Le génie pour l'industrie

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# MICROSTRUCTURAL ANALYSIS OF BANDED STRUCTURE IN FRICTION STIR WELDING OF AA6082 ALUMINUM ALLOY

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ICSOBA *Québec, 3 – 6 October 2016*

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# Contents

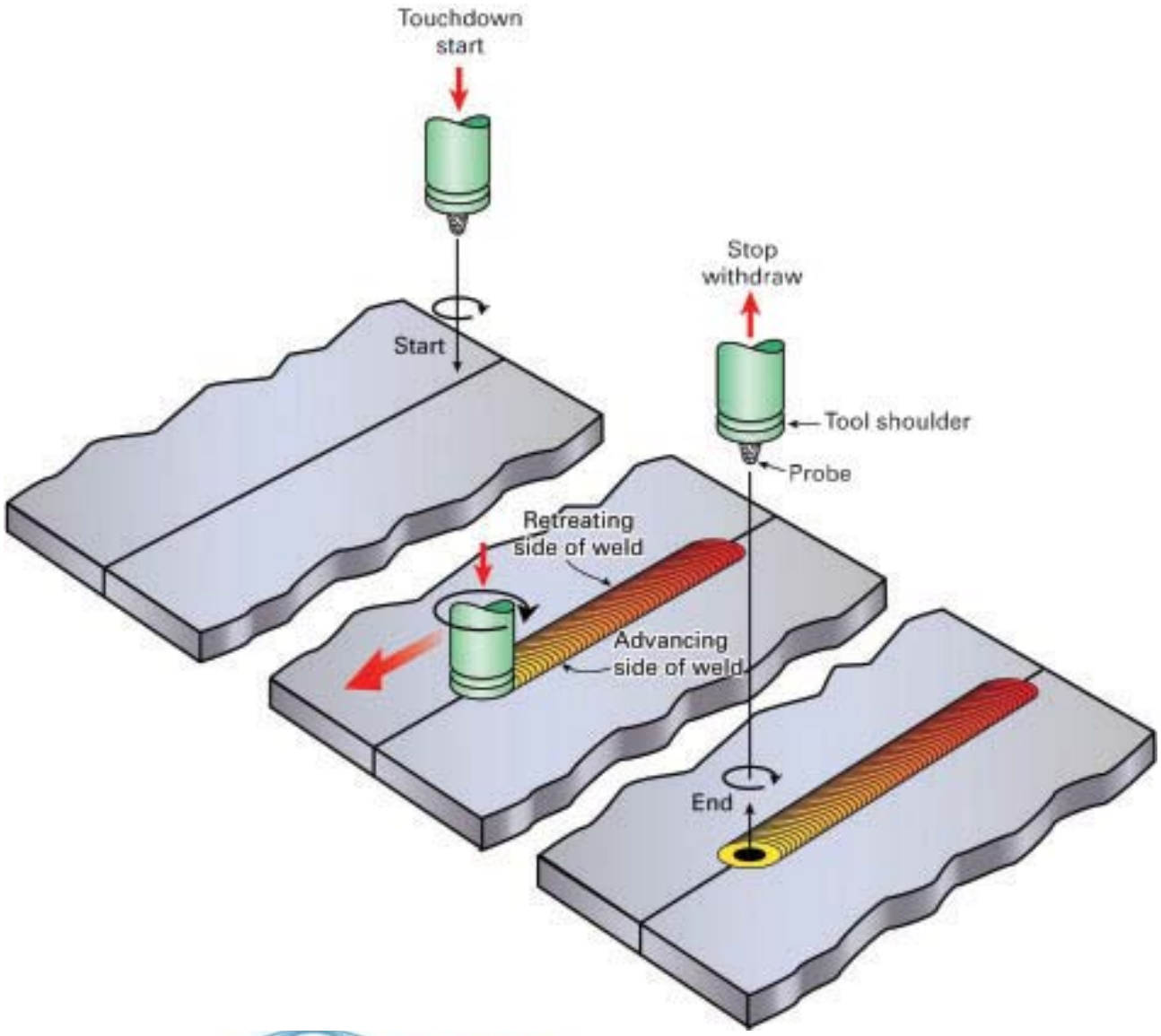
# Introduction

- **Since the invention of the friction stir welding, several studies have been conducted to understand the influence of process parameters on the microstructural, thermal and mechanical characteristics to improve the weld quality.**
- **Banded structures better known under the name of "onion rings" are one of phenomena that appear in the microstructure during this process. The welding parameters leading to their appearance as well as their effect on the quality of the joint are still subject to many investigations.**

# Friction Stir Welding (FSW)

- **FSW is a solid state joining process invented at The Welding Institute in 1991.**
- **The weld is carried out by the forward movement of a specially designed rotating tool in the joint line which softens the material without melting [1].**
- **The image shows a schematic diagram of FSW process [2].**

# Friction Stir Welding (FSW)



# Advantages

- **Solid phase nature of the process [3].**
- **FSW is used for high strength aluminum alloys (2xxx and 7xxx series) and other metallic alloys hard weldable [1].**
- **Good mechanical and metallurgical properties are obtained.**
- **Environmentally friendly (no consumables and no welding fume).**
- **Good finishing aspect.**

