Abrasion Resistance of 304L and 316L Stainless Steel Subjected to Deep Cryogenic Treatment

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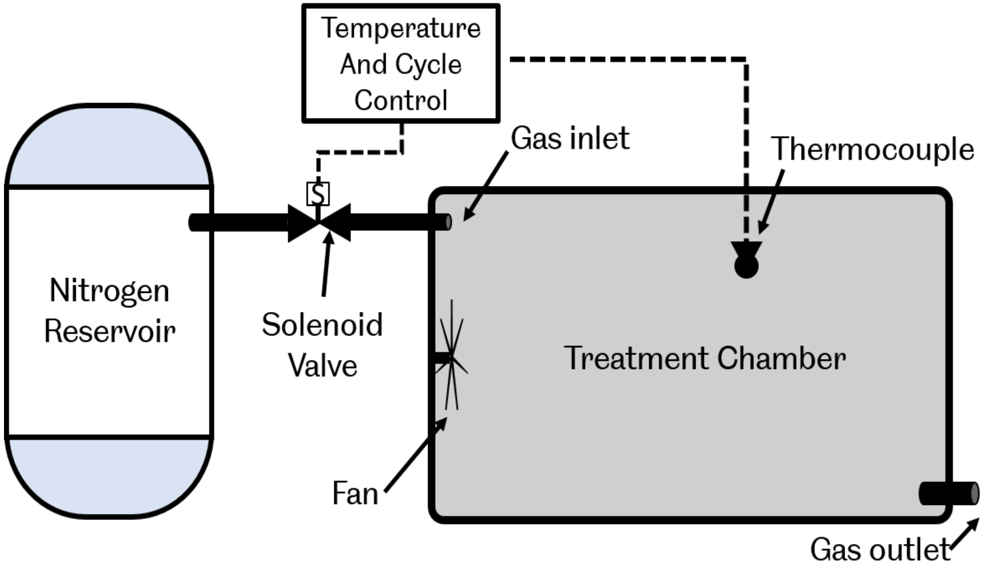
Cryogenic Treatment

- Benefits from temperature below 193 K (-80 °C or -112 °F)
- Used along conventional heat treatment
- Relatively recent - first half of the 20th century



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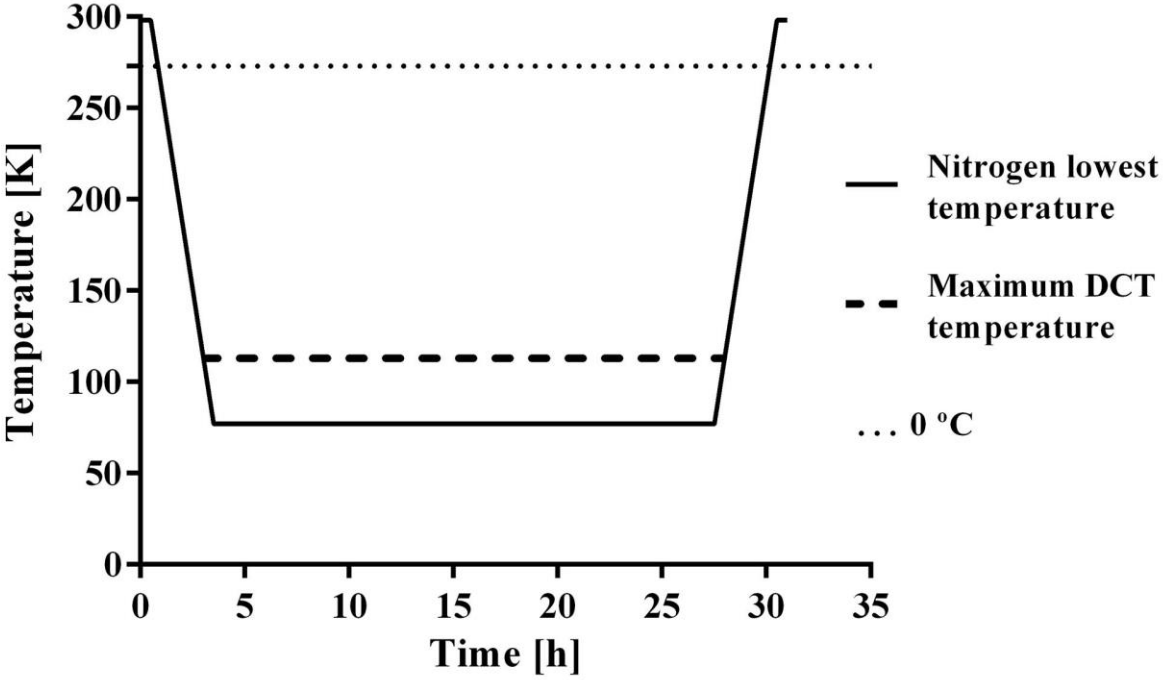
Cryogenic Treatment

- Typical stages: cooling, soaking and heating



Cryogenic Treatment

Reported benefits

- Presents good dimensional stability
- Can improve mechanical properties
- Common changes mechanisms in steel alloys:
  - Transformation of retained austenite in martensite
  - Precipitation and distribution of Nano-carbides
  - Increase in dislocation and twins
- Some industrial use, particularly in tooling
  - E.g. improving abrasive wear resistance with minimal change to finished product

Slatter, T. & Thornton, R. (2016). Cryogenic Treatment of Engineering Materials. Reference Module in Materials Science and Materials Engineering. 10.1016/B978-0-12-803581-8.09165-7.

