Effects of the grain refinement gradient layer on high entropy alloys

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Abstract

Most high entropy alloys (HEAs) are cast for form single phase solid solution. The grain size and hardness/strength at room temperature (RT) under the as cast condition is typically large and low, respectively, though their high temperature (HT) properties might be more promising. While the high temperature creep and radiation resistance of high entropy alloys (HEAs) appear to be promising, their room temperature hardness and yield strength, especially for the single FCC phase solid solution, are often lower than expectation, as compared with Ni or Fe based superalloys. In the research, the ultrasonic surface mechanical attrition treatment (SMAT) is conducted on the surface of two HEAs, FeCoNiCrMn and FeCoNiCrMn-Al, to upgrade their room temperature surface characteristics. By proper SMAT multiple paths, the grain size can be reduced from ~50 mm down to ~0.1-1 mm, the hardness increased from ~2.5-5.0 GPa up to ~5.0-8.5 GPa, and the tensile strength and elongation can be nearly doubled. The gradient refined and strengthened surface layers are demonstrated to appreciably upgrade the HEA performance. The strengthening mechanisms and superposition rules are established and are compared well with the experimental measurements.

Results and discussion

Table 1. The results of EDS analysis

Elements	Fe	Co	Ni	Cr	Mn	Al
FeCoNiCrMn (at%)	19±2	20±1	22±3	20±1	19±2	-
FeCoNiCrMn-Al (at%)	16±2	19±1	23±3	18±1	16±2	8±1

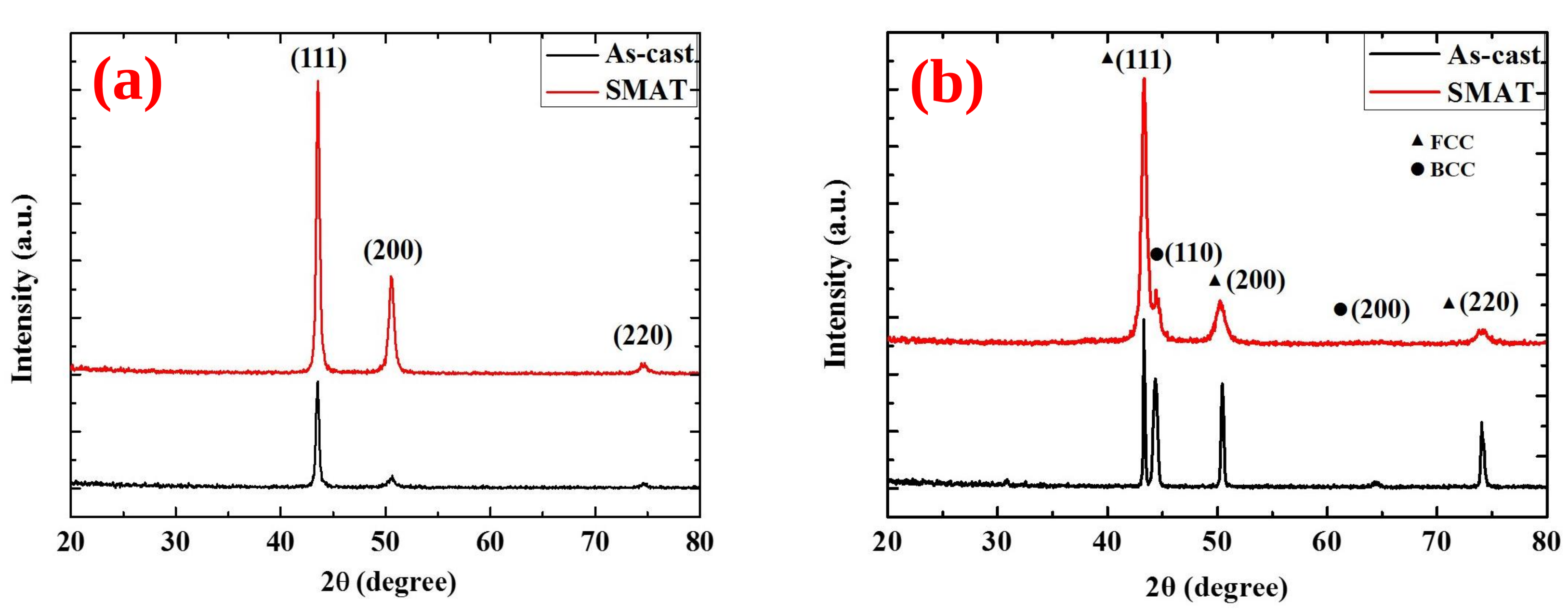

Figure 1 XRD profiles taken from the flat surface as-cast and SMATed (a) FeCoNiCrMn and (b) FeCoNiCrMn-Al HEA samples (facing SMAT bombarding).

