



Introduction de la journée thématique

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11 Mai 2015

Dans le cadre de la conception, l'optimisation et le développement de procédés métallurgiques classiques et **innovants**, plusieurs nécessités s'imposent actuellement :

- se placer en **rupture** avec la métallurgie dite traditionnelle ;
- mettre à jour des **concepts** permettant l'exploration et l'émergence de **nouveaux matériaux (métalliques)**.

RESEARCH NEWS

Alloyed pleasures: Multimetallic cocktails

S. Ranganathan

Current Science, Vol. 85 (10), 25 nov 2003

Apparition progressive des concepts matériaux comme l'*alloy(ing) design* aboutissant au développement - entre autres - des verres métalliques, des alliages superélastiques, superplastiques ...

Depuis 2004, nouvelle (?) approche du *design* d'alliages en considérant de multiples composants principaux dans proportions proches de l'équimolarité

Appellations diverses et variées : HEA, baseless alloys, multicomponent alloys, compositionally complex alloys (CCAs) ...

**Nanostructured High-Entropy
Alloys with Multiple Principal
Elements: Novel Alloy Design
Concepts and Outcomes****

By Jien-Wei Yeh,* Swe-Kai Chen, Su-Jien Lin,
Jiong-Wen Gan, Tsung-Shun Chin,
Tao-Tsung Shun, Chun-Huei Tsau,
and Shou-Yi Chang



Materials Science and Engineering A 375–377 (2004) 213–218



Microstructural development in equiatomic multicomponent alloys

B. Cantor, I.T.H. Chang*, P. Knight, A.J.B. Vincent

Department of Materials, Oxford University, Parks Road, Oxford OX1 3PH, UK
School of Metallurgy and Materials, Birmingham University, Birmingham B15 2TT, UK

"Alloying was an accidental discovery" - S. Ranganathan, 2003

Initialement, Cantor et ses co-auteurs souhaitaient obtenir de nouvelles et prometteuses nuances de ... verres métalliques !



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Abstract

Multicomponent alloys containing several components in equal atomic proportions have been manufactured by casting and melt spinning, and their microstructures and properties have been investigated by a combination of optical microscopy, scanning electron microscopy, electron probe microanalysis, X-ray diffractometry and microhardness measurements. Alloys containing 16 and 20 components in equal proportions are multiphase, crystalline and brittle both as-cast and after melt spinning. A five component $\text{Fe}_{20}\text{Cr}_{20}\text{Mn}_{20}\text{Ni}_{20}\text{Co}_{20}$ alloy forms a single fcc solid solution which solidifies dendritically. A wide range of other six to nine component late transition metal rich multicomponent alloys exhibit the same majority fcc primary dendritic phase, which can dissolve substantial amounts of other transition metals such as Nb, Ti and V. More electronegative elements such as Cu and Ge are less stable in the fcc dendrites and are rejected into the interdendritic regions. The total number of phases is always well below the maximum equilibrium number allowed by the Gibbs phase rule, and even further below the maximum number allowed under non-equilibrium solidification conditions. Glassy structures are not formed by casting or melt spinning of late transition metal rich multicomponent alloys, indicating that the confusion principle does not apply, and other factors are more important in promoting glass formation.

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Keywords: Multicomponent alloys; Equiatomic; Casting

Nanostructured High-Entropy Alloys with Multiple Principal Elements: Novel Alloy Design Concepts and Outcomes**

By Jien-Wei Yeh,* Swe-Kai Chen, Su-Jien Lin,
Jon-Yew Gan, Tsung-Shune Chin,
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ADVANCED ENGINEERING MATERIALS 2004, 6, No. 5

DOI: 10.1002/adem.200300567

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299

Il est possible de former une ou plusieurs solutions solides simples à partir d'un mélange d'au moins 5 éléments "chimiquement compatibles" dans des proportions comprises entre 5 et 35% atomique.

La forte entropie du mélange est la clé du concept pour Yeh ($>1.5/1.6R$). Les critères de formation sont structuraux, chimiques mais surtout ... empiriques !

(présentations IG / MLB)

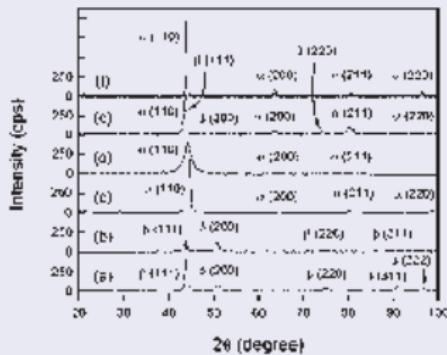


Fig. 2—XRD patterns of (a) as-cast CuCoNiCrFe bulk alloy, (b) as-cast CuCoNiCrAl_{0.5}Fe bulk alloy, (c) as-cast Cu_{0.5}CoNiCrAl bulk alloy, (d) as-sputtered Cu_{0.5}CoNiCrAl film, (e) as-cast CuCoNiCrAlFeTiV alloy, and (f) as-splat-quenched CuCoNiCrAlFeTiV foil (α : bcc, β : fcc).