# Microstructural Characterisation

- The weld is composed of 3 distinct zones:
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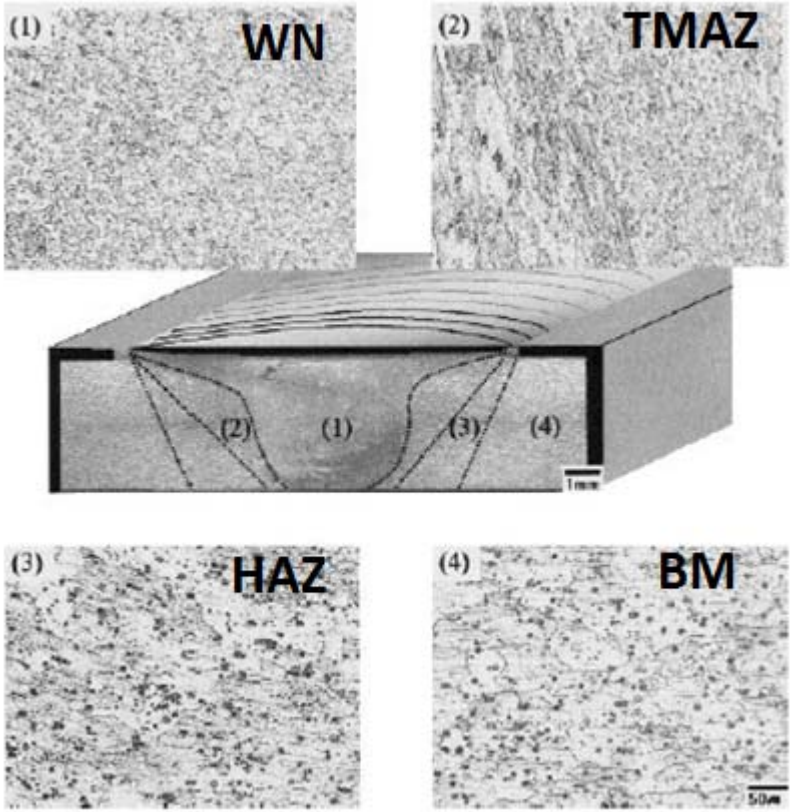
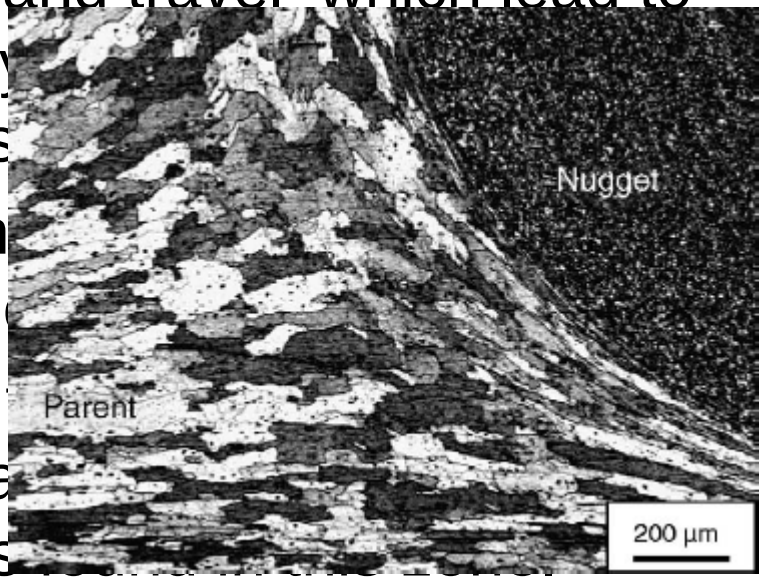
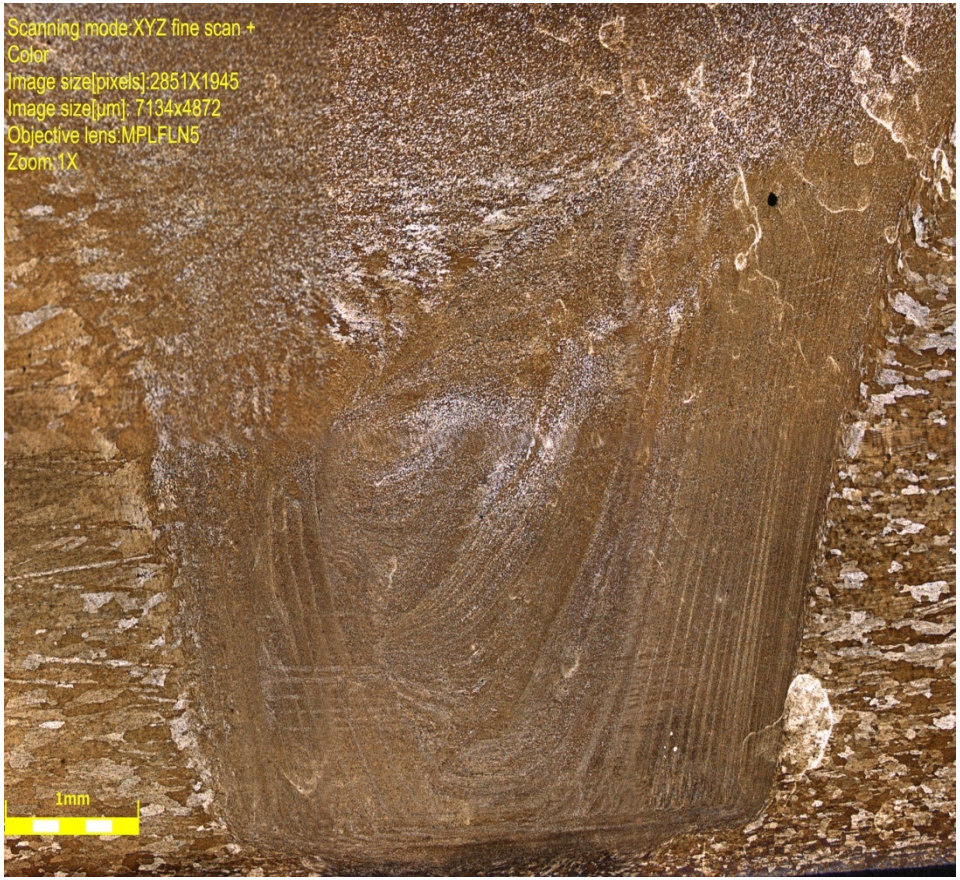



Microstructure in FSP of 7075 Al [1]

Microstructure in FSWed 6061-T651 Al [4]

# Origin of “Onion Rings”

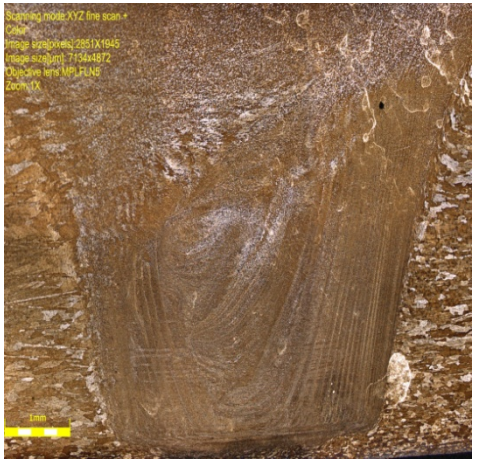



## Onion rings in 6082-T6 Al (1500 rpm; 400 mm/min)

Tongne, A., *Étude expérimentale et numérique du procédé de soudage FSW (Friction Stir Welding). Analyse microstructurale et modélisation thermomécanique des conditions de contact outil/matière transitoires*. 2014, Saint-Etienne, EMSE.