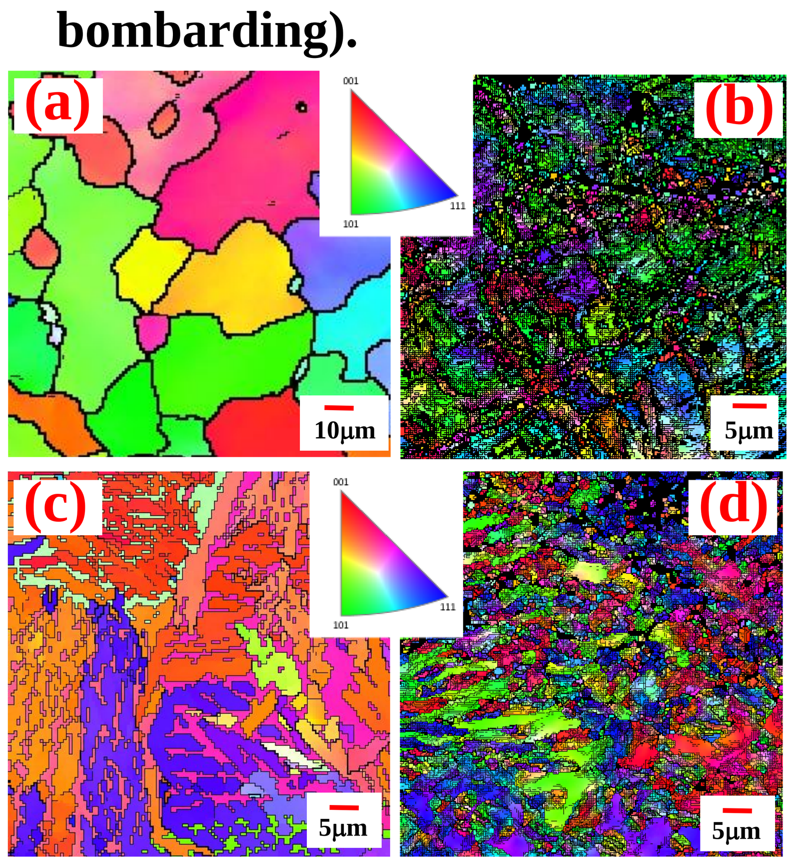

Figure 2 Typical EBSD images taken from the FeCoNiCrMn (a) as-casted (b) SMATed surface, and FeCoNiCrMn-Al samples (c) as-casted (d) SMATed surface.

