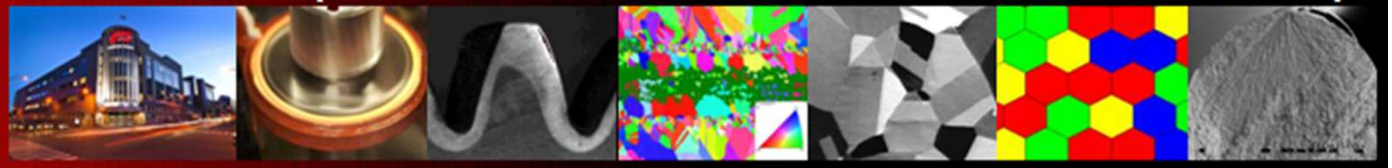
Laboratoire d'Optimisation des Procédés de Fabrication en Aéronautique



ÉTS
Le génie pour l'industrie

Monday, June 17th 2013

CRIAQ MANU419 project meeting :

"Water droplets erosion mechanims of Ti-alloys used for gas turbine compressor"

CRIAQ www.criaq.aero

NSERC CRSNG

Rolls-Royce

PhD – Nelly Kamkar – ÉTS

supervisors : Florent Bridier
Philippe Bocher

Objectives :

1) Understanding the influence of impingement speed and droplet size on erosion rates of Ti64

2) Understanding the influence of LSP and LPB surface treatments on erosion kinetics of forged Ti64

3) Understanding the effect of crystallographic texture/impingement direction on erosion mechanisms of rolled Ti64

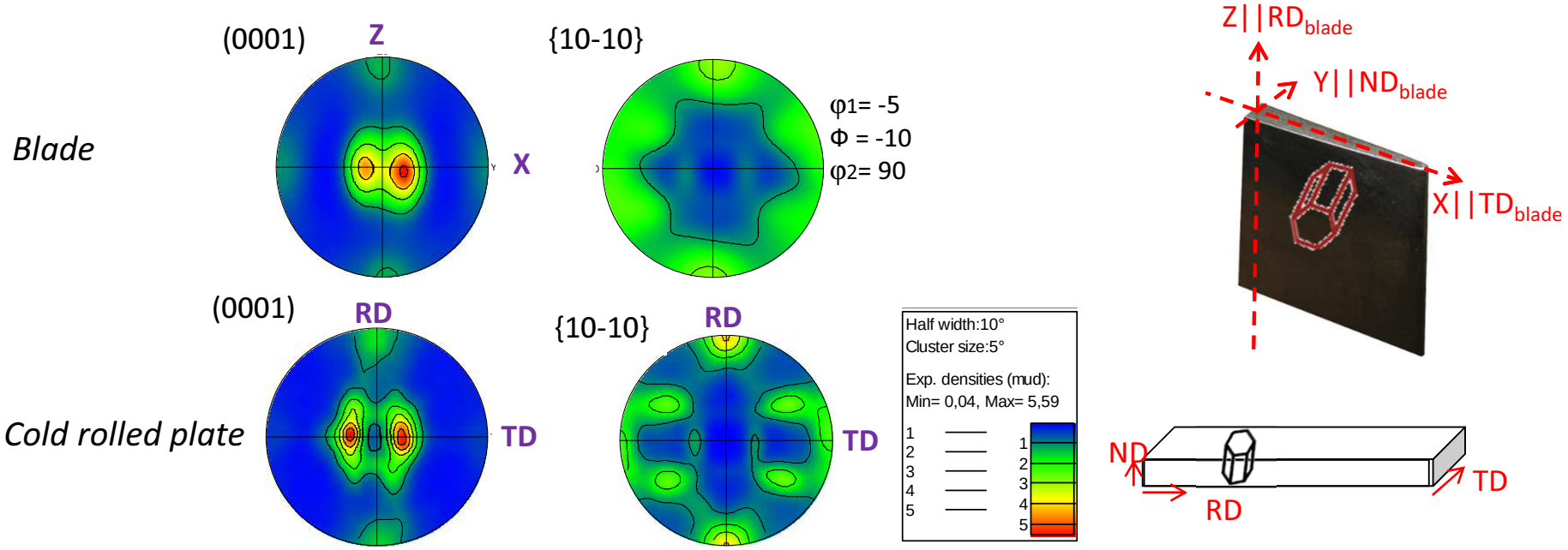
Highlights :

- Events :
  - Presentation and publication of the article to Wear of Materials Conference & Journal
  - Meeting with Concordia on stress field analyses and accordance of experiments and modeling

- Research work :
  - Appropriate material is selected for rig test at Concordia (cold rolled Ti64).
  - Samples from the rolled plate are designed and manufactured for all the rig tests at Concordia.
  - LPB coupons (tested at Alstom) are fully characterized.
  - Residual stress measurement are performed on LSP and LPB coupons.

Base material selection for rig test at Concordia

- Cold rolled Ti-6Al-4V texture: basal or nearly basal texture with the poles tilted up to 40° towards TD



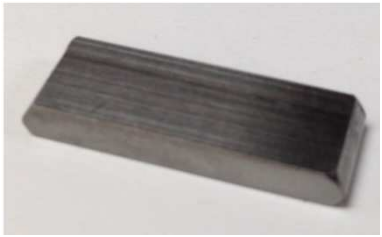
(Wang and Huang, 2003)

↳ Cold rolled plate is selected for base material study

1-1 Influence of Impingement speed and droplet size on erosion rates of rolledTi64

Sample

Untreated flat coupons from rolled plate



-Design and manufacturing of samples ✓

Test

Rig test: 3 velocities and 3 droplet sizes at Concordia university

-Optimization of experimental plan ✓

Velocity variation

Droplet size (µ)	Speed (m/s)	Erosion stage
400	350	Steady state
400	300	Steady state
400	280	Steady state

Droplet size variation

Droplet size (µ)	Speed (m/s)	Erosion stage
600	350	Steady state
400	350	Steady state
200	350	Steady state

Analyses

-Obtaining the erosion curves

-Erosion characterization

-Comparison of the coupons and understanding the influence of impingement speed and droplet size

1-1 Influence of Impingement speed and droplet size on erosion rates of rolledTi64

Time table

Activity	2013											
	Q1			Q2			Q3			Q4		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Representativity of the in-service condition												
Tests on the coupons with speed variation												
sample fabrication												
rig test at final stage												
sample preparation												
erosion characterization												
Tests on the coupons with droplet size variation												
sample fabrication												
rig test at final stage												
sample preparation												
erosion characterization												

1-2 Influence of LSP and LPB surface treatments on erosion kinetics of forged Ti64

Sample

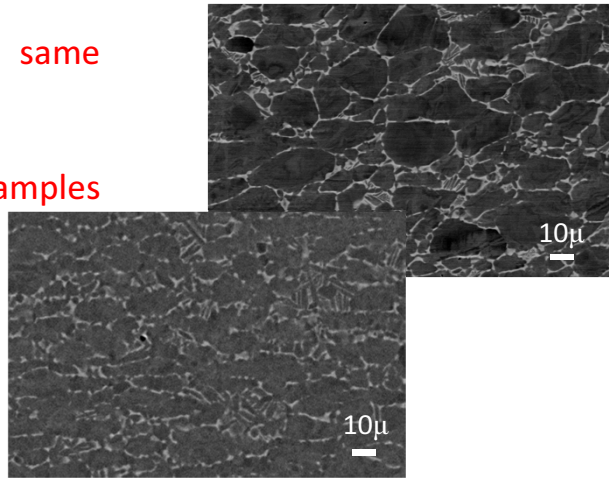
Forged coupons

- LSP
- LPB
- Untreated

! Issue

LPB samples did not have the same microstructure.

=> There is a need to produce samples with the same microstructure



Sample manufacturing

Untreated

- Extraction from the blade root and manufacturing ✓

LPB

- Extraction from the blade root and manufacturing
- LPB application on the coupons

Test

Rig test at Alstom

- LSP (standard and heavy, 0.2 and 0.6mm droplet size) ✓
- LPB (low load parameters and high load parameters, 0.6mm droplet size)
- Untreated (4 different stages, 06mm droplet size) ✓

1-2 Influence of LSP and LPB surface treatments on erosion kinetics of forged Ti64

Test

Rig test at Alstom

LPB

LPB condition	Droplet size (µ)	Speed (m/s)	Erosion stage
Low Load	600	350	Steady state
High Load	600	350	Steady state

Untreated

Droplet size (µ)	Speed (m/s)	Erosion stage
600	350	Incubation
600	350	Onset of material removal
600	350	First steady state
600	350	Final steady state

Analyses

-Erosion characterization and comparison of the erosion mechanisms in LSP, LPB and untreated samples tested at Alstom; relating the erosion rate and mechanisms to the residual stress/surface treatments.