# Origin of “Onion Rings”

- Banded structure better known under the name of “onion rings” is one of the features that occurs in FSW due to complex thermomechanical phenomena.
- “onion rings” are formed in the stir zone and consist of alternated “clear” and “dark” bands seen after chemical etching. Their shape, their extent and the number of bands depend on the welding parameters.
- Onion rings have been subjected to many investigations; however a general unique definition of their nature and their effect on mechanical properties are still missing.



Onion rings in 6082-T6 Al (1500 rpm; 400 mm/min) [5]

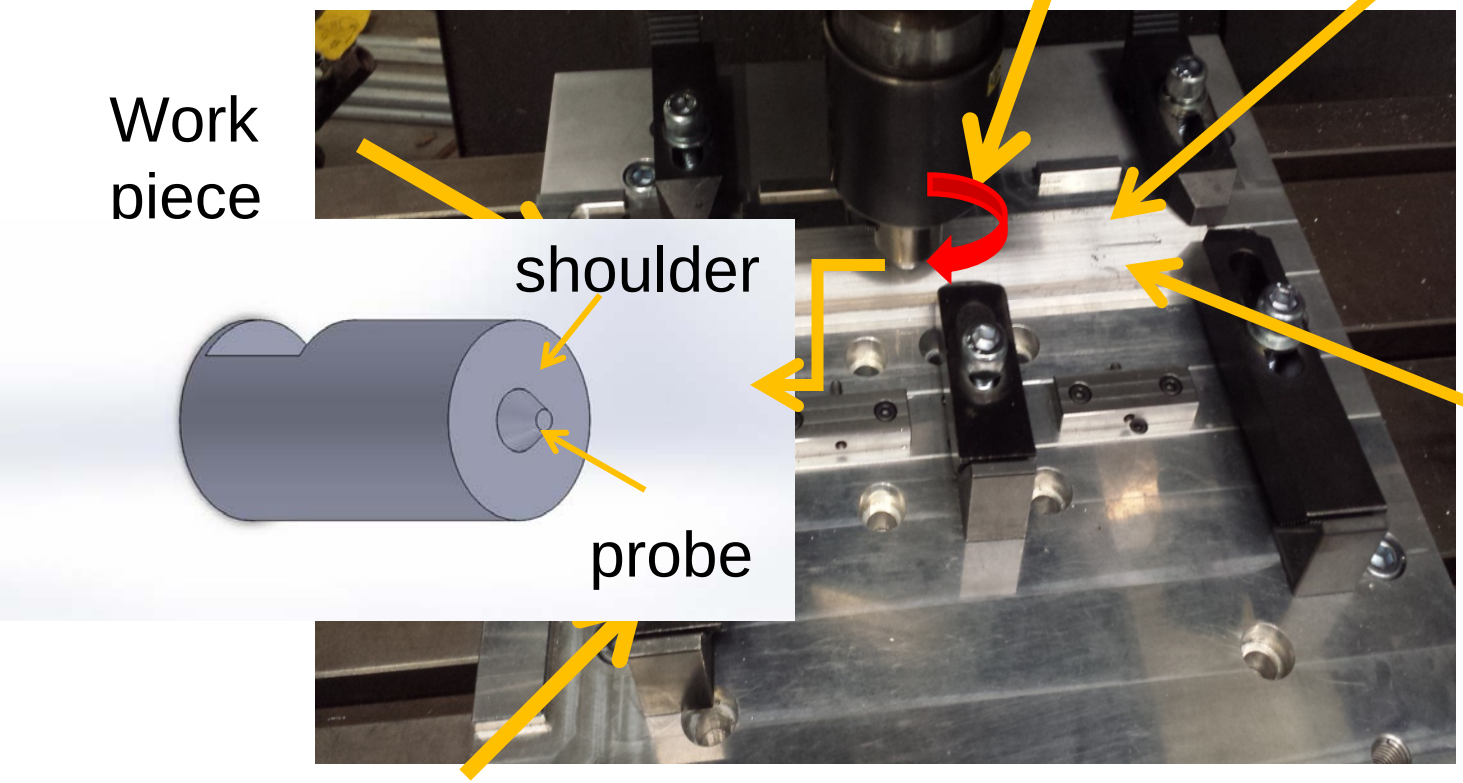
# Origin of “Onion Rings”

- Krichnan and Threadgill explained that the formation of onion rings is due to the frictional heat caused by the rotation of the tool and the movement of the material to the retreating side. Extruded layer s are successively superposed after each revolution [2,6].
- Biallas suggested that the layers are formed due to the softened material contact with the cooler heat affected zone [8].
- Other researchers suggested that the difference between the banded structure is due to an unequal distribution of secondary phase particles. The dark layer is a "particle-poor" layer and the light one is a "particle-rich" layer [9].