Cryogenic Treatment

Limitations

- Long processing time (hours) and hardware requirements limiting for some applications
- Some of ‘classic’ literature is lacking in explanation for observed reported results
- Industrial interest in process means that bulk of research is on tool steels

Slatter, T. & Thornton, R. (2016). Cryogenic Treatment of Engineering Materials. Reference Module in Materials Science and Materials Engineering. 10.1016/B978-0-12-803581-8.09165-7.

Abrasive wear

- Wear is a life limiting factor
- Most common cause of mechanical failure
- 50% of all wear in industry is due to abrasive wear
- Complex mechanism
- High influence of environmental parameters

Eyre ,T.S. Wear characteristics of metals. Tribol Int. 1976;9(5):203–12.

Abrasive wear testing

- Specific test rigs for each application
- Comparable tests
- Dry-sand/Rubber-wheel abrasive test:
  - ASTM G65
  - Commonly used in industry
  - Ease of use
  - Low-stress three-body abrasion test
- Some limitations e.g. designated sand and wheels difficult to obtain

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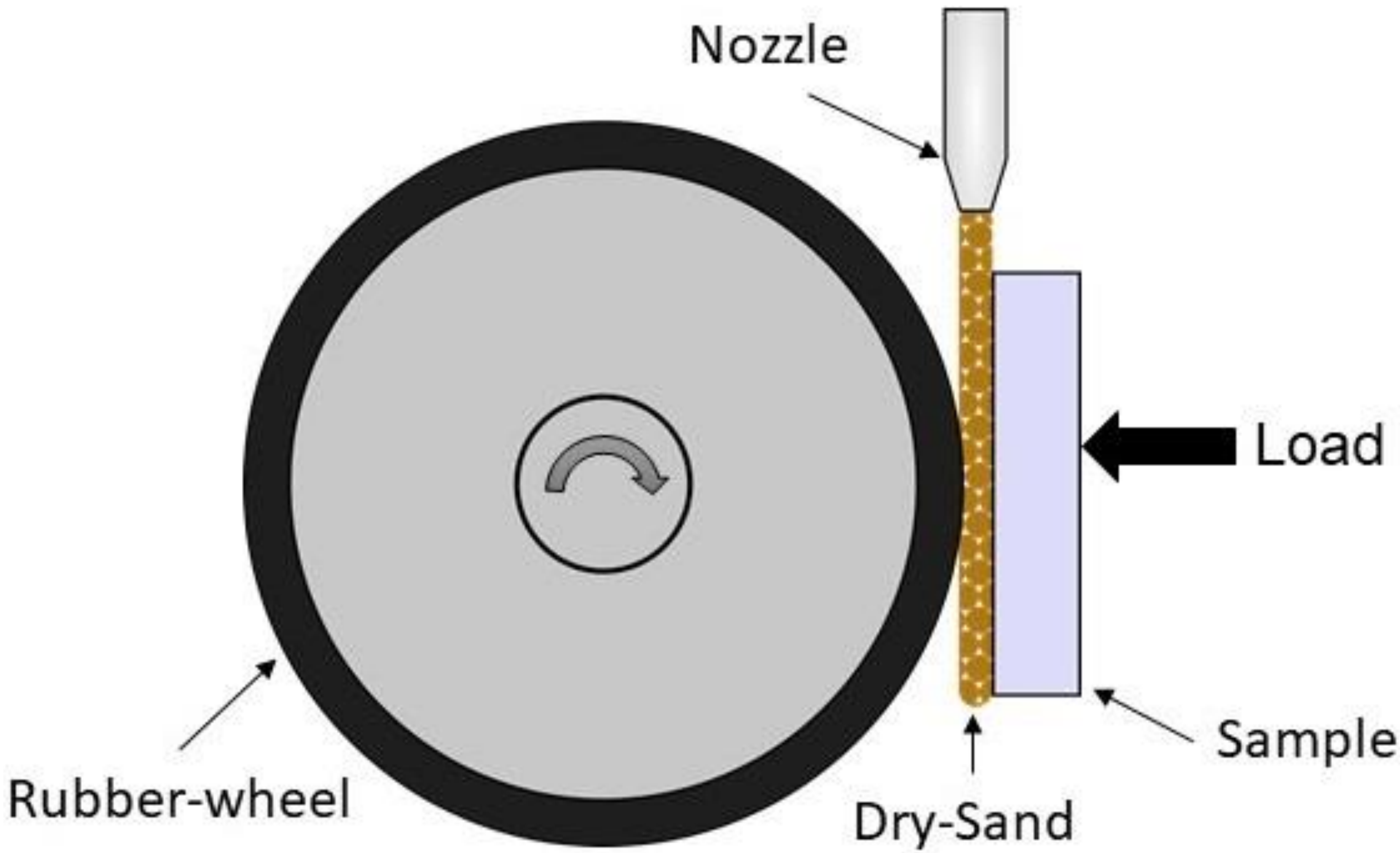
ASTM-G65



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Aim of this research

- To analyse the effect of the deep cryogenic treatment on alloys used in engineering applications.

