Beam spot diameter:1mm
a) Pulse Duration: 10 ms, Energy: 12.6 J, Power density: 40 kWcm^{-2}
b)Pulse Duration: 50 ms, Energy: 30.3 J, Power density: 77 kWcm^{-2}

Higher interaction time

NiTi foils 0.34 mm thick

AISI 316L 0.47 mm thick

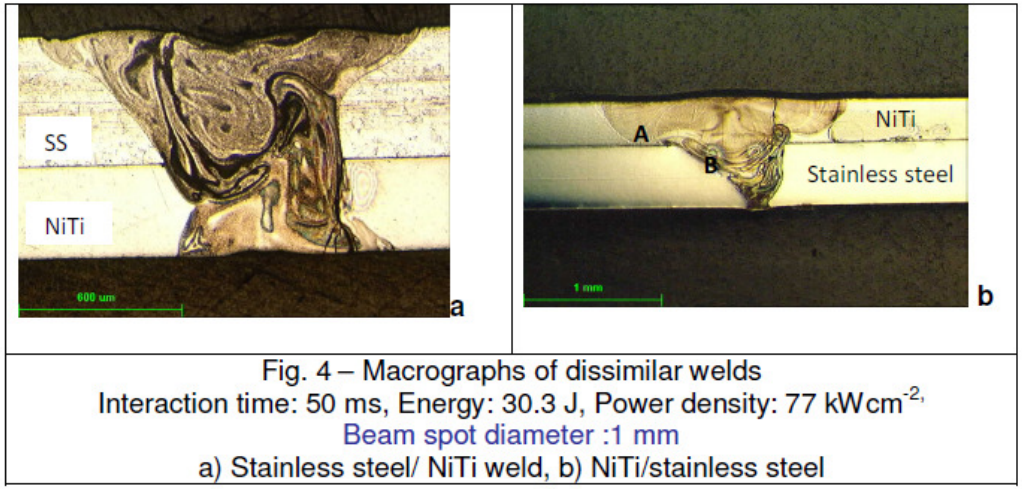


Fig. 4 – Macrographs of dissimilar welds
Interaction time: 50 ms, Energy: 30.3 J, Power density: 77 kWcm^{-2},
Beam spot diameter :1 mm
a) Stainless steel/ NiTi weld, b) NiTi/stainless steel

Material sequence
different bead shapes

NiTi above SS - wider weld bead

NiTi has a lower Tm (1240-1310 ºC) than SS (1300-1400 ºC), and diffusivity about half of SS, so heat is dissipated in the NiTi foil slower than in SS

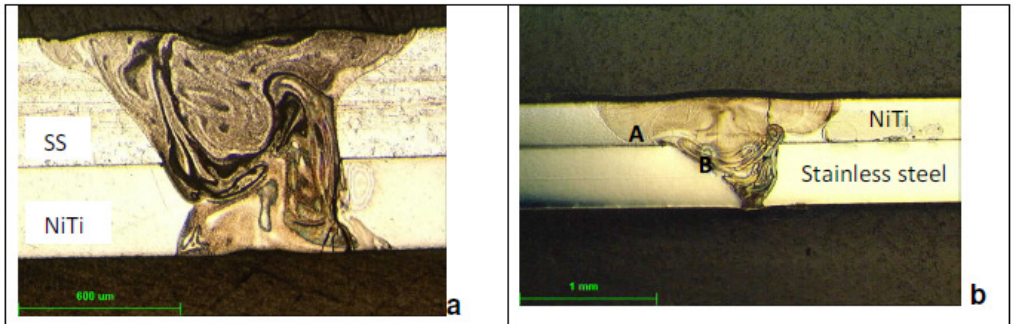
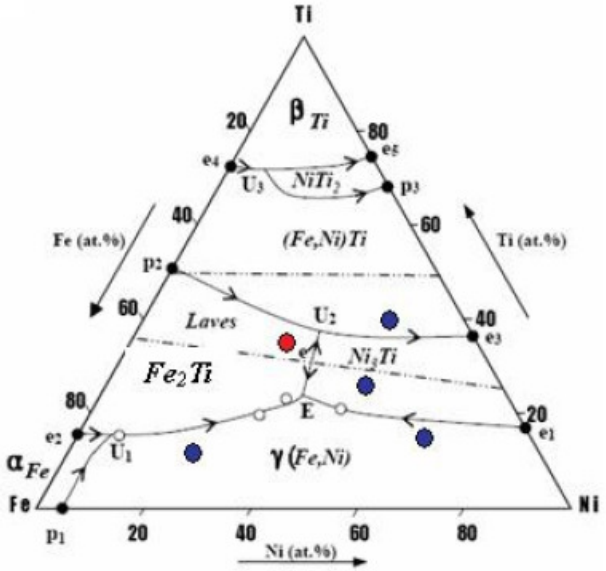


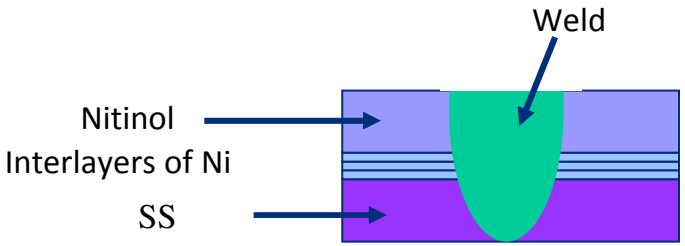
Fig. 4 – Macrographs of dissimilar welds
Interaction time: 50 ms, Energy: 30.3 J, Power density: 77 kWcm^{-2},
Beam spot diameter :1 mm
a) Stainless steel/ NiTi weld, b) NiTi/stainless steel