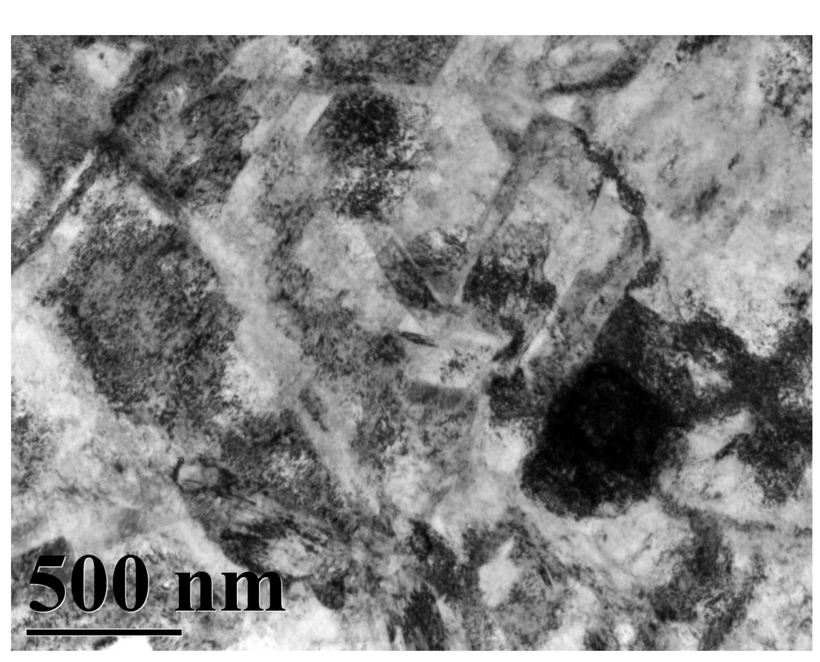

Figure 3 Typical TEM bright field images taken from the FeCoNiCrMn sample, showing the fin grains near the free surface (about 1 μm in depth).

Table 2 The Vicker's hardness Hv values taken form the specimen.

Case	As-cast		SMATed
	Hv	Nano-indent	Hv
FeCoNiCrMn	147±4	2.5±0.2 GPa	370±50
FeCoNiCrMn-Al	290±5	5.0±0.2 GPa	650±50

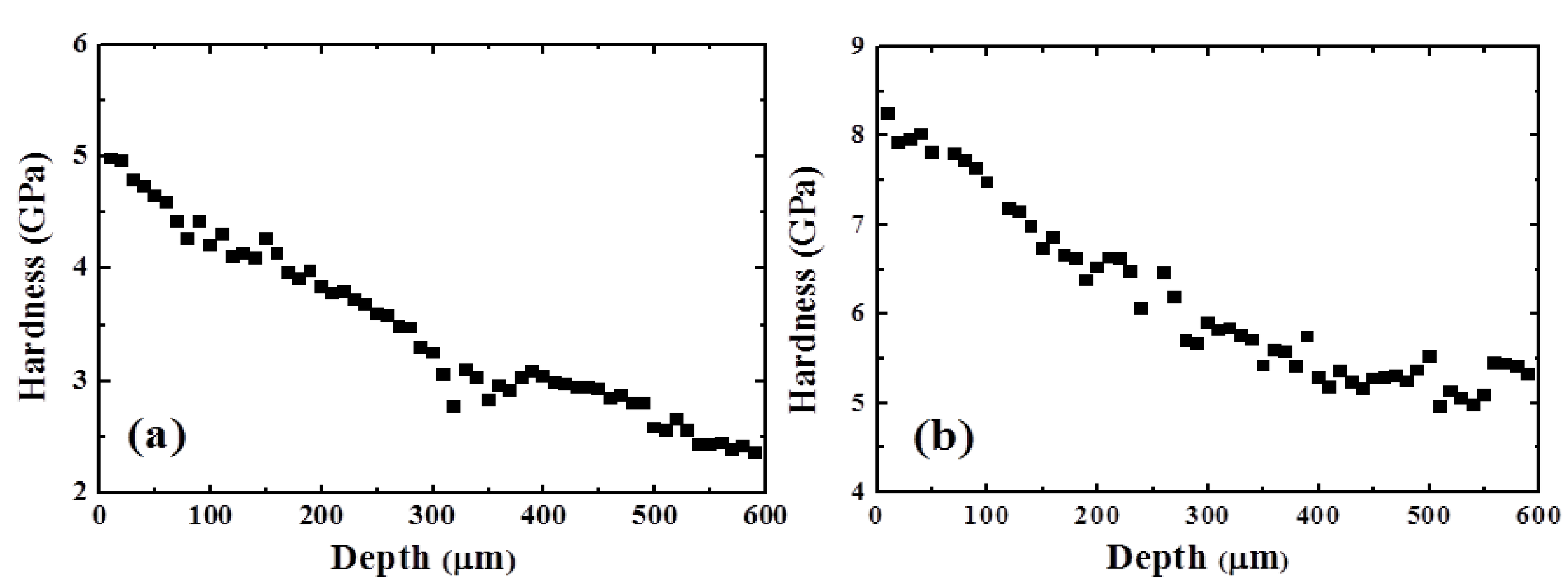

Figure 4 The gradient variation of the nanoindentation hardness measured from the cross section of a representative SMATed (a) FeCoNiCrMn and (b) FeCoNiCrMn-Al HEA samples.

