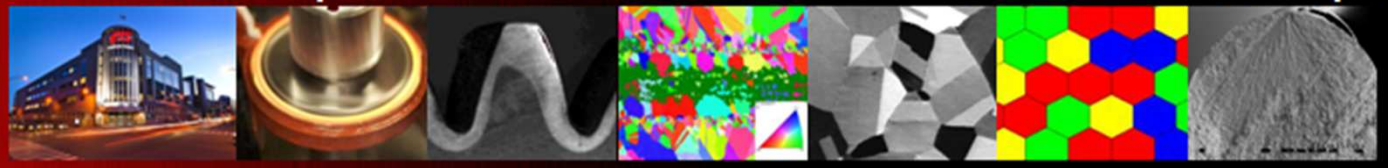
Laboratoire d'Optimisation des Procédés de Fabrication en Aéronautique



ÉTS
Le génie pour l'industrie

Friday, September 27th 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 rolled Ti64

-Flat coupons testing at Concordia

2) Understanding the erosion mechanism of the forged Ti64 focusing on earlier stages

-Bolt coupons testing at Alstom

3) Influence of surface treatments on erosion mechanism of forged Ti64

Content

I – Influence of impingement speed and droplet size on erosion rates of rolled Ti64

- Erosion curves at various conditions
- Erosion features and crater description
- Crack studies

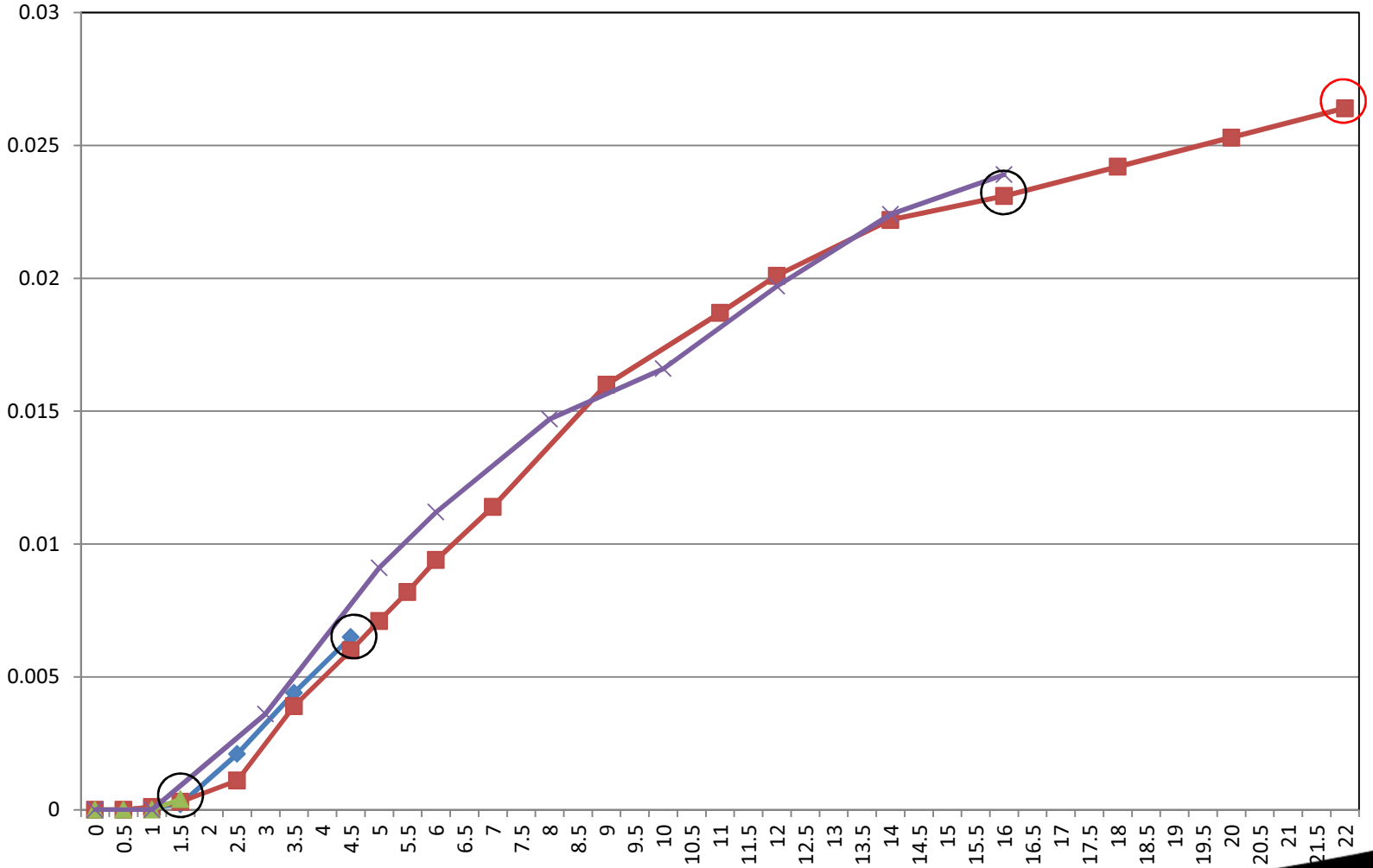
II – Erosion mechanism of the forged Ti64 focusing on earlier stages

- Erosion curves on different stages
- Erosion features and crater description
- Erosion features at earlier stages

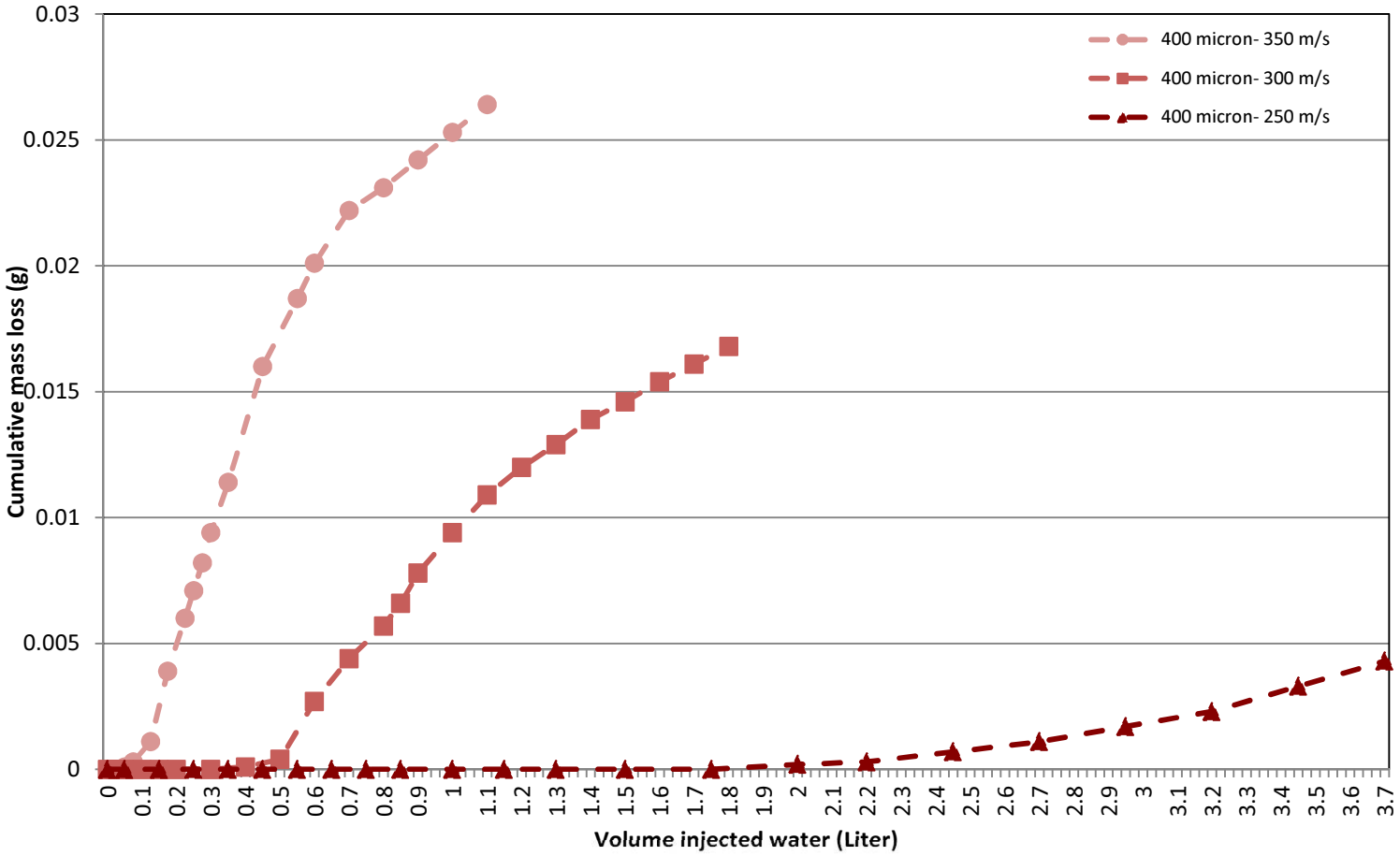
III – Influence of surface treatments on erosion mechanism of forged Ti64

