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Microstructure and mechanical behavior of hot-work tool steels processed by Selective Laser Melting

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ABSTRACT

The present study is aimed at identifying and testing high-strength alloys for tooling applications featuring suitable processability for laser-based additive manufacturing technologies. The microstructure and mechanical properties of the H11 hot-work tool steel and a leaner version of the same alloy (L-H11) processed by Selective Laser Melting were assessed as a function of specific microstructural conditions obtained by performing different heat treatments. Tempering was performed on quenched alloys or simply from as built material. The rapidly solidified microstructures revealed able to respond directly to precipitation hardening treatment without performing any prior solution annealing. The microstructure of the as-built alloys revealed characterized by α-Fe dendritic cells decorated at boundaries by C-rich γ-Fe regions. Air quenching was responsible for the transformation of the solidification cells into lath martensitic structures and for the formation of the M_3C phase, which transformed into more complex carbide species on tempering. The hardness of quenched and tempered H11 steel is similar to that obtained by processing the alloy with conventional routes, and the final hardness gap between the two SLM processed H11 and L-H11 alloys treated according to optimal tempered condition was limited to 62 HV.

1. Introduction

Additive manufacturing (AM) gives amazing opportunities for producing parts with complex shapes, including lattice and porous structures, which can hardly be produced by conventional processes. Several technologies belong to the AM family, in particular Selective Laser Melting (SLM) is the main reference process for metals. It is based on local melting of a powder bed by means of a high-power laser beam [1–3]. The materials produced by SLM form distinctive microstructures, resulting from the interaction of a high energy density laser beam over a metal powder bed that leads to high heating and cooling rates, rapid solidification, and large thermal gradients within the melt pools [4]. On the macro-scale, as-built alloys show evident solidification tracks that are similar to many adjacent welding beads, whereas, on the micro-scale, they show very fine cellular dendritic structures that are responsible for the high mechanical properties of AM parts [2,5]. SLM has recently attracted the attention of the tool and die makers owing to the possibility of producing parts with sophisticated geometry and conformal cooling channels. So far, despite the high interest in this technology, only few alloys have been tested under the special condition offered by the SLM and, in particular, only few studies have been published on high strength steel grades for tooling. Most of them focus on the maraging steels, paying attention to the material processability and the effects of post-process heat treatments on mechanical and microstructural properties of the alloys [6–9]. Further studies investigated the AISI M2 high-speed steel [10,11] and few other tool steel grades [12,13], showing auspicious results even though these materials are considered as hardly processable due to their high content of carbon and alloying elements. Very recently, a few works on the AISI H13 tool steel processed by SLM have also been published [14–17]. Safka et al. showed the possibility of producing fully dense H13 steel by SLM [14], Mazur et al. explored the possibility of producing conformal cooling channels and lattice structures [15]. Holzweissig et al. published a study on the microstructural and mechanical properties of H13 steels produced by SLM [16]. The works focused on as built condition and no information on the effect of quench hardening and tempering was provided.

The present study addresses the need to identify, test and make available additional alloys featuring suitable processability for AM and high-strength properties for tooling applications. In particular, it is aimed at investigating the mechanical behavior and wear resistance of the AISI H11 hot-work tool steel (1.2343 equivalent to type

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Table 1
Chemical composition (weight %) of the gas atomized powders.

	C	Si	Cr	Mo	V	S	P	Mn
H11 steel	0.34	0.93	5.15	1.24	0.49	0.005	0.006	0.37
Low-C steel	0.088	0.54	1.10	0.51	–	0.005	0.006	0.90
L-H11 steel	0.24	0.77	3.53	0.95	0.29	0.005	0.006	0.58

Table 2
SLM parameters adopted for the processing of the investigated materials.

Laser power, P [W]	245
Focal position, Δz [mm]	0
Scan speed, v [mm/s]	233
Hatch spacing, h [μm]	60
Layer thickness, t [μm]	50
Volume energy density, VED = $\frac{P}{v\,h\,t}\left[\frac{J}{mm^3}\right]$	350

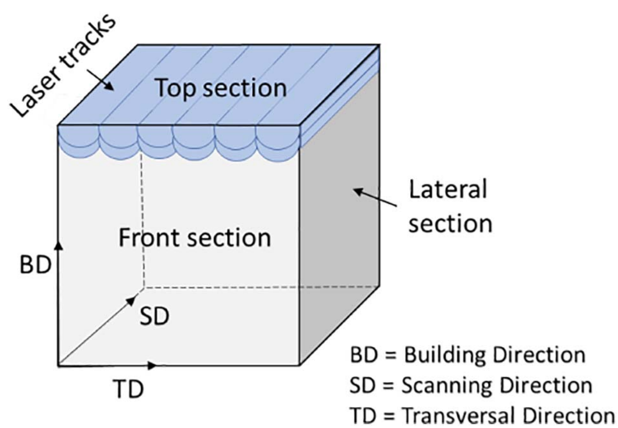

Fig. 1. Schematic of the main directions and views of SLM samples.

