FRACTURE OF MULTI-PRINCIPAL ELEMENT ALLOYS

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Abstract
Yield strength and fracture toughness are often mutually exclusive properties in metals and their alloys. The CrCoNi-based face-centered cubic (*fcc*) multi-principal element alloys (MPEAs) are known to possess extraordinary high fracture toughness that is enhanced at cryogenic temperatures; however, their relatively low yield strengths limit their engineering applications. This study investigates the role of sub-grain cellular structures in CrCoNi introduced by laser powder bed fusion (LPBF) that enhance its strength, with small compromise to the fracture toughness.

1. Introduction
The equiatomic *fcc* high-entropy alloy CrMnFeCoNi and medium-entropy alloy CrCoNi have been found to possess high fracture toughness,[1–2] which is further increased at cryogenic temperatures. As revealed in prior studies,[3–4] the exceptional fracture toughness at temperatures from ambient to 77 K predominantly originate from a sequence of deformation mechanisms, such as the formation of stacking faults and deformation twinning. In our recent work, we have found that the CrCoNi alloy at even lower temperatures, close to that of liquid helium (20 K), displays a crack initiation toughness of 459 MPa√m: the highest toughness of any known structural material on record.[5] However, in CrCoNi such high fracture toughness makes yield strength the limiting property for structural applications. In our continuing work, we are trying to increase the yield strength of the CrCoNi alloy by microstructural modifications while retaining the high fracture toughness of the alloy. Therefore, we are studying the role of sub-grain cellular structures in achieving a synergy of strength and fracture toughness in the CrCoNi alloy from room temperature to 77 K.

2. Results
Tensile and fracture toughness tests were performed on cellular-structured CrCoNi. The results are briefly summarized below:

a. A significant increase in yield stress is noted. At room temperature the yield stress is enhanced 57%, from 440 MPa in conventionally processed (cast, rolled, and heat treated) CrCoNi to 691 MPa. At 77 K the yield stress is enhanced 44%, from 657 MPa to 944 MPa.[2]
b. Instantaneous strain hardening rates remain high, despite the significant increase in strength. There is a drop in tensile ductility, however, with strain to failure decreasing significantly from conventionally processed CrCoNi to LPBF CrCoNi at all temperatures.
c. Fracture toughness of LPBF CrCoNi decreases slightly at all temperatures.

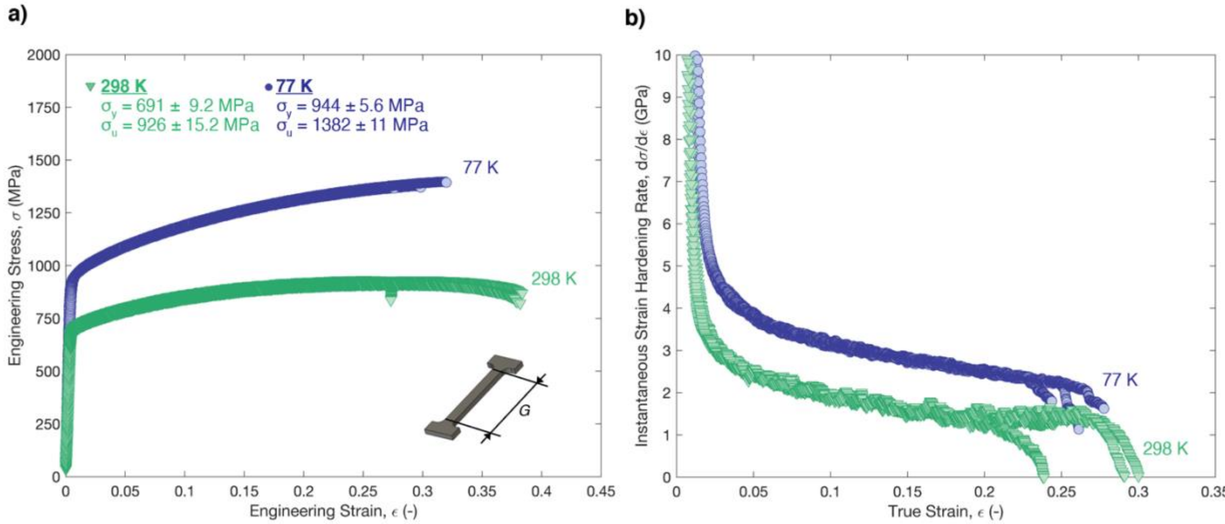

Fig. 1. a) Uniaxial tensile tests performed on LPBF CrCoNi show a significant increase in strength at room temperature and 77 K compared to traditionally processed CrCoNi. **b)** Instantaneous strain hardening measurements show an increase in strain-hardening rates from room temperature to 77 K.

3. Conclusions

Additively manufactured CrCoNi displays a significant increase in strength, with minimal losses to fracture toughness. This processing route creates potential new avenues for designing materials that can circumvent the strength/toughness trade-off.

References

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