-Understanding the mechanism of erosion in forged microstructure at different stages.

1-2 Influence of LSP and LPB surface treatments on erosion kinetics of forged Ti64

Analyses

Different microstructures

Analyses/Samples	LSP standard	LSP heavy	LPB low load	LPB high load
Base material studied(Microstructure/texture)				
SEM imaging	✓	✓	✓	✓
EBSD maps/pole figures	---	✓	x	---
Hardness profile	✓	✓	✓	✓
Residual stress	In progress	✓	✓	✓
Erosion characterization				
Erosion curve	✓	✓	✓	✓
Crater width/ depth	✓	✓	✓	✓
Mechanism studies	✓	✓	✓	✓
Cracks studies	✓	✓	✓	✓

! All the analyses were done for LSP and LPB coupons, however the LPB coupons do not have the same microstructure as the LSP's. Hence these analyses should also be done on the LPB coupons with the same microstructure.

1-2 Influence of LSP and LPB surface treatments on erosion kinetics of forged Ti64

Time table

Activity	2013											
	Q1			Q2			Q3			Q4		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Effect of surface treatments												
Analyses of the LSP coupons												
sample preparation												
erosion characterization												
residual stress												
Analyses of the LPB coupons												
sample preparation												
sample fabrication												
rig test at Alstom												
erosion characterization												
residual stress												
Analyses of the untreated coupons												
sample fabrication												
rig test at 3 stages												
sample preparation												
erosion characterization												

1-3 Effect of crystallographic texture on erosion mechanisms of rolled Ti64

Sample

Untreated flat coupons from rolled plate

-Design of samples at 3 different directions

-Design of sample holder ✓

0 ° ✓
45° X
90° ✓

! Plate thickness is not enough for 45◦

Manufacturing

-Samples at two direction (0 ° and 90°) ✓

-Sample holder ✓

Test

Rig test on different impingement directions and on 3 stages of erosion at Concordia

ND

Droplet size (µ)	Speed (m/s)	Erosion stage
400	350	Steady state
400	350	Intermediate
400	350	Onset of erosion

RD

Droplet size (µ)	Speed (m/s)	Erosion stage
400	350	Steady state
400	350	Intermediate
400	350	Onset of erosion

1-3 Effect of crystallographic texture on erosion mechanisms of rolled Ti64

Analyses

-Erosion characterization and comparison of the coupons to understand the influence of impingement direction.

-Understanding the mechanism of erosion in rolled microstructure at different stages.

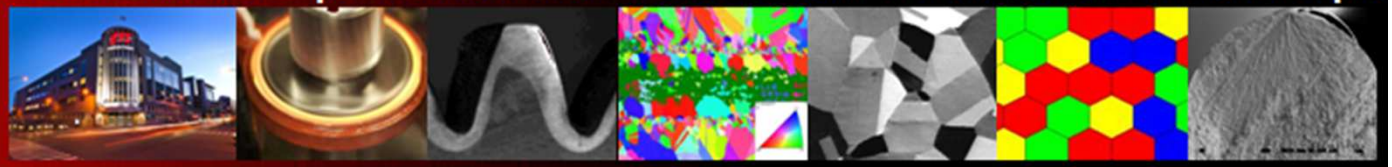
1-3 Effect of crystallographic texture on erosion mechanisms of rolled Ti64

Time table

Activity	2013											
	Q1			Q2			Q3			Q4		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Effect of basematerial												
Analyses of the erosion at 3 different directions; variation of impingement angle												
sample fabrication												
rig test at 3 stages												
sample preparation												
erosion characterization												

1-4 Work schedule

Activity	2013											
	Q1			Q2			Q3			Q4		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Representativity of the in-service condition												
Tests on the coupons with speed variation												
Tests on the coupons with droplet size variation												
Writing the first article								X				
Effect of surface treatments												
Analyses of the LSP coupons												
Analyses of the LPB coupons												
Analyses of the untreated coupons												
Writing the second article										X		
Effect of basematerial												
Analyses of the erosion at 3 different directions; variation of impingement angle												
Writing the third article												X



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Thank you.

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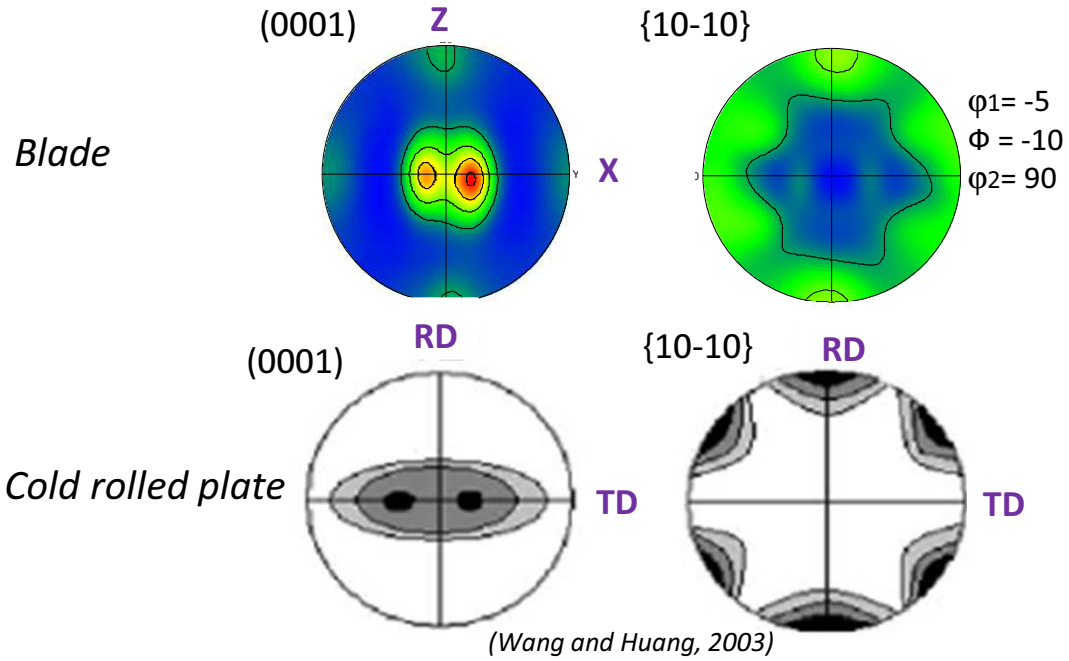
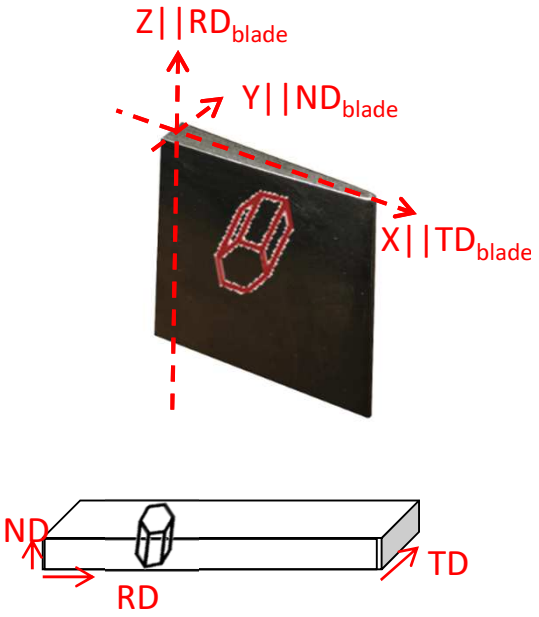
Base material selection for rig test at concordia

- Cold rolled Ti-6Al-4V texture: basal or nearly basal texture with the poles tilted up to 40° towards TD



(Wang and Huang, 2003)

