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Making iron aluminides out of scrap

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ABSTRACT

The abundance of iron and aluminum raw materials is often quoted as a strategic advantage of iron aluminides against other competing materials (not only stainless steels, but also nickel and titanium aluminides). These raw materials, however, are not only abundant in the form of ores in earth's crust, but also as scrap produced in the extensive technological activity associated with these base metals. The present work reports results of two prospective experiments designed for obtaining iron aluminides exclusively from readily available scrap (aluminum cans, carbon steel strips and stainless steel sheet metal forming residues, this last as a source of chromium and molybdenum). Two base alloys with nominal composition Fe–30Al–6Cr and different carbon contents were molten in a laboratory induction furnace with no atmosphere protection other than blowing Argon over the melt surface. The produced ingots were characterized concerning their microstructures and final composition, which allows estimating the incorporation efficiency of the alloying elements using this processing route.

Oxidation tests at the temperature range of 800–1100 °C under air were performed to demonstrate that these alloys show similar behavior as the ones obtained using conventional processing routes. The results are discussed concerning the viability of this low-cost processing route for the industrial production of iron aluminides.

1. Introduction

Iron and aluminum are two of the major components of earth's crust. Estimated reserves of iron ore and bauxite amount to 180 billion and 28 billion tons, respectively [1,2]. These two base metals also define two large industrial branches, which leads to the extensive processing of these ores into metallic products. As a consequence of this extensive technological activity, metallic residues, known as scrap, are produced. These scraps, produced during the processing of the metal, are known as new (or prompt) scrap and have a higher value than old (or post-consumer) scrap.

Secondary metallurgical techniques, used to recover these metals, are well developed (and, in the case of iron products, more than hundred years old), such that about all aluminum or iron new scrap produced in the iron and aluminum industry are recycled into metal in a second stage processing [3,4].

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A technical iron aluminide, in addition, is not merely a binary Fe–Al alloy. A typical technical composition includes many alloying elements, *e.g.* Cr, Mo and C, among others [5]. The first two metals are quite expensive in the pure form, but may be, for example, available in stainless steel scrap, since they are added as alloying elements in a larger amount in this class of materials. Carbon on the other hand, although not expensive, may be difficult to incorporate in the melt if graphite is used as additive, mostly due to the large difference in densities between the melt and graphite, surface tension issues, and also due to the excessive melting temperature of the later. Carbon, however, comes as a natural alloying element (already incorporated in the alloy) in carbon steel.

The use of special melt processing techniques (vacuum smelting, ladle degassing) is also an issue. While this is justified in the case of nickel aluminides (due to the high added value of the produced part) and unavoidable in the case of titanium aluminides, prospective applications of iron aluminides in the automotive industry require productivity and cost reduction. Processing of conventional aluminum and iron-based alloys, on the other hand, may be well done under air with little atmosphere protection.

Finally, the quality of the produced alloy: as expected, alloys produced using recycled raw materials are subject to incorporating higher levels of impurities and presenting higher defect densities. Here, however, two apparently paradoxical results support the use of impure alloys in the case of iron aluminides. Alexander et al. [6] investigated the mechanical properties of B2-FeAl produced by casting, ingot metallurgy and powder metallurgy followed by extrusion. These authors observed that the powder-processed samples showed superior tensile elongations and fracture energy on impact testing than the ones produced in the other routes, in spite of possessing a large number of oxide particles in the matrix. They attributed this result to the observation of multiple crack branching events starting at the intersection of the main crack and the oxide particles. Similarly, Matsuura et al. [7] investigated iron aluminides produced using recycled raw materials, comparing with conventionally produced alloys, obtaining slightly better results for the former. The authors attribute this observation to solid solution strengthening, but an explanation in the line of the one described above could well be in place.

The aim of the present work is to investigate the viability of a recycled raw material-based processing route in the production of an iron aluminide. In order to be consistent, the melt was processed in a conventional laboratory induction furnace, with simple means of atmosphere protection.

2. Methodology

2.1. *Raw materials*

The selected raw materials were AISI 1020 steel strips (as the ones used in steel making), AISI 444 stainless steel sheet metal forming residues and conventional used aluminum cans. The products were cleaned (with a conventional detergent) to remove possible organic contaminants and dried in a muffle furnace at 120 °C. Table 1 presents the analyzed composition of the three materials, the values for the steels are averaged analyzed values and those for the aluminum cans are averaged literature data, considering all components of the cans [8]. Chemical analysis was performed using a calibrated energy dispersive spectroscopy (EDS) sensor, installed in a Scanning Electron Microscope (SEM), for all elements, except carbon, which was analyzed using the usual combustion method.

2.2. *Alloy preparation*

Based on the values presented in Table 1 two alloys were prepared, targeting a composition close to Fe – 30 at.% Al (17.2 wt.% Al) – 6 at.% Cr (6.6 wt.% Cr). Two 1 kg loads were prepared and their final projected compositions are 16.6 wt.% Al, 7.3 wt.% Cr, 0.76 wt.% Mo and 0.09 wt.% C. With these values we were able to estimate the incorporation efficiency in the smelting process. In addition, alloy A was molten using a graphite crucible, which allowed the alloy to reach carbon content corresponding to the equilibrium with the melt at high temperatures. Alloy B, on the contrary, was molten using an alumina crucible, resulting in much lower carbon content.

The load was placed in the furnace chamber according to the scheme suggested by Deevi and Sikka [9]. According to this sequence, the steel pieces were placed at the bottom and the aluminum cans were placed over them. The reaction of the molten aluminum with the iron in the steel is highly exothermic and helps in the quick melting of the load.

After melting, the alloys were poured into cast iron ingot molds. The first ingot presented extensive cracking during solidification. In the second alloy an attempt to avoid this cracking was made by heating the ingot mold to about 500 °C prior to melt pouring, but the cracking still persisted.

2.3. *Sample preparation, characterization and metallography*

Samples taken from the ingots were prepared for metallographic observation using standard techniques. Microstructure of the samples was analyzed in a Scanning Electron Microscope (SEM) equipped with EDS accessory; therefore, the samples were observed in the unetched condition.

During this investigation it was observed that both alloys presented profuse precipitation of carbides. In order to investigate the stability of this microstructure, one annealing experiment was performed by subjecting one sample from each alloy to 1200 °C/4 h heat treatment and quenching it in water. These annealed samples were later submitted to an aging treatment at 800 °C/10 min to investigate the possibility of producing a fine carbide distribution in this microstructure.

Vickers hardness testing using 3 N load to obtain a large impression area (including matrix + carbides) and 0.5 N to restrain the impression only to the matrix were performed. Ten measurements were made in each case and the average was computed. Dispersion was found to be negligible, so only the average values will be reported.

Finally, the "as cast" samples were analyzed using X-ray diffraction, using Cu Kα radiation.

Samples for the oxidation experiments were prepared by cutting