Ti	Ni	Fe	Cr	Mn	Si	O
18.2	20.79	24.8	7.16	0.65	1.38	18.33

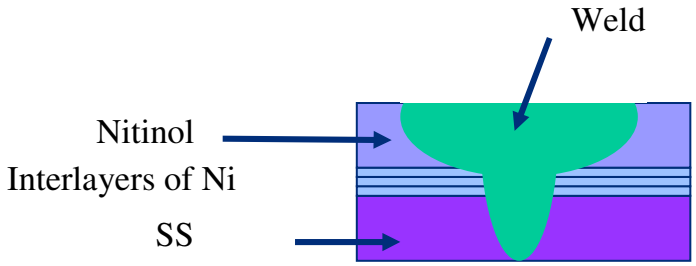
Table 5: Composition of the weld metal (at.%)



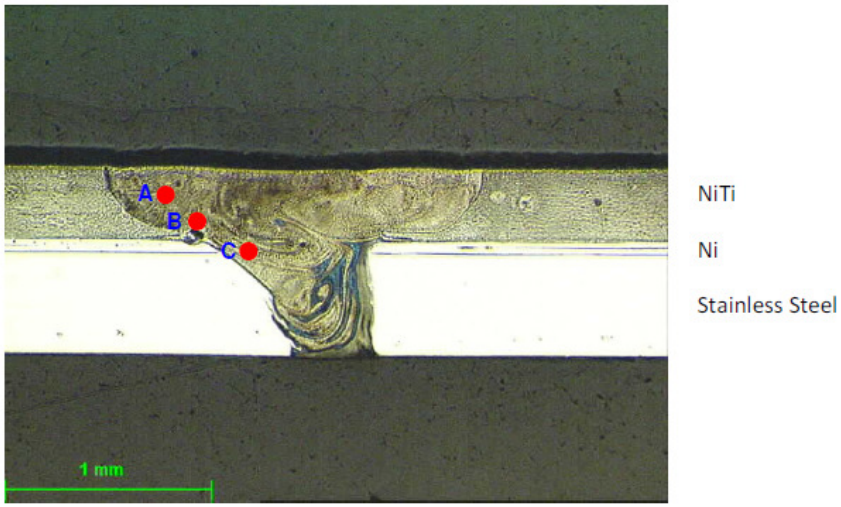
- Avoiding the intermetallic phase rich in Fe and Ti, solidification cracking reduces as Ni_3Ti is more ductile
- Weld metal > 40% Ni or Fe and < 45% Ti
- Overall chemical composition rich in Ni produce better (sound) welds



Expected Shape



Shape obtained



FZ - larger at the top

low thermal conductivity of NiTi modified the volume fraction of each material and the weld pool composition.

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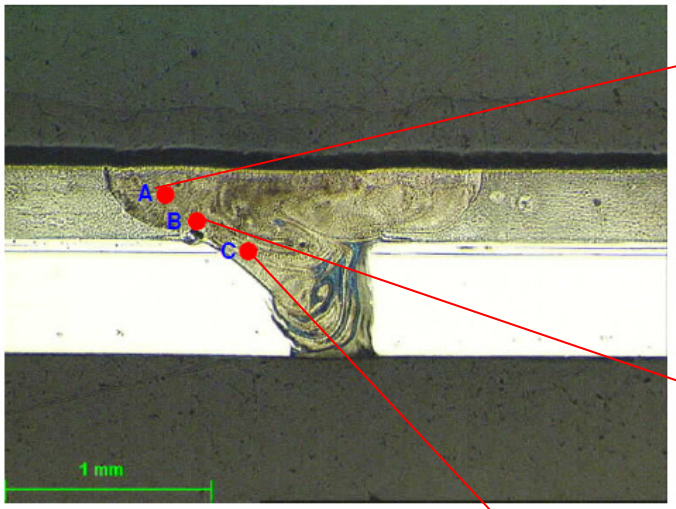


NiTi

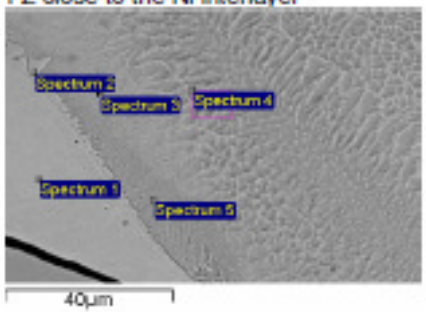
Ni

Stainless Steel

NiTi / Ni (0.05 mm) / SS
Laser spot diameter: 1 mm
Pulse energy: 30 J
Pulse duration: 50 ms
Intensity: 77 kW/cm²