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Objectives

1. Investigate the effect of the commercial cryogenic treatment on the mechanical performance (Vickers hardness, abrasive wear resistance, microstructural change) of industrially relevant steel alloys
2. Investigate the effect of a cryogenic treatment with modified parameters (time, temperature) on selected samples
3. Propose an optimise cryogenic treatment process for the studied alloys

Material

- Austenitic Stainless Steel:
  - AISI 304L
  - AISI 316L
- Heat Treatment:
  - Subjected to a stress relieving heat treatment at 1228 K (955 °C or 1750°F) for 30 minutes, air cooled to room temperature
- Deep cryogenic treatment (DCT):
  - 93 K (-180 °C or -292 °F) for a period of 14 hours, with cooling and heating rate of ~2 K/min (2 °C/min or 3.6 °F/min)

Component	304L Wt.%	316L Wt.%
C	0.03	0.03
Cr	18 - 20	16 - 18
Mn	2	2
Ni	08 - 12	10 - 14
P	0.045	0.045
S	0.03	0.03
Si	1	0.75
Mo		2 - 3

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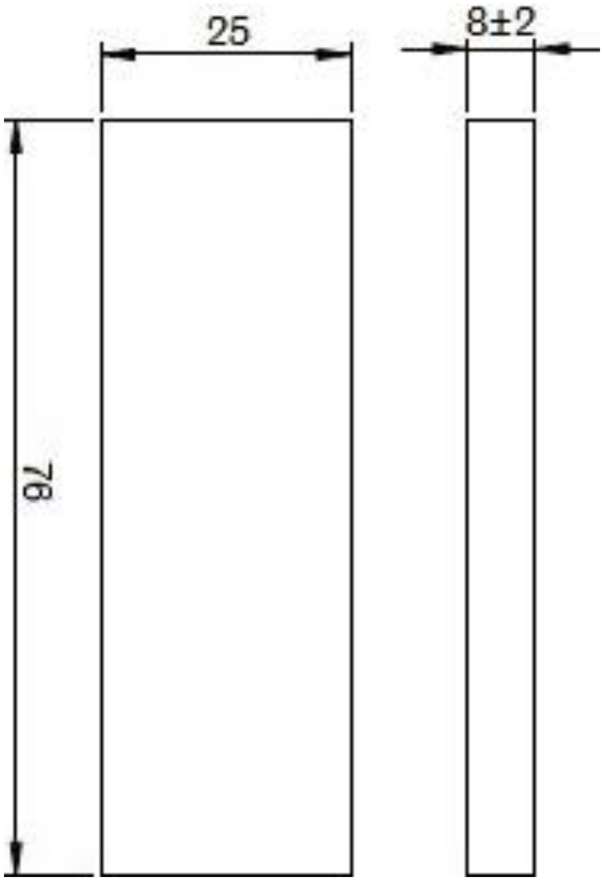
Samples

- ASTM G65 samples:
  1. Samples from commercial alloy
  2. Heat treatment
  3. Final polish

- Tests:
  1. Surface characterization
  2. Abrasive wear test
  3. Advanced microscopy
  4. Metallography



