Study on properties of AISI 316L produced by laser powder bed fusion for high energy physics applications

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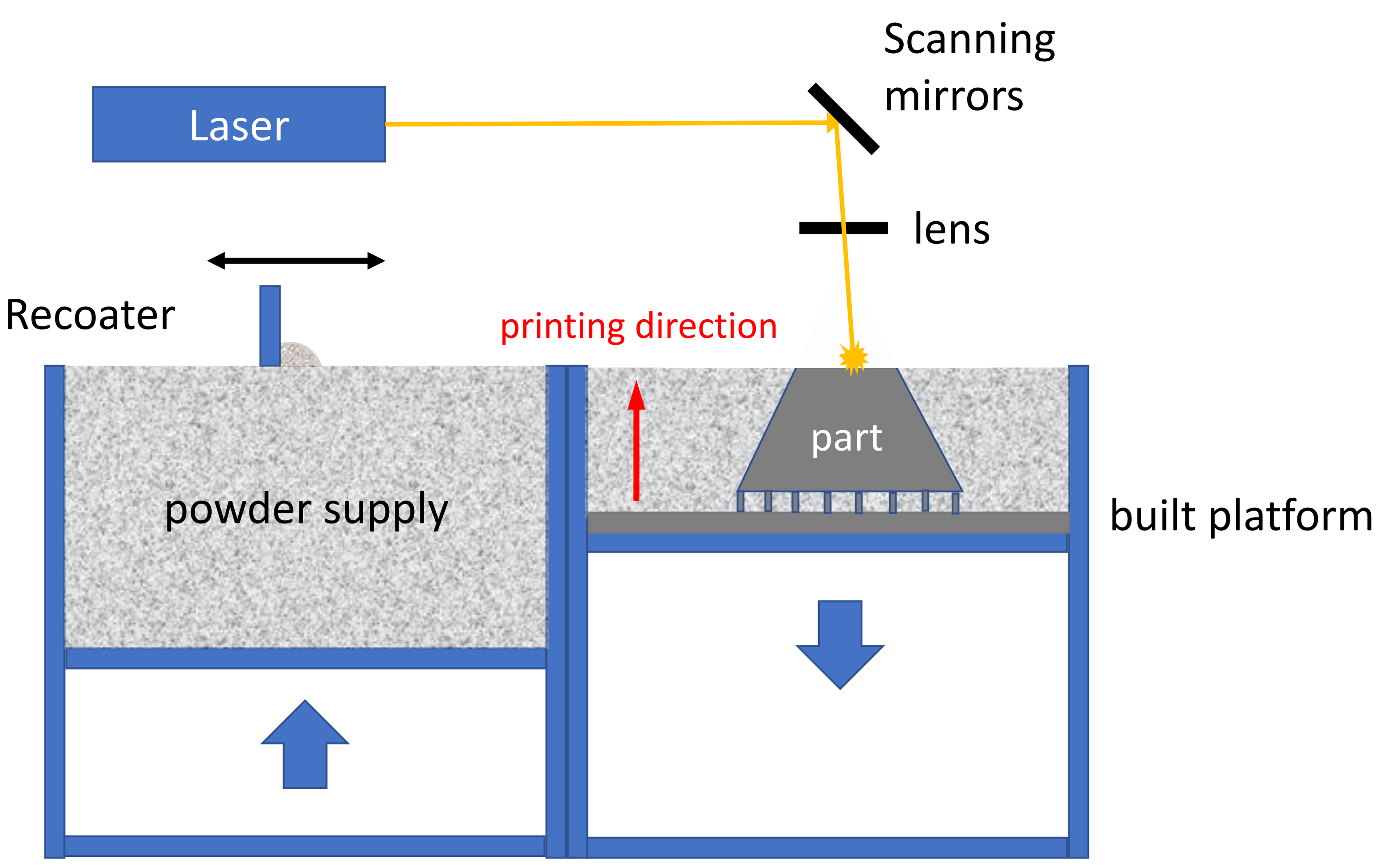
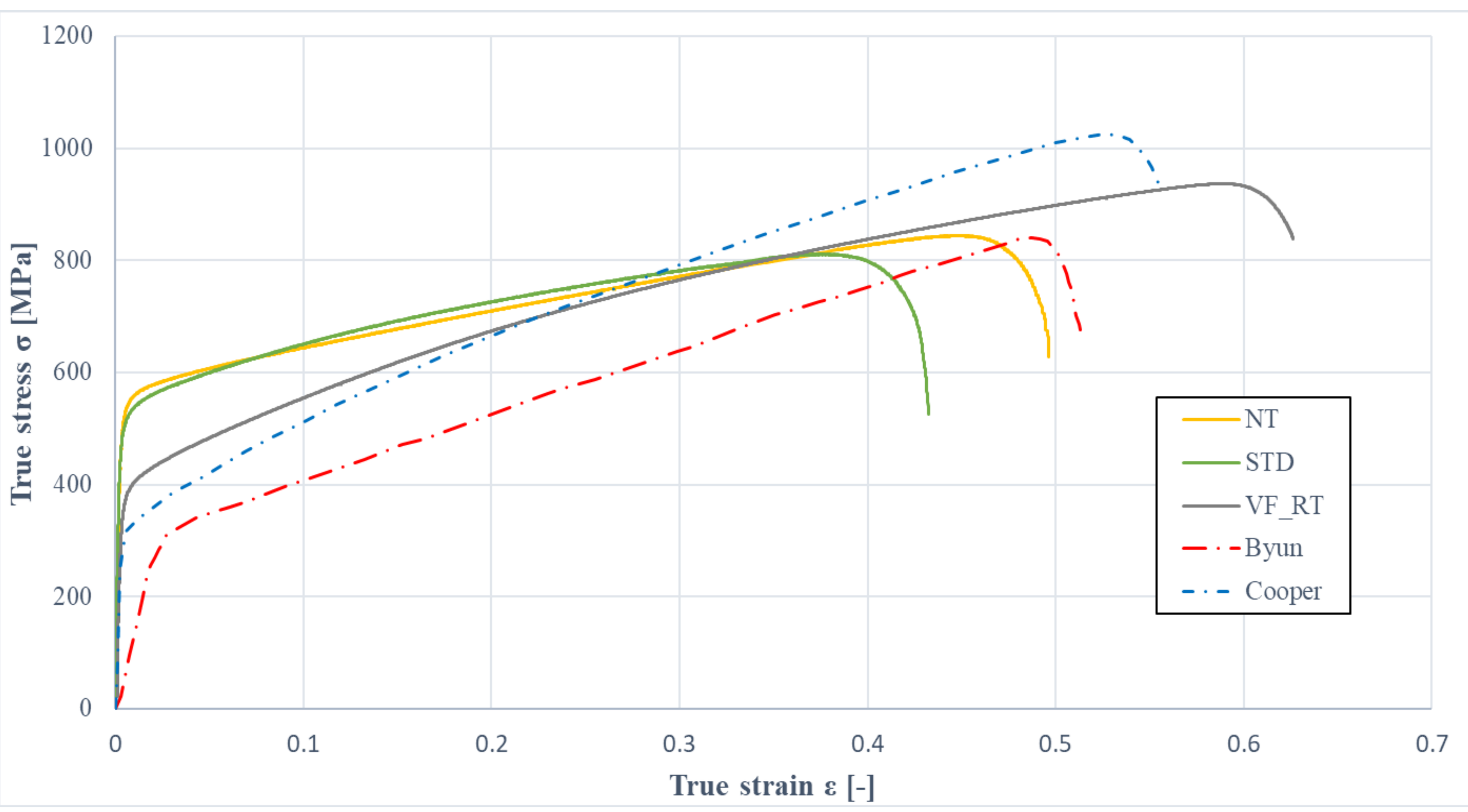
Nowadays additive manufacturing (AM) is catching on and spreading across various fields at an astonishing rate. High energy physics, where materials are often exposed to special environmental conditions, is also starting to use this technology. The aim of this paper is to compare traditional and 3D printed stainless steel AISI 316L products with an eye turned to the specific high energy applications. Experimental tests are carried out on a set of samples to analyse the material composition and to assess properties such as mechanical performance in cryogenic application, high radiation resistance and ultra-vacuum compatibility.



