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Multiple Component Alloys: The Way Forward in Alloy Design

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Alloy development is integral to the evolution of human society. Comparatively superior (isolated or combination of) properties are always desired and required by engineers as the services conditions are continuously getting stringent and high performance expectations and enhanced levels of reliability is always sought by end users. Besides, engineers are always stretching the limits of materials primarily through alloy design and utilizing composite technology.[1,2] The history of alloy development goes thousands of years back, however, number of alloys developed were limited due to absence of scientific knowledge and characterization techniques. Most of the materials (alloys) development than was by trial and error. Significant progress in science from 19th century onward triggered the development of wide spectrum of alloys which were principally based on one primary alloying element. During the latter part of 20th century, advanced steel, nickel based alloys, aluminium based alloys and titanium based alloys made inroads into multiple engineering and biomedical applications adding to the convenience and comfort in the life of humans and simultaneously strengthening the defence forces of the countries. In early part of 21st century, high entropy alloys (HEAs) were reported.[3] These alloys contained multiple alloying elements and were designed principally based on configurational entropy (Fig. 1). Equiatomic compositions and single phase structure was initially targeted and subsequently non-equiatomic compositions and multiphase microstructures were also reported. In the early stage of research, high density elements such as Fe, Cu, Ni were used and multiple applications of HEAs were identified (Table 1). Materials scientists, following the discovery of HEAs started classifying all the alloys principally based on configurational entropy as illustrated in Fig. 1. Intense research efforts are continuing over about last 15 years by researchers worldwide to explore development of multi-component high entropy alloys with different combination of elements and different combination of properties.[4]

Table 2 shows the properties realized by HEAs especially with density values lower than 3g/cc targeted for weight critical applications.[5] High density HEAs on the other hand as indicated in Table 1 are more suitable for applications such as in nuclear sector and principally in unmovable systems. The development of light

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weight HEAS was triggered to stem global warming which is deteriorating with every passing day due to significant expansion in automobile, aerospace and maritime sectors. High density HEAs while showing promise in certain engineering sectors have almost minimal scope in conventional transportation sector.

In this context, it must be noted that in recent past not many new alloys are introduced in other metal systems particularly the one exhibiting densities lower than conventional aluminium alloys. To replace aluminium alloys, magnesium technology is rapidly emerging and do provide a viable solution for weight reduction. However, even in case of magnesium alloys the number of commercial alloys are limited and so is the spectrum of properties they exhibit.[2] In the context of classification of alloys based on configurational entropy, practically all conventional alloys comes under the category of low entropy alloys. Over past century, the properties of low entropy or traditional alloys were tailored primarily through controlled secondary processing and/or heat treatment processes. These methods of enhancing and tailoring properties of traditional alloys based on their end application are almost saturated. To further note that the process of heat treatment is an additional step for microstructural engineering and adds to the cost of the end material or finished product. From the perspective of enhancing properties attention has to be placed on compositional control and to develop

Low Entropy Alloys	Medium Entropy Alloys	High Entropy Alloys
$\Delta S_{conf} \leq 1R$	$\Delta S_{conf} = 1\text{-}1.5R$	$\Delta S_{conf} \geq 1.5R$
Less than 3 element.	Typically 3-4 elements	Typically > 5 elements
Non-equiatomic. Multiphase microstructure.	Equiatomic or non-equiatomic. Multiphase microstructure.	Equiatomic or non-equiatomic. Single or multiphase microstructure

Fig. 1: Configurational entropy based classification of metallic alloys.

Table 1: Applications and Properties Targeted From HEAs[4]

Applications	Desired/Targeted Properties
Engine Materials	High temperature strength. Oxidation resistance.
Nuclear Materials	High temperature strength and toughness. Low irradiation damage.
Tool Materials	High room and elevated-temperature strength and toughness. Wear resistance. Low friction. Oxidation resistance.
Waste Incinerators	Improved elevated-temperature strength. Wear resistance. Corrosion resistance. Oxidation resistance.
Chemical Plants	Improved corrosion resistance. Wear resistance. Cavitation resistance.
Marine Structures	Improved corrosion and erosion resistance.
Heat Resistant Building Materials	Superior elevated temperature strength.
High Frequency Communication Materials	High electrical resistance and magnetic permeability above 3 GHz.
Functional Coating Materials	Improved wear and corrosion resistances. Low friction coefficient.
Hydrogen Storage Materials for Automobiles	High reversible volumetric and gravimetric density of hydrogen.
Light Transportation Materials	Near ambient cycling condition.

Table 2: Density and Compressive Properties of HEAs with low Densities[5]

Alloy System	Density	CYS (MPa)	UCS (MPa)	CFS (%)
Mg43(MnAlZnCu)57	2.51	500	500	3.72
Mg45.6(MnAlZnCu)54.4	2.3	482	482	4.06
Mg50(MnAlZnCu)50	2.2	340	400	4.83
AlLiMgZnSn	3.88	600	615	1.2
AlLi0.5MgZn0.5Sn0.2	2.98		546	0

multi-component alloys where the secondary phases are developed inherently during processing step to exhibit superior combination of properties without the need of heat treatment. The necessary expectations from these multicomponent alloys will be superior combination of properties when compared to conventional alloys in any possible processed or heat-treated state. This should lead to the development of multiple component alloys in both low and medium entropy classifications besides HEAs. Judicious use of alloying elements and better understanding of multi-component phase diagram can enable the researchers to move along this direction. While high density HEAs have their own niche application areas, research in lightweight multicomponent alloys in all the categories (low, medium or high entropy) is the need of the day for the better health of planet earth and its inhabitants.

Concluding Remarks

Development of traditional metallic alloys using one or two principal alloying elements has reached a saturation point. Various secondary processing techniques and simple to complex heat treatments have been utilized to realize best properties from these alloys over last seven decades. Multicomponent alloy design and development is the way forward to realize much superior combination properties. In addition, such alloys have the potential to eliminate the need of heat treatment to further enhance the properties thus reducing the cost of end material.

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