- Sample and test description
- Residual stress measurements

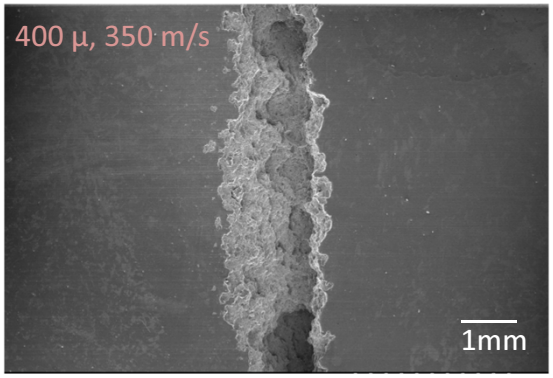
- Erosion test up to different stages of erosion

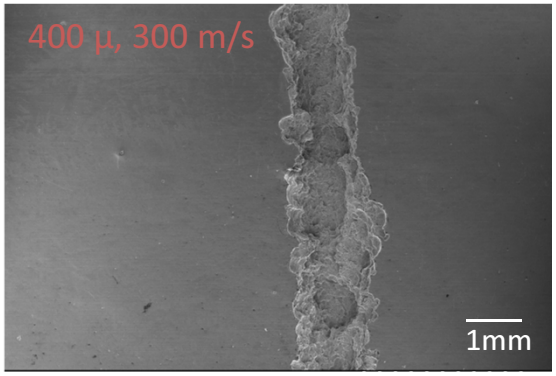


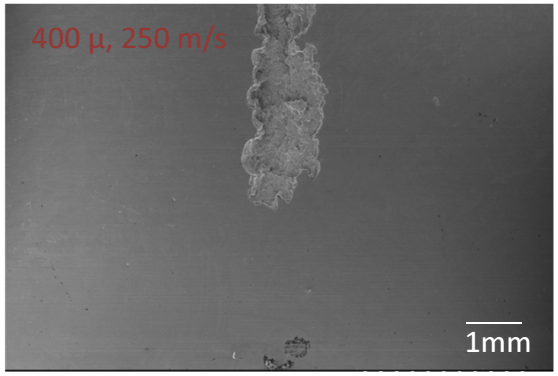
- Erosion curve comparison of various condition



- Erosion features and crater description







- Crater width (mm)

400 µ, 350 m/s	400 µ, 300 m/s	400 µ, 250 m/s
Final stage: 1.70 ± 0.31	Final stage: 1.52 ± 0.32	Final stage: 1.19 ± 0.21
Deceleration: 1.55 ± 0.18	Deceleration: 1.37 ± 0.31	
First steady state: 1.22 ± 0.20	First steady state: 1.01 ± 0.30	
Incubation(few pits): 0.5 ± 0.20	Incubation(few pits): 0.4 ± 0.11	

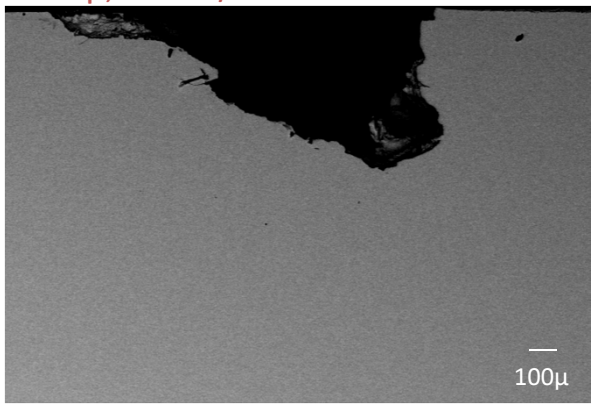
⇒ Crater width are smaller when the speed decreases.

⇒ Crater width follow an increasing trend from incubation to final stage of erosion

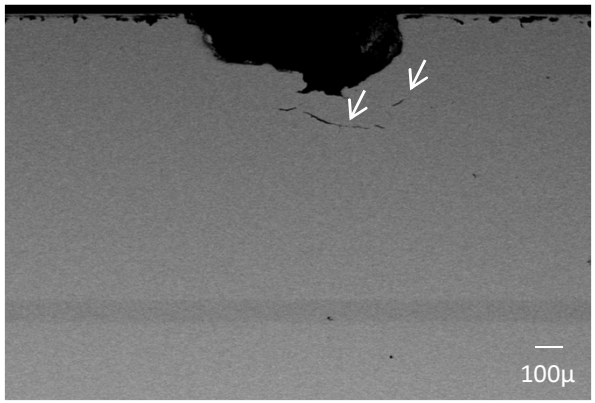
- Erosion features and crater description

400 µ, 350 m/s

400 µ, 300 m/s



400 µ, 250 m/s



⇒ Crater depth are smaller when the speed decreases.

⇒ Crater depth follow an increasing trend from incubation to final stage of erosion

⇒ Observation of sub-surface cracks mainly at initial stages of erosion

- Erosion *features*

⇒ Various features were observed.

