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LLNL-SR-837505

Microstructurally-Inspired Strategies to Print Tantalum and Tantalum-Tungsten Alloys

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July 15, 2022

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Microstructurally-Inspired Strategies to Print Tantalum and Tantalum-Tungsten Alloys

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Duration of Project: 2 years (from October 1, 2022 to September 30, 2024)

Statement of Work

Objective. The goal of this project is to investigate strategies to print tantalum and tantalum-tungsten alloys, which are notoriously difficult to print with consistent results because of the sensitivity of the properties to small concentrations of interstitial impurities (particularly oxygen) and microstructure, and hence to processing conditions. The stunning variation of the ultimate tensile stress (UTS) for non-additively manufactured Ta as a function of temperature is shown in Fig. 1(left). In direct metal laser sintering (DMLS) Ta, a strong dependence of porosity, grain morphology and texture on processing conditions was found [1].

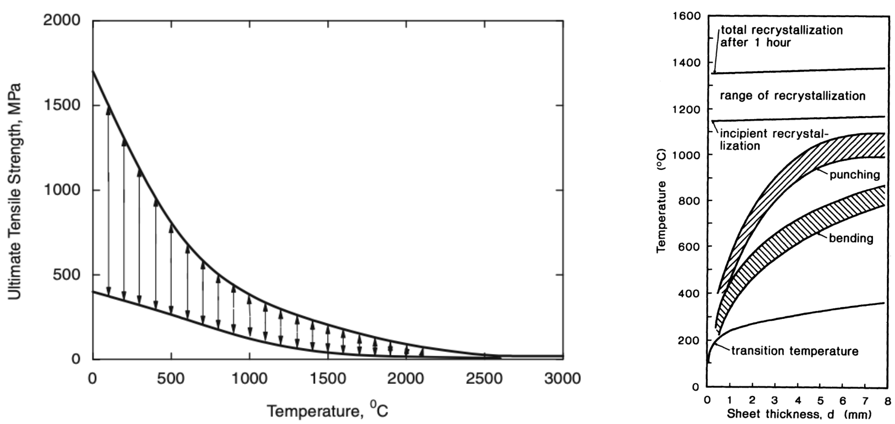

Fig. 1: (Left) The range of variation of the ultimate tensile strength of annealed commercially pure tantalum with temperature (the upper portion of the marked area is characterized by high strain rates and high interstitial content, whereas the lower portion of the marked area is characterized by low strain rates and low interstitial content). Figure and caption extracted from [2]. (Right) Ductile-to-brittle transition and recrystallization temperatures, and recommended temperature range for bending and stamping a tungsten sheet as a function of thickness, from [3]. Notice that the recommended temperature is often significantly above the transition temperature.

A similar behavior is observed in pure tungsten, in which the UTS can vary from 1432 MPa in the stress-relieved condition to 38 MPa in the recrystallized condition [4]. Additionally, Ta-W alloys with $> 90\%$ tungsten are prone to fracture while printed. These difficulties to print majority-tungsten alloys parallels the known difficulties to form it, as illustrated in Fig. 1(right). The wide, microstructurally-dependent range of the UTS makes it impossibly challenging to find the printing conditions to minimize crack appearance in tungsten printing.

Finally, it does not help that tungsten and tantalum are the elements with the first and fourth highest melting temperature, respectively. While printed, the material undergoes large thermal cycles and thermal expansion, and depending on how this cycling is performed, extensive recrystallization. It is precisely the dependence of the recrystallization temperature on the presence of impurities that has been argued as responsible for the observed range of mechanical behavior.

Tantalum-tungsten alloys are traditionally made with 2.5%-10% tungsten in order to strengthen Tantalum while retaining its ability to be formed. However, additive manufacturing of Ta-W alloys opens the possibility of obtaining net shape parts, and hence the ability to take advantage of further strengthening that may result of higher tungsten mass fractions.

Proposed Work. We approach this challenge with the idea of first (a) devising a way to characterize and control the level of impurities present in the powder and in the printing process, and second (b) designing optimized printing strategies to control the thermal history of the part as it is printed. This should result in optimized processing conditions for these materials. To this end, we plan to:

- Take advantage of the soon-to-arrive new LPBF printer at Stanford equipped with a glove box that will allow us to keep control of potential impurities (e.g., oxygen and carbon) in the atmosphere. This will allow us to establish consistency in the experimental results and exploration of the sensitivity to process parameters under a controlled atmosphere.
- In the FLAME system at LLNL, capture the thermal field on the top surface of a Ta-W substrate with high-speed thermal imaging, and use it to calibrate a thermal model.
- Use the thermal model to emulate the temperature history under the surface, and correlate it to microstructural observations (SEM, EBSD, Optical, micro-CT).
- Explore the possibility creating custom Ta-W alloys by mixing Ta and W powders and use the resulting powder for printing. This would enable a faster exploration of the alloy space.
- Design printing strategies (laser power, speed, *and* path) to print that emulate a desired thermal history (for example, keeping the recently-printed parts hot for the longest time to promote recrystallization, or not), and then print parts and characterize them. We will find inspiration for the design of printing strategies from the use of computational path optimization tools that we have been developing over the last couple of years. This is the riskiest part of the project.

Success in this project will be first measured by how consistently we can print the same part with similar microstructure across independent experiments. Obtaining some degree of control on the microstructure would be desirable, but it is, as mentioned, a challenging goal.

Deliverables and timeline. The following list contains the final deliverables of this project.

- By March 31, 2023: Proven method to control the impurity content in the powder and the printed part, and a calibrated thermal model for Ta substrates, in the form of a report.
- By September 30, 2023: A method to print Ta cubes with consistent mechanical properties and characteristic microstructure, and progress on the design of printing strategies based on the thermal model, both in the form of a report. In the same report we will also describe the results of exploring the creation of custom Ta-W alloys by mixing powders and using them to print. This will decide whether such alloys need to be purchased or not.
- By March 31, 2024: A method to print Ta-W cubes with consistent mechanical properties and characteristic microstructure, with 2.5% and 10% tungsten content, and progress in explaining manufacturing factors that affect the mechanical properties in printed samples, in the form of a report.

- By September 30, 2024: Demonstration of the printing of a complex geometry with Ta-W alloys, and characterization of mechanical and metallurgical properties of such part. If possible, exploration of alloys with tungsten content above 10%.

References

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