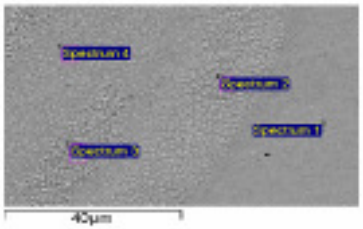
No pores, no cracks

FZ close to the Ni interlayer



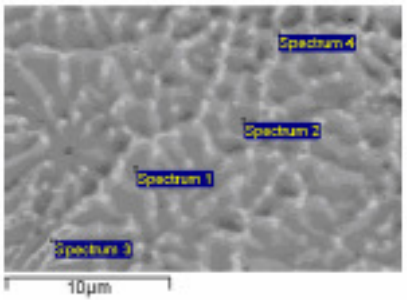
Spectrum Label	Ti	Cr	Fe	Ni
1				100
2	21.8	2.28	12.27	63.65
3	28.69	3.33	13.99	53.99
4	38.3	2.25	9.62	49.83
5	27.42	4.37	16.23	51.98

FZ close to the steel side



Label	O	Ti	Cr	Fe	Ni
1	2.46		18.43	68.99	8.04
2		12.62	12.96	48.9	25.52
3		19.86	9.31	35.03	35.81
4		18.45	10.72	39.02	31.81

FZ close to the steel side



Spectrum Label	Ti	Cr	Fe	Ni
1	37.85	2.46	10.89	48.8
2	38.51	2.2	9.81	49.48
3	30.7	3.92	13.02	52.37
4	32.33	3.77	11.23	52.66

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NiTi-SS - CONCLUSIONS

•. Fixing device acts as a heat sink.

• There is a pulse energy threshold below which welding is not obtained. The longer the pulse duration, the better is the mixing inside the weld pool.

• For the maximum pulse duration tested (50 ms), the variation of elements in the weld pool had been found not to vary more than 5% .

• The weld pool composition was found to determine the brittleness of the weld. Ni additions suppress the formation of the brittle intermetallic Fe_2Ti as the primary solidification occurs from the γ (FeNi) and the Ni3Ti phases.

• Weld metal with more than 40% Ni or Fe and less than 45 % Ti is less prone to cracking.

• The weld shape depends on the joint configuration (sequence of layers when applicable), laser welding parameters and thermal properties of the materials involved.

In: J. Pouquet, R. Miranda, L. Quintino, S. Williams “Dissimilar Laser Welding of Nitinol to Stainless Steel”. Int J of Adv Manuf Tech.2012.61.205-212

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NiTi /Ti6Al4V

Laser welding

Thickness: 1 mm

Butt welds

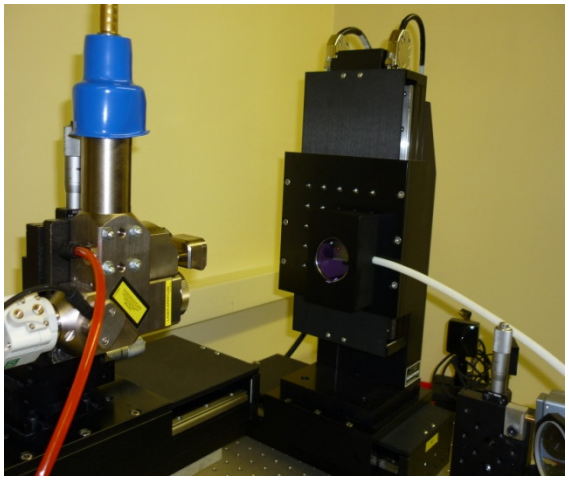
CW Nd:YAG laser

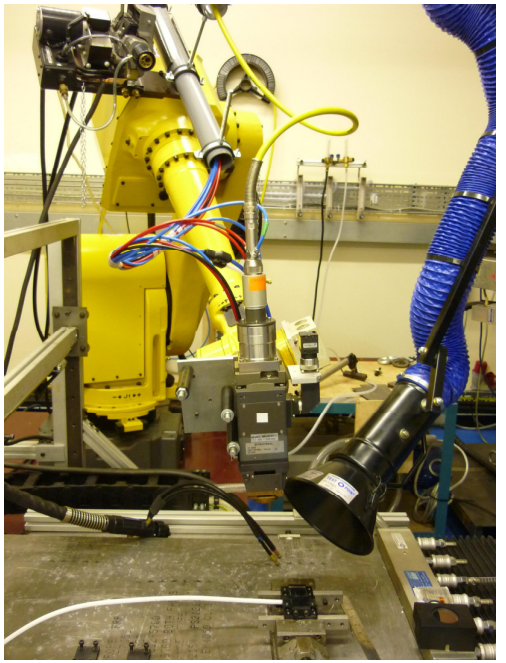
Gas: Argon 40l/min face + 20l/min root

Sample ref.	**Power** [W]	**Welding speed** [mm/s]	**Heat input** [J/mm]
E	1320	26	60
F	1320	26	60
I	890	25	36

CW Yb fiber laser

Sample reference	**Power (W)**	**Travel speed (mm/s)**	**Heat input (J/cm)**
A	900	25	360
B	900	21,7	415
C	900	16,7	539
D	1100	16,7	559