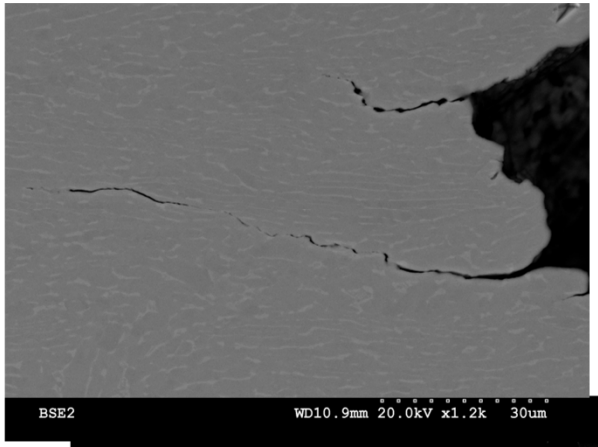
-surface and sub-surface cracks

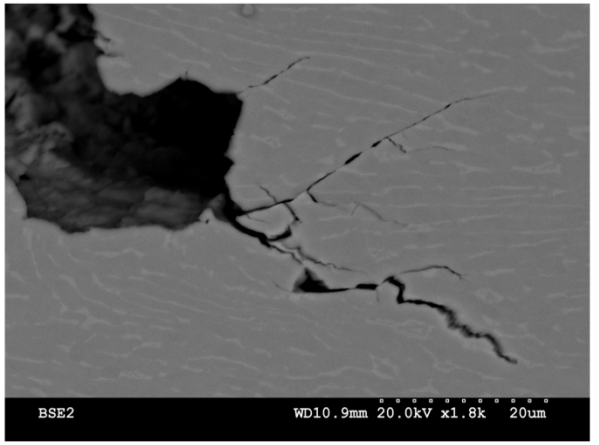
-striation marks

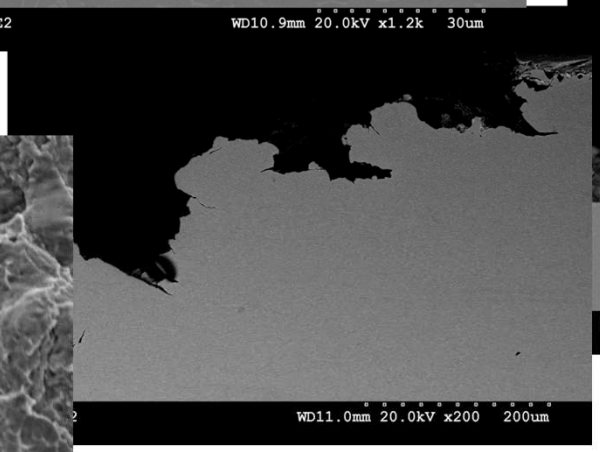
-linking of cracks

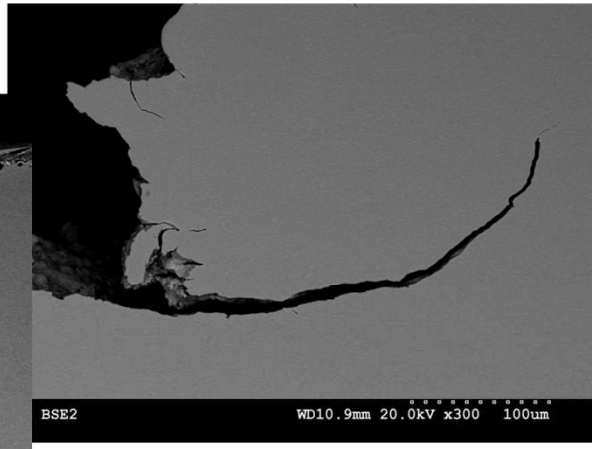
-crack meeting each others leading to material chipping off

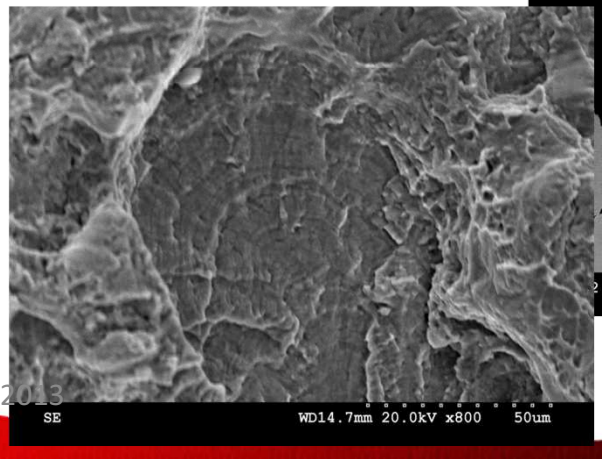
-Sub-tunnel formation









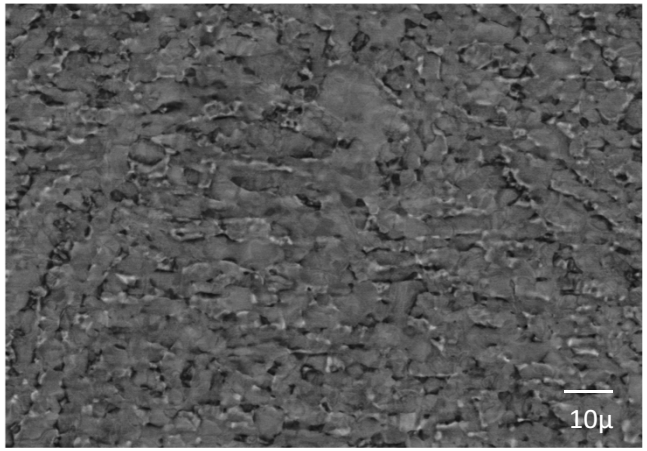


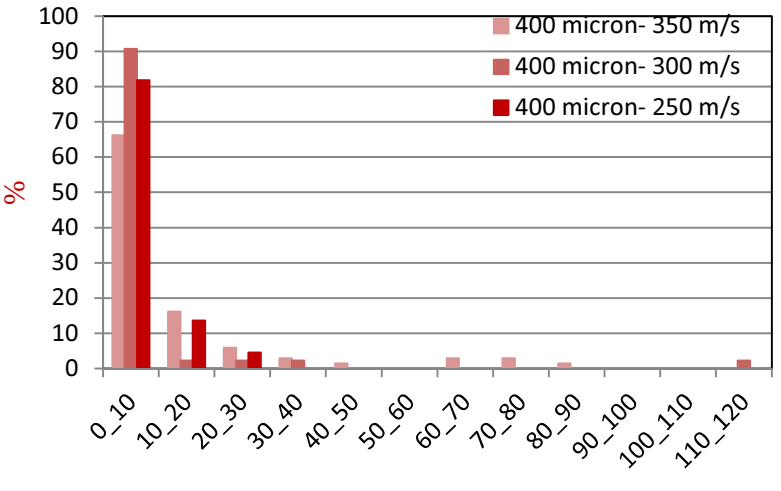
- Crack studies

Crack size and inclination measurements

-speed variation at different stages

-droplet size variation (near future)





