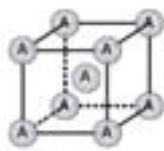


Multi-element High-entropy Alloys 多元高熵合金

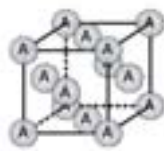
This technology extends the conventional alloy design based on a single principal metallic element typically at greater than 40 atom percents by synthesizing nanostructured high entropy alloys with several principal elements each at 5 to 35 atom percents, resulting in much expanded versatility in alloy design, property enhancements and applications. Early applications in sporting goods such as golf driver heads have already been demonstrated.

為擴展傳統的合金以單一元素為主的設計觀念（主元素含量在40 %原子比以上），本研究為開發一種具奈米結構之多元高熵合金（每一主元素含量約在5-35 %原子比），藉此能發現新材料、新現象、新理論、與新應用。此類材料可望應用於運動器材如高爾夫球桿桿頭、鑄造或鍛造用之刀工具或模具。

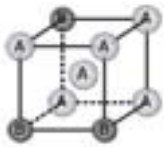
(a) BCC: pure A



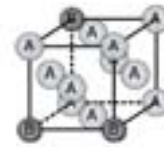
(b) FCC: pure A



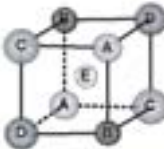
(c) BCC: solute B in matrix A



(d) FCC: solute B in matrix A



(e) BCC: 5 different elements



(f) FCC: 5 different elements



- Extended definition of crystalline structures from one principal element to multi-principal elements.

- At an arbitrary choice of a group of 13 metallic elements, we can obtain a total of 7099 possibilities for designing equal-mole high-entropy alloy systems with 5 to 13 elements, such as CuCoNiCrAlFe:

$$C_5^{13} + C_6^{13} + C_7^{13} + C_8^{13} + C_9^{13} + C_{10}^{13} + C_{11}^{13} + C_{12}^{13} + C_{13}^{13} = 7099$$

2003/04

Applications

- Tools, molds, dies, mechanical parts and furnace parts, etc., requiring high strength, thermal stability, and wear and oxidation resistance.
- Anticorrosive high-strength materials in chemical plants, IC foundry, and even marine uses for piping, pump components, propellers, impellers, ...among others.
- Functional coating such as hard-facing of golf heads and rollers.

Nano scale microstructure after casting



- Spinodal structure 1 (about 70 nm width)
- Spinodal structure 2 (about 100 nm width)
- Nano precipitates in spinodal structure 2 (from 7 to 50 nm)
- Nano precipitates in spinodal structure 1 (about 3 nm)

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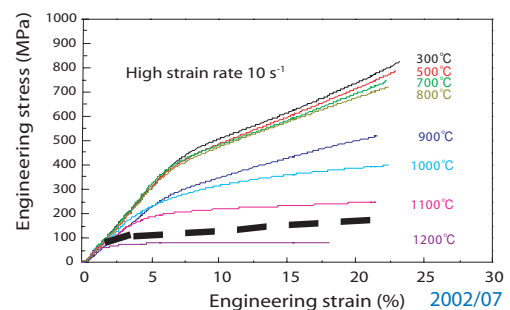
Nano crystallization after cold working



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Superior performance of strength and work hardening up to 800°C

Stress-Strain curve of compression test



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Golf Club Heads

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