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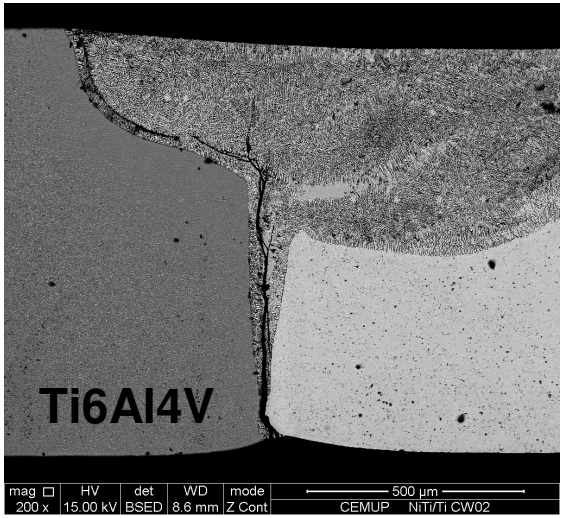
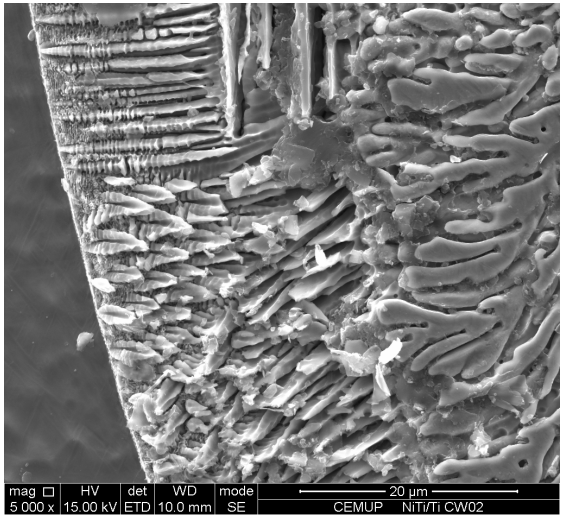
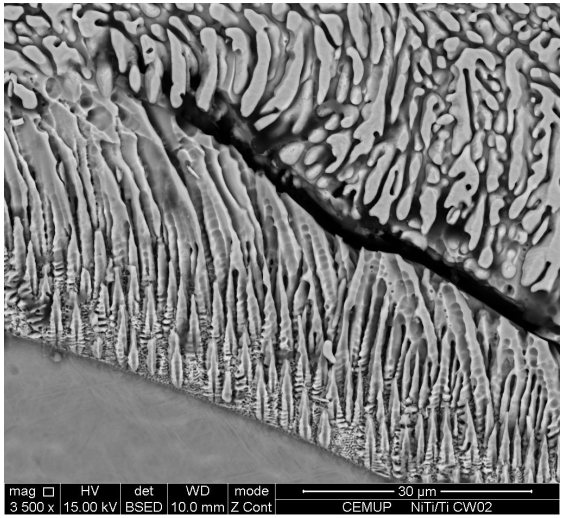
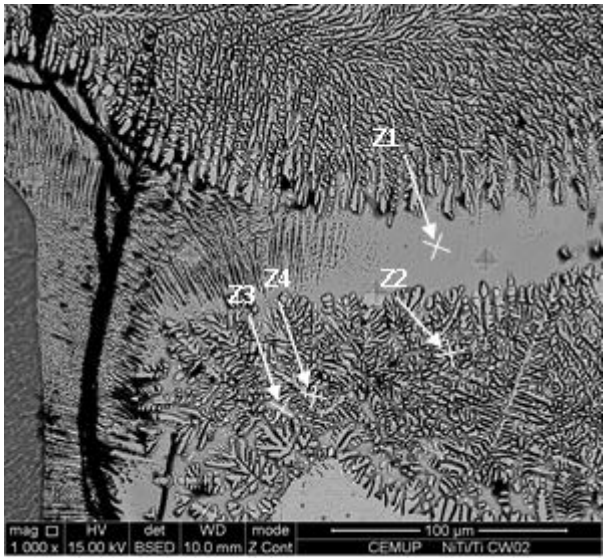
Extensive cracking in the Ti side









EDS	Element analysis (at. %)			
Point reference	Al	Ti	V	Ni
Z1	4.52	61.8	0.59	33.09
Z2	1.49	48.84	0.00	49.67
Z3	1.76	62.34	0.11	35.70
Z4	1.08	49.14	0.00	49.79