Average : 14.03 µ

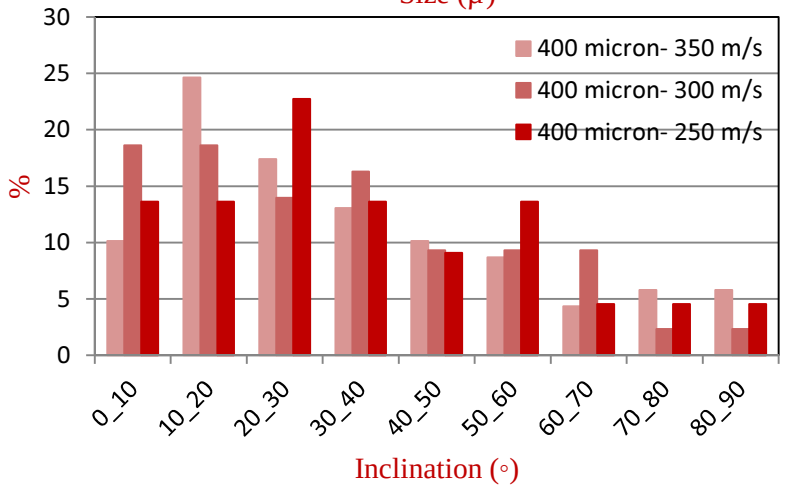
Max: 81.6 µ , Min: 1 µ

Average : 7.85 µ

Max: 116 µ , Min: 1.3 µ

Average : 6.78 µ

Max: 20.83 µ , Min: 1.82 µ



Average : 33.5 ◦

Max: 89 ◦ , Min: 0 ◦

Average : 32.6 ◦

Max: 90 ◦ , Min: 0 ◦

Average : 35.8 ◦

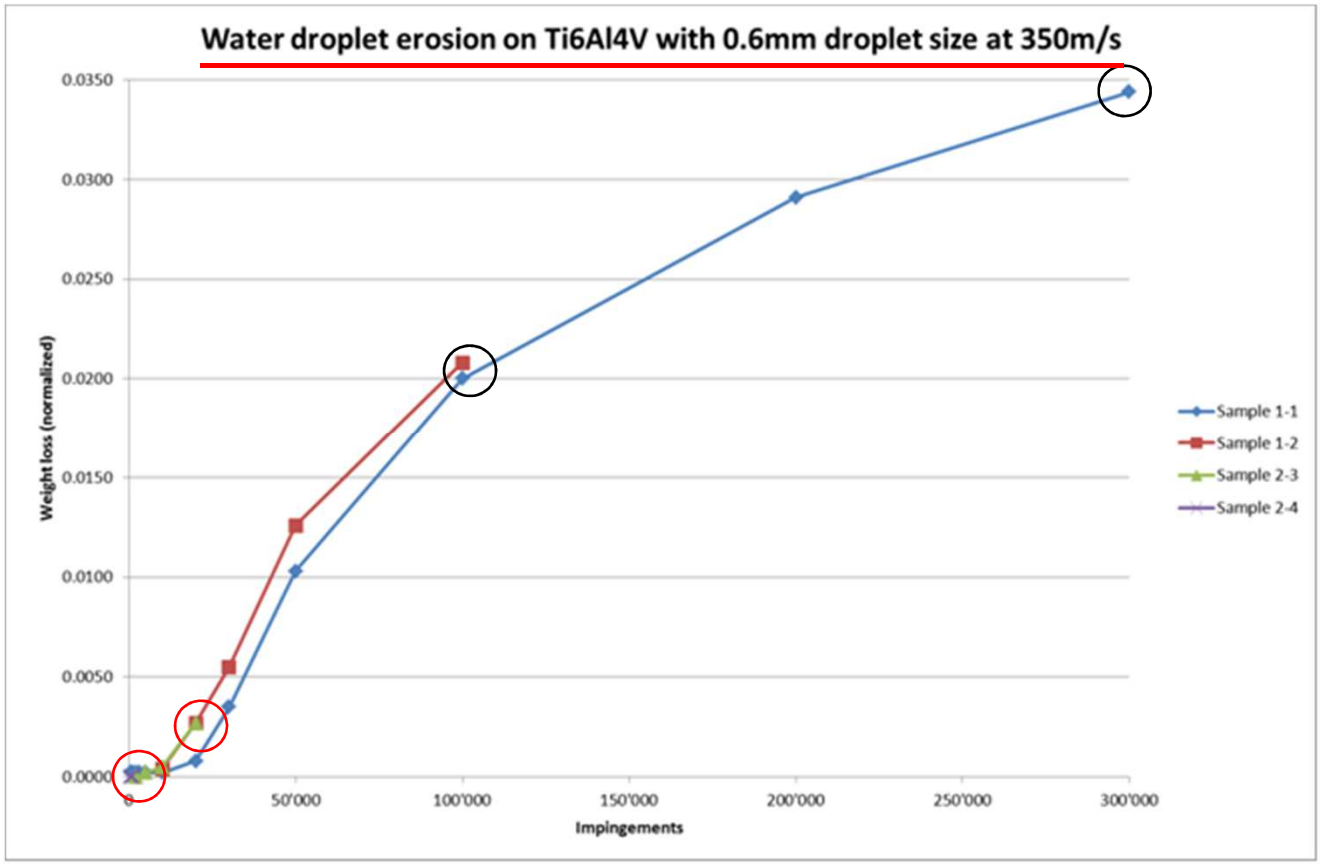
Max: 89 ◦ , Min: 0 ◦

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												

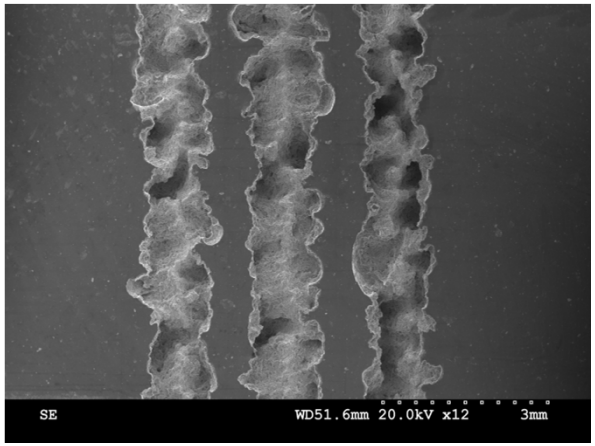
- Erosion test up to different stages of erosion



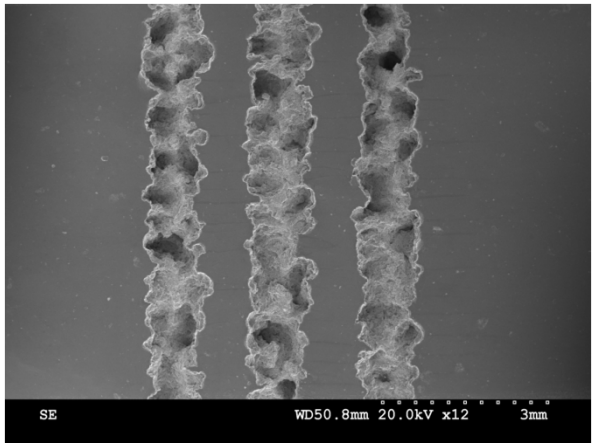
Focus of the study is on earlier stages.

- Erosion features and crater description

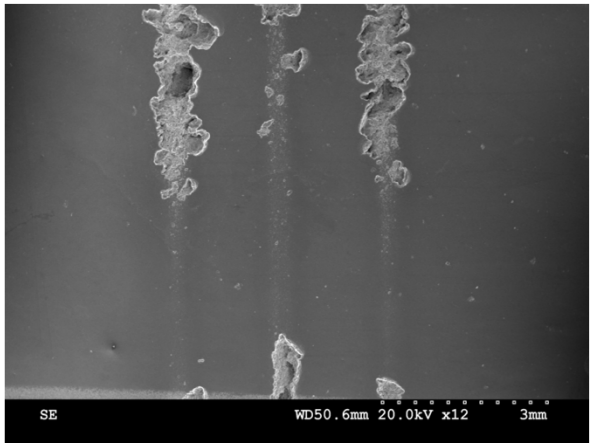
Final stage



Intermediate stage



Material removal onset

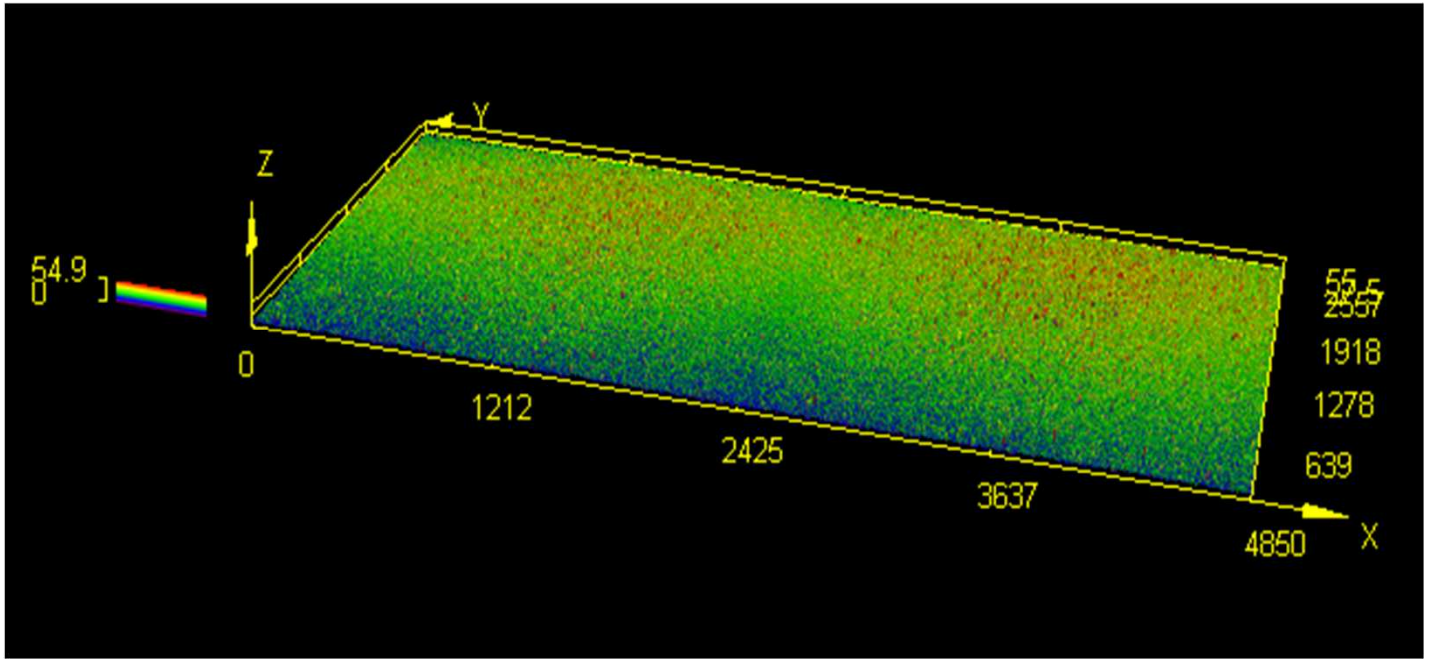


- Crater width (mm)

Final stage	Intermediate stage	Material removal onset
0.739	0.553	0.239

⇒ Increasing trend were observed for crater width, from initial stages to final stage of erosion.

