Paragraph Ran in the Queries

Paper Title: Realizing high strength and toughness of gradient high-entropy alloy coating by in-situ interface reaction of FeCoCrNi/FeCoCrAl

Content :

Cross-section hardness analysis of HEA composite coating

Fig. 9 is the cross-section microhardness cloud map of the HEA coating. As observed, it is wholly blue in the coating region in the FeCoCrNi HEA hardness cloud map, with a hardness value of approximately 170$Hv_{0.5}$. The red coating region refers to the FeCoCrAl HEA, with a hardness of 600$Hv_{0.5}$ around, and there is a fine transition zone at the interface between the coating and the substrate. Most interestingly, as exhibited by the results of the cross-section microhardness cloud map of the FeCoCrNi/FeCoCrAl HEA composite coating, there are three layers, namely red, green, and blue, as well as large transition zones between red and green and between green and blue. This indicates that there is a region with stable performance (hardness) in the middle of the interface layer formed in situ, and this is not the gradual change result of the common composite coating. This may be associated with the unique stability of HEAs. The intermediate interface layer is not only a transition zone, but also a new dual-phase HEA (FeCoCrNiAl HEA) formed by recrystallization. There are wide transition zones among the FeCoCrNi, FeCoCrNiAl, and FeCoCrAl HEAs, according to the previous study results of the microstructure, phase, and recrystallization degree.

To further investigate the performance change of the cross section of the HEA composite coating, the hardness test is performed at the micro-nano scale. The top, middle, and bottom of the coating were tested by selecting three points. The results of the corresponding load-displacement curves, hardness, Young's modulus, $W_{elastic}$, and $W_{plastic}$ are presented in Fig. 10. For the top, middle, and bottom of the coating, under the same load (20 mN), the indentation depths are 220.68 nm, 342.08 nm, and 378.99 nm, the hardness is 9.85 GPa, 5.53 GPa, and 4.86 GPa, and the Young's modulus is 277.71 GPa, 245.9 GPa, and 235.12 GPa, respectively. It shows a decreasing trend from the top to the bottom of the coating, which can be explained by the change in the phase structure and microstructure of the coating. The gradual change in the mechanical properties of the coating is conductive to alleviating the stress concentration and improving the overall strength, toughness, and wear resistance of the coating.

Impact resistance analysis of the HEA composite coating

The impact test results of the FeCoCrNi HEA coating, FeCoCrAl HEA coating, and HEA composite coating designed in this paper are presented in Table 6 and Fig. 14. As observed, compared with the 38CrMoAl impact sample, the sample with a single FeCoCrNi HEA coating exhibits an impact energy with increase of 14.52 %, while the sample with a single FeCoCrAl HEA coating shows an impact energy reduced by 4.3 %. However, the HEA composite coating sample designed and prepared in this paper achieves an impact energy increase of 11.29 % while preserving the high hardness and high strength characteristics of the FeCoCrAl surface layer, thus achieving a favorable synergy between strength and toughness. By further exploring the fracture mechanism by virtue of the fracture morphology, it can be known that the fracture morphology of the FeCoCrNi HEA sample is dimple, and that its fracture mechanism is ductile fracture. Meanwhile, the fracture morphology is segmented into two regions (indicated by the red line in Fig. 14 (c)). As clearly observed, the dimples in the upper region (FeCoCrNi) are smaller, while those in the lower region (38CrMoAl) are larger. Studies have indicated that small dimples have superior material toughness [70], and the overall impact energy of FeCoCrNi is improved by virtue of the superior toughness. For the fracture morphology of the sample with a single FeCoCrAl HEA (Fig. 14 (e-h)), some of the fractures of the coating are found to be angular and rocky, with huge cracks distributed. In addition, there is a smooth cross section presented in the grain boundary, and the fracture mechanism is intergranular fracture [71]. Additionally, the transition zone between the coating and the substrate is mixed with small cracks, indicating a river-like morphology, and tearing dimples appear in the transition zone near the substrate. This high-hardness FeCoCrAl coating directly transforms to 38CrMoAl, thus leading to the expansion of a wide range of intergranular fractures to the entirety during the impact process, and finally reducing the impact energy.