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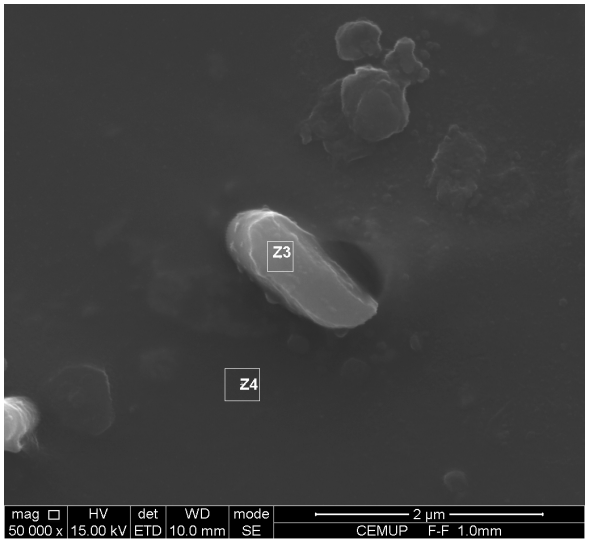
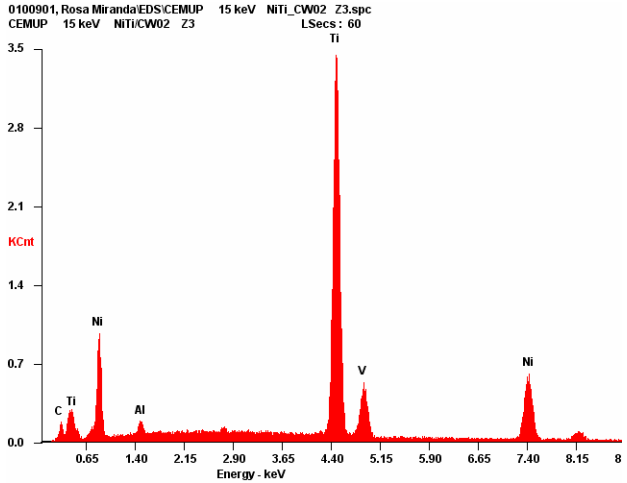
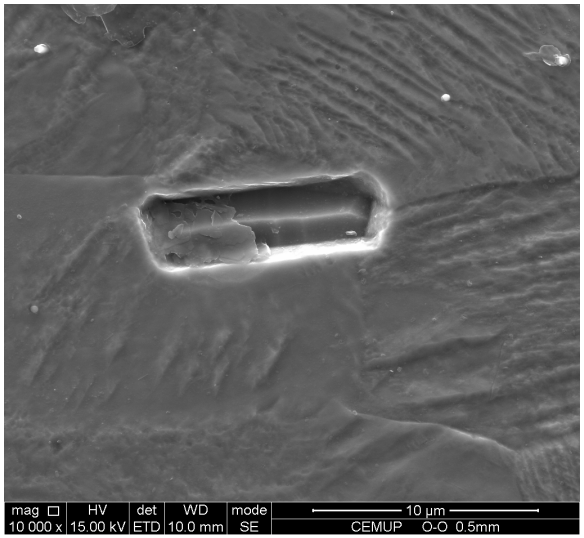
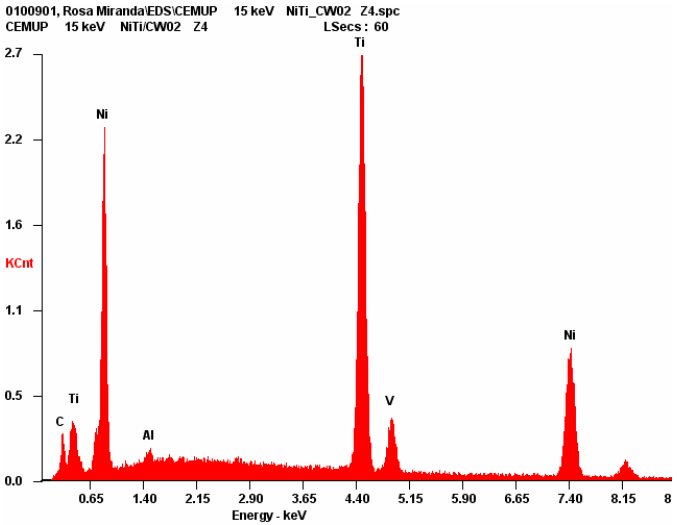


