Paragraph Ran in the Queries

Paper Title: Low cycle fatigue properties of CoCrFeNiMn high-entropy alloy with heterogeneous microstructure

Content :

Monotonic mechanical behavior and microstructure evolution during straining

Fig. 4a displays a set of true stress versus true strain plots after PDA at different temperatures. The mechanical properties, including the yield stress (YS), ultimate tensile strength (UTS), and uniform total elongations are illustrated in Fig. 4b. The results confirm that although the tensile strength of the CoCrFeNiMn HEA increased from 600 to 1125 MPa after cold deformation, the uniform elongation reduced from 34 to 9 %. However, the results suggest that PDA improves the strength and ductility synergy in which annealing at 650 °C led to the value of UTS of 1040 MPa and the uniform elongation of 13 %. In order to investigate the deformation mechanism of the annealed samples at 650, 700, 750, and 800 °C, the strain hardening rates of different samples are shown in Fig. 4c in which the plot of strain rate hardening is divided into two stages. In the first stage, the value of strain rate hardening dropped significantly due to elastic-plastic transition [[51], [52], [53]]. In the second stage, there is a gradual decrease in the strain rate hardening which is related to the formation of deformation-induced twins [4,54]. The formation of deformation-induced twins during straining in the CoCrFeNiMn HEA has been reported widely due to the fact that the stacking fault energy of the alloy is in the range of twinning-induced plasticity (TWIP) alloys (~22 mJ m^{-2}) [10,50]. Nevertheless, it was reported earlier that there is a critical grain size of 2–3 μm in which deformation twinning is suppressed during straining in th is HEA [4,24]. It is worth mentioning that the formation of deformation twins in the microstructure is feasible in the annealed samples at 700, 750, and 800 °C due to their higher grain size than 2 μm. Close inspection of Fig. 4c reveals that the mechanical behavior of the annealed sample at 650 °C with heterogeneous microstructure is different in comparison with other conditions. The strain rate hardening of this sample is composed of three stages which is typical for materials with heterogeneous microstructure [27,29]. It is important to note that the average grain size of this sample is ~1.5 μm which is lower than the critical grain size for deformation twinning. The Hollomon plots of the samples are represented in Fig. 4d. It is reported that martensitic phase transformation or deformation twinning during straining results in a deviation from the Hollomon equation [55,56]. Close inspection of these plots confirms that all samples deviate from the Hollomon equation because of the deformation twinning except for the annealed at 650 °C which follows the Hollomon equation during straining. It readily confirms that the dominant deformation mechanism in this sample is the dislocation slip.

ECCI images of the annealed samples at (a,b) 650 and (c,d) 700 °C after tensile testing are illustrated in Fig. 5. Some annealing twins are detectable in the recrystallized region together with deformation twins which appear in the recrystallized grain with a size of ~7 μm. It is important to note that the thickness size of annealing twins is significantly higher than that of deformation twins which is in agreement with other research papers [27]. It is interesting to note that some stacking faults can be observed in the recrystallized grains (shown by the green arrow). Furthermore, some deformation twins can be detected in the non-recrystallized region (not shown) which remains from plastic deformation prior to annealing. It can be reasonable due to the fact that the temperature of annealing is not high enough to complete recrystallization which leads to the annihilation of these twins. The sustainability of these twins can make a profound contribution to enhancing mechanical properties because they are highly worthwhile for reducing the mean free path of dislocation and acting as a barrier for dislocation slip (dynamic Hall-Petch) [10]. The microstructure of the annealed sample at 700 °C after tensile testing also contains deformation and annealing twins (Fig. 5c and d). All microstructure observations are in agreement with the mechanical behavior explained earlier.