HIGH ENTROPY ALLOYS WITH SHIELDING PROPERTIES FOR AGGRESSIVE MEDIA

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Applications in a variety of industries (radio frequency, electromagnetic medicine, military, etc.) that require electromagnetic shielding are currently solved by using conductive materials such as Cu, Al, Fe, Ni, Au, Mo, etc. This paper presents CoCrFeNiMo a high entropy alloy produced by mechanical alloying with good corrosion and wear resistance according to recent studies, but also having economic efficiency when utilized as a coating. When the material was tested for its electromagnetic shielding properties, the obtained results presented values between 19.1-57.97 dB in 100 kHz – 13.5 GHz frequency range. The proposed material could represent a solution for a variety of applications.

Keywords: electromagnetic (EM) shielding, EMC, high entropy alloys, corrosion.

1. Introduction

The EMC (electromagnetic compatibility) refers to the capacity of a system to operate satisfactorily in its electromagnetic environment without causing intolerable electromagnetic disturbance [1]. Electromagnetic compatibility consists of two components: emission (energy that can affect the performance of an electronic system) and susceptibility (level of which electronic equipment fails). In order to protect devices from environmental interference, a variety of electromagnetic shielding materials are developed [2]. According to the European Space Agency (ESA) [3], a wide range of satellite frequencies are in use for protocol communication, starting with the marine navigation that used low frequencies ranges 3-30 kHz and could go up to 30-300 GHz for radio astronomy.

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For the military domain, applications as missile and missile defense, man-portable communications, stationary shelters, aviation, satellites, ground vehicles and electronic radar systems, the electromagnetic interference is a requirement according to East Coast Shielding [4]. For radar applications, the X-band (8-12 GHz) is primarily used by military and government institutions as a main secure satellite frequency. Electromagnetic shielding could be accomplished by totally enclosing/covering a device in order to protect it from environmental interference in which it is located.

According to literature [5,6], there are 3 main standards that are of high interest in military, MIL-STD-461, MIL-STD-462 and MIL-STD-464, the last one being the most common military standard for system levels of electromagnetic compatibility. These standards indicate limits specification that include the frequency range of the measurement performed in this paper, such as: CE102 – 10 kHz to 10 MHz frequency range having applicability in power leads, CE106 – 10 kHz to 40 GHz frequency range used in antenna terminals of receivers and transmitters, CS104 – 30 Hz to 20 GHz frequency range suitable for radar receivers, electronic warfare receivers, RF amplifiers, CS116 – 10 kHz to 100 MHz for interconnecting cables and individual power leads. Under the same standards are the limits for radiated emissions that apply for our research: RE102 (electric field) – 10 kHz to 18 GHz – equipment or subsystem enclosures and RE103 – 10 kHz to 40 GHz.

This research was focused on developing a high entropy alloy that could represent a possible solution for the presented case. Based on the specific effects of these types of alloys [7-9], for this paper, CoCrFeNiMo high entropy alloy electromagnetic shielding properties were studied. According to recent research, corrosion resistance properties are also expected, due to low corrosion rate obtained in aggressive environments such as geothermal steam or saline solution [10,11].

2. Materials and Methods

Cobalt, chromium, iron, nickel and molybdenum high purity, raw metallic powders were used in order to obtain a solid state processed high entropy alloy.

Mechanical alloying was performed in a Pulverisette 5® Fritch, Idar-Oberstein, Germany planetary mill with 2 posts. In order to reduce the contamination of the material to a minimum during the process, stainless steel vials and balls were used. 2% N-Heptane was added to the composition as a process control agent due to the benefits of improving the alloying degree and reducing the alloying time. The alloying and contamination degree of the metallic powder was analyzed by Scanning Electron Microscopy (SEM) with a FESEM-FIB Workstation Auriga produced by Carl Zeiss, Germany equipment and Energy-dispersive X-ray spectroscopy (EDS) SDD, X-MaxN, Oxford

Instruments. The samples were taken from the homogenized mixture and after 30 h of mechanical alloying.