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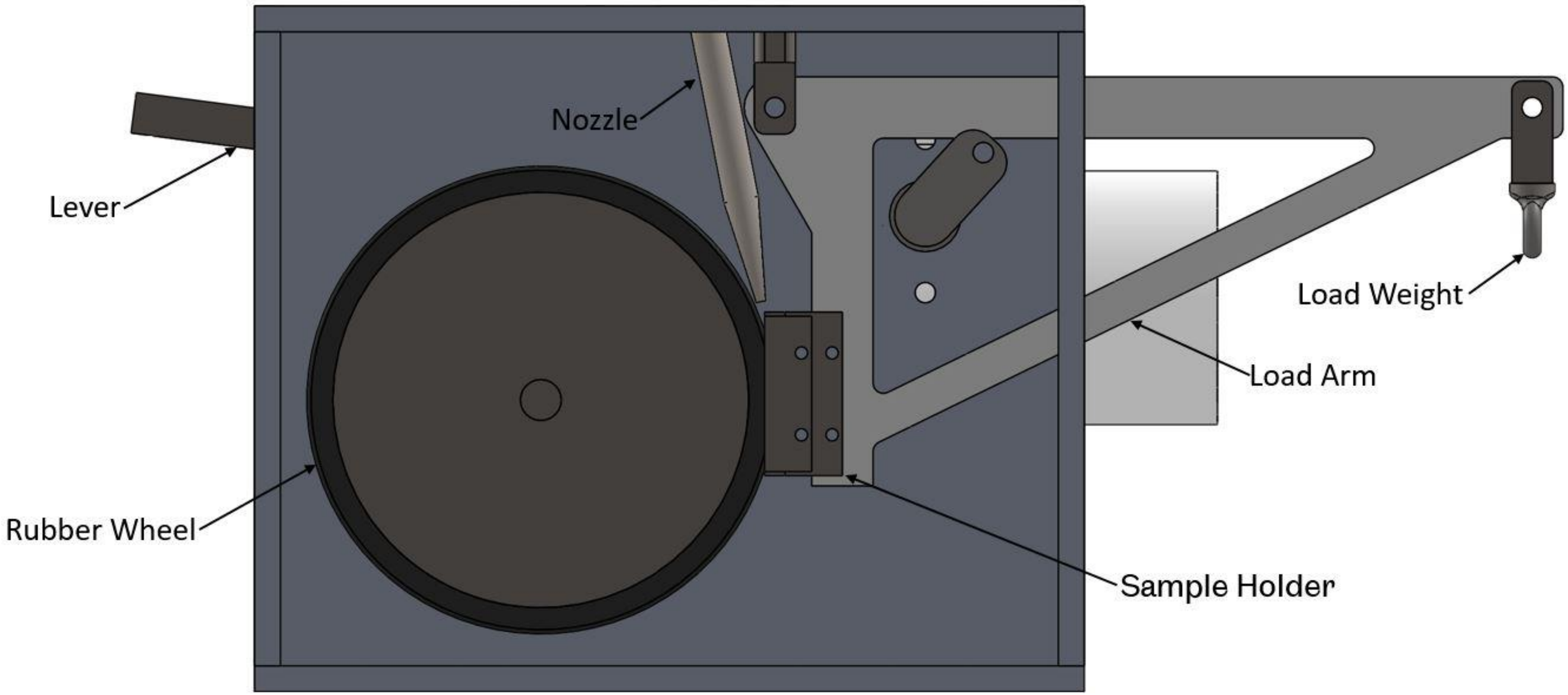
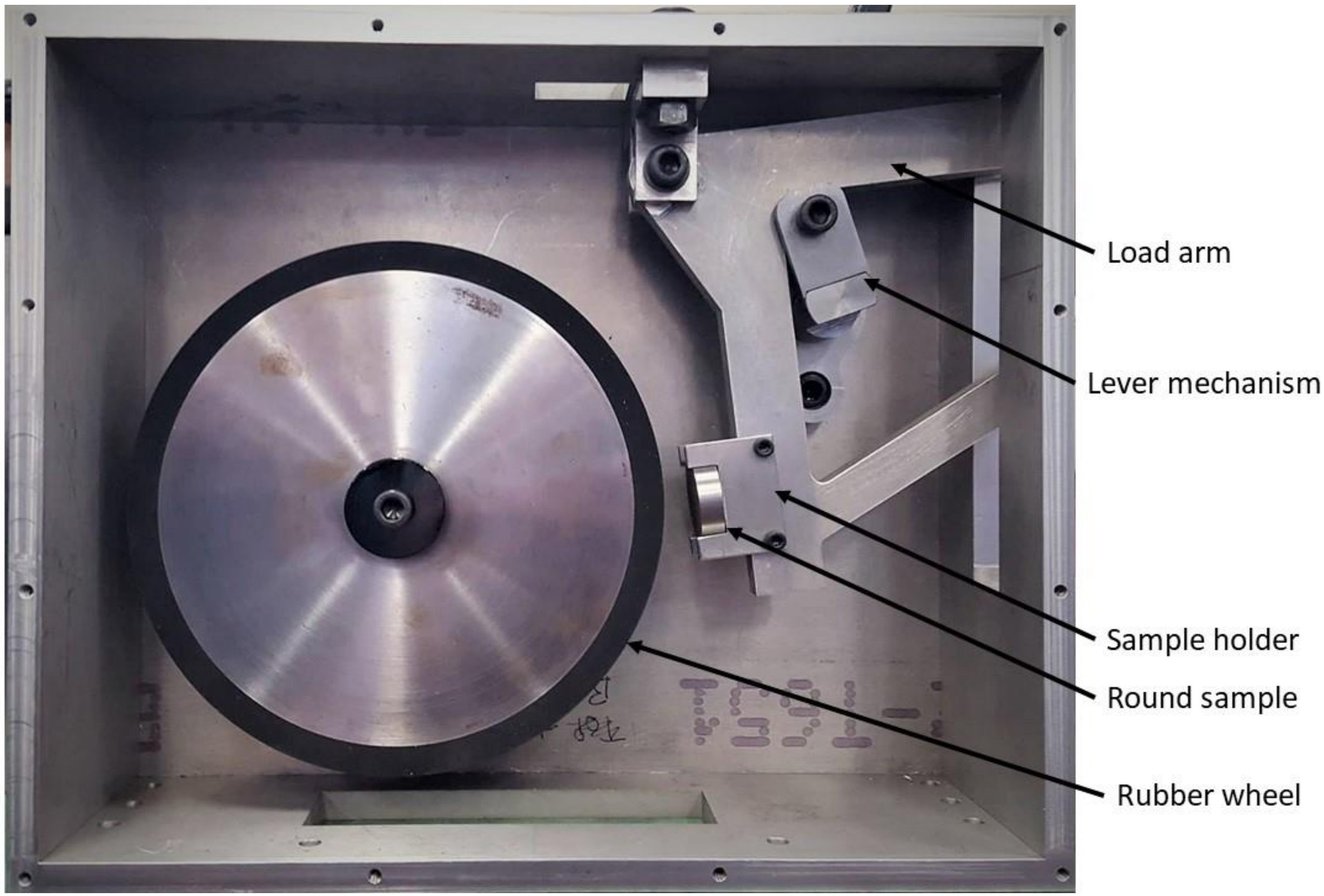
Dry-Sand/Rubber-Wheel