Z3





Z4



$NiTi_2$

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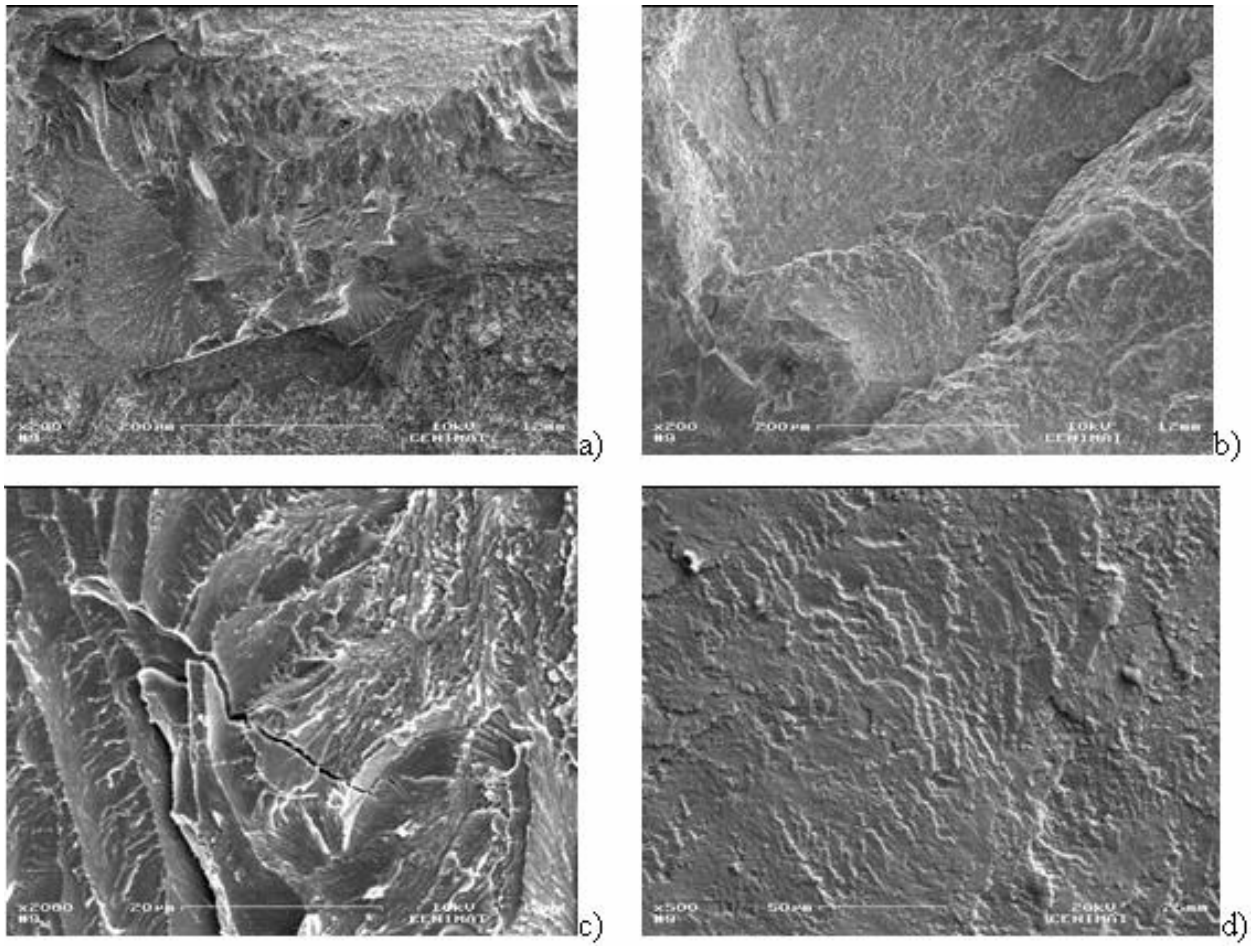
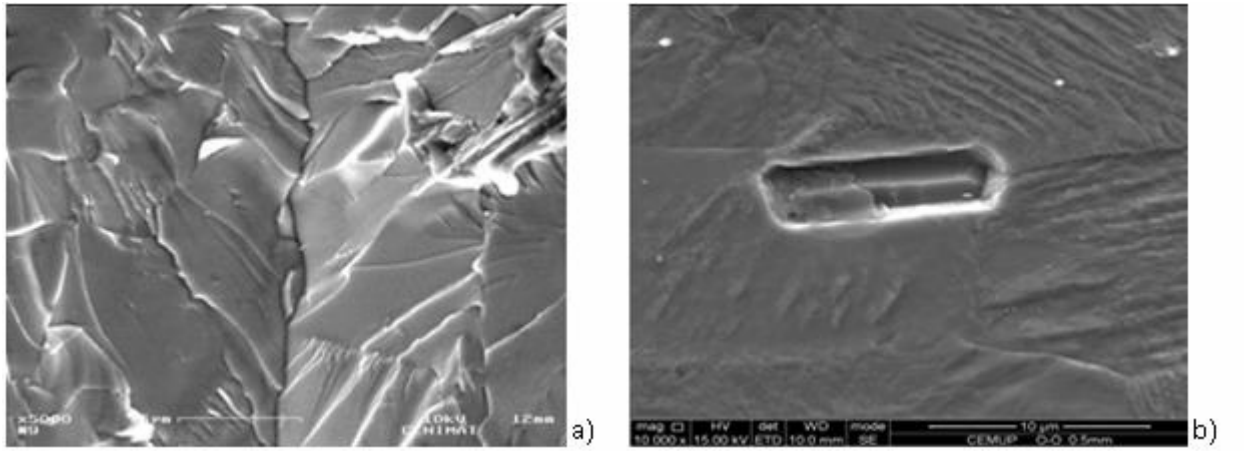
RESULTS

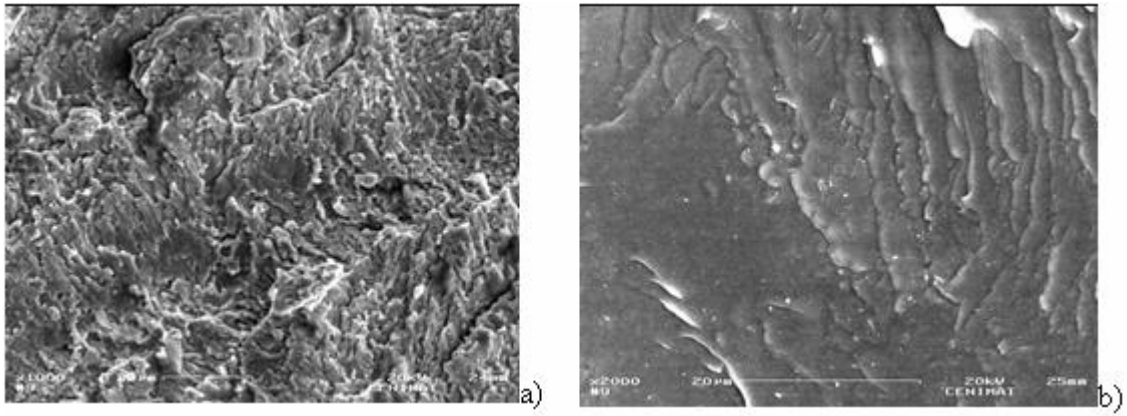


Fracture aspects on the Ti6Al4V side (a) and NiTi sides (b-d)