- Erosion features on initial stages of erosion
  - Surface profile



Future work and objectives

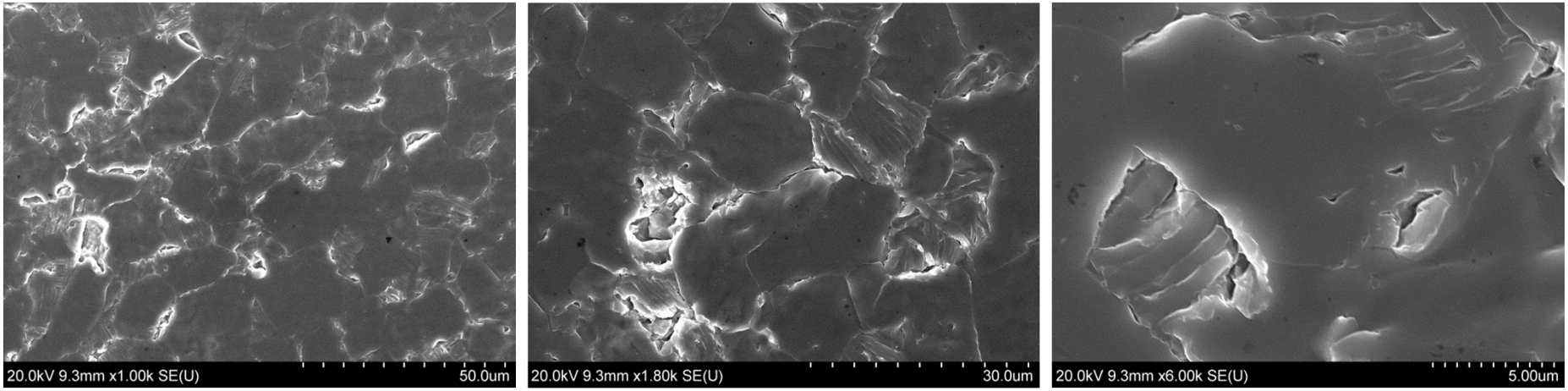
-AFM of the original surface without damage to see the change in surface topography

-Analyzing the possible local plastic deformation

-Grain boundary description and grain tilting

- Erosion features on initial stages of erosion

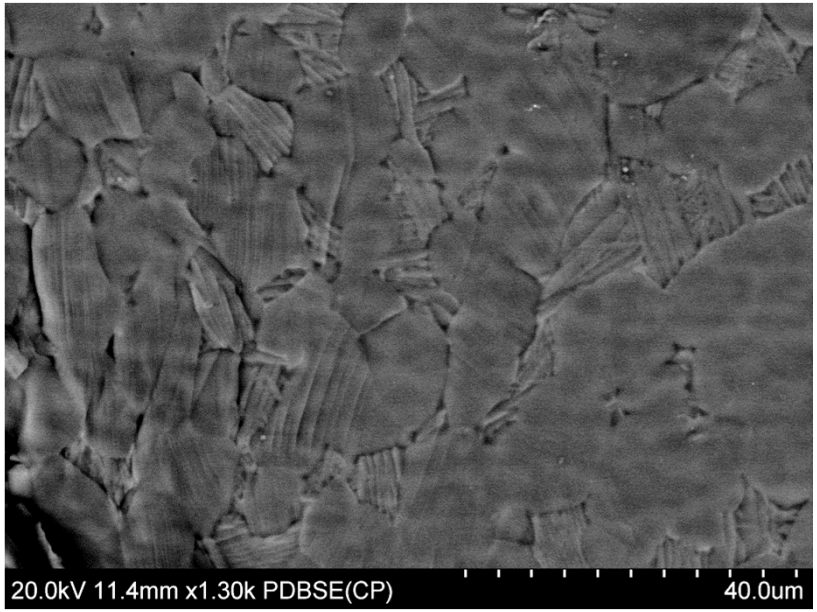
Material removal onset- less eroded zone

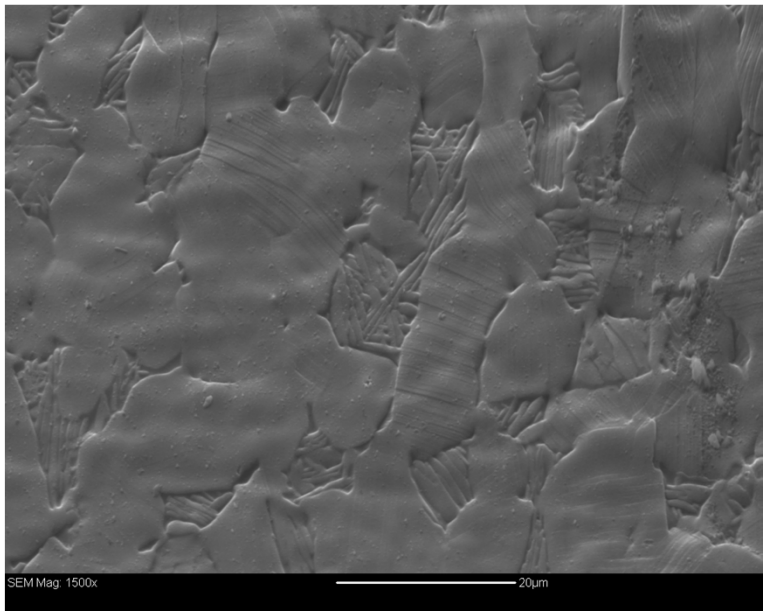


⇒ Observation of particularly inter-granular cracks on erosion surface impacted with few numbers of droplets.

- Erosion features on initial stages of erosion

Material removal onset- crater side zone





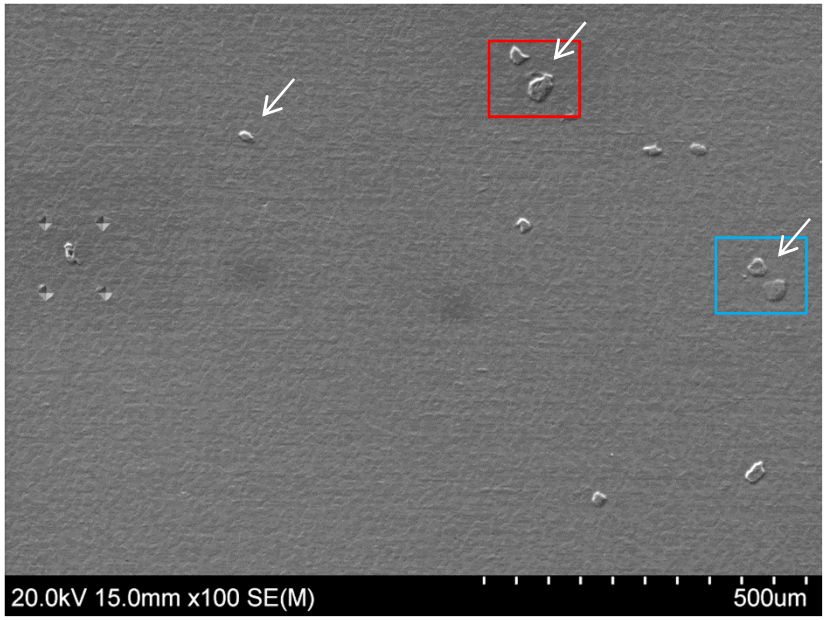
⇒ Observation of slip bands next to the crater