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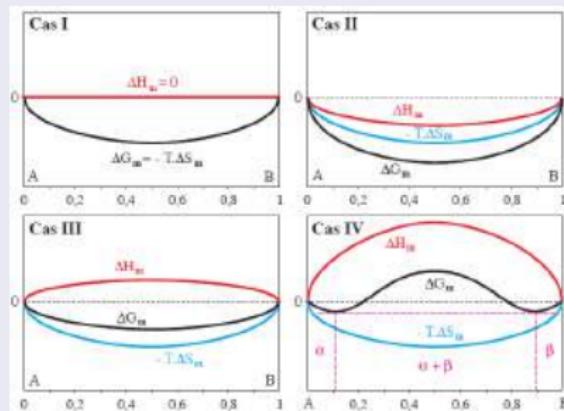
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299

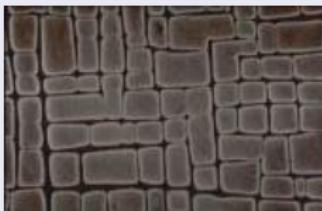
Il est possible de former une ou plusieurs solutions solides simples à partir d'un mélange d'au moins 5 éléments "chimiquement compatibles" dans des proportions comprises entre 5 et 35% atomique.

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(thème 1 - présentation MLB)

La motivation principale reste la stabilisation de la ou des solution(s) solides par l'entropie du mélange afin d'éviter la formation de phases intermétalliques, qui, dans la stratégie et le concept même des alliages de haute entropie, sont susceptibles de fragiliser l'ensemble. Discutable, surtout pour les applications structurales aux hautes températures ...



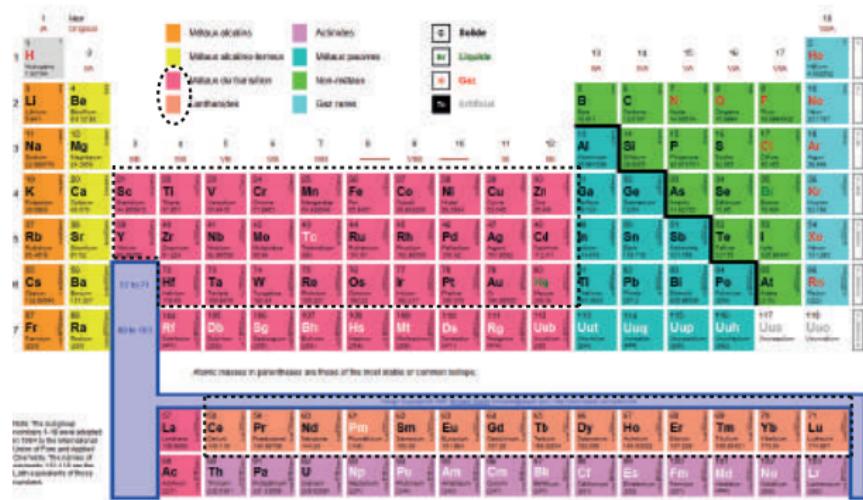
(source : ONERA.fr)

Il existe évidemment des bénéfices à cette stratégie :

- nombre incroyable d'alliages possibles ;
- formation de phases simples alliant bonne résistance mécanique ET ductilité importantes (sans parler des possibles gains sur les propriétés fonctionnelles)
- totalement en rupture et offrant des challenges scientifiques pertinents ...

Matériaux à base de métaux de transition voire de lanthanides, pour lesquelles les règles de Hume-Rothery sont susceptibles d'être respectées.

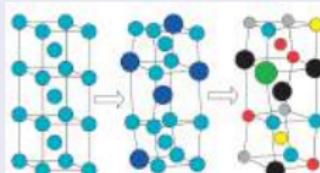
Deux grands blocs d'alliages étudiés pour l'instant : colonnes 4,5,6 (nuances réfractaires) et milieu/fin de ligne 4 (Fe,Cr,Ni...). ; les solutions solides sont souvent cristallographiquement "simples" (cc, cfc) mais peuvent être plus complexes (orthorhombique, hexagonal).



