In-situ SLM Alloying for Development of High Strength Supersaturated Alloys

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The improvement of mechanical properties is a continuous need for nearly all applications. The mechanical properties of alloys are related to their microstructure and one of the well-known method for alloy strengthening is solid solution hardening which increases the shear stress for dislocation movement. The limitation of this method is the maximum solubility of solute atoms in a matrix which presented by equilibrium phase diagrams. Rapid solidification permits to overcome this limitation. However, the main restriction of this method is the design limitation to obtain near-net shape parts. Selective Laser Melting is process in which by controlling printing strategy, it would be possible to control the cooling rate of molten pool and be able to put more solute atoms in matrix. The present investigation focused on the in-situ development of Cu-Sn alloy using 15wt% Sn with the potential to replace Cu-Be alloy. The printed parts showed the microstructure not achievable by classical elaboration and the UTS near 500MPa.

Improving the mechanical properties of alloys is a continuous challenge in scientific and technical worlds. It is well known that the mechanical properties of alloys are related to their microstructure. Solution hardening is a well-known mechanism of improving and controlling the strength of alloys [1]. In this regard, increase the alloy strength is given by

$$\Delta\tau = Gb\varepsilon^{\frac{2}{3}}\sqrt{c}$$

where "Δτ" is increasing the shear stress for dislocation movement, "G" is shear modulus, "b" is burger's vector, "ε" is lattice strain due to the solute and "c" is concentration.

Alloy strengthening by solute solution has the limitation defined by the maximum solubility of solute atoms in the matrix and generally presented by equilibrium phase diagrams [2]. Rapid solidification was used to overcome this limit and add more solute atoms in the matrix [3,4,5]. The main limitation of this method is the design limitation of the final shape of a functional part, while SLM technology alloys to overcome it.

By correctly establishing the SLM printing strategy it would be possible to control heating and cooling rate and approach the classical rapid solidification conditions. This would permit in one hand to put more solute atoms in the matrix and overcome the limit of solubility and on the other hand fabricate directly near net-shape parts.

The present study focused on in-situ alloying of Cu-Sn by SLM. Equilibrium Cu-Sn phase diagram [3] shows the maximum of solubility of tin in copper of 15.8 wt% at 520° which decreases to 1.3 wt% at 200°C. Cu 10 wt%Sn powder was used and mixed with 5wt% pure Sn powder. The process was developed and optimized to obtain the sample with density more than 98%. The alloy could fill in one hand the compromise between strength and conductivity (Figure 1) and on the other hand potential to be comparable with Cu-Be alloy.

The chemical composition measured Cu + 13.8 wt%Sn. The microstructural observation (FIB/TEM) shows (Figure 2) presence of very fine microstructure with the lamella having the thickness of about 20 nm in the matrix with grain size about 400 to 600 nm large. The EDS analysis showed that the fine lamella contains about 33.4 ± 1.6 wt%Sn and the grains having the chemical composition of 11.6 ± 0.8 wt%Sn. The phase analysis of X-Ray pattern (Figure 2) showed presence of two crystalline phases: α Cu (saturated to 11.6 wt%Sn) and δ of Cu44Sn11 confirming manufacturing the phases which is not possible based on equilibrium phase diagram at RT.

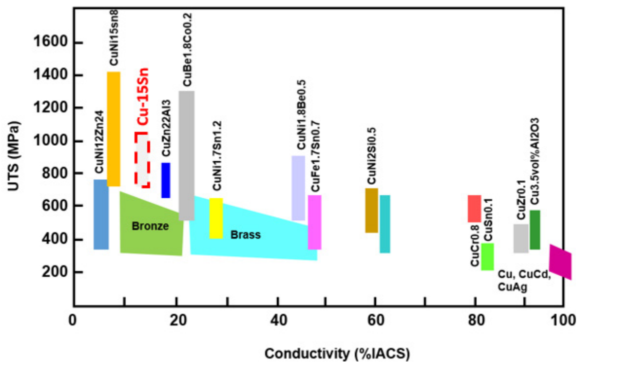

Figure 1: Strength and electrical conductivity (IACS) of Cu based alloys [6]. The goal of investigation was to achieve the UTS about 950 MPa and IACS about 18% nearly comparable to Cu-Be alloy.

Tensile test samples were prepared by the optimized SLM process. The mechanical properties found with the maximum tensile strength about 500MPa and the ductility less than 2%. The presence of some unmelted particles and microcracks could explain the low ductility of the sample.

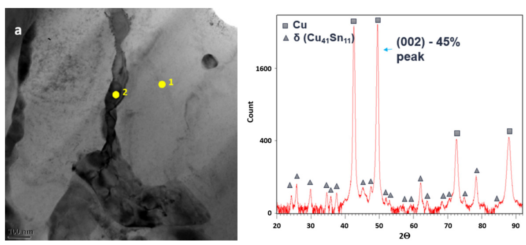

Figure 1: TEM micrograph, matrix "1" presents 11.6 ± 0.8wt% and phase "2" 33.4 ± 1.6wt% of Sn. Phase identification (right) reveals presence of two phases: α of Cu and δ of Cu44Sn11.

The primary objective of this feasibility study was to show potential of the in-situ alloying combined with the freedom in the design aspects for the final part fabrication for high strength non-conventional alloys.

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