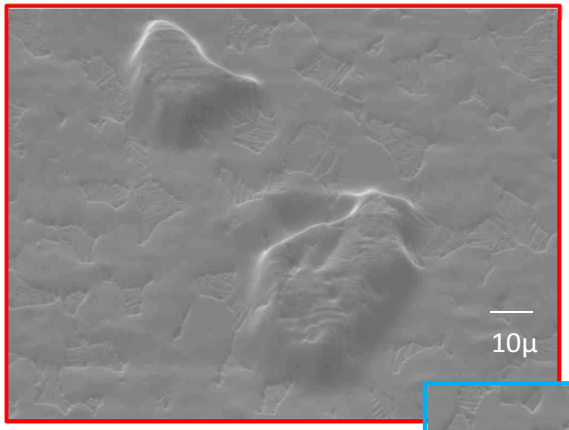
Further investigation:

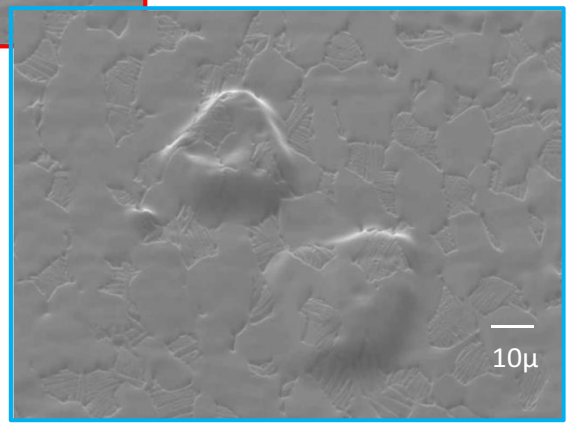
- EBSD analyses of the slip bands directions.

- Erosion features on initial stages of erosion

Incubation stage

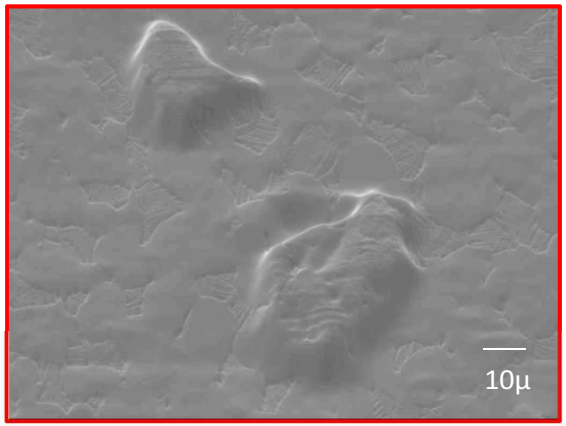


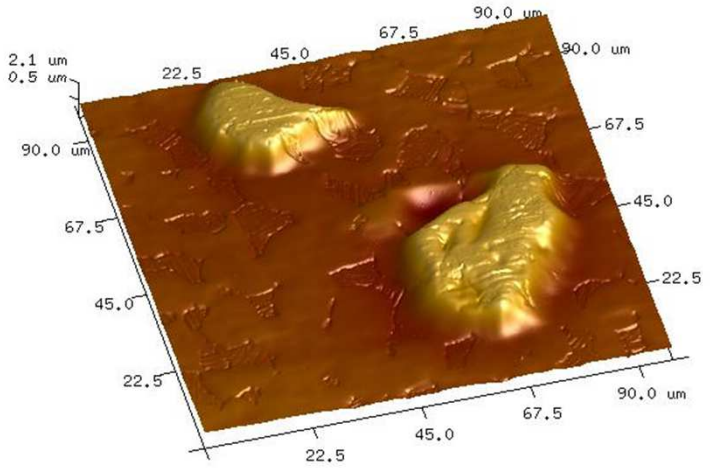


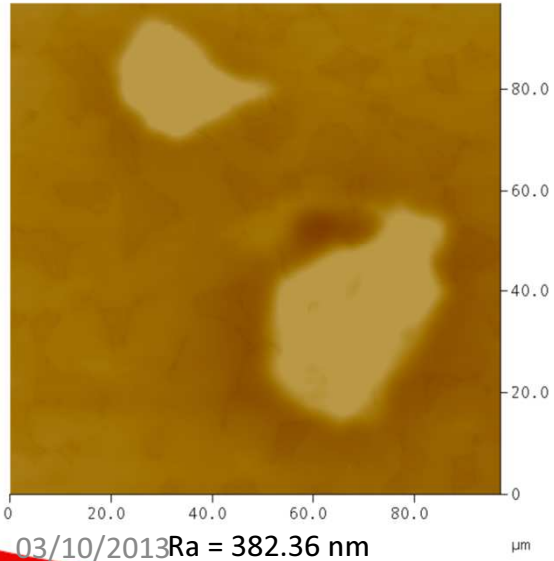


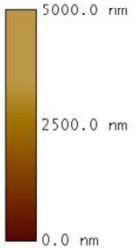
⇒ Observation of bumps on the surface of very initial stage of erosion. These might be due to stress concentration under the surface that causes the bumps on the surface impacted with few number of droplets (further investigation is needed).

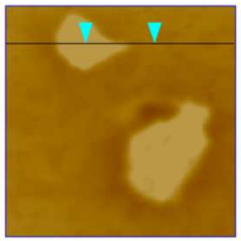
- Erosion features on earlier stages of erosion
  - AFM on bumps