Selective laser melting technology working principle: the recoater spreds a metallic powder bed on the built platform, the laser selectively melts the powder and the part is build layer by layer from bottom to top.

sample	shape	dimension	machined	heat treatm.	Test
1, 2, 3	cylinder	D = 6 mm, L = 75 mm	tensile sample	NT	Tensile test at Room Temperature (RT)
4, 5, 6				STD	
7				VF	
8, 9				VF	Tensile test at 77 K
10	cube	L = 20 mm	-	NT	Composition and Microstructure; Ferrite content; Magnetic permeability
11				STD	
12				VF	

*NT: no heat treatment, STD: standard heat treatment (*180°C/h ramp up to 550 °C; maintain T for 6 hours; cooling down at RT*), VF: vacuum firing heat treatment (*200°C/h ramp up to 950 °C; maintain T for 2 hours; cooling down at RT*)*

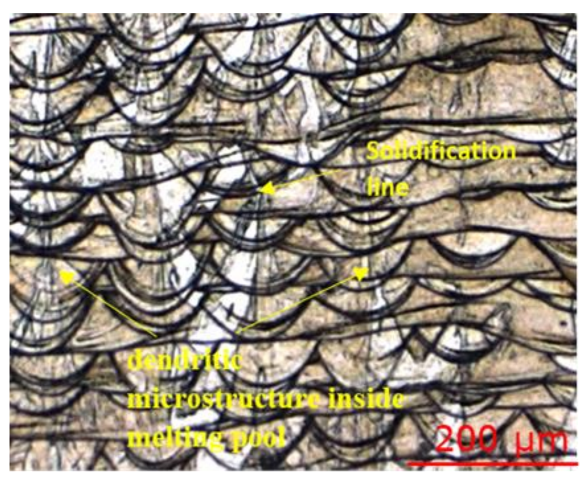


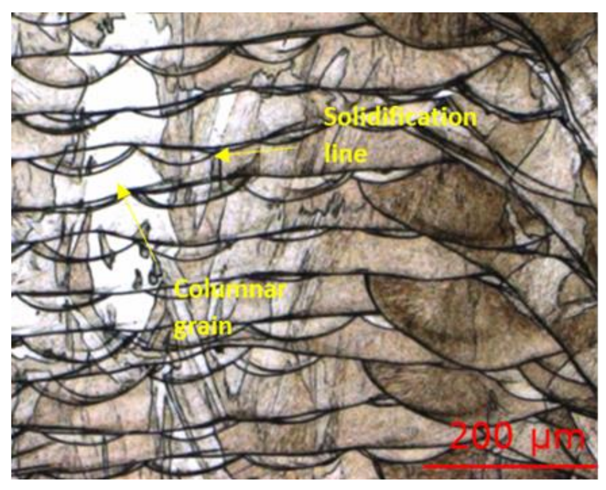
Comparison of true stress strain curves at RT: AISI 316L AM parts subjected to different heat treatment (NT,. STD and VF) vs. bulk parts ([1], [2])

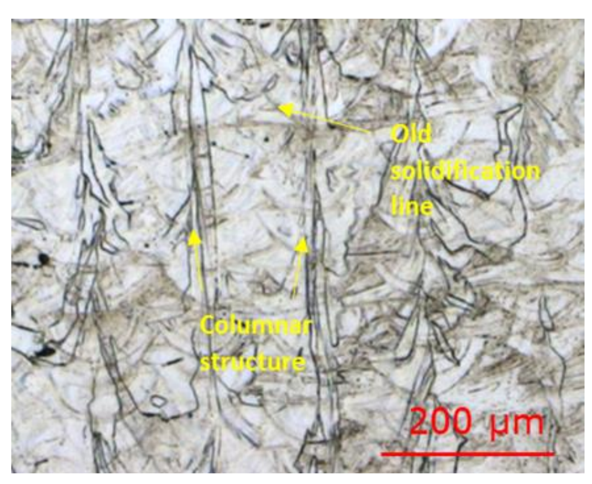
Microstructure analysis: Global columnar structure parallel to printing direction due to thermal gradient during printing process.
NT : dendritic microstructure stopped by melting pool boundaries
STD : more elongated grains though melting pools, dendritic structure are blurred.
VF: more homogeneous structure, melt pool boundaries dissolved, only grains are visible

	Rp0.2 [N/mm²]	Rm [N/mm²]
NT	506 ± 13	589 ± 2
STD	492 ± 5	608 ± 6
VF_{RT}	369 ± 5	593 ± 5
Bulk[1]	400	500-930

[1] According to ISO EN 10088-3 - 1.4404







NT & STD → higher *Rp0.2* (yield stress)→ due to presence of a dendritic structure in the melting pools, consequence of rapid solidification in the AM process.
VF → higher *Rm* (ultimate tensile stress)→ material consolidation