# Research Objective

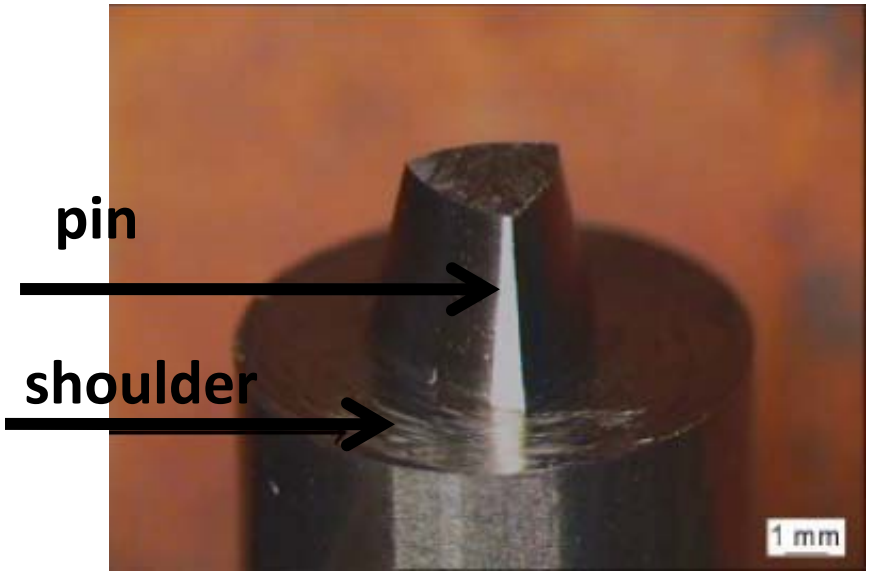
- **The objective of this research work is to determine various characteristics of the "onion rings" and correlate them to processing conditions (speed, travel speed, alloy, tool).**
  - **Grain size & orientation**
  - **Mechanical properties: shear punch test**

# FSW Setup




ÉTS : Lipps FSW set-up

# Experimental Procedure (FSW Parameters)




Trigonal tool made with commercially grade tungsten carbide

**Dimensions of the tool used**

| | |
|---|---|
| Shoulder diameter | 12 mm |
| Bottom pin diameter | 4 mm |
| Top pin diameter | 6 mm |
| Pin height | 5.5 mm |

# Experimental Procedure (FSW Parameters)

| Aluminum alloy | Tool | Rotation speed (rpm) | Travel speed (mm/min) |
|---|---|---|---|
| AA 6082-T6 | Triangular * | 1500 | 400 |
| | | 1750 | 200 |
| | | 1500 | 300 |
| | | 2000 | 600 |
| | Conical | 800 | 100 |
| | | 1600 | 100 |
| | | 1120 | 160 |
| AA 6061-T651 | | | |

* Test done by Amèvi Tongne, France

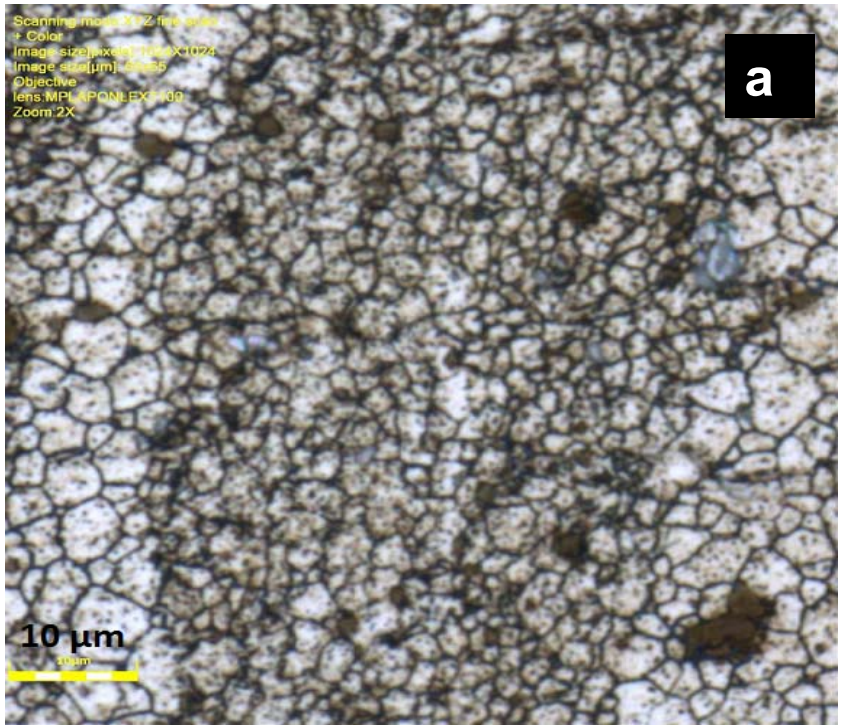
# Results & Discussions

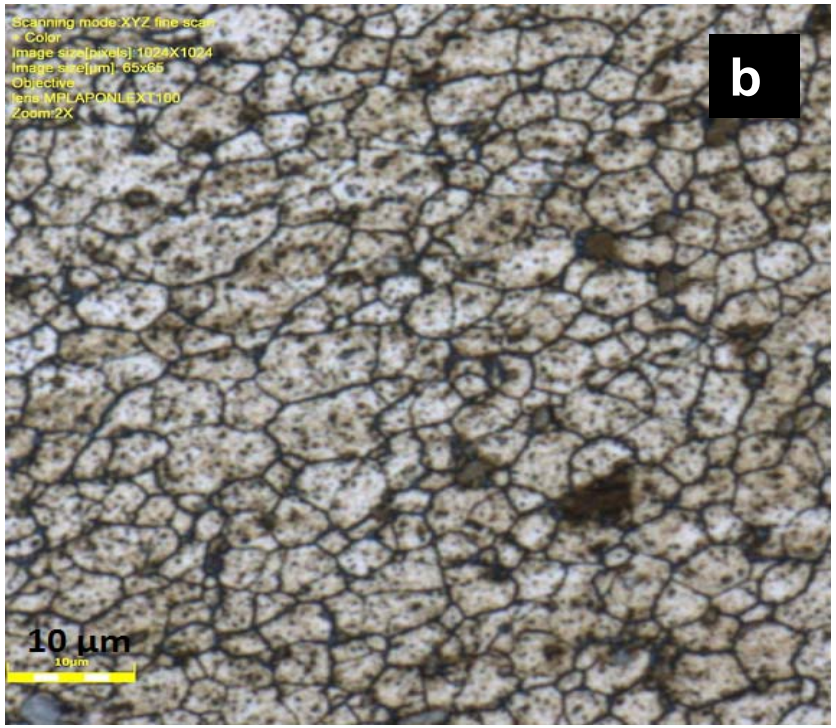
# Microstructural Observations

- In friction stir process samples , onion rings are always formed at the advancing side with a cavity at the extremity of this area at the bottom of the stirred zone.
- For plates joined by friction stir welding, onion rings are spread over both advancing and retreating sides. When the rotation and advance speed ratio is high a similar behaviour to the friction stir process is observed.
- Bands of OR respond differently to chemical etching. This can be due to the difference in grain size between the layers.