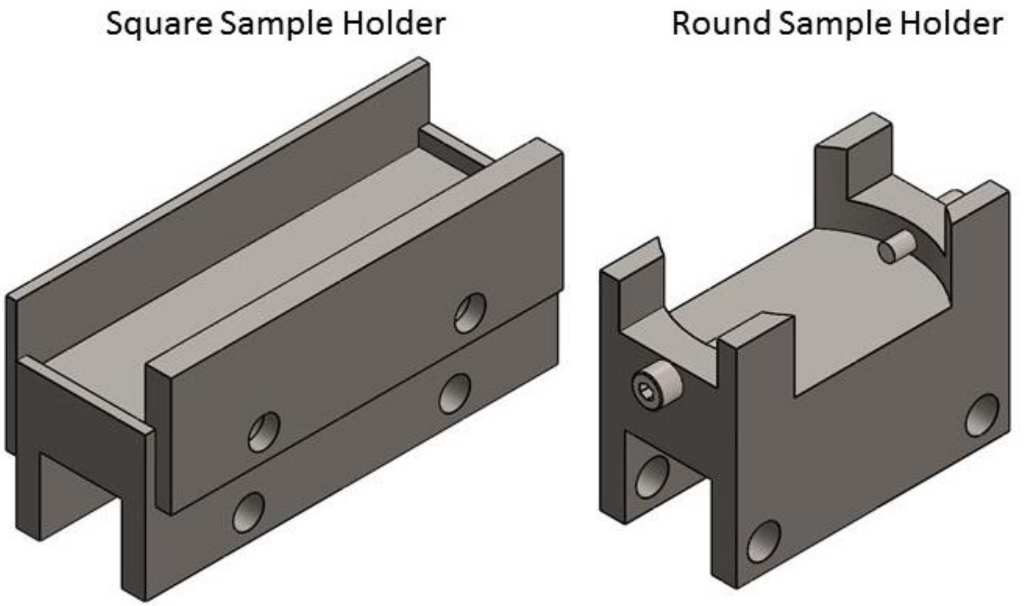
DSRW Test Rig



DSRW Test Rig

- ASTM G65 standard dimensions
- Designed for a smaller form factor
- Possibility of using

  non-standard samples
- Customizable test parameters



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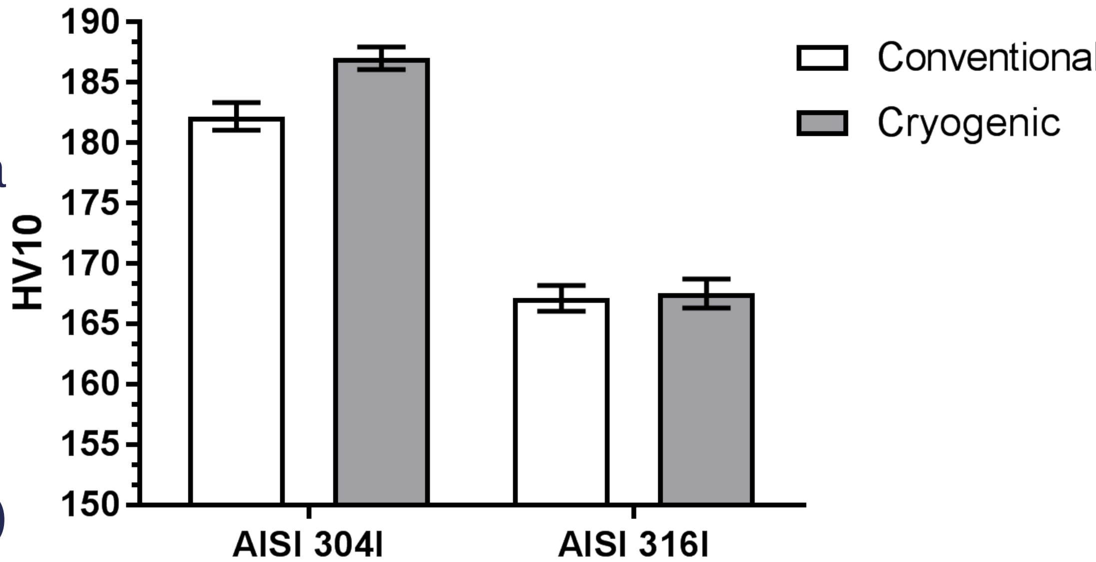
Results - Hardness