The metallic powder was pressed into ring shape samples using Sirio Dental Srl, P400 Meldota FC, Italy manual pressing equipment with a ring shape custom mold of ext dia. 7 mm and int. dia. 3 mm and height of over 10mm, according with the specific dimensions of the coaxial cell. In order to obtain the ring shape samples and to be able to handle them, 20 wt.% paraffin was used as binder and at a 2 MPa pressing force.

The measurements were performed using 2 equipment's: a spectrum analyzer and a signal generator with a coaxial cell connecting them. The spectrum analyzer used was a ROHDE&SCHWARZ FSP13 Munchen, Germany with 9 kHz – 13.6 GHz frequency range which had the following setup settings for our measurements, presented in table 1.

Table 1

Electromagnetic shielding measurements parameters

Frequency Range	Measurements	Detector	Trace	RBW [kHz]	SPAN [kHz]
100 kHz – 13.5 GHz	60	RMS	Average	10	200

The second equipment used was a signal generator Agilent E8257D Santa Clara, California, United States which is a fully synthesized signal generator with a high output power and little phase noise with 250 kHz to 40 GHz frequency range. It was configured with the following setting: Amplitude = 10 dB. The electromagnetic shielding measurements setup is presented in Fig. 1.

Fig. 1. Electromagnetic shielding measurements setup

In order to determine the electromagnetic shielding, the setup for the measurements starts from the signal generator connected through a cable with the spectrum analyzer, in the middle of the cable being the coaxial cell. In the first phase, we measured without a sample for the reference values and in the second phase, we attached the sample and repeated the same measurements on the same frequencies and maintaining the same signal level as in phase 1. The electromagnetic shielding properties of the measured material are determined by the difference between the two phases.

3. Results and Discussions

After the mechanical alloying process of the CoCrFeNiMo mixture was performed, the homogenized sample and the sample taken after 30 h of milling were microstructurally analyzed and the results are presented in the next Fig..

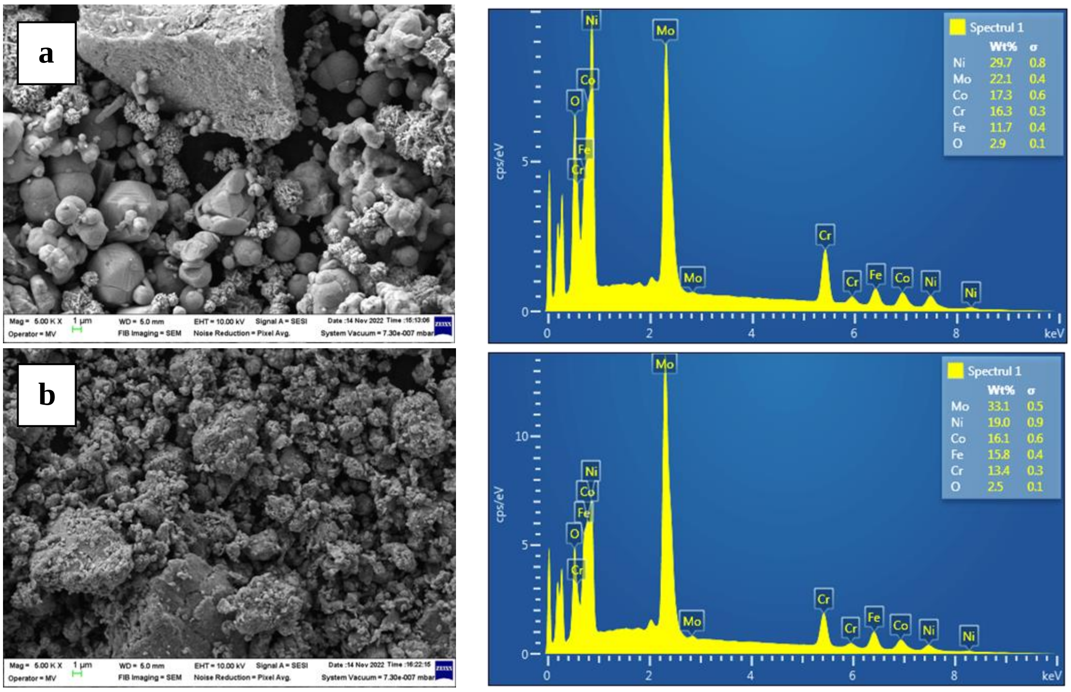

Fig. 2. Microstructural analyzes results for the alloyed CoCrFeNiMo a) homogenized sample and b) after 30 h of mechanical alloying in a planetary ball mill