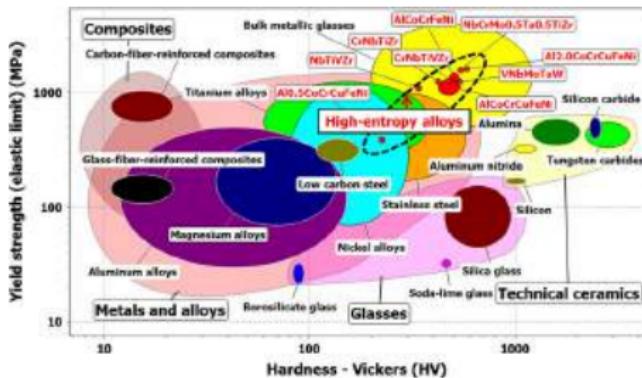
Quelles conséquences ?

- composite à l'échelle atomique ;
- distortions de réseau à priori sévères ;
- durcissement par solution solide attendu plus intense que dans les alliages conventionnels ;
- diffusion limitée ;
- effet cocktail - possibilité de faire varier les propriétés en fonction des éléments d'alliage

(thèmes 2/3 - présentations IG/JPC, GD)



Zhang et al., Adv Eng Mat, 10(6), 2008



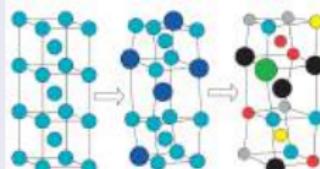
Tang et al., JOM, 65(12), 2013

Fig. 1. An Ashby map showing the range of yield strength (σ_y) versus HV for structural materials, such as composites, glasses, ceramics, and metallic alloys, along with the properties of BMGs, 3d TM-based HEAs with different Al content ratios^{3,24–33} and refractory HEAs.^{6,10,17,18,35–37} The black-dashed ellipse indicates the whole family of HEAs. For the interpretation of the references to color in this figure legend, the readers are recommended to refer to the online version of the article.

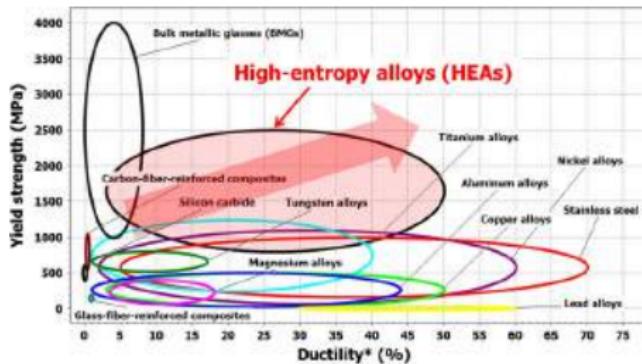
Quelles conséquences ?

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Zhang et al., Adv Eng Mat, 10(6), 2008



Tang et al., JOM, 65(12), 2013

* Ductility combines both tensile and compressive deformations at room temperature.

Fig. 2. An Ashby map showing the range of yield strength (σ_y) versus ductility for structural materials, such as composites, ceramics, and metallic alloys, along with the properties of BMGs, and HEAs.^{3,6,10,17,18,24,29,30,33,35-43} For the interpretation of the references to color in this figure legend, the readers are recommended to refer to the online version of the article.

Introduction - intérêt(s), potentialités

METAL ALLOYS

A fracture-resistant high-entropy alloy for cryogenic applicationsBernd Gludovatz,¹ Anton Hohenwarter,² Dhiraj Cates,³ Edeline H. Chang,⁴ Easo P. George,^{4,5} Robert O. Ritchie^{4,6}

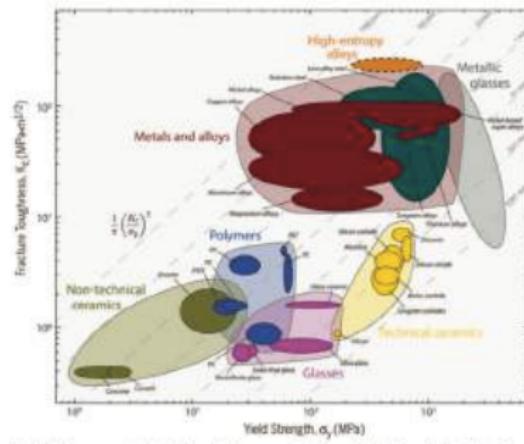
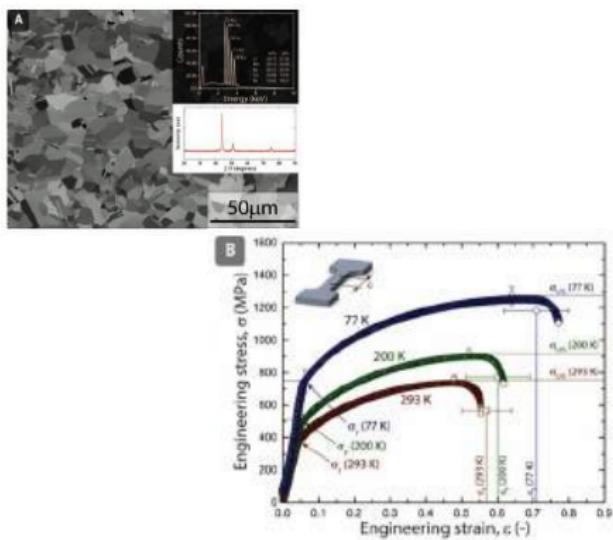
High-entropy alloys are equiatomic, multi-element systems that can crystallize as a single phase, despite containing multiple elements with different crystal structures. A rationale for this is that the configurational entropy contribution to the total free energy in alloys with four or more elements is large enough to overcome the enthalpy of formation of various microstructures. We examined a five-element high-entropy alloy, Cr_{0.5}CoCr_{0.5}, which forms a single-phase face-centered cubic solid solution, and found it to have exceptional damage tolerance at low temperatures. It can withstand cyclic loading at 77 K without exceeding 200 MPa $\sigma_{\text{f}}^{(20)}$. Furthermore, its mechanical properties actually improve at cryogenic temperatures; we attribute this to a transition from planar-slip dislocation activity at room temperature to deformation by mechanical twinning with decreasing temperature, which results in continuous steady strain hardening.

