Process Optimization and Wearing Characterization of As-Cast and Heat-Treated Cocrfemnni(Alx) High Entropy Alloy

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Abstract: This study aims to study a CoCrFeMnNi(Alx) High Entropy Alloy (HEA) with high wear resistance produced by standard induction melting from scrap and ferroalloys.

To the HEA base alloy, Al was added to promote a decrease in grain size and improve the final wearing properties The thermal treatment (TT) was optimized to increase the solubility of alloying elements at 1,100ºC for 36 hours and immediately water cooling.

The coefficient of friction (COF) and wear rate values are like those obtained from pure metals and with multiple remelting phases by vacuum arc melting. Adding Al in the alloy promotes a decrease in hardness and COF, and an increase in wear rate values, which is anomalous in metals. TT increases hardness and decreases COF and wear rate. The study of samples explains the abnormal behavior by the finer microstructure in Al as-cast samples and the presence of more precipitates in TT samples. The obtained processes and alloys can have future use in automotive or energy applications.

Keywords: HEAs; Wear; Induction melting, Scrap.

1 Introduction

HEAs are very promising because of their excellent mechanical and wear properties. The Cantor alloy [1] is obtained by the combination of five molar metallic elements (5-35%), with a single-phase solid solution structure. These alloys exhibit improved wear [2]. Wear properties information is still scarce, especially for Cantor alloys alloyed with different amounts of Al.

This study focuses on preparing a Cantor alloy by an industrial standard process and using low-cost and CO_2 emissions raw materials. Al addition has been added to increase the wear properties. Al can modify the microstructure of Cantor alloy, promoting smaller grains and precipitates with an increase in wear properties [3].

2 Experimental procedure

30 Kg of casting samples were produced in an induction furnace with no atmospheric protection. Steel scrap, ferroalloys, and an aluminum alloy were employed as raw materials. First, a base of iron scrap melt was obtained, and the highest melting point ferroalloys were added sequentially. The melt was maintained for 5 minutes at 1,650ºC, cleaned, and poured into a sand mold.

Hardness was measured using the Vickers diamond indentation test with a load of 10 kg for 10 s according to UNE EN ISO 6507-1. Dry sliding-wearing friction tests were carried out in a sphere-on-plate reciprocating configuration using a ball-on-disk mode tribometer according to the ASTM G99-05 standard without any lubricant, with a load of 10 N, 0.1 m/s, and 1,000 m.

3 Result and discussion

In Table 1, we can observe the obtained compositions.

Table 1: Compositions of studied alloys (wt.%).

Alloy	Co	Cr	Fe	Mn	Ni	Al
CoCrFeMnNi	20.4	17.7	20.5	18.9	21.8	-
CoCrFeMnNiAl$_{0.03}$	20.5	17.9	20.5	19.4	21.0	0.3
CoCrFeMnNiAl$_{0.3}$	19.8	17.4	20.0	18.9	20.5	2.8

In Table 2, we can observe the obtained hardness values.

Table 2: HV10 Hardness values of studied alloys.

Alloy	As-cast	TT
CoCrFeMnNi	148.5±2.6	149.6±4.2
CoCrFeMnNiAl$_{0.03}$	136.0±4.7	140.4±6.6
CoCrFeMnNiAl$_{0.3}$	132.9±1.0	122.0±4.8

Al addition decreases the hardness and treatment slightly increases the hardness, but not significantly, except in CoCrFeMnNiAl$_{0.3}$. TT increases hardness in samples without Al or with low aluminium.

Microstructure shows a dendrite structure with an interdendritic area and precipitates, with FCC#1 the solid solution of the alloy and FCC#2 the interdendritic phase richer in Mn and Ti. The as-cast sample with 0.03% Al has more precipitates but 0.3% samples less. Cubic precipitates are slightly richer in Cr-Mn [4] and Al dark phase precipitates in TT Al samples alloyed (Approx. Al68CoCrFeNi32 wt.%).

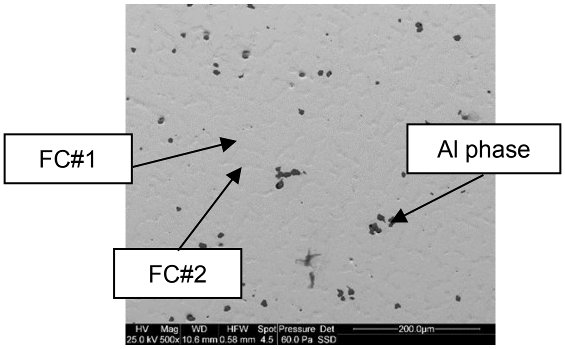

Figure 1 Microstructure of TT CoCrFeMnNiAl0.3 alloy

In Table 3, we can observe the ball-on-disk results.

Table 3: COF and wear rate values (mm3/N.m).

Alloy	μ, COF	Wear rate
CoCrFeMnNi	0.74±0.00	8,72E-04±0.11
CoCrFeMnNiAl$_{0.03}$	0.75±0.01	8,32E-04±0.13
CoCrFeMnNiAl$_{0.3}$	0.71±0.02	1,14E-03±0.14
TT-CoCrFeMnNi	0.73±0.00	8,28E-04±0.06
TT-CoCrFeMnNiAl$_{0.03}$	0.72±0.01	8,94E-04±0.02
TT- CoCrFeMnNiAl$_{0.3}$	0.68±0.02	1,06E-03±0.02

The addition of Al in the alloy promotes in general a decrease in hardness and COF (in disagreement with the decrease in hardness) and an increase in wear rate values, which is not common in HEAs [5,6]. TT samples showed smaller COF (in agreement with the increase in hardness values in TT samples except in CoCrFeMnNiAl$_{0.3}$) and smaller wear rates than as-cast samples (except in CoCrFeMnNiAl$_{0.03}$).

The wear analysis shows the transition from abrasive and adhesive wear to delamination that induces large plastic strains and strain gradients near the worn surface, with smaller wear in the samples with more precipitates, reducing the delamination effect.

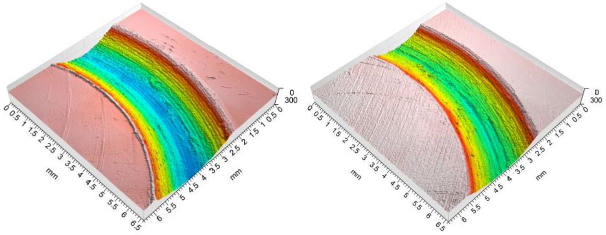

Figure 2 As-cast and TT CoCrFeMnNiAl0.3 alloy 3D profile.

Conclusions

The main results of the study of the new alloy are:

- Obtained wearing values are like high-purity multi-melted vacuum Cantor alloys.
- Adding Al decreases the COF and increases the wearing rate by having a higher matrix area.
- TT samples had smaller COF and smaller wearing rates by presenting more hard precipitated phases.
- Low Al addition seems to act similar to a grain refiner.
- The obtained processes and alloys can have future use in automotive or energy applications.

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