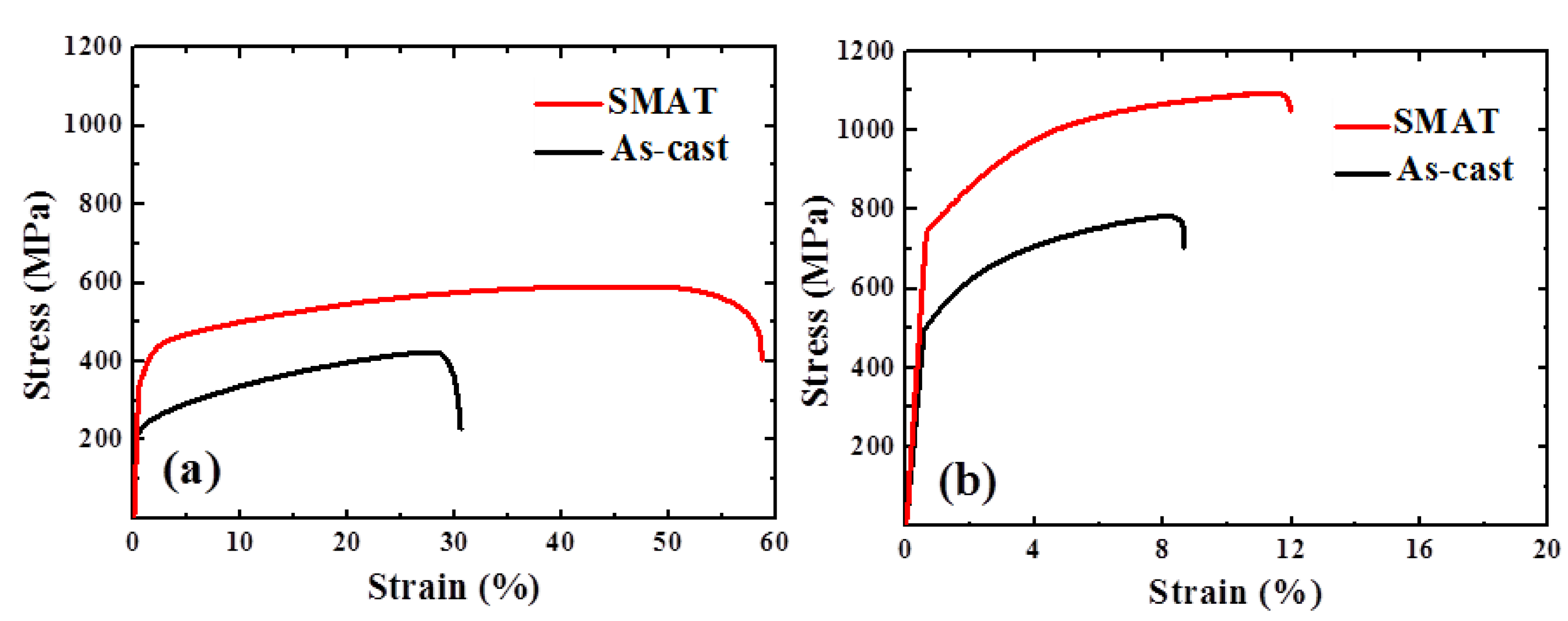

Figure 5 Representative room temperature tensile engineering stress –strain curves for (a) FeCoNiCrMn and (b) FeCoNiCrMn-Al. Each condition has been tested for at least three times to ensure reproducibility.

Conclusion

By a simple surface mechanical attrition treatment (SMAT) on the FeCoNiCrMn and FeCoNiCrMn-Al HEAs, the apparent surface hardening and grain size refinement in a gradient manner from the SMAT surface into the inner portion, the samples become much stronger and tougher. Experimentally, the cross-sectional hardness of FeCoNiCrMn can increase from 2.5 GPa at the inner central region up to 5.0 GPa at the surface, an increment of 2 times. In parallel, the hardness of FeCoNiCrMn-Al can increase from 5.0 GPa up to 8.5 GPa, also an increment of 1.7 times. The tensile tests also demonstrate that the tensile UTS and elongation can be improved by SMAT from 400 MPa and 33% up to 600 MPa and 60% for FeCoNiCrMn, and from 750 MPa and 9% up to 1100 MPa and 13% for FeCoNiCrMn-Al.