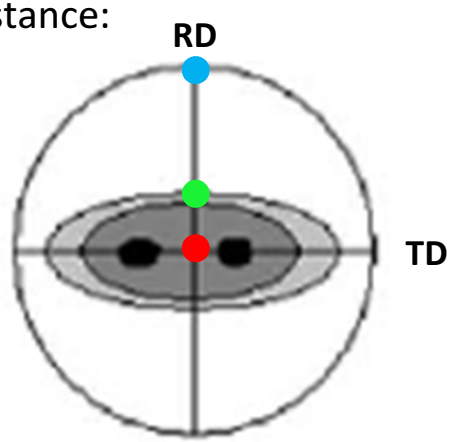


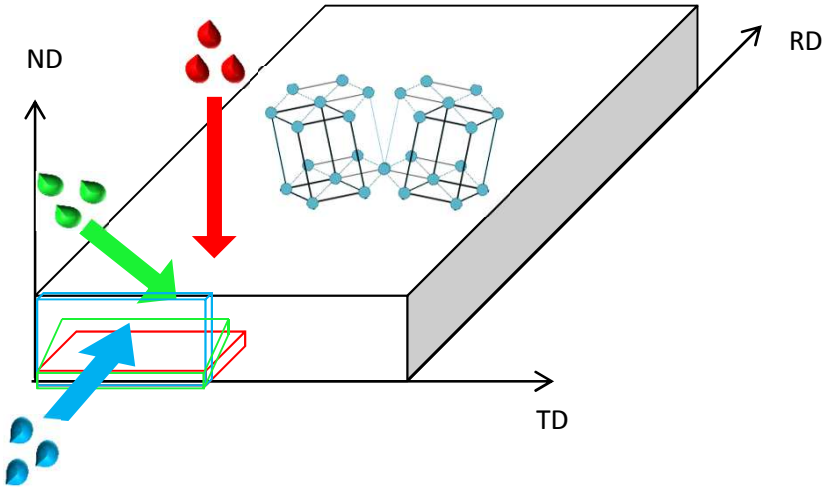
↳ Cold rolled plate is selected for base material study

impingement direction influence

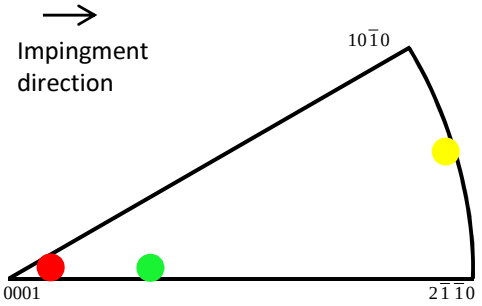
- Experimental plan to investigate influence of crystallographic texture of base material on water erosion resistance:

Pole figure



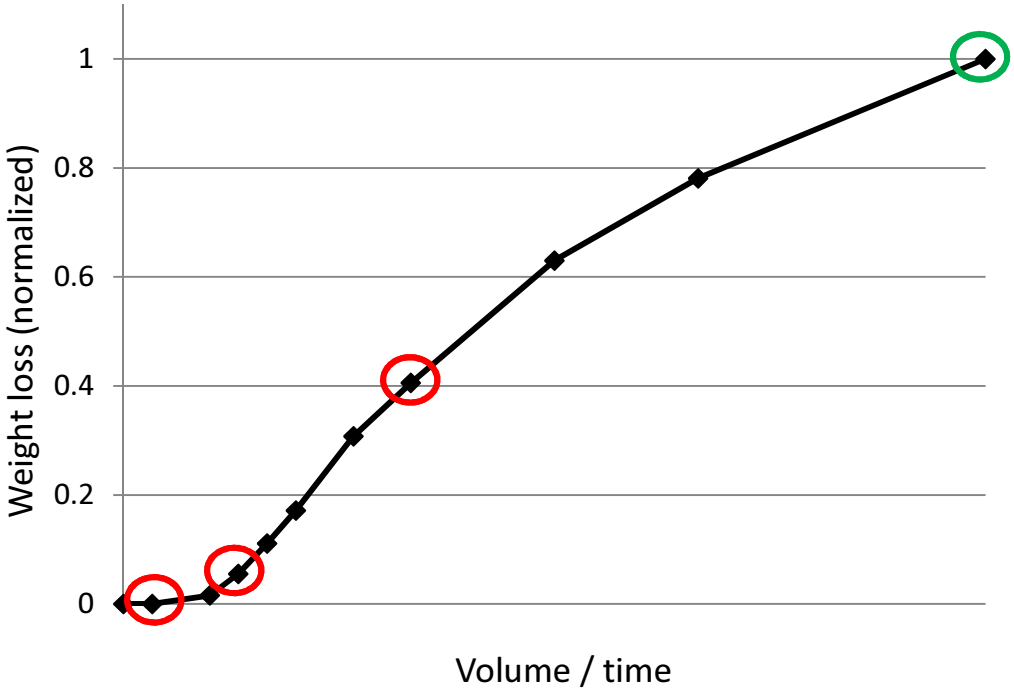


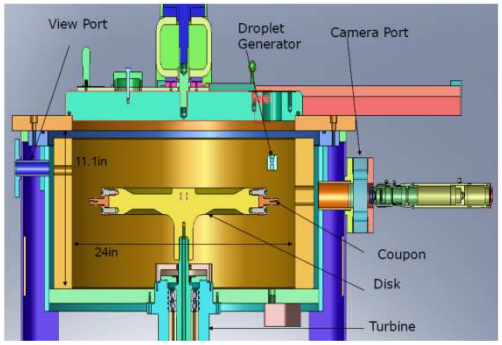
Inverse pole figure



↳ different impingement directions relative to cold rolled plate

Rig test for impingement direction influence





1 test until steady state with many interruptions for weight measurement

2 or 3 other tests up to early and intermediate stages of erosion

Detailed experimental plan are provided.

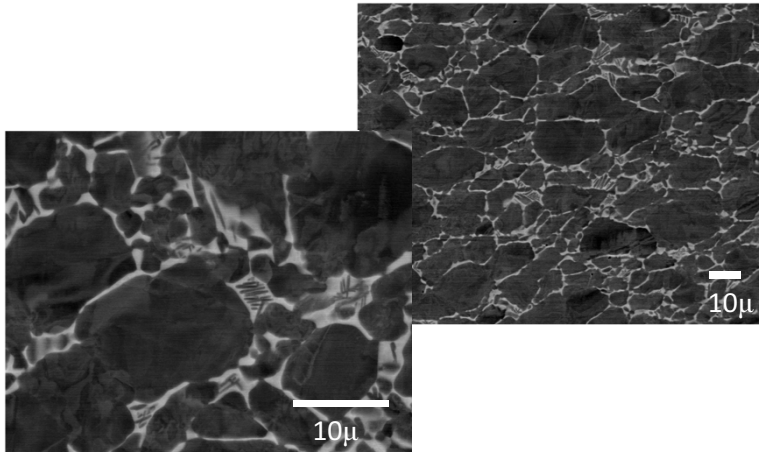
Base material studies for effect of surface treatment studies

- Microstructure

  ↳ microstructure at different scale

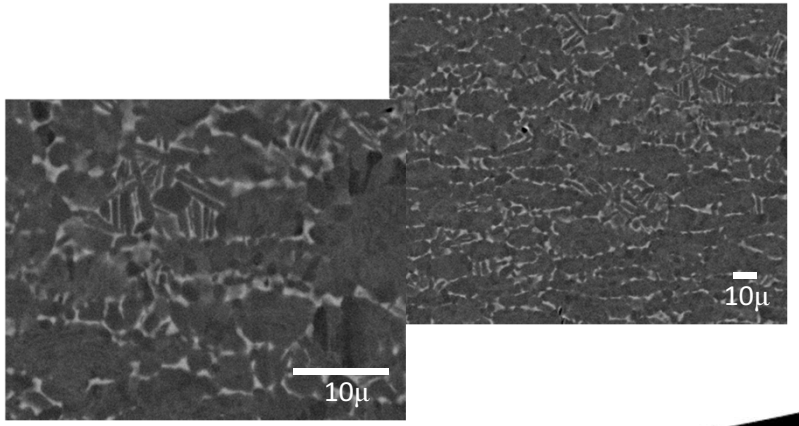
-LSP

mostly globular microstructure with areas of α-primary embedeb in β matrix /Lamellae



