ENHANCED STRENGTH AND DUCTILITY OF MULTILAYERS MADE BY ELECTROLYTIC ADDITIVE MANUFACTURING

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Recent improvements in the understanding of the mechanisms underlying the enhancement of metal strength by changes in microstructural length scale [1], create the opportunity for stronger/lighter and safer components. Grain size refinement is a well-known strengthening method, but can reduce ductility. Strength will also reduce if grains grow when service temperatures exceed 40% of the melting point. Multilayers are attractive as a method to prescribe the structural length-scale of a material; multilayering of dissimilar materials is an obvious avenue to explore to increase service temperature robustness and to control other properties/performance, e.g. elastic properties and thermal expansion coefficients etc. Hou et al. (2019) showed that interfaces can enhance the strength of pillars beyond the strength of the strongest individual material on either side of the interface.

Electrolytic additive manufacturing (EAM) was used to deposit 500 µm thick tensile test samples of polycrystalline Cu, Ni and Ni/Cu multilayers from 2 layers (250 µm thickness in each layer) to 16 layers (31.25 µm thickness in each layer). EAM was used as it has potential for bulk additive manufacturing. EAM is the most sustainable manufacturing method (low waste, low energy) and does not require potentially explosive and hazardous-to-health particles. It is an easily scalable process as deposition time scales only with thickness (not volume). Since deposition is layer by layer it is ideally suited to manufacturing of multilayered parts. The thickness and the width of the samples were measured using a Coordinate Measuring Machine with 0.001 mm uncertainty. Uniaxial tensile tests were performed at 0.3 mm/min strain rate.

Figure 1 shows that the stress vs. strain curves for the multilayered structures lie between those for the pure metals; All the multilayers having a yield stress and UTS lower than that of Nickel (highest yield stress and UTS) and higher than pure copper (lowest yield stress and UTS). However, the ductility of the multilayers seems to be increased compared to the Ni (pure metal) and the structures with Bilayers and 4 layers seem to have increased ductility over pure copper.

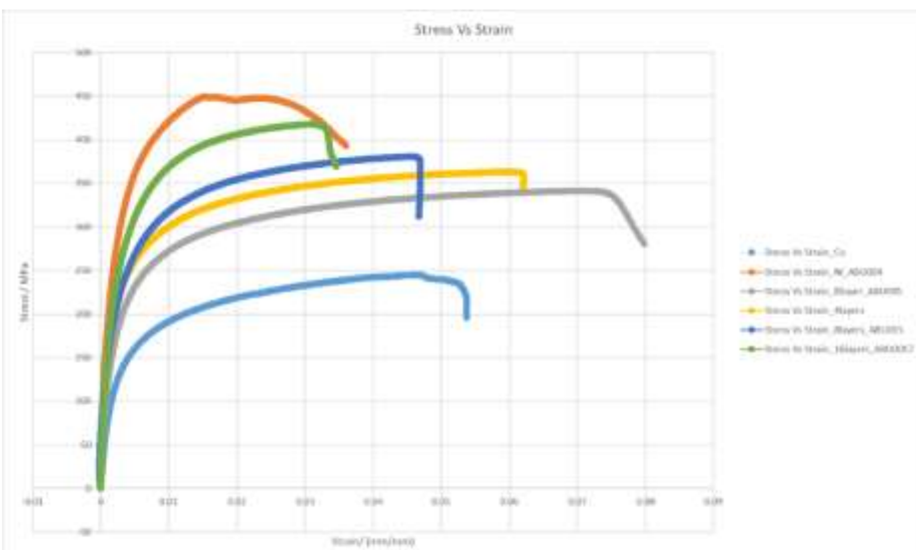

Figure 1 – Experimental Engineering Stress Vs Strain Curves for 0.5 mm total thickness of pure metals and for multilayers with 2-16 layers.

One possible explanation for this behaviour could be that the presence of an interface to a stronger material prevents the localization of plasticity in the weaker material. This allows more slip planes to activate and accumulate more plastic strain before failure occurs. To investigate this idea, atomistic simulations have been carried out to compare the behaviour of pure polycrystalline Nickel, Copper, Ni/Cu bilayers (all grain sizes 56 nm) and same material Bilayers with different grain size in each layer (56 nm and 40 nm). Comparison of results with experiment are made (as far as the differences in grain size allow).

[1] Hou Jennett, Acta Mater. 60 (2012) 4128
[2] Hou, Krauss, & Merle, Scripta Mater. 165 (2019) 55-59