# Microstructural Observations

Grains in the “light” band are bigger than the ones in the “dark band”.
Grains in OR are smaller than the ones in the adjacent zone to them.

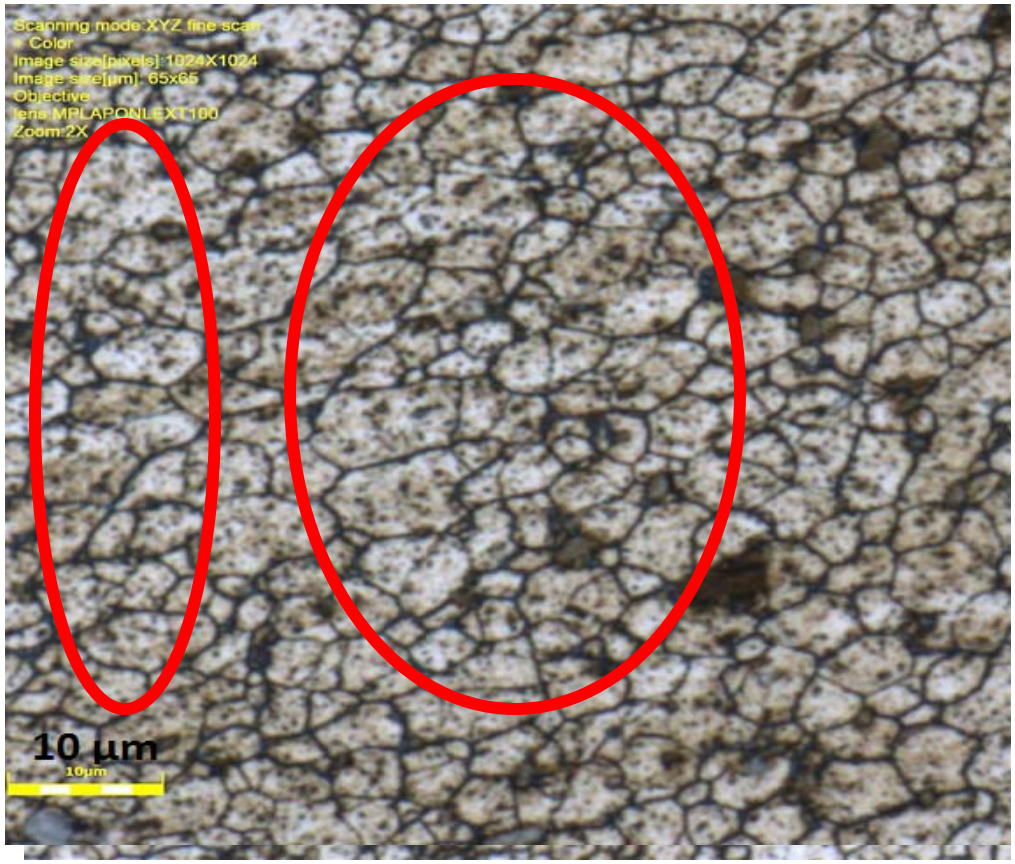



Optical micrographs of sample 016: (a) onion rings bands; (b) OR adjacent zone

# Grain Size

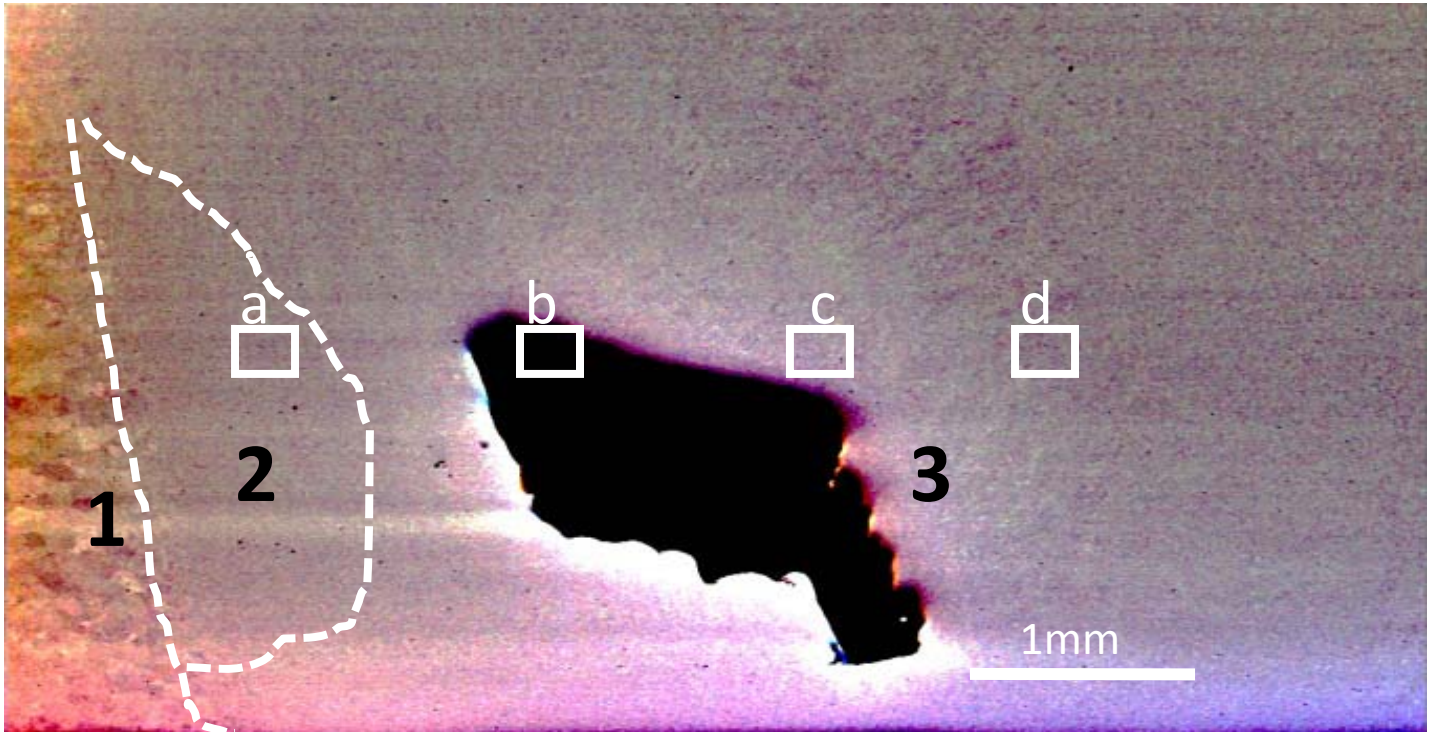
| | grain diameter (µm) |
|---|---|
| “Dark” band | d< 3 |
| “Light” band | 3 < d< 9 |
| OR’ adjacent zone | d≈ 8 |