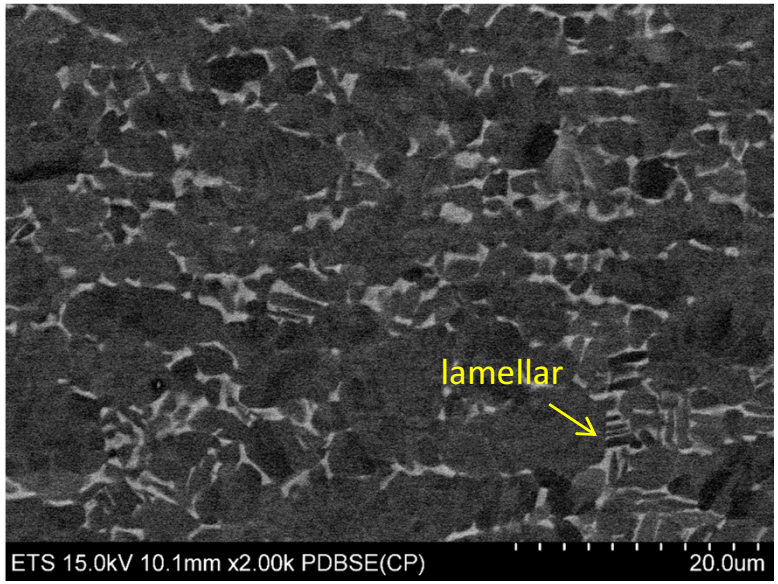
-LPB

Globular and elongated microstructure with some lamellar areas

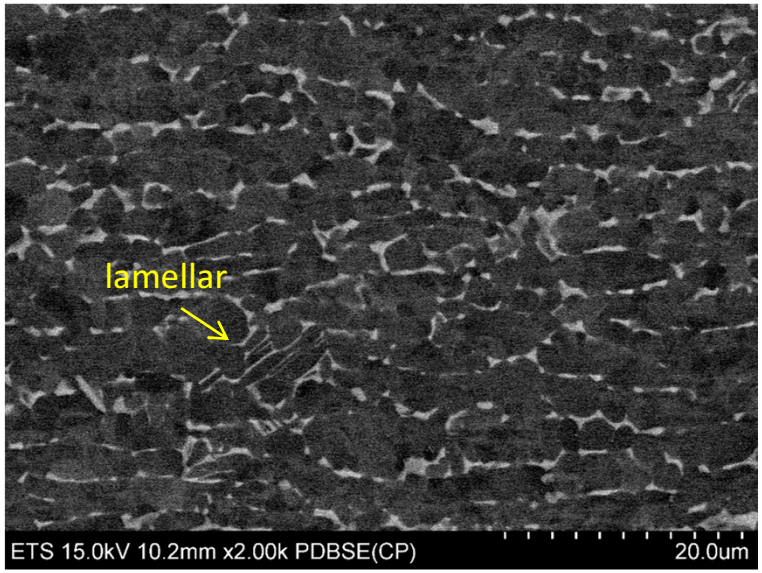


Base material studies for effect of surface treatment studies

- Microstructure of LPB



Globular part

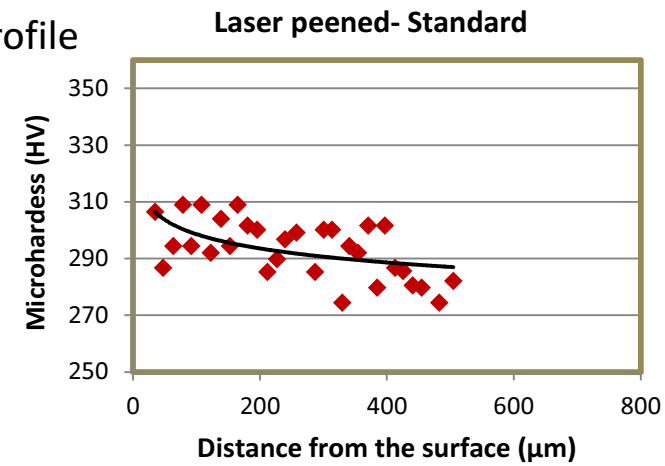


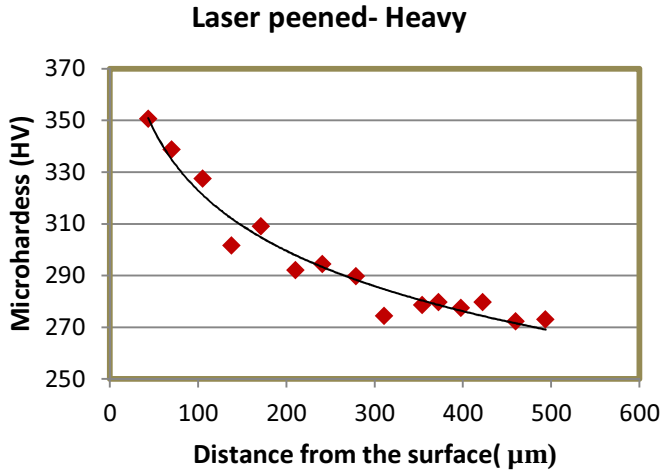
Elongated grains part

Base material studies for effect of surface treatment studies

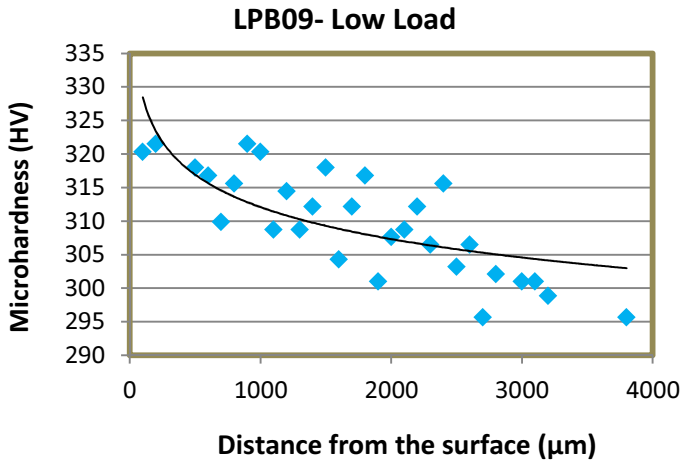
- Hardness profile

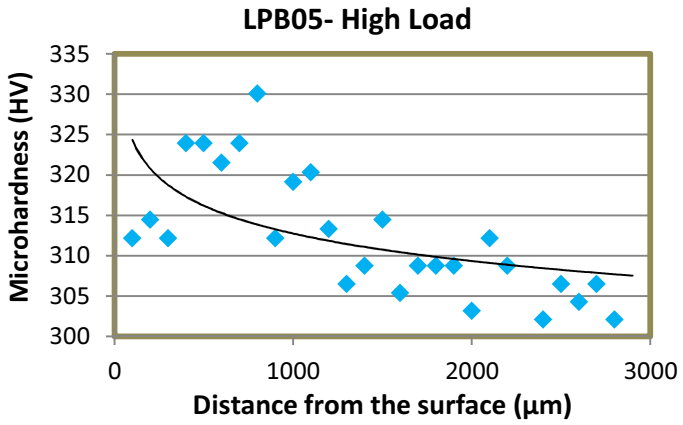
-LSP





-LPB

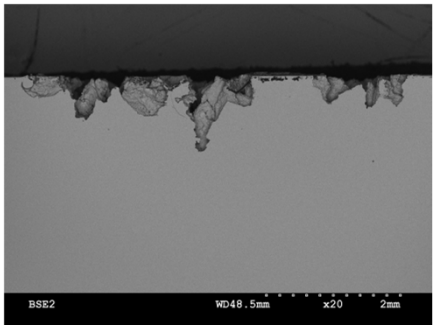


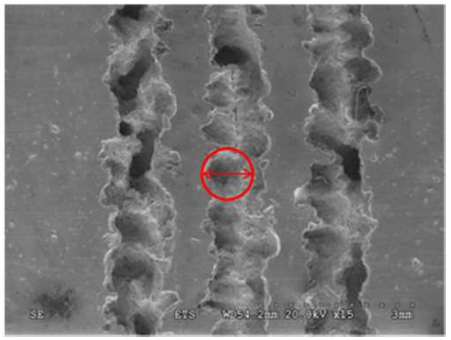


⇒ No significant increase in microhardness of the LPB coupons rather than LSP coupons