RESULTS



Intergranular Ni_2Ti precipitate



Fracture surface in WM a) Ti6Al4V side (a) and NiTi side

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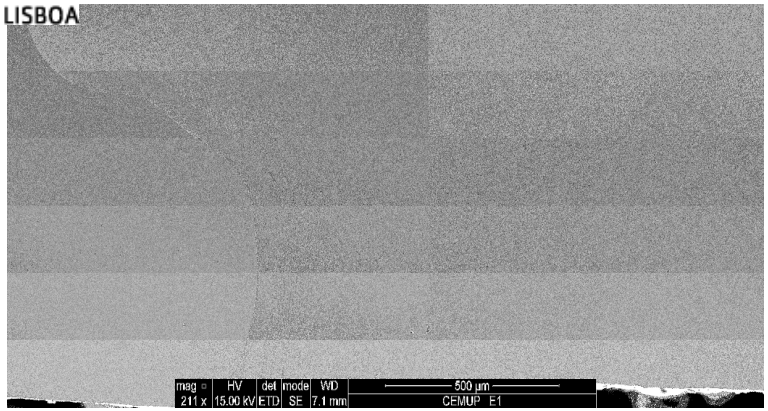
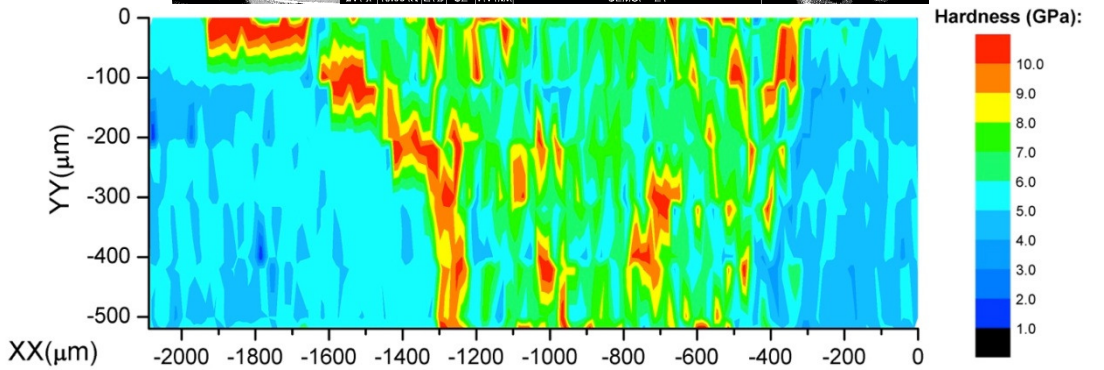
Ti6Al4V