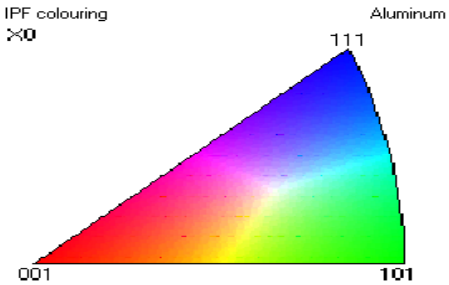
# Grains Orientation

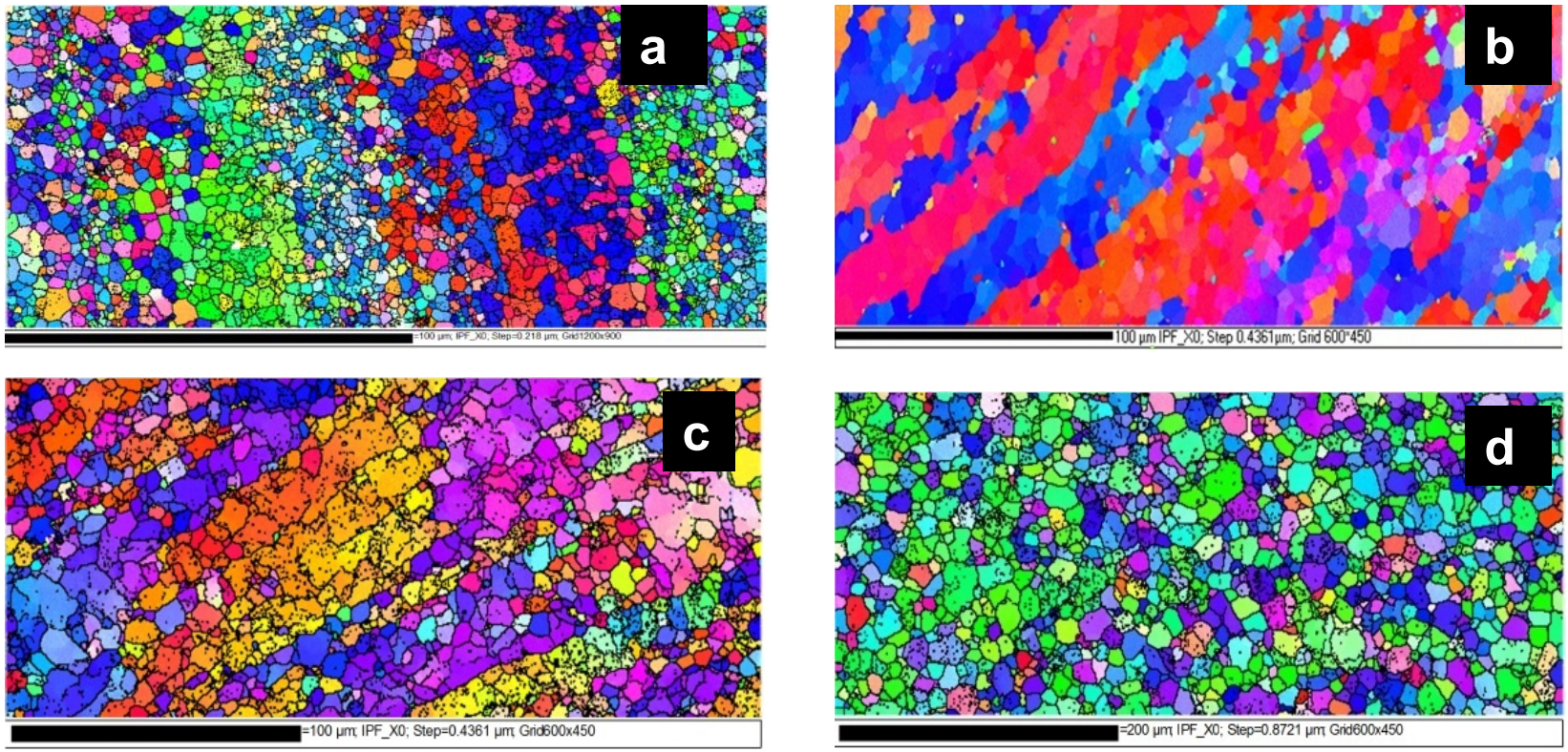
- A cross section slice of the weld with 0.9 mm thickness perpendicular to the welding direction was cut and prepared following standard metallography techniques. Then it was polished for 24 h in a Vibromet® polishing machine with 0.05 µm colloidal silica. EBSD analysis was done using Hitachi SU-8230 FE-SEM.