Base material studies for effect of surface treatment studies

- Description of craters depth and width:





-Average crater width

Untreated (Rolled)	LSP standard	LSP heavy	LPB low load	LPB high load
1.27 ± 0.18 mm	1.12± 0.07 mm	1.13±0.05 mm	545 µ	577µ

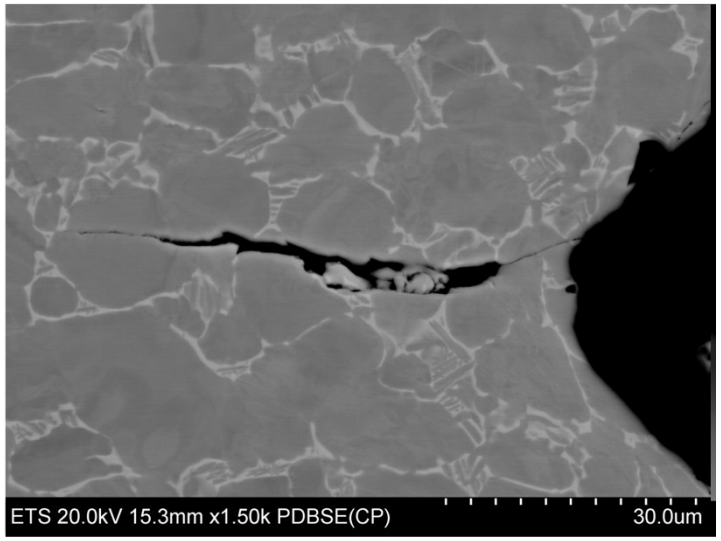
-Average crater depth

Untreated (Rolled)	LSP standard	LSP heavy	LPB low load	LPB high load
--	--	--	575 µ	486 µ

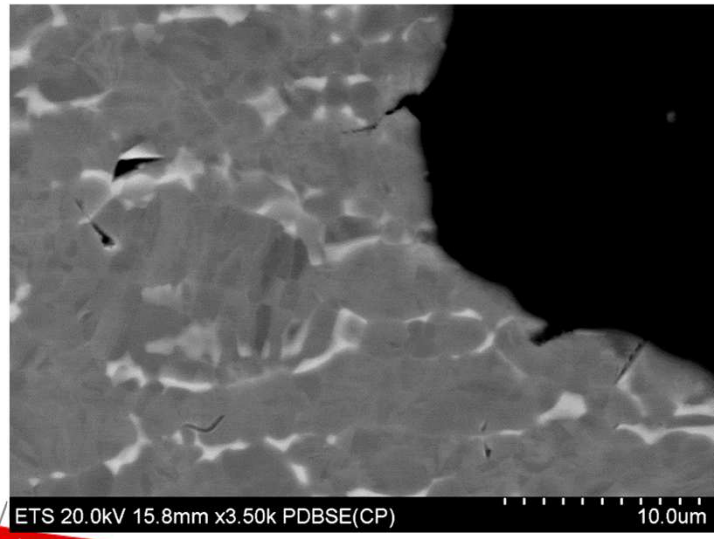
⇒ LPB coupons show smaller crater width (almost one half of the LSP and untreated rolled coupons)
⇒ No significant decrease in crater width from low parameters to high parametesr for LPB coupons, neither for LSP coupons from standard to heavy treatments
⇒No conclusion on depth as of now

Erosion characterization

LSP



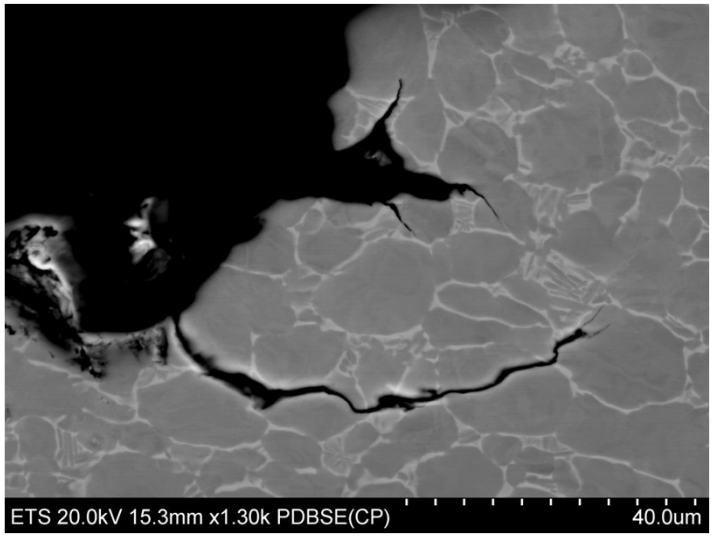
LPB



⇒ Surface and sub-surface cracks were observed in both samples, however the number of sub-surface cracks visually are more in LPB couppons rather than LSPs.

Erosion characterization

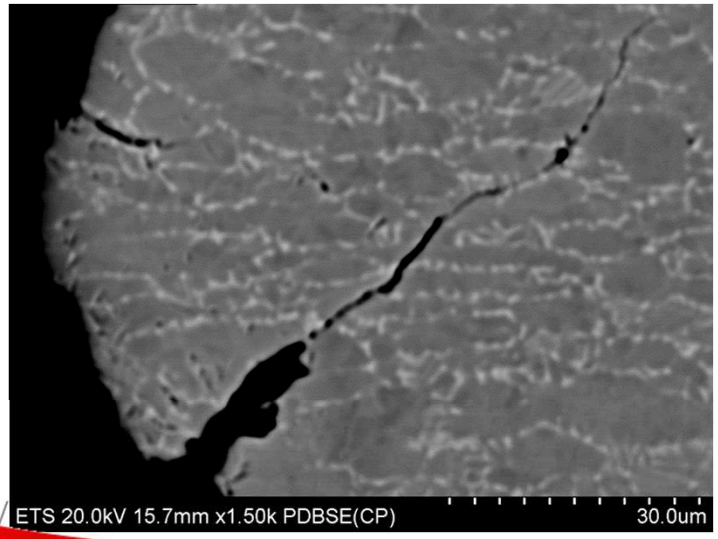
LSP

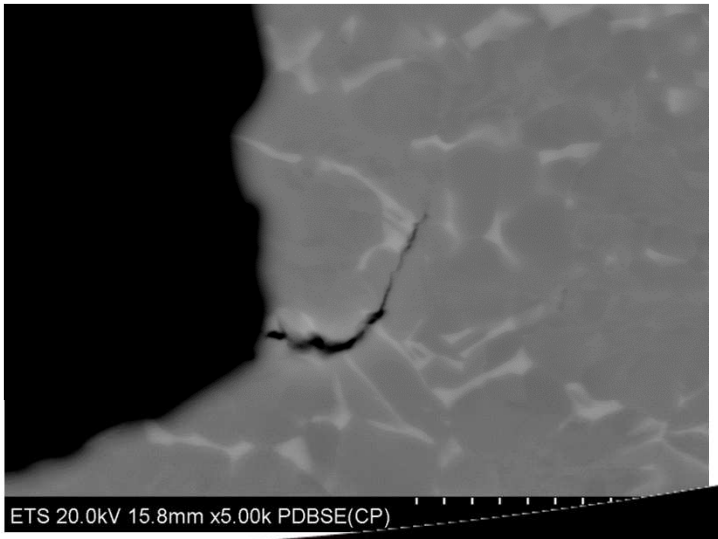


⇒ Cracks tend to propagate within α_p grains in transgranular manner in LSP coupons