X38CrMoV5-1 grade) processed by SLM as a function of specific microstructural conditions obtained by performing different heat treatments. Special attention was given to the possibility offered by SLM to perform tempering right after the building process, thus skipping quench hardening. It has indeed been showed that fast solidification and high cooling rate induced by SLM lead to wide metastable solid solutions that can be exploited by tailored thermal treatments, such as aging or tempering, to improve specific mechanical properties [8,18]. The evolution of the microstructure was monitored by electron microscopy and with the support of X-ray diffraction (XRD) carried out by means of high-energy synchrotron radiation. A leaner version of the H11 steel, with 30% less carbon, was also proposed and investigated in this work. It was indeed reported that a lower amount of carbon can

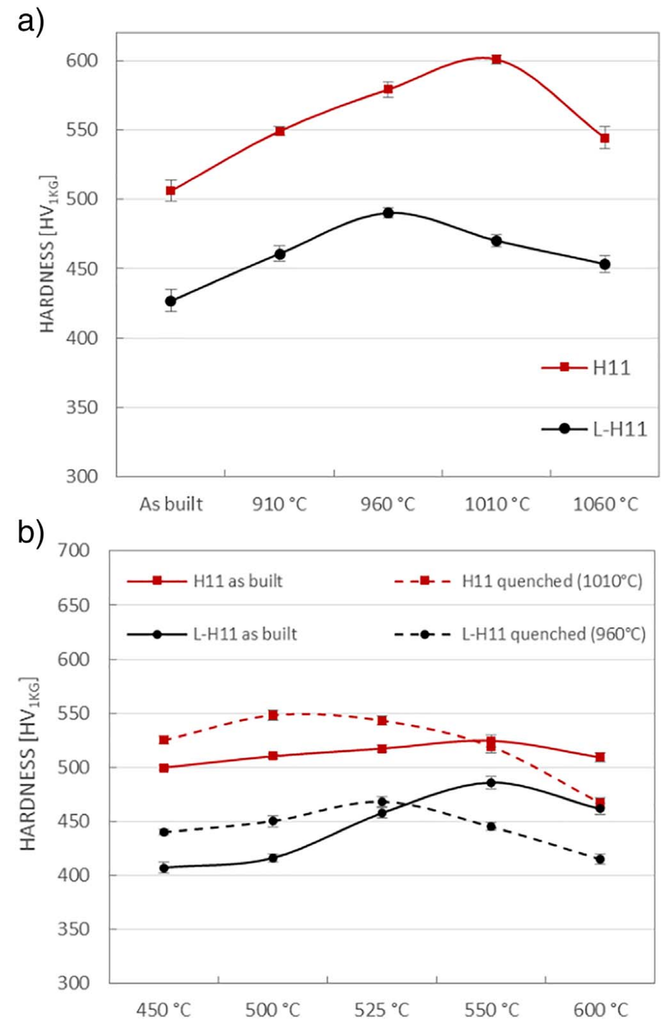

Fig. 3. Hardness values of H11 and L-H11 samples (a) after quench hardening and (b) after tempering at different temperatures.

positively affect the processability of steels by SLM [19]. It reduces the formation of cracks and other microstructural defects, especially in parts with complex shapes and severe notches.

2. Materials and experimental methods

Gas atomized AISI H11 hot-work tool steel powder (D_{10} = 22.75 μm, D_{50} = 37,64 μm, D_{90} = 60.51 μm) was used for the experiments. The powder used to produce the carbon-lean version of

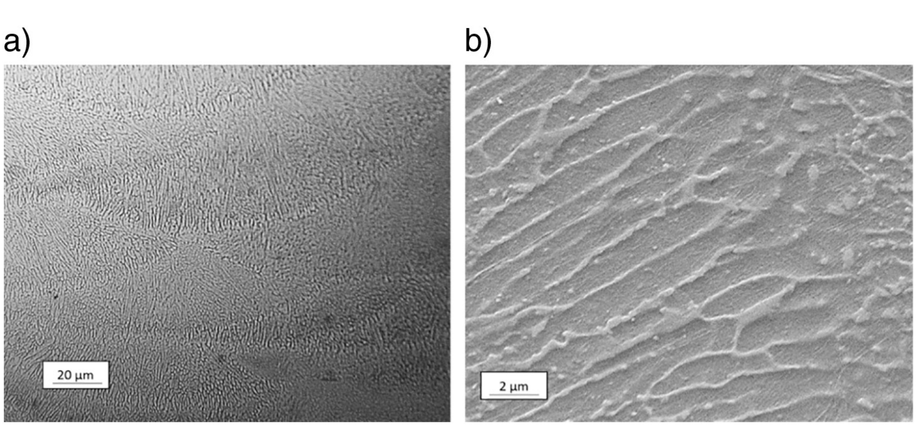

Fig. 2. a) Optical and b) SEM micrographs of the front view of an as built H11 sample.