# Grains Orientation




**Low enlargement view of the left part of the nugget showing TMAZ of the advancing side (1), onion rings (2) and retreating side (3) together with the wormhole or tunnel defect**
**a, b, c and d are the zones where EBSD analysis was done**




**EBSD maps of different zones in the nugget**

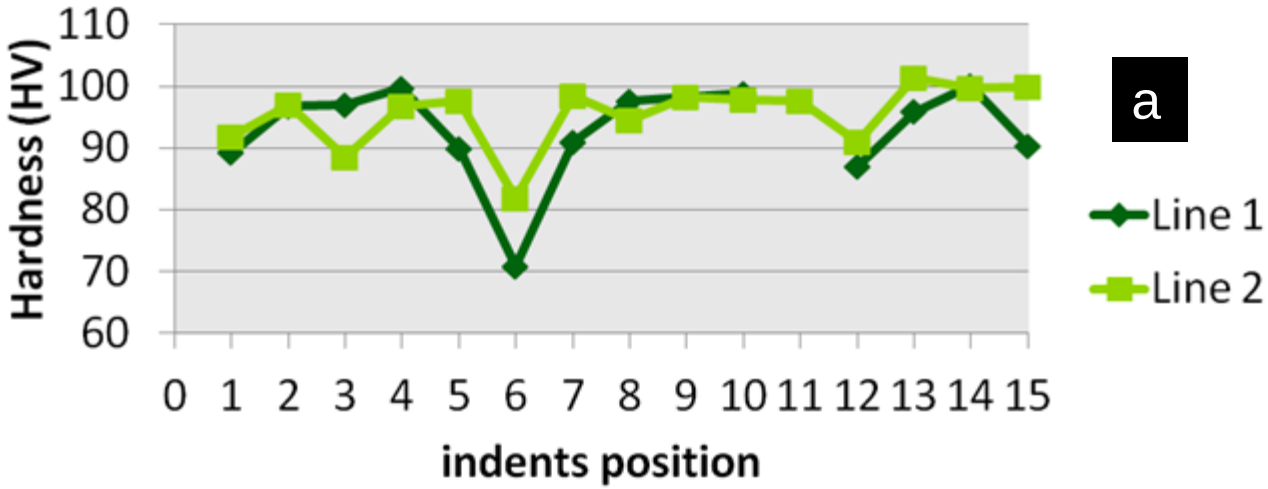
# Grains Orientation

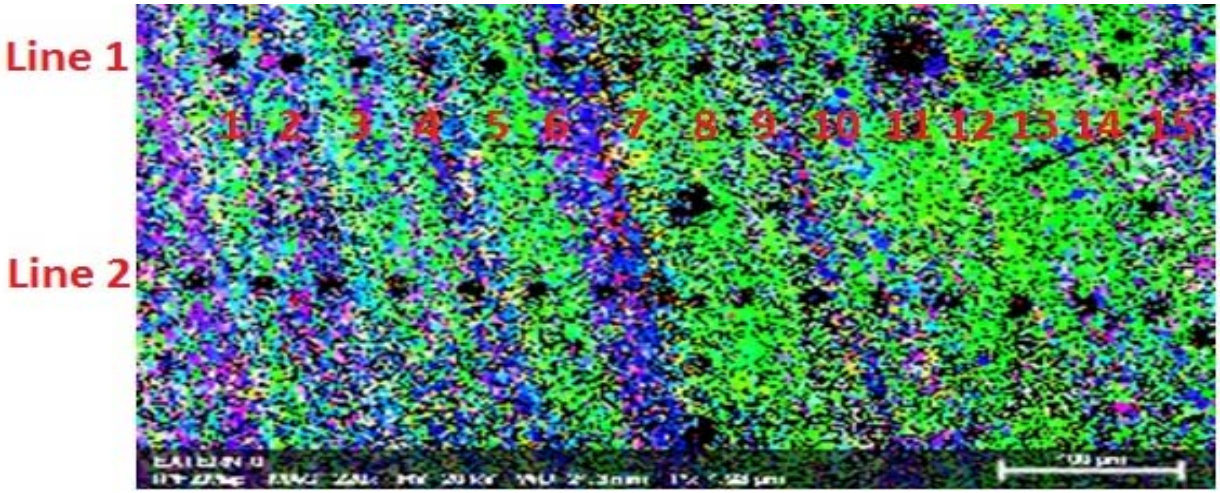
- In the advancing side, where onion rings were found (zone a), the larger grains show mostly (111) orientation, manifested by the blue color, while the smaller ones indicate (101) orientation manifested by the green color.
- It is noted that the border between these two bands is not sharp and a transition area may be recognised between them in which grains (mostly small) have an orientation between (101) and (111) manifested by blue-green or bright blue.
- Zone b and c show mostly (111) and (001) orientations manifested by blue and red colors.
- Finally, by coming to zone d, the orientation is totally changes to (101) so that the green color dominates.

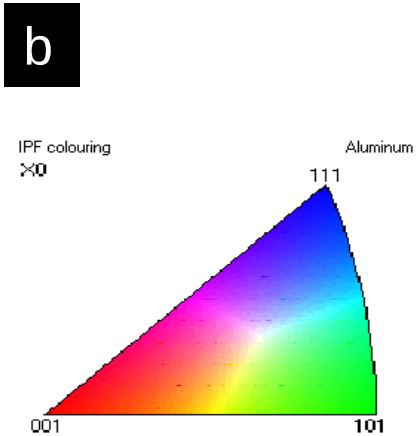
# Nano-indentation Test

- Hardness was measured in "onion rings" area to see the impact of the difference in the grain size between the bands.