⇒ Trans and intergranular propagation modes were observed for LPB coupons

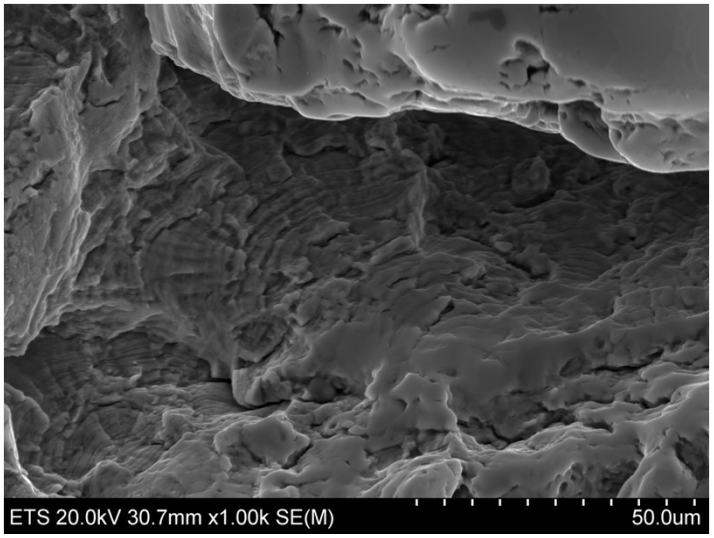
LPB



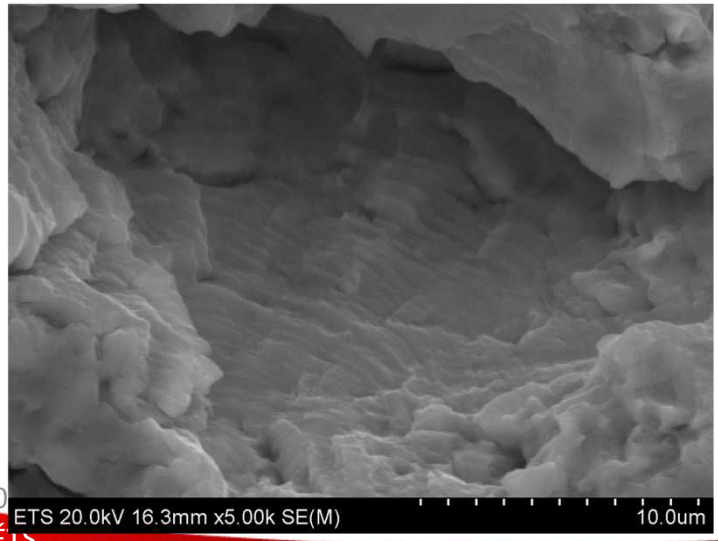


Erosion characterization

LSP



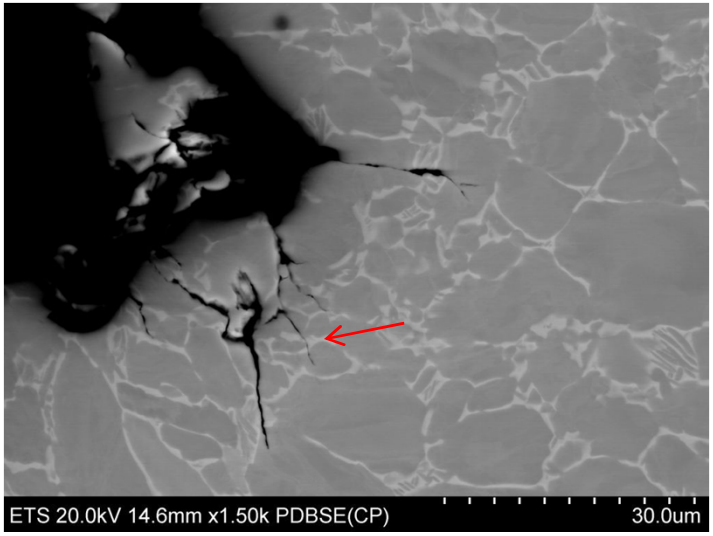
LPB



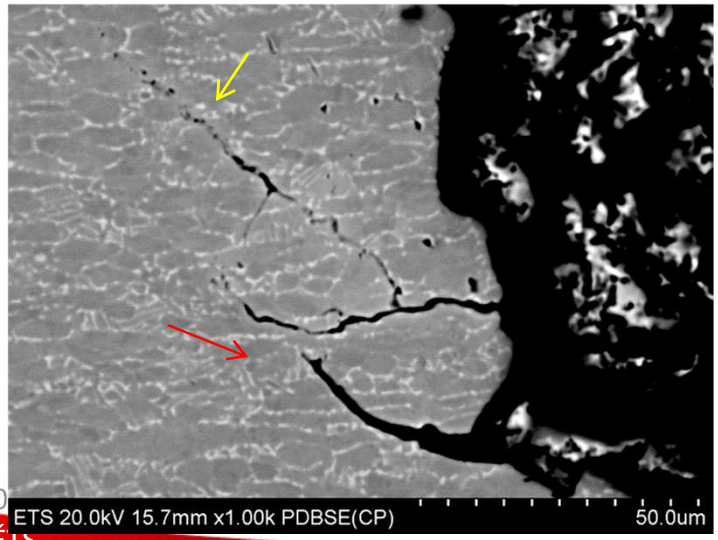
⇒ Presence of striation marks indicate cyclic propagation mode in both LSP and LPB coupons, however number of striations were less in LBP than LSP coupons (needs more investigation)

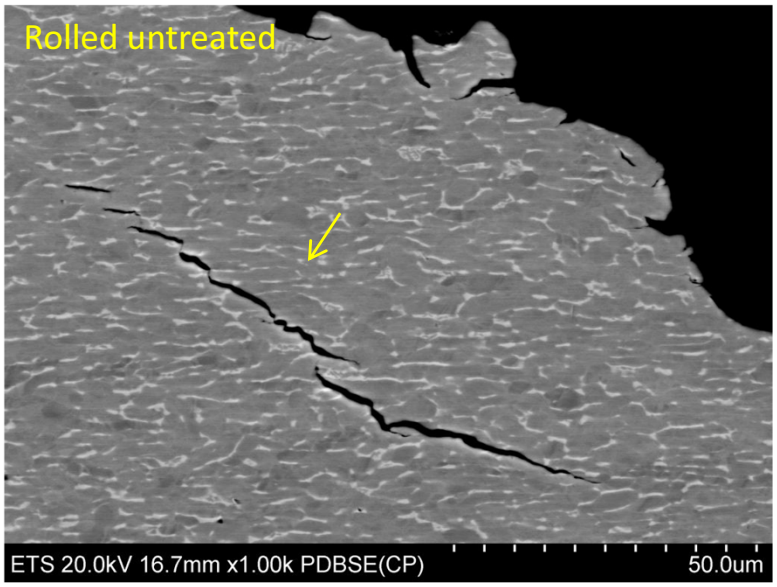
Erosion characterization

LSP



LPB



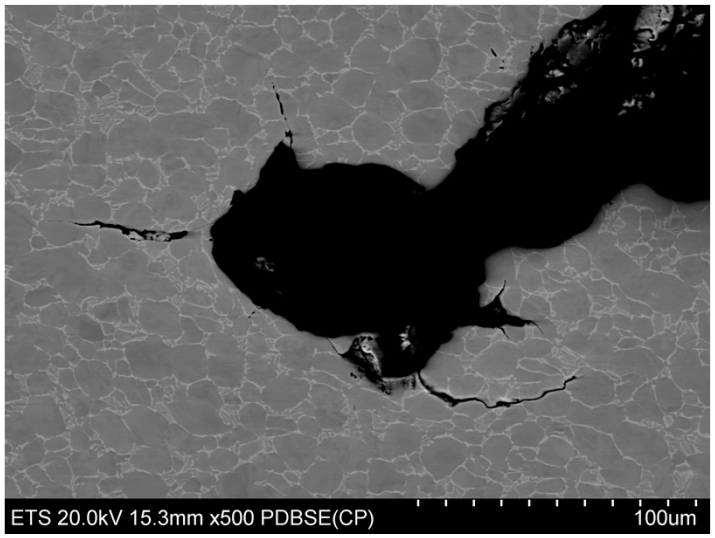


=> Propagation of cracks from the surface and linking of two cracks and results in material chipping off.