As it can be observed from the microstructural analyzes after 30 h of milling the particles have polygonal shapes, an improved uniformity of the size and color, compared to Fig. 2.a where for each element could be observed different characteristics as shape, size and color of the particles. The results indicate that the alloying process was produced.

From the EDS analyzes (Fig. 2.b) no traces of contaminants were found in both samples, only a low degree of oxidation.

After the high entropy alloy was homogenized with the binder, ring shape compacted samples were obtained by pressing and presented in Fig. 3. The green samples were produced based on the coaxial cell dimension requirements. As observed, the binder aided the pressing process, so the handling could be performed without damaging the samples.

Fig. 3. High entropy alloys metallic powder compacted into ring shape samples

After the samples were compacted into ring shape, they were placed in the coaxial cell and the shielding effectiveness (SE) was measured. Fig. 4 shows the SE values obtained as a function of frequency.

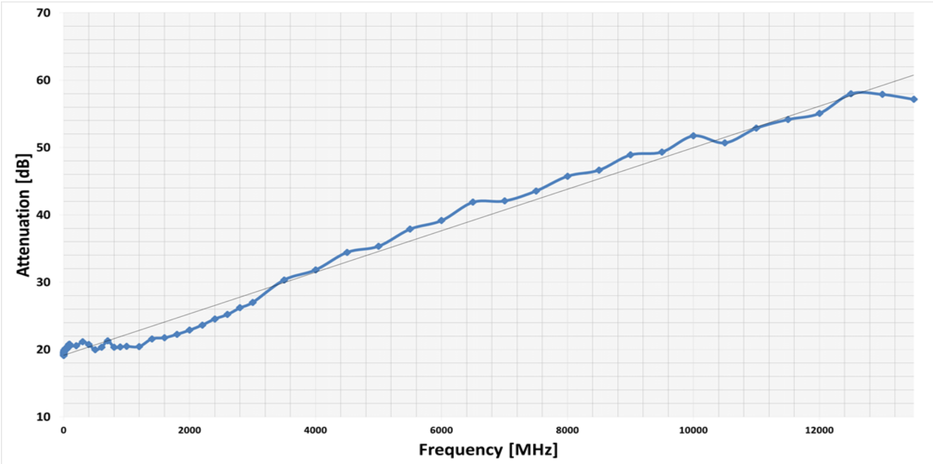

Fig. 4. EMI shielding effectiveness of CoCrFeNiMo in the 100 kHz – 13.5 GHz range

It can be observed that, as the frequency increases, the shielding effectiveness of the tested material also increases. For frequencies up to 2 GHz it is noticed that the shielding effectiveness values were relatively low, with a maximum of approximately 25 dB. The maximum value of shielding effectiveness was 57.97 dB and was reached at the frequency value of 12.5 GHz, resulting that the alloy is suited for high frequencies domains.

6. Conclusions

After 30h of milling in a planetary ball mill, a high degree of alloying was obtained, with no contamination of the powder being observed according to the EDS analyses, the results being presented. The ring shape high entropy alloy compacted samples were obtained, and measurements were performed.

Electromagnetic shielding measurement results showed shielding effectiveness values between 20 dB and 57.97 dB in the 100 kHz – 13.5 GHz frequency range, the maximum value being at 12.5 GHz, which indicates that the proposed alloy could represent a possible option as a shielding material for a wide range of applications in the selected frequency range.

Future work will be focused on developing high entropy alloy electromagnetic shielding coatings for various topographies and environments.

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