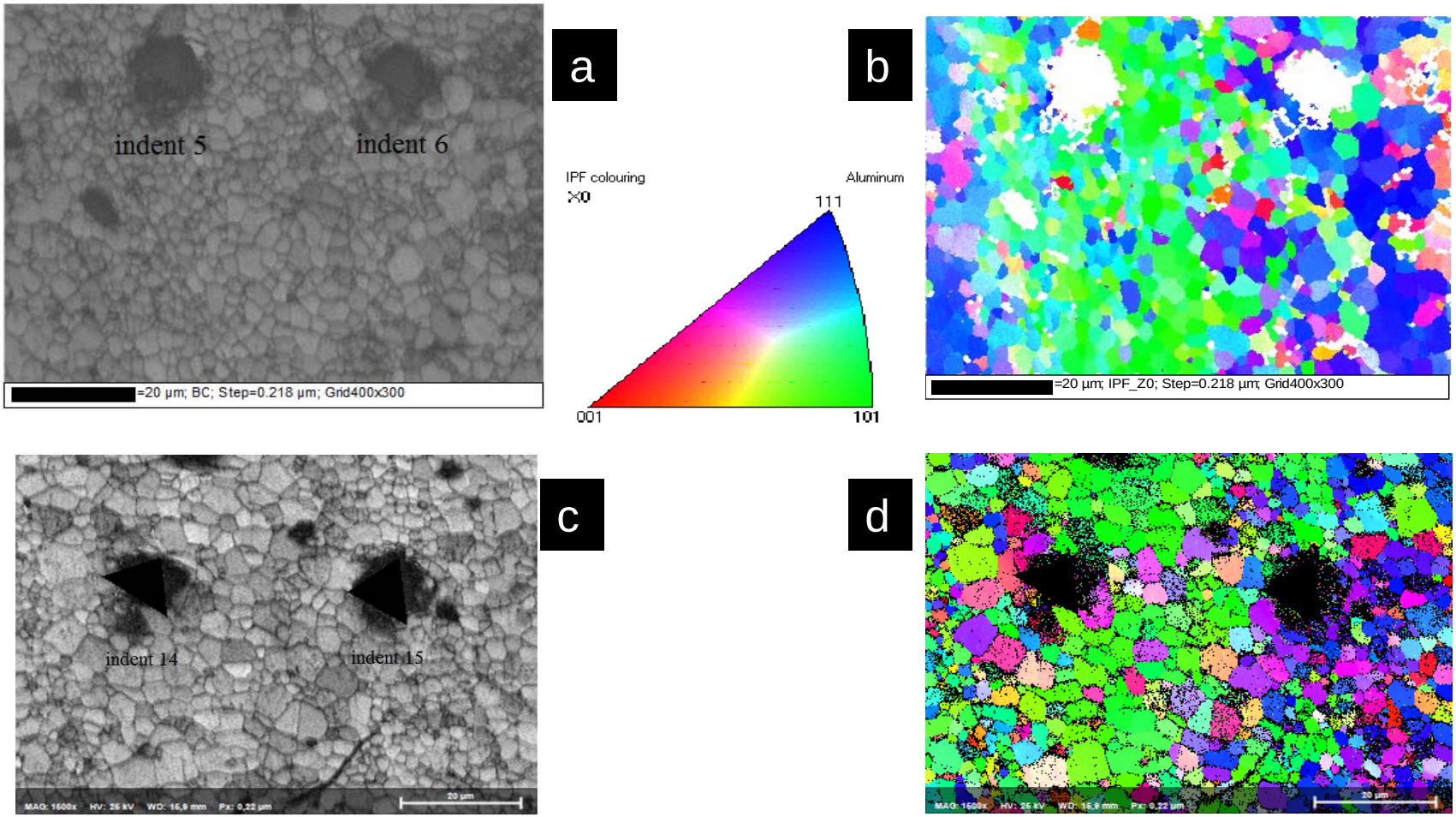
- Nano indentation test was performed using a Hysitron's PI series indenter installed in SEM to measure the hardness in banded structure.




**Hardness profile (a) measured by means of nano-indentation over the onion rings shown as two separated lines 1 and 2 in the EBSD map (b)**




(a) SEM image of the area around indents 5 and 6; (b) IPF maps of the area around indents 5 and 6; (c) SEM image of the area around indents 14 and 15 and (d) IPF maps of the area around indents14 and 15.

# Nano-indentation Test

- Hardness measurement using nano-indentation passing over the bands showed some fluctuations which did not necessarily matched with the grain size changing.
- It cannot be said that as a general rule the (101) orientation has higher hardness than the (111) orientation.
- Other factors, such as the presence of precipitates may influence hardness trends in the bands.

# Conclusions

- **Onion rings were observed as dark and bright bands after etching and optical microscopy. The dark bands contain smaller grains than the bright ones.**
- **It was also found that overall grain sizes in the banded structure were smaller than those in the rest zones of the nugget.**
- **EBSD study of the banded structure revealed that crystal orientation of the grains is also different in the bands.**
- **Hardness measurement using nano-indentation passing over the bands showed some fluctuations which did not necessarily matched with the grain size changing.**

# References


- 1. Mishra, R.S. and Z.Y. Ma, *Friction stir welding and processing.* Materials Science and Engineering: R: Reports, 2005. 50(1–2): p. 1-78.
- 2. Threadgill, P.L., et al., *Friction stir welding of aluminium alloys.* International Materials Reviews, 2009. 54(2): p. 49-93.
- 3. Vilaça, P., C. Vidal, and J. Gandra, *Linear friction based processing technologies for aluminum alloys: surfacing, stir welding and stir channeling*. 2012: INTECH Open Access Publisher.
- 4. Lim, S., et al., *Tensile behavior of friction-stri-welded Al 6061-T651.* Metallurgical and Materials Transactions A, 2004. 35(9): p. 2829-2835.
- 5. Tongne, A., *Étude expérimentale et numérique du procédé de soudage FSW (Friction Stir Welding). Analyse microstructurale et modélisation thermomécanique des conditions de contact outil/matière transitoires*. 2014, Saint-Etienne, EMSE.
- 6. Krishnan, K., *On the formation of onion rings in friction stir welds.* Materials science and engineering: A, 2002. 327(2): p. 246-251.
- 7. Biallas, G., et al. *Mechanical properties and corrosion behavior of friction stir welded 2024-T3*. in *1st International Symposium on Friction Stir Welding, Thousand oaks, CA, USA, czerwiec*. 1999.
- 8. Hamilton, C., S. Dymek, and M. Blicharski, *A model of material flow during friction stir welding.* Materials Characterization, 2008. 59(9): p. 1206-1214.
- 9. Guduru, R.K., et al., *Evaluation of mechanical properties using shear–punch testing.* Materials Science and Engineering: A, 2005. 395(1–2): p. 307-314.

# Thank you !