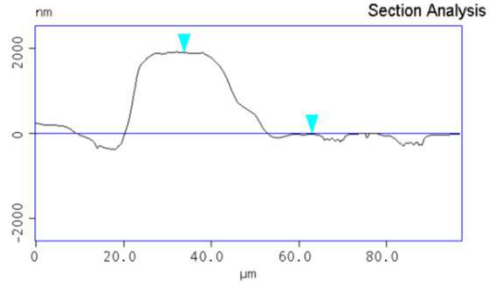


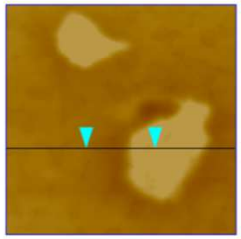


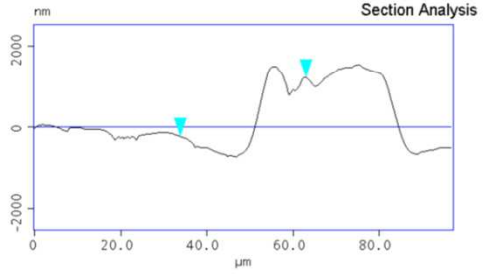






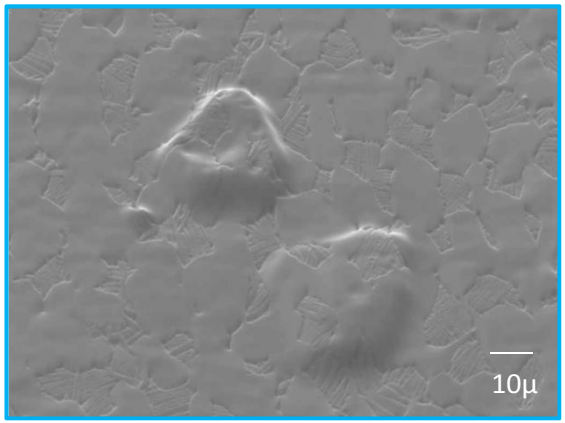


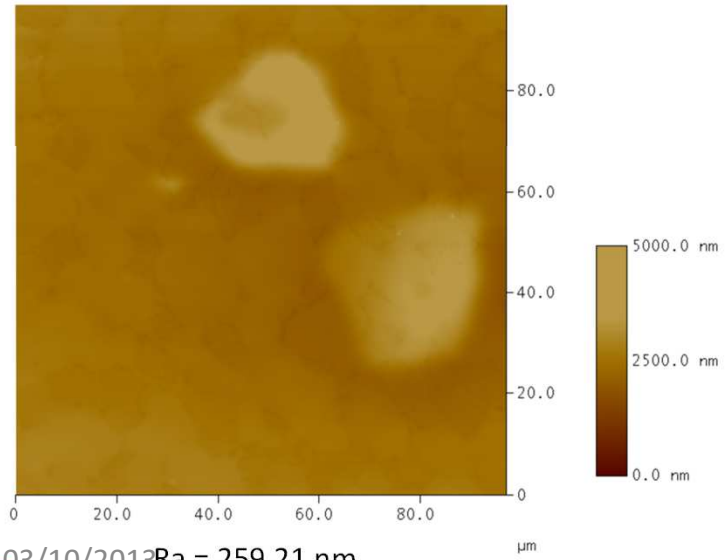


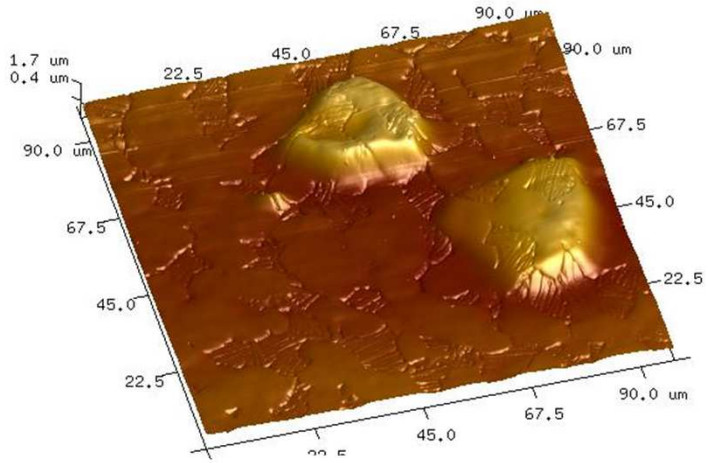


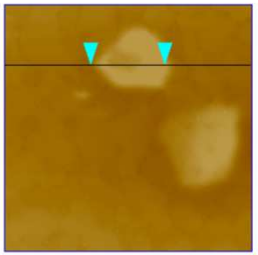
Ra = 382.36 nm

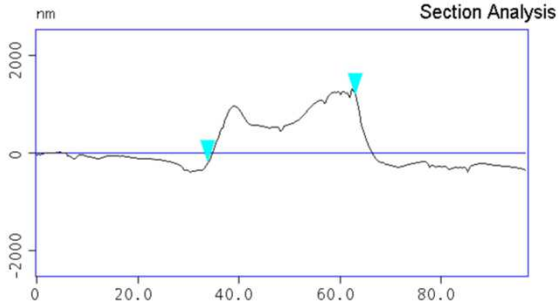
- Erosion features on earlier stages of erosion
  - AFM on bumps

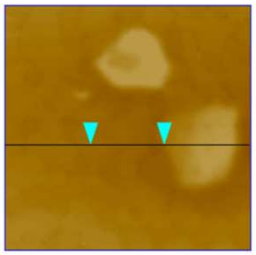


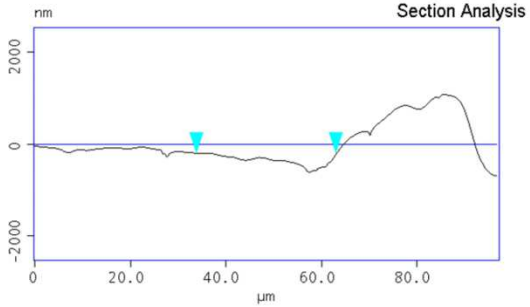








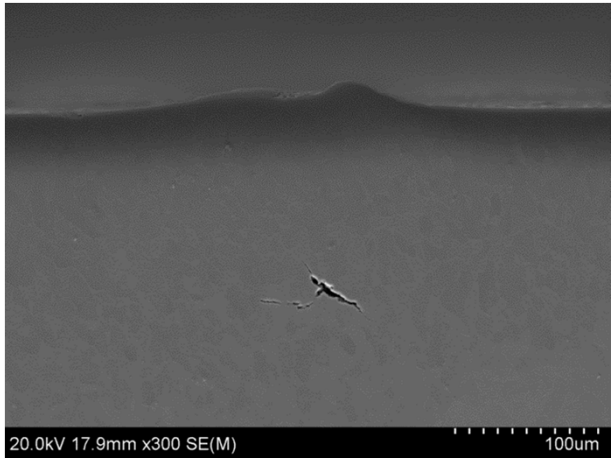


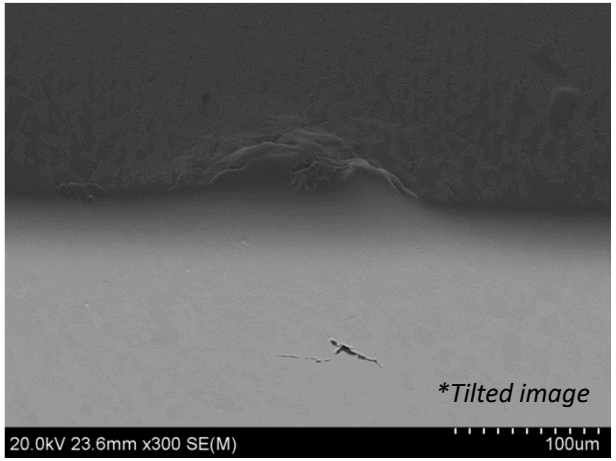


Ra = 259.21 nm

- Erosion features on earlier stages of erosion
  - Bumps from cross sectional view

Methodology: Polishing of the cross section along the erosion line until reaching the bumps on the half





⇒ Observation of the micro-cracks below the bumps

Further investigation:

- Progressive cross-sectional polishing and observation of more bumps underneath
- EBSD analyses on the bumps
- Similar investigation on the rolled coupons and comparing them to the forged on initial stages

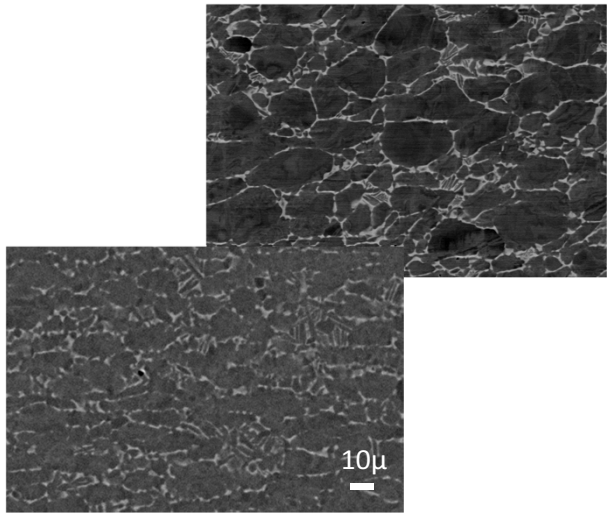
2- Erosion mechanism of the forged Ti64 focusing on the earlier stages

Activity	2013											
	Q1			Q2			Q3			Q4		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forged Ti64 erosion mechanisms												
Analyses of the erosion of the eroded forged coupons with specific focus on initial stages												
sample fabrication												
rig test at initial stages												
sample preparation												
erosion characterization												