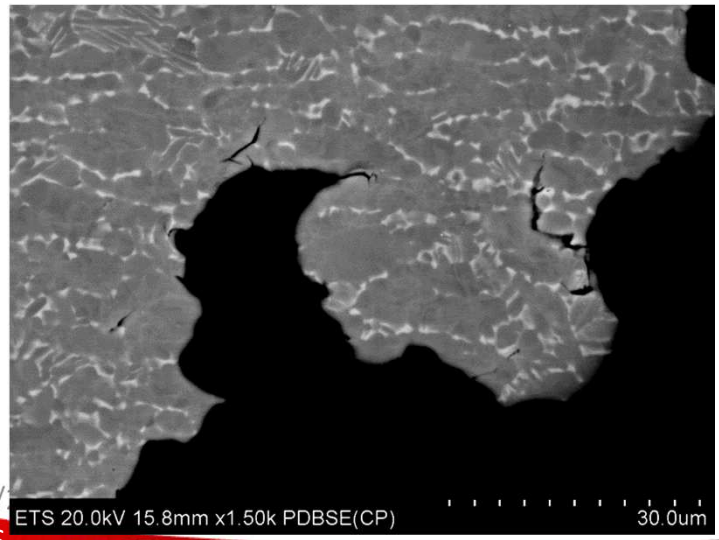
=> Observation of multiple crack nucleation and linkage (as observed in rolled microstructure) in LPB samples; due to the elongated grains in some area of the microstructure

Erosion characterization

LSP



LPB

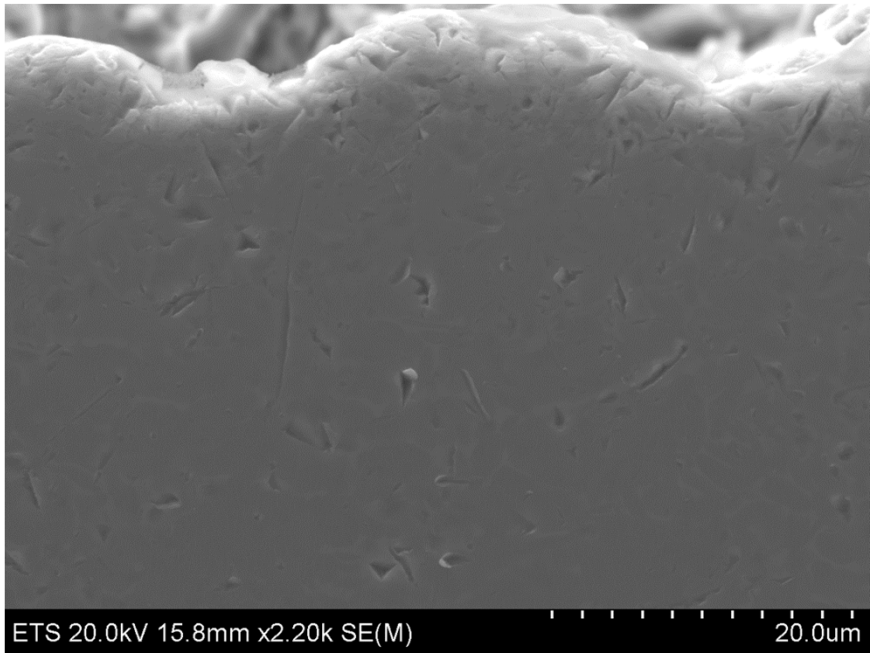


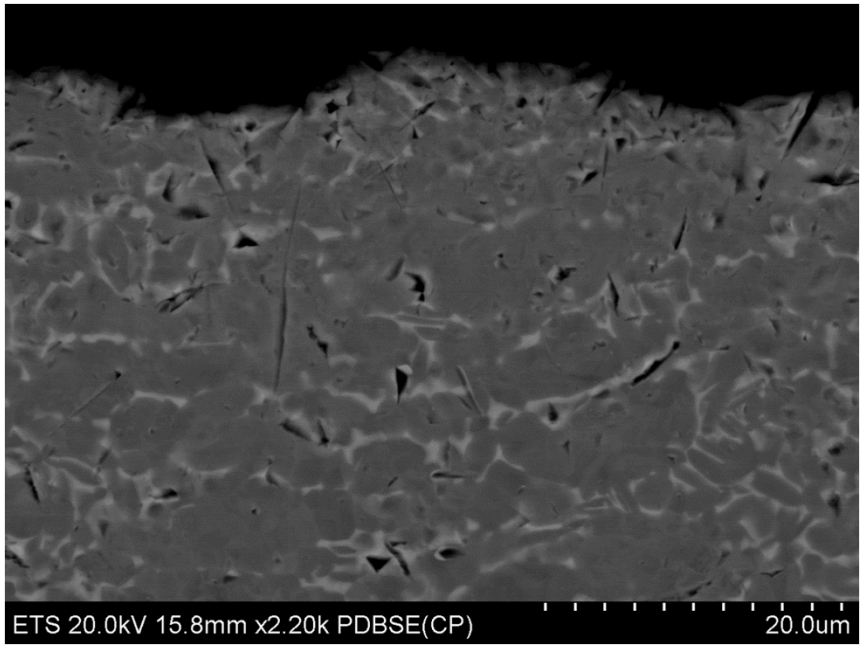
=> Cracks tend to propagate in any directions

=> Sub-tunel formation observed in both LSP and LPB coupons

Erosion characterization

- Some features in LPB coupons

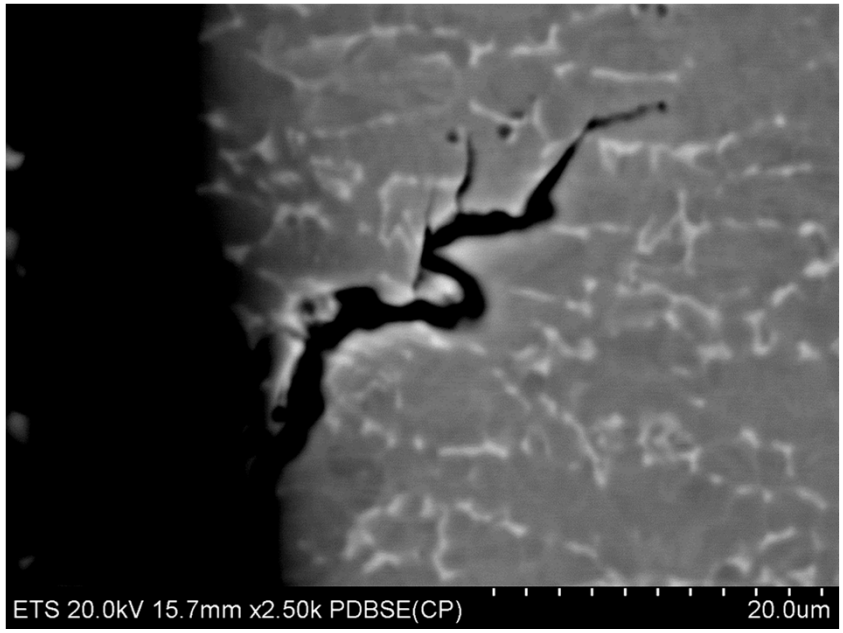


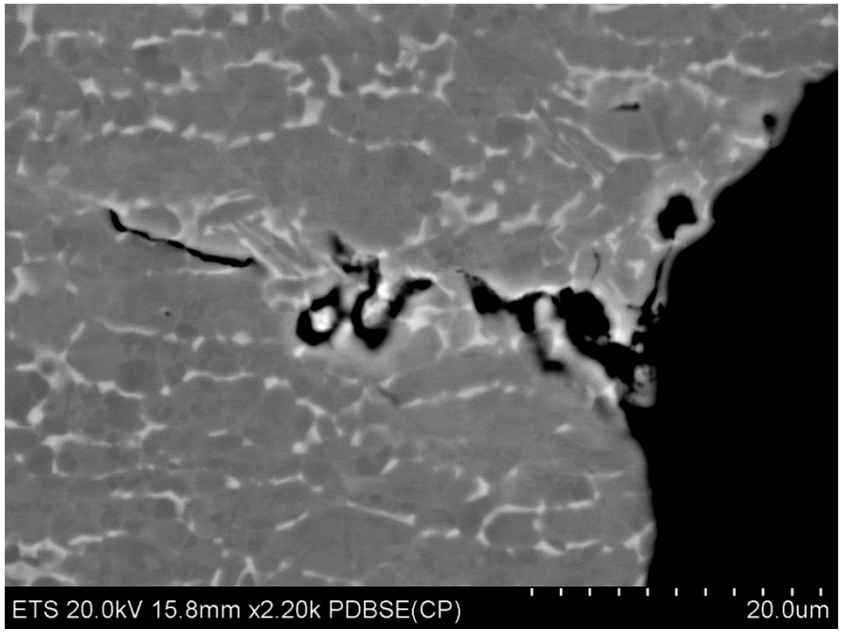


⇒ Presence of areas with many sub-surface cracks (needs more investigations-EBSD maps)

