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High Entropy Alloy Systems- (HEAs) – A Review

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High entropy alloys (HEAs) are the most recent in terms of materials and manufacturing focus, based on a century of alloy development from steels to super alloys. Some publications referred to them as multi-component alloys (MCAs), while others as high-strength alloys. Of course, many researchers referred to them as Compositionally Complex Alloys (CCAs), as the word suggests the difficulty in comprehending their behavior. The HEAs field started the studies only about 12 to 15 years ago. A wide range of research opportunities can be found in the HEAs field for newer materials. As a result of the overwhelming display of mechanical, structural, electrical, and chemical properties of HEAs, researchers actively embrace and explore newer ideas and combinations of approaches for additional findings in depth of emerging progress in this innovative domain. Although conventional techniques such as stir casting, powder metallurgy, and surface coating are not very easy to procure, HEAs ultimately encompass various advanced technical processes such as stir-friction welding, rapid solidifying methods, extrusion reciprocation, spray-forming methods, the spark plasma sintering technique, nano-material forming, thermo-mechanical, and chemical treatments, etc within a more substantial number of fields of applications. For a specific targeted application in an exotic environment where requirements are particularly severe, a HEA can, of course fulfill that requirement with the correct specific alloying of elemental composition and suitable manufacturing process. The final goal of HEA development is to not only address the unique needs of applications in harsh environments but also provide longer life and increased service, which may lower production costs, production time, and even allow for energy savings. This paper gives some examples of HEAs that are suitable for certain purposes, as well as some manufacturing processes that reveal whether there is near, mere, or scary toil involved in their proper manufacture.

Keywords: HEA, High Strength alloys, Stir Casting.

1. Introduction

Materials have evolved from simple metals to sophisticated mixtures based on humanity's capacity to meet needs. This leads to better material performance and efficacy, and alloys help human civilizations develop. Over the last century, significant evolution and development have led to the creation of special alloys such as high-speed steels and super alloys.

History of HEAs.

From the beginning of human history, man has been constantly looking for newer materials to meet newer challenges in daily life, starting with basic materials like rock and a garment and progressing to native metallic materials like copper, silver, and gold, and later invented and used alloys made of iron, tin, mercury, lead, and so on. It is the ongoing growth of the use of various materials for a wide range of purposes since the industrial revolution [1] and continues to the present day. For the past century, the majority of these materials have been generated using traditional procedures [2]. However, due to the great rise of requirements and comforts in recent years, it has become necessary to identify newer materials with specialized applications at a competitive cost and with significantly increased life that can be produced easily. In the early 1980s, a modern and novel notion arose to address such needs.

Cantor has been working with his undergraduate student Alain Vincent at Sussex University to study essentially equiatomic multi-component alloys, and one of the experimental alloys included 20 components [3]. They demonstrate that there is only one atomic percent composition of 20Co - 20Cr - 20Fe - 20Mn - 20Ni, which is a single Face Centered Cubic phase, and that all five elements were combined to form a unique solid solution with a distinct dendritic structure. This study was not published at the time, but it was published in Materials Science and Engineering-A in 2004, making it well-known as unique for its period [4].

HEAs were given the moniker 'High Entropy Alloys' because, during the creation of HEAs, equi-atomic sized elements were mixed in almost equal proportions, and the entropy rise of the mixing was significantly larger due to the huge number of elements in the mix [5].

There is no formal definition provided for high entropy alloys. Yeh et al. originally described HEAs as alloys comprising at least five elements in concentrations ranging from 5 to 35 atomic percent [6]. However, some authors and researchers ignore the entropy idea and even single-phase alloy purpose, instead focusing solely on the multi-component alloy space spectrum [7, 8, and 9]. Though there are various definitions for HEAs, some are composition-based definitions, others are entropy-based definitions, and some have mixed meanings, many of which cause misunderstanding. The condition for equimolar concentrations is limiting, therefore the following sentence broadens this definition to include "principal elements with the concentration of each element being between 35 and 5 at.-%." Thus, HEAs do not have to be equimolar, which dramatically increases the quantity of HEAs. HEAs may also have small features that affect the attributes of the base HEA, hence increasing the number of HEAs [10]. J.Baburao et al. created a high-strength alloy (HSA) by adding a ternary alloy Al-20Mg-10Cu particle, which has high strength particulate in AA2024 and can also be regarded a multi-component alloy to achieve high strength [11].