- Repeated 30 times for each condition
- Standard error < 1%
- AISI 316L did not present a difference
- AISI 304L Cryogenically treated presented a hardness 1.4% higher (Confidence interval >99%)



Material	Conventional Heat Treatment [HV]	Cryogenic Treatment [HV]
AISI 304L	182.19 ± 1.15	187.00 ± 0.93
AISI 316L	167.12 ± 1.06	167.52 ± 1.19

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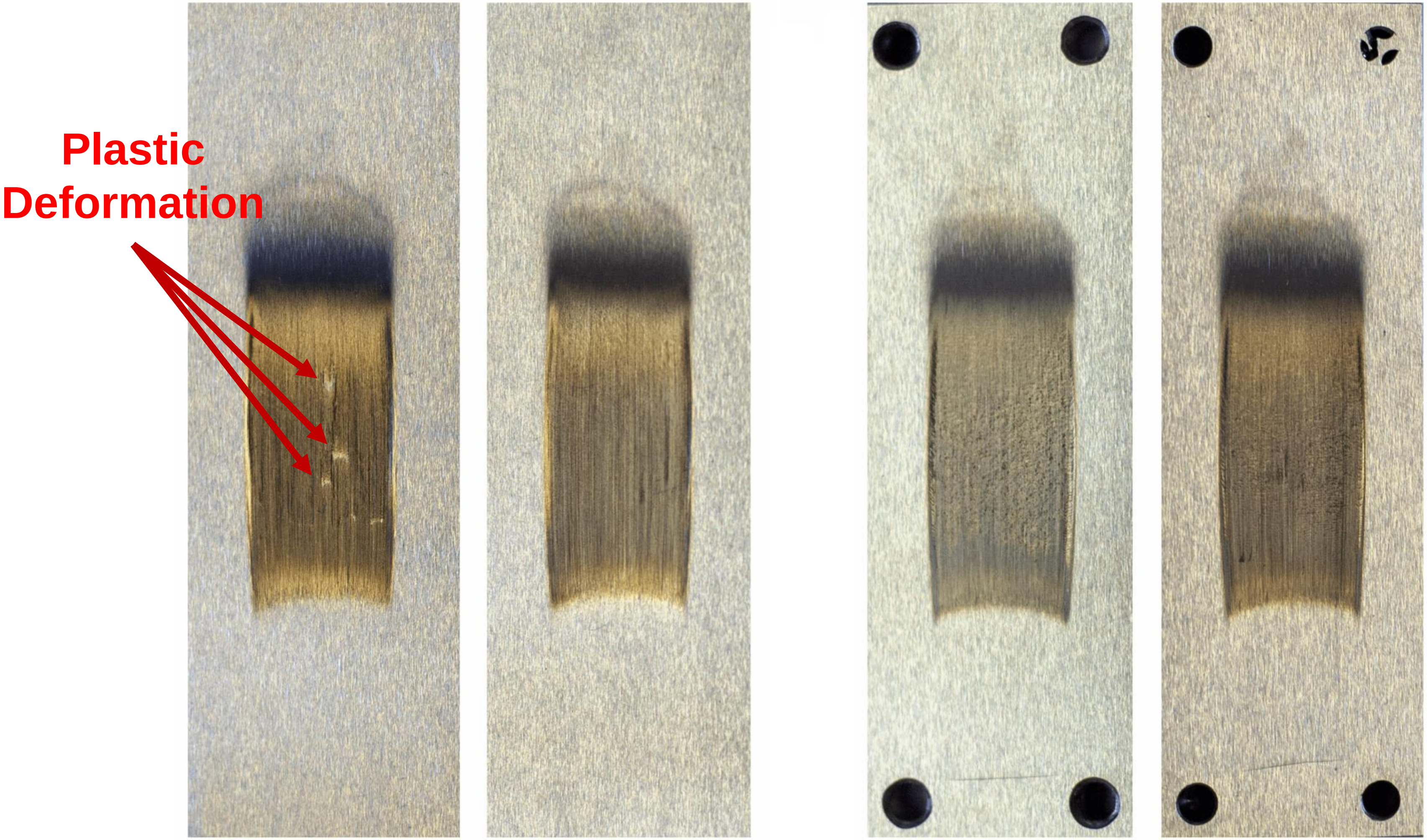
Results - Wear