- Sample state description

Forged coupons

- LSP
- LPB (not same microstructure as LSP coupons)
- Untreated



<u>Sample manufacturing</u>

Untreated

- Extraction from the blade root and manufacturing ✓

LPB

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

<u>Test</u>

Rig test at Alstom

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

- Analyses and objectives

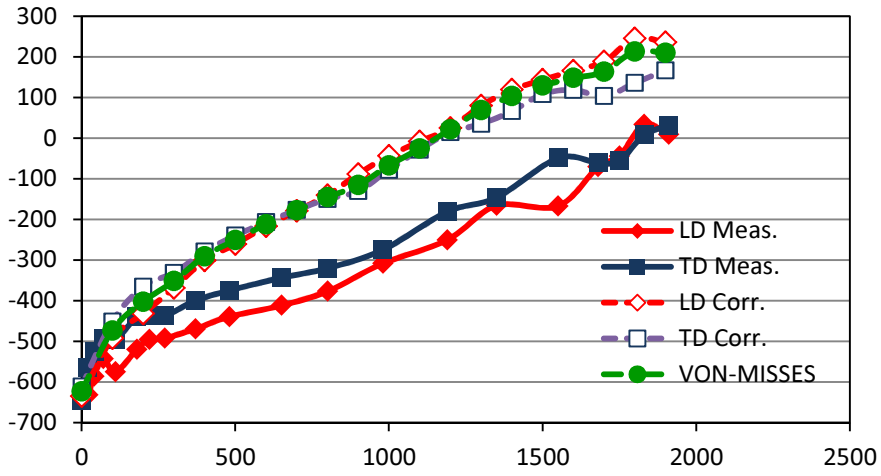
-Analyses of the coupons at final/advance stages of erosion

-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.

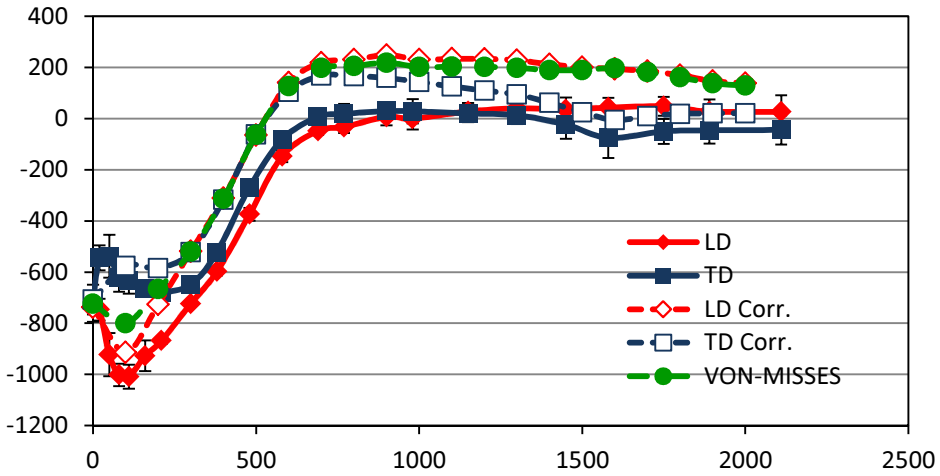
- Residual stress measurement

  - X-ray measurements and electro-polishing
  - Ansys correction

Heavy LSP



Low Parameter LPB



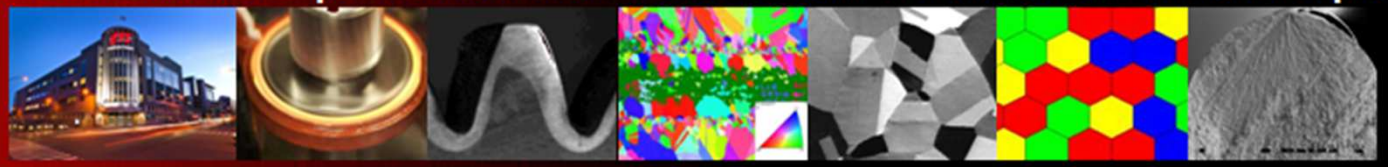
3- Surface treatment influence (beyond the 2013)

Time table

Activity	2013												2014		
	Q1			Q2			Q3			Q4			Q1		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
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															

4- Influence of impingement direction on erosion behavior of rolled Ti64

(not part of the objectives of this project anymore)



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Thank you.

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CRSNG

Rolls-Royce

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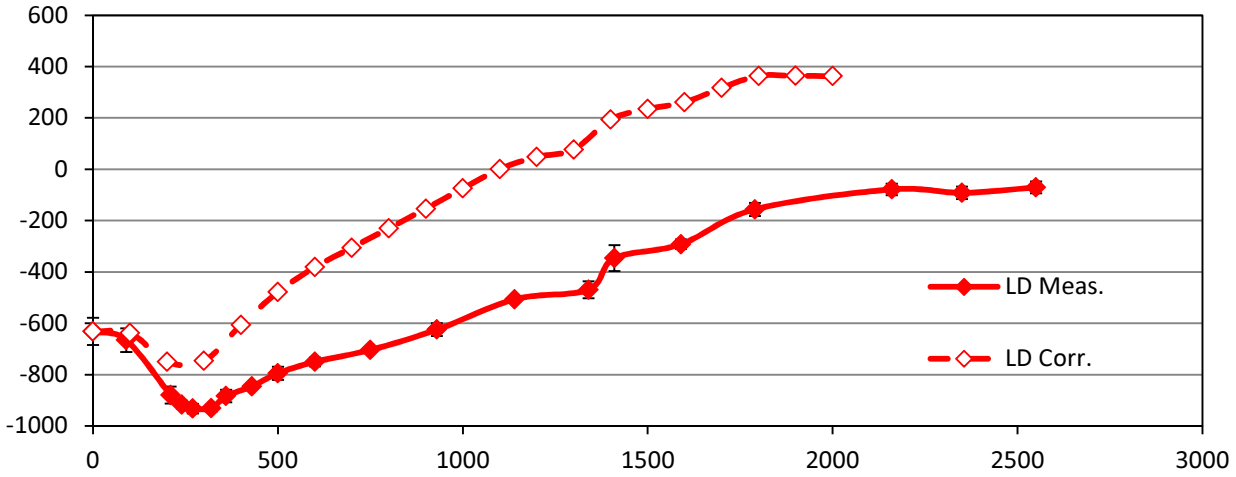
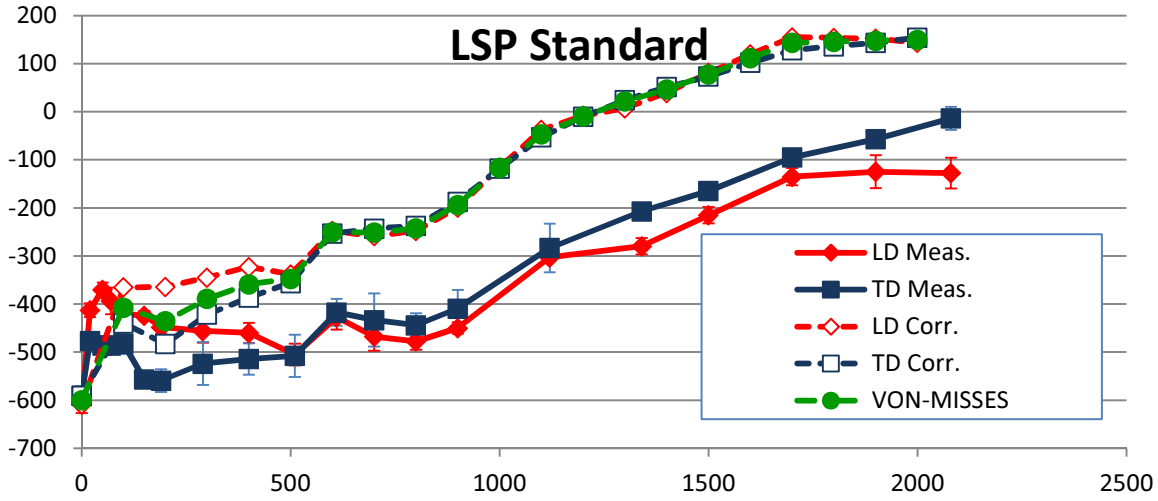
High load parameter LPB





Previous objectives of the works

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												