Erosion characterization

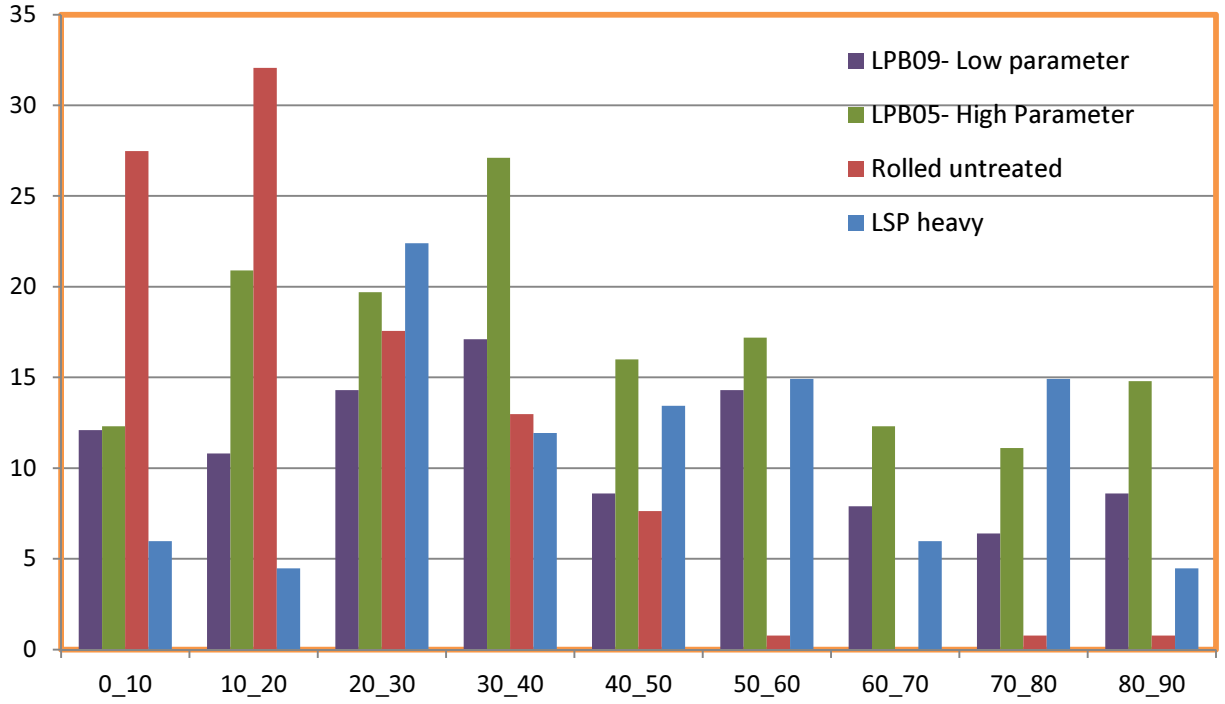
- Some features in LPB coupons





⇒ Cracks change their propagation orientation (due to the crystallographic orientation or they tend to propagate intergranular ? Needs more investigation, EBSD maps)

Cracks studies- Inclination



Untreated Rolled

Angle average: 20˚

Max: 86˚ & Min:0˚

Number of cracks: 131

LSP Heavy

Angle average: 45˚

Max: 88˚ & Min: 0˚

Number of cracks: 67

LBP Low parameter

Angle average: 41˚

Max: 90˚ & Min: 0˚

Number of cracks: 138

LBP High parameter

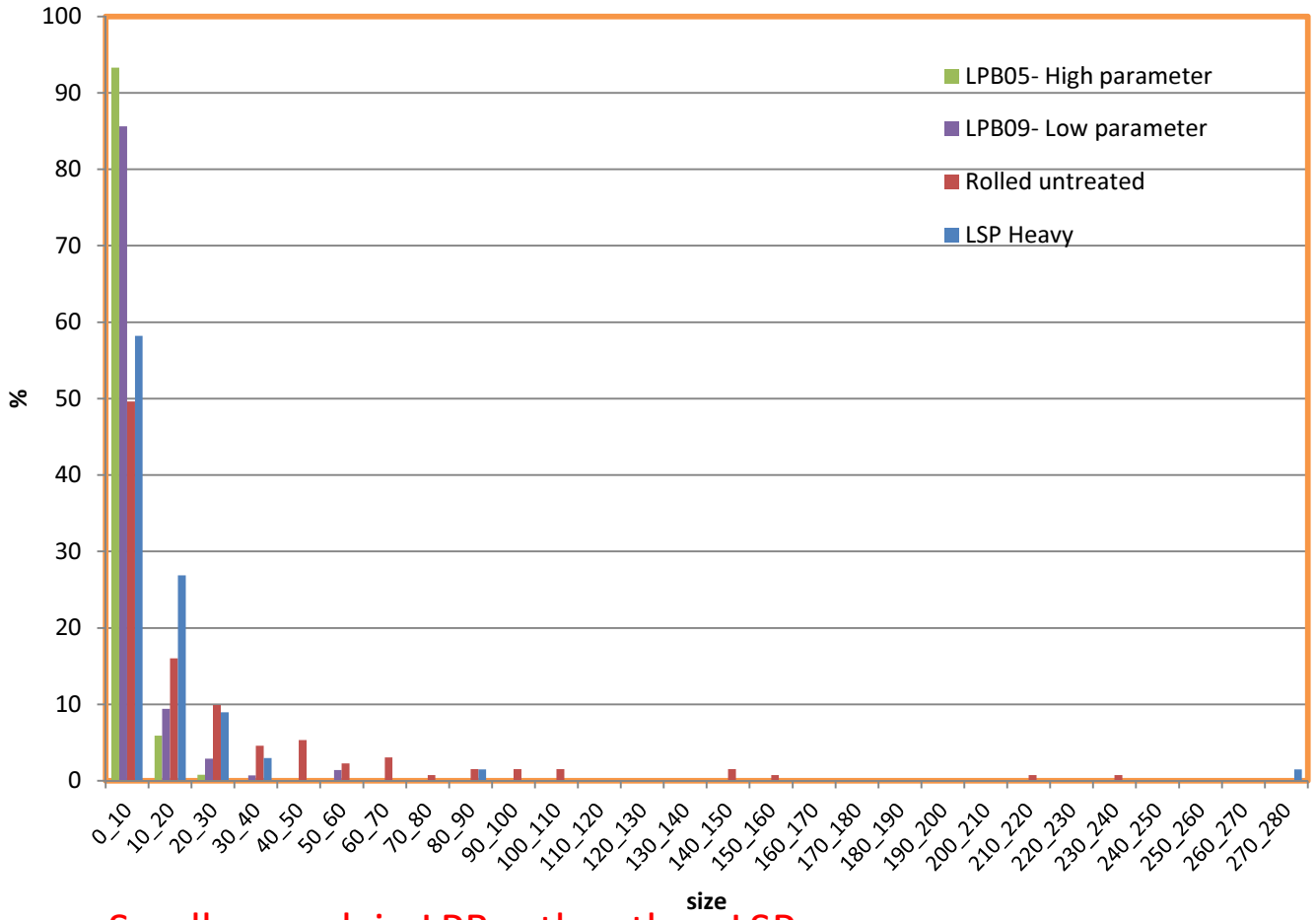
Angle average: 43

Max: 90˚ & Min: 1˚

Number of cracks: 123

⇒ no preferential orientation of cracks for LSP and LPB

Cracks studies-Size



Untreated (Rolled)

Size average: 27µ

Max: 230µ & Min: 1.45µ

Number of cracks: 131

LSP heavy

Size average: 14µ

Max:272.26µ &Min: 1.58µ

Number of cracks: 67

LBP Low parameter

Size average: 6.26µ

Max: 57.49µ & Min: 1µ

Number of cracks: 138

LBP High parameter

Size average:4.06 µ

Max: 23.32µ & Min: 1.06µ

Number of cracks: 123

⇒ Smaller crack in LPB rather than LSP coupons