AISI 304l | AISI 304l Cryogenic | AISI 316l | AISI 316l Cryogenic

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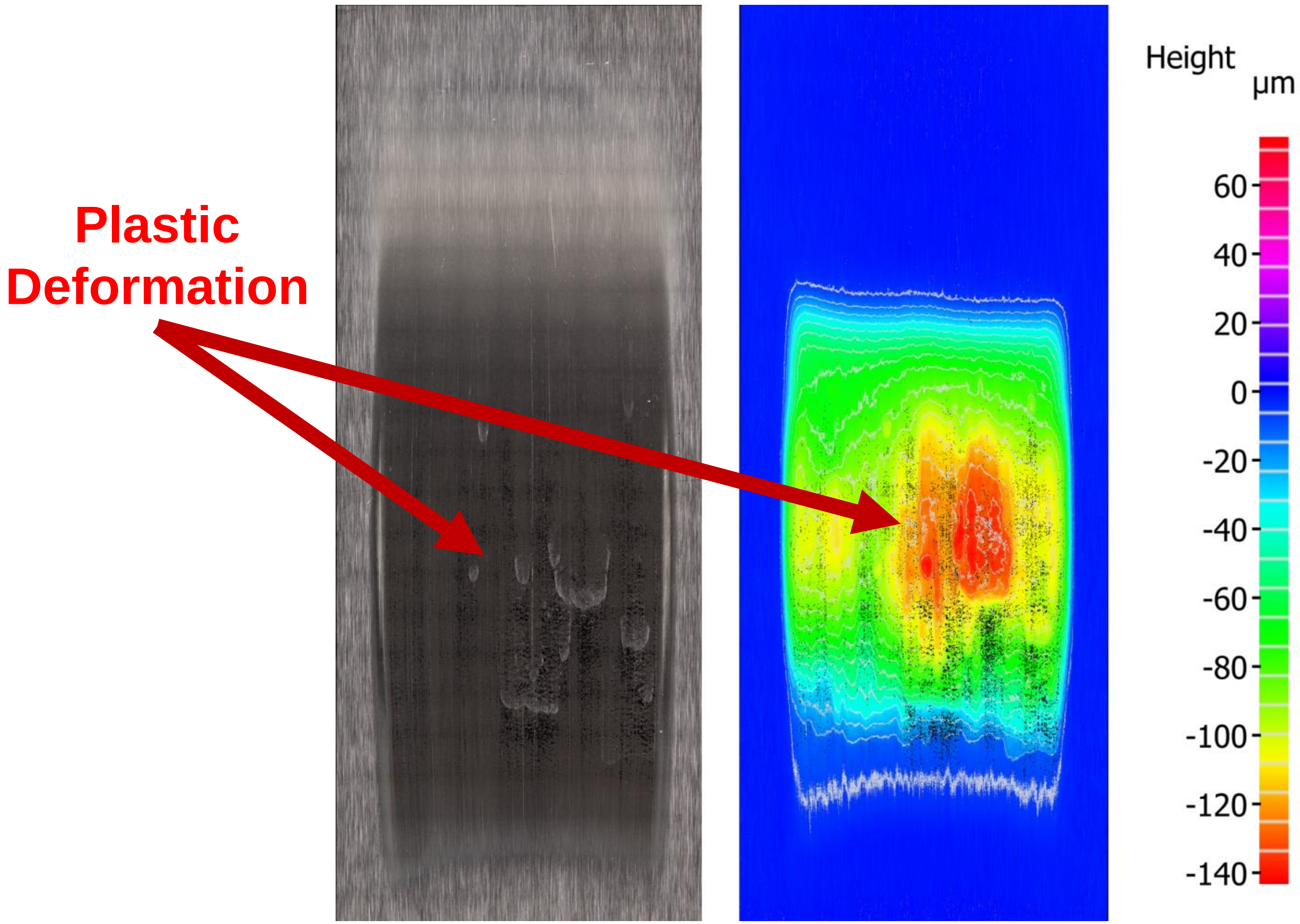
Results - Wear