Different heat treatments:
- no difference in ferrite content
- no difference in the magnetic permeability

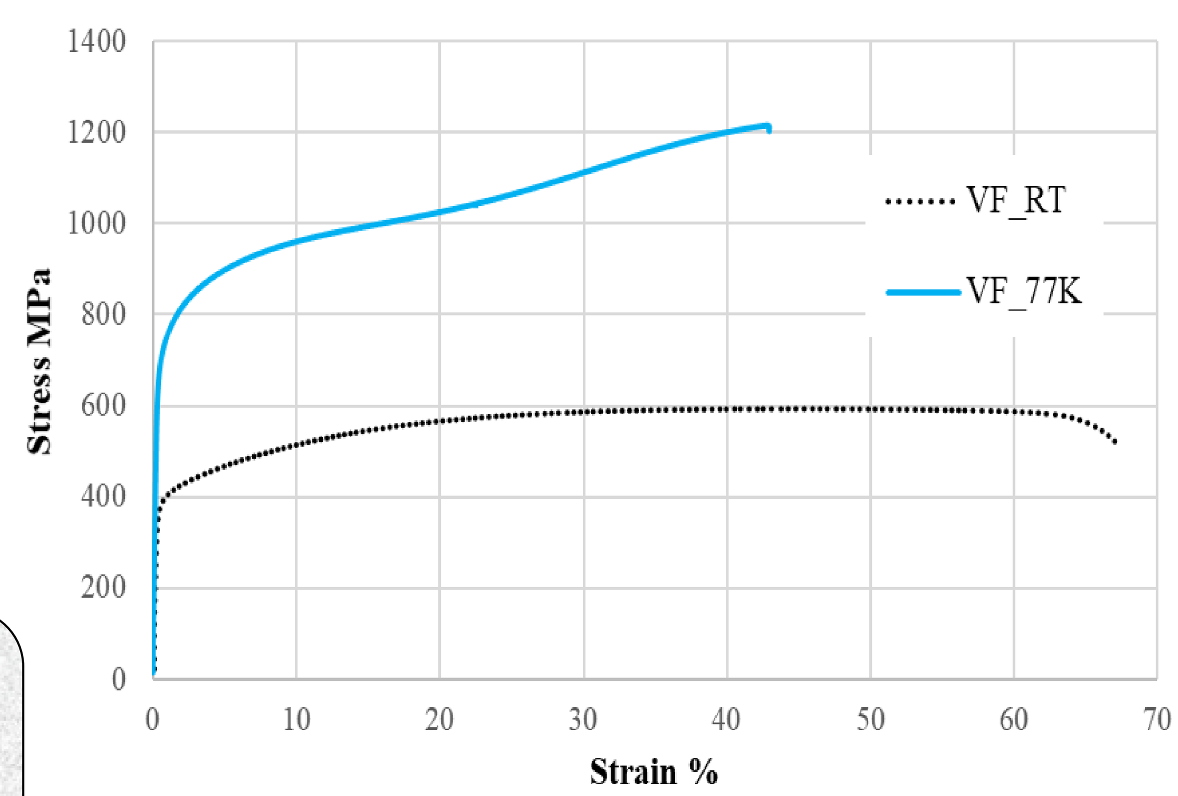
	Ferrite content check (Ferriscope FMP30)	Magnetic permeability (Magnetoscope 1.069)
NT	0.14±0.02 %	1.004 ± 0.004
STD	0.15±0.02 %	1.004 ± 0.004
VF	0.1±0.02 %	1.004 ± 0.004

Ferrite content @tensile sample fracture:

VF_{RT}	0.24±0.02 %
VF_{77K}	32.9±0.02 %

Confirmation that sample consolidation due to creation of martensitic phase from austenitic, which corresponds to the development of a magnetic behaviour.

↑*Rp0.2* and ↑*Rm* : thermal effect on dislocation movement & appearance of martensitic phase. Same behaviour as bulk material.



Representative stress-strain diagram of VF sample: RT vs. T = 77K

[1] Cooper, Adam J., W. J. Brayshaw, and A. H. Sherry. "Tensile fracture behavior of 316L austenitic stainless steel manufactured by hot isostatic pressing." Metallurgical and Materials Transactions A 49.5 (2018): 1579-1591
[2] Byun, T. S et al. (2021). Mechanical behavior of additively manufactured and wrought 316L stainless steels before and after neutron irradiation. Journal of Nuclear Materials, 548, 152849..