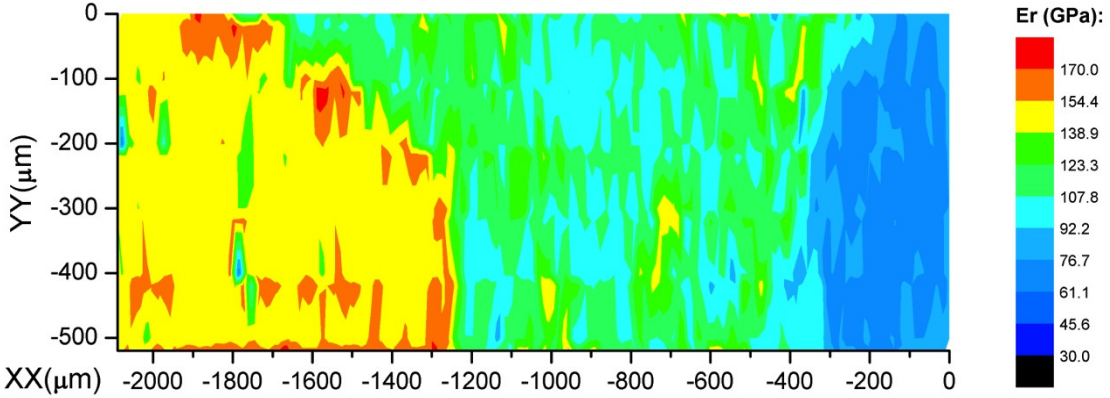


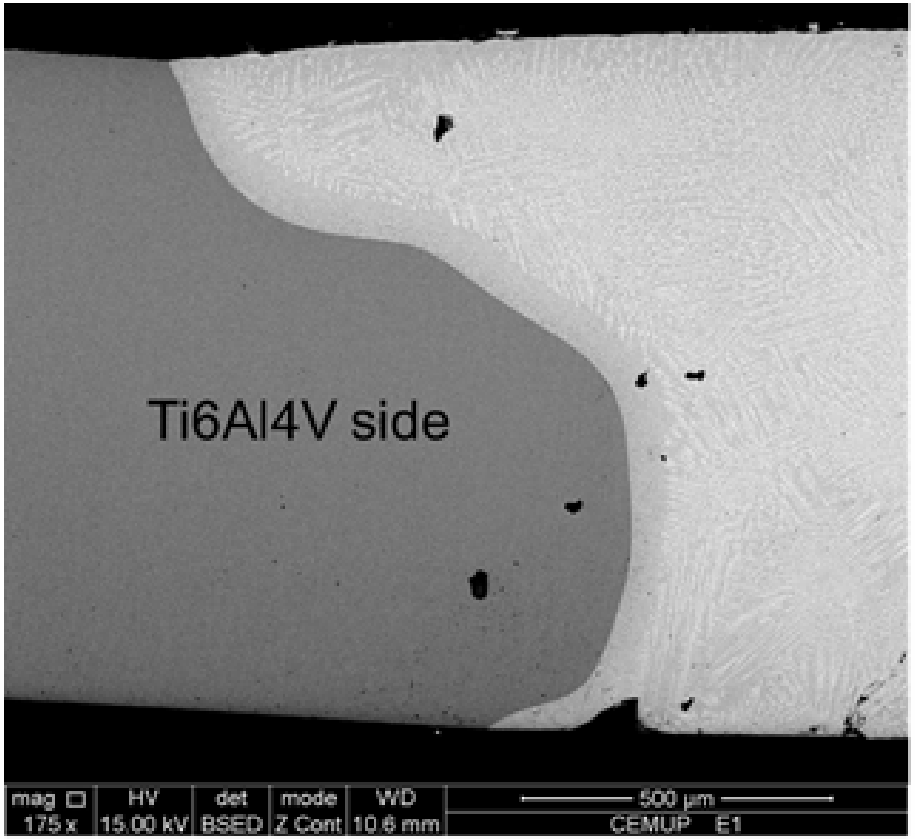
NiTi

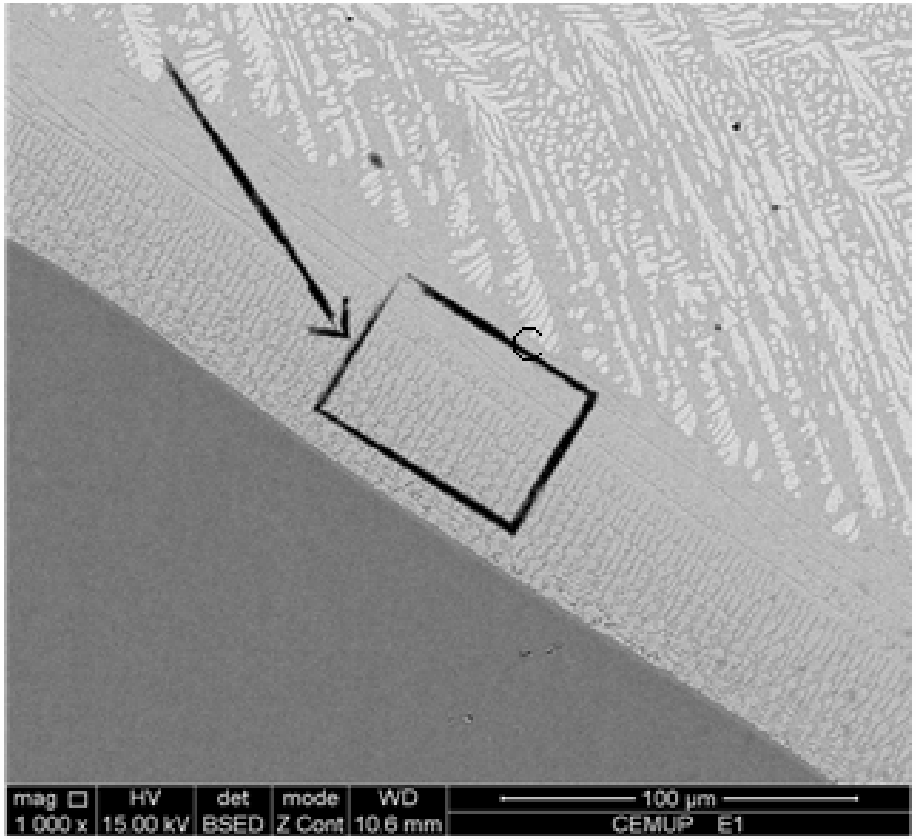
Hardness



Young's modulus distributions







- On the Ti6Al4V side of the weld a band structure appears (60~70 µm) along the whole weld
- Global composition along the band structure (**C**) is $Ti_{64}Ni_{28}Al_8$

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NiTi-Ti - CONCLUSIONS

- Microstructural observations carried out on dissimilar butt joints to Ti-6Al-4V produced using a Yb fiber laser revealed the presence of a fine dendritic structure in the fusion zone, mainly constituted by NiTi and Ti2Ni like phases.

- The Marangoni effect randomly distributes the phases in the weld pool.

- Brittle fracture occurs mainly on the Ti-6Al-4V side in the weld metal along different oriented dendrites with decohesion.

- Ni migration and dissolution in the liquid Ti originates precipitates upon cooling.

- The catastrophic nature of the fracture is associated to the presence of brittle phases.

The cracking phenomenon is a solidification cracking one difficult to prevent without the addition of a filler material that controls the chemical composition of the molten metal.

However, good bonding was observed in some areas of YAG laser welds being investigated by CEMUC - UC

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Thank you for your attention!