A fracture-resistant high-entropy alloy for cryogenic applications

Bernd Gludovatz et al.

Science 345, 1153 (2014);

DOI: 10.1126/science.1254581



Pour l'anecdote

Properties and potential uses [edit]

HEAs, because of their high formability and strength combined with low density, are expected to replace [superalloys](#) in energy sectors and aero-space applications. Because HEAs are a cocktail of metallic elements, a wide range of materials can be produced which can serve future requirements at a lower cost with superior mechanical properties.

Recent research has also indicated that magnetic properties of high entropy alloys could also be promising.^[12]

Applications potentielles ...

accelerate development. Structural materials require many other properties to be successful, and some work already reports on the corrosion resistance, oxidation behaviour and wear properties of structural HEAs.⁵ High entropy alloys also have properties that may be attractive for functional applications. Electrical, thermal and magnetic properties of HEAs have already been measured.⁵ The HEAs have been considered as diffusion barriers for microelectronics, for hydrogen storage and for applications that require catalytic properties or resistance to irradiation damage.⁵

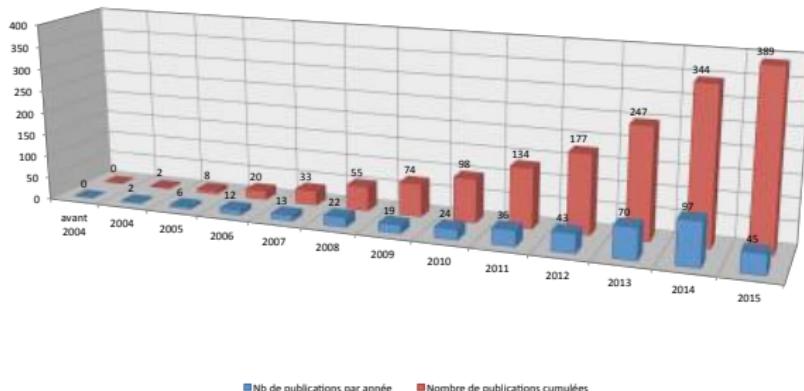
Miracle, Mat Sci Tech, (uncorrected proofs), 2014

MAIS les travaux effectués jusqu'à présent ne s'attachent qu'à démontrer l'attractivité de ces matériaux ...

Effervescence dans la communauté scientifique internationale depuis 2004 (TMS, european meeting 15-18/07/2014) ... mais finalement assez peu en France (journée annuelle de la SF2M 2015) !

- ICMPE, LSPM
- Groupe GREMI (couches minces) - Anne-Lise Thomann, Orléans
- Laboratoire Georges Friedel (ingénierie) - Anna Frackiewicz, St Etienne
- Institut P' - Gilles Laplanche, Poitiers

Source: Web of Knowledge - mot clé: "high-entropy alloys"
06 mai 2015



Journée scientifique de découverte, d'échanges, de débats et de ... transversalité sur un sujet où les problématiques sont multiples et multi-échelles :

- échelle atomique : critères de formation ? thermodynamique ? simulationS ? outils adaptés à l'étude de ces alliages ? (*thème 1*) ;
- échelle micro-méso : comportements microstructuraux ? mécanismes de déformation plastique ? (*thème 2*) ;
- échelle macroscopique : propriétés fonctionnelles ? mécaniques ? environnementales ? (*thème 3*) ;
- futur : quelles voies privilégier, et pour quelles applications potentielles ?