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Fabrication of MMCs from metal and alloy powders produced from scrap

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Abstract

Metal matrix composites (MMCs) present a lot of advantages over conventional engineering materials due to their improved properties. In the present work, Ni_3Fe–Al_2O_3 and (3Ni + Fe)–Al_2O_3 composites with a 100–65 wt% metals or alloy content were prepared. For that purpose, lower cost Ni, Fe and Ni_3Fe powders, recovered from ferrous scrap by a hydrometallurgical process recently developed, with properties similar to typical commercial grades, were used along with commercial Al_2O_3 powder. An established simple and economical fabrication technique was applied, comprising uniaxial cold pressing and sintering. The composite microstructures were characterized by optical, scanning electron microscopy, EDX and XRD analysis. Density measurements were also performed by the Arcimedes' method. The used metallic powders generally showed a satisfactory behavior in the fabrication steps leading to the successful development of particle reinforced MMCs containing no phases other than the constituent and exhibiting a sintering degree varying with the ceramic content. Important porosity levels were revealed, that were more pronounced in the Ni_3Fe-based composites, in which zinc stearate was demanded as a lubricant.

Keywords: Metal matrix composites; Alloy matrix composites; Metal powders; Alloy powders; Scrap; Microstructure

1. Introduction

Due to their improved properties, the metal matrix composites (MMCs) present a lot of advantages over unreinforced metals [1–3]. Consequently, the commercial applications of MMCs are increasing rapidly today and the market is expected to expand considerably in the near future. However, the final barrier to be overcome is their higher cost in comparison to conventional engineering materials. Therefore, there is a challenge of developing such composite materials, while reducing the production cost.

Samuel has already introduced direct conversion of granulated Al-2014 scrap alloy, as a low cost raw material, into ceramic fiber reinforced MMCs [4]. In the present research program, the use of lower cost metal and alloy powders recovered from ferrous scrap, a largely available and low price waste material, in the elaboration of MMCs reinforced with a commercial grade ceramic powder, through an established simple and economical powder metallurgy route, is attempted. The powders production from scrap was realised by a hydrometallurgical process recently developed, with many advantages in its steps [5–7]. It must be noticed, that the recovery of metals from scrap is nowadays more than ever necessitated not only by economical but also environmental reasons.

The encouraging results from the application of so-produced Ni powder to Ni–Al_2O_3 MMCs development [8,9], suggest a similar elaboration of Ni alloy matrix composites, expecting an improved behavior. Intermetallic-ceramic composites represent an interesting class of materials for high-temperature applications. Recently, Ni–Fe alloys have attracted much attention due to their interesting mechanical and magnetic properties. Ni_3Fe in particular, is also known for its high ductility and its insensitivity toward the testing environment [10]. In addition, there are ordering

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tendencies near this composition, generally improving mechanical performance. Bose et al. [11] have fabricated Ni_3Fe–Y_2O_3 composites starting from Ni and carbonyl Fe powders. Nowadays, there exists an increasing interest in utilizing prealloyed powders, produced by mechanical alloying, to develop alloy matrix composites. In the present research, Ni_3Fe alloy powder, also produced from ferrous scrap by the above mentioned hydrometallurgical process, was used as a raw material, instead of the elemental powders, in the development of Ni_3Fe matrix composites, a novel approach. The aim of developing lower cost MMCs suggests the use of commercial grade Al_2O_3 powder as the reinforcement. Besides, a significant stage of the present study should be the comparison between these composites, developed using the Ni_3Fe alloy powder (Ni_3Fe–Al_2O_3), and those prepared by mixing the appropriate amount of Ni and Fe powders (weight ratio of 3:1) of the same origin ((3Ni + Fe)–Al_2O_3). From an economical point of view, if the elaboration of comparable performance composites was achieved, the use of the metal powders mixture would be preferable to the corresponding alloy powder. The effects of several fabrication parameters on the composite microstructures are also discussed in this work.

2. Experimental

2.1. Materials

The starting material that yielded metal and alloy powders for use in MMCs in the present study was ferrous scrap consisting of discarded cutting tools. It can be classified as stainless steel 316 [6,9]. This waste material was cut into smaller pieces and then treated by the aforementioned hydrometallurgical process: Ni and Fe powders were produced by reduction with hydrogen of the Ni and Fe chlorides, respectively, which resulted from dissolution of the scrap with HCl_{aq} and were selectively extracted by Versatic acid 6 (Shell Company Ltd.) from their acidic solution and then crystallized. Ni_3Fe alloy powder was produced from the Ni and Fe chlorides mixtures of the same origin in a similar way.

The characteristics of the produced and then used Ni, Fe and Ni_3Fe powders are listed in Table 1. It can be seen that their values are generally similar to these of typical commercially available powders produced by atomization, thus encouraging for powder metallurgical purposes. Typical SEM micrographs (Jeol JSM 35 CF) of these powders are presented in Fig. 1.

Commercial α-Al_2O_3 powder (corrundum, 0.9 μm mean particle size, 99% purity) from Aldrich Chemical Company, Inc. was selected as the ceramic reinforcement.

2.2. MMCs fabrication

(3Ni + Fe)–Al_2O_3 and Ni_3Fe–Al_2O_3 MMCs with a 100–65 wt% metals or alloy content, respectively, were elaborated through powder metallurgy route: the metal (or alloy)

Table 1
Comparison of Ni, Fe and Ni_3Fe powders recovered from ferrous scrap with typical commercial grades

	Ni powder		Fe powder		Ni_3Fe powder	
	Commercial grade (atomization)[a]	Recovered from scrap	Commercial grade (atomization)[a]	Recovered from scrap	Commercial grade (atomization)[b]	Recovered from scrap
Specific gravity (g/cm^3)	8.63	8.83	7.81	7.70	8.53	8.41
Specific surface (cm^2/g)	3100	3500	2500	1500		
Granulometry (μm)	−125 + 56:44%, −56:56%	−125 + 56:28%, −56:72%	−90:100%	−200:60%, −90:30%	−100 mesh	−125 + 56:30%, −56:70%
Particle shape	Hexagonal	Angular	Spherical	Spherical	Spherical	Angular
Apparent density (g/cm^3)			3.93	3.35		
Purity		99.90%		99.86%		99.85%

[a] INCO SA.
[b] ALFA AESAR (Ni–Fe: 80-20 wt%).