Paragraph Ran in the Queries

Paper Title: Cryo-pre-straining contributes to achieving high yield strength in high-entropy alloys
Content :

Tensile properties and hardness

Fig. 7(a–c) shows the room-temperature tensile properties of the samples. It can be observed that the room temperature ultimate and yield strength are significantly increased after CR, with the ultimate tensile strength increasing from 733 MPa (before CR) to 840 MPa (10% RR) to 888 MPa (10% CR) to 1032 MPa (20% CR) to 1268 MPa (30% CR) and the yield strength increasing from 281 MPa (before CR) to 597 MPa (10% RR) to 702 MPa (10% CR) to 948 MPa (20% CR) to 1231 MPa (30% CR), while the ultimate and yield strength of the samples after 10% RR are lower than those after CR, indicating that CR is a more effective way to increase the room-temperature yield strength of HEAs. Additionally, after 20% CR + HT (ultimate and yield strength is 934 MPa and 771 MPa, respectively), the reduction of dislocation density due to the recovery effect results in a slight decrease in strength but a significant increase in ductility compared to 20% CR (elongation of the samples before CR, after 10% RR, 10% CR, 20% CR, 20% CR + HT, and 30% CR is 91.5%, 56.4%, 46.5%, 29.7%, 42.1%, and 16.4%, respectively). Fig. 7(c) shows the work hardening rate curves of these samples, it can be seen that in the first stage, work-hardening rate of these samples dropped sharply due to elastic-plastic dominated deformation transition. The work-hardening rate of the 30% CR sample is the highest, which is attribute to the highest-density defects in the sample after 30% CR. In the second stage, the work-hardening rate of all samples decreases, and the work-hardening rate of 30% CR sample decreases significantly. It can be inferred that this is related to the shear localization operated at cryogenic temperature, as reported by Reza Gholizadeh [38]. However, the specimen with 30% CR still exhibits good ductility due to a coherent orientation relationship between the HCP phase and the matrix [[39], [40], [41], [42], [43]], as validated by the selected area diffraction patterns in Fig. 4(c). Fig. 7(d) shows Vickers hardness of the samples, where the hardness of the samples before CR, after 10% RR, 10% CR, 20% CR, 20% CR + HT, and 30% CR is 146, 216, 251, 345, 288, and 362, respectively. The hardness of the samples is consistent with the tensile properties. For comparison with the tensile properties of FCC MEAs/HEAs, Fig. 9(b) displays the yield strength and elongation. It's clearly that our HEAs with ultrahigh yield strength as well as good ductility than the referenced alloys. It also suggests that the yield strength of the HEAs can be regulated by modulating the crystal defects through cryo-pre-straining.

Fig. 8 shows the fracture surfaces of the samples. The fracture morphology of the specimens before CR, 10% RR, and 10% CR specimens all exhibit ductile fracture characteristics with numerous dimples formed on the fracture surface. In comparison to the sample before CR, the sample fractured with a larger number and smaller size of dimples after 10% RR, while smaller and shallower dimples are observed after 10% CR. However, the fracture surface of the sample after 10% CR is flatter and distributed with some unevenly sized dimples, but still exhibits ductile fracture characteristics. The formation of these dimples is related to the aggregation of micro-voids and the interaction of dislocations with micro-voids. The high density of dislocations increases the nucleation rate of micro-cracks and so reduces the size of the dimples and thus reduces the alloy ductility, which is consistent with the tensile properties results in Fig. 7. In addition, the coarser dimples with cleavage features on the fracture surface are often contain particles that are rich in Mn or Cr oxides, formed during the melting or casting process in HEAs [44].