Limitations and barriers:

With a higher density of 2.67 g/cc and micro hardness of 4.90 – 5.80 GPa 20Al-20Li-10Mg-20Sc-30Ti alloy which is of nano single-phase has been developed , which gives an estimated strength-to-weight ratio comparable to that of ceramic materials such as SiC, Al_2O_3 [12], but the high cost of scandium limits the possible uses [13]. So a substitute for scandium should be investigated that suit to particular applications. Similar many barriers are to over cross.

Corrosion of HEAs – a critical limitation to be analyzed:

Chen et al.17 conducted very basic work on the corrosion characteristics of HEAs at early lines of HEAs development. They investigated the corrosion behavior of the $Cu_{0.5}$NiAlCoCrFeSi alloy in different solutions and compared with that of corrosion properties of AISI 304 SS (an austenitic stainless steel). it was observed that the $Cu_{0.5}$NiAlCoCrFeSi alloy had a lower rate of corrosion than AISI 304 SS in all the test solutions [14].

The influence of different alloying elements on the corrosion of Compositionally Complex Alloys (CCAs):

The influence of aluminum on the corrosion of CCAs :

Aluminium (Al) is one among light, cheaper and abundant metal used to gain lower the density of CCAs. It has also been reported that Al serves to increase the mechanical strength of the HEAs synthesize with Fe, Ni, Cr, Co and Ti [15 - 16]. The corrosion rate of CCAs with Al may be expected to increase with increasing Al content in depassivating conditions or conditions that promote dissolution [17].

The influence of copper on the corrosion of CCAs :

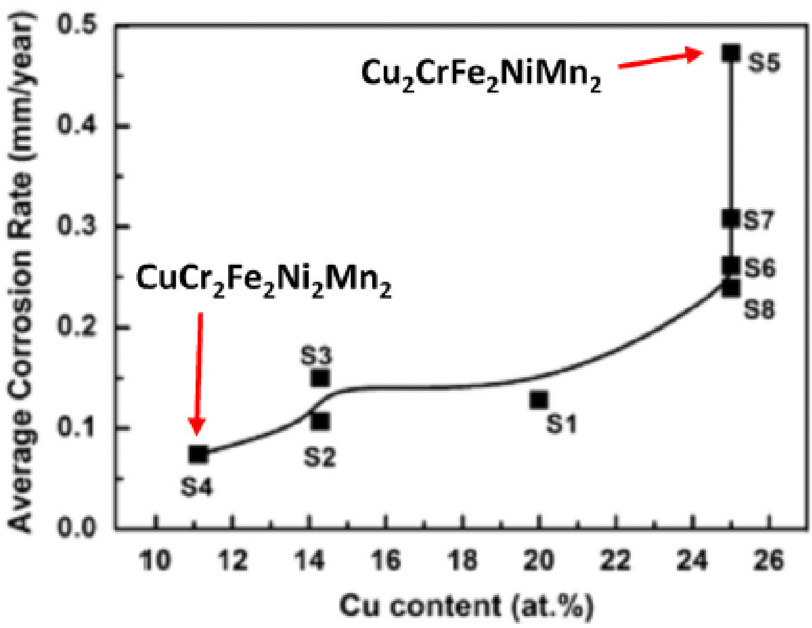

Fig. 1 Effect of Cu content on the rate of corrosion

Many researchers have revealed the effect and influence of copper on electro-chemical response and on the corrosion of CCAs [18].

The effect of Cu on the corrosion of the CuCrFeNiMn system was also investigated by Ren et al. using immersion tests and potentio-dynamic polarisation tests. The $CuCr_2Fe_2$-Ni_2Mn_2 alloy with a low Cu content had the highest corrosion resistance as minimum amount of elemental segregation, whereas the Cu_2Cr-Fe_2Ni_2 -Mn_2 alloy with the higher Cu content had the poorest corrosion resistance as more substantial Cu elemental segregation as shown in fig.1 [19].

2. Conclusions:

HEAs area is emerging and has huge scope for investigation and innovation. Various compositions of alloying elements lead to different microstructures with different properties in different directions. Moreover, different techniques are available and all the techniques and methodologies are suitable for this area. As an outcome, correlations between composition, methodologies, properties, and microstructure in HEAs provide unlimited research issues for both scientific interest, applied sciences and industry. But the investigations in the direction of solutions for challenges like cost, corrosion and correlation with the application area are to be accelerated.

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