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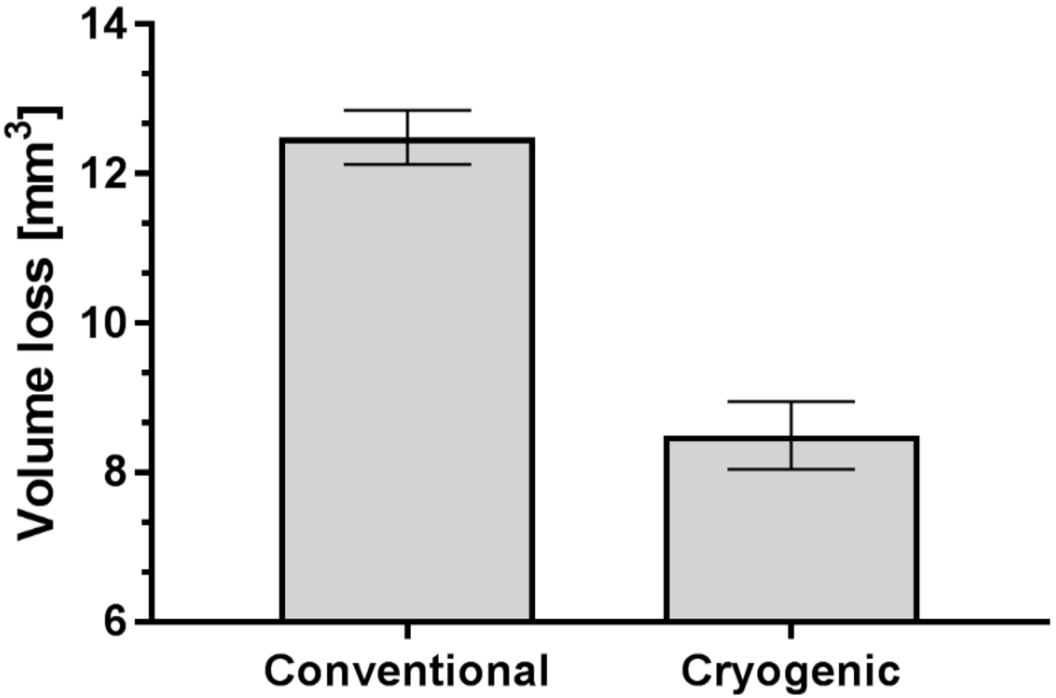
Results – Wear AISI 304L

- Repeated 4 times for each condition
- Standard error < 6%
- AISI 304L presented different wear scars for each condition (as showed)
- AISI 304L Cryogenically treated presented volume loss 26.1% smaller (Confidence interval >99%)



Treatment	Volume loss [mm³]	Improvement
Conventional	12.49 ± 0.37	-
Cryogenic	8.50 ± 0.45	26.1%

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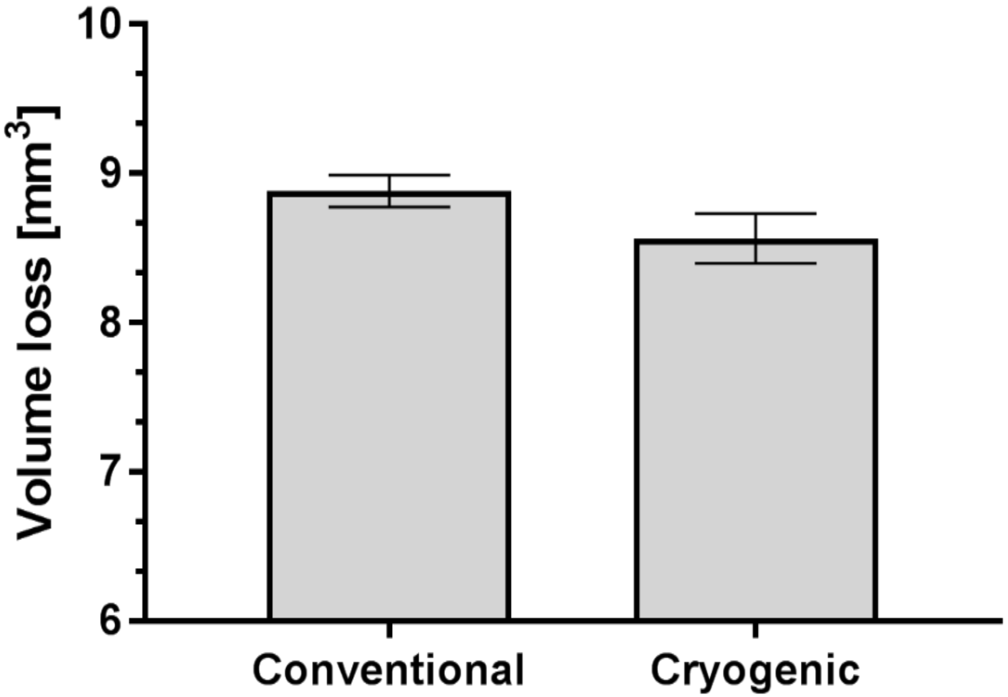
Results – Wear AISI 316L

- Repeated 5 times for each condition
- Standard error < 2%
- AISI 316L did not present a difference
- The improvement of 0.5% is no relevant (Confidence interval ~17%)



Treatment	Volume loss [mm^3]	Improvement
Conventional	8.88 ± 0.11	-
Cryogenic	8.57 ± 0.17	0.5%

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Conclusions so far

- There were no measurable differences in the results found for the 316L samples
- 304L presented an increase of 1.4% in hardness and 26.1% in wear resistance when submitted to the DCT
- The changes present in the 304L are possibly due to strain induced martensite in the structure
- More tests are needed

Future work

- Abrasive test repeats
- Samples analyses:
  - Metallography
  - Advanced microscopy
  - Wear scar analyses
  - XRD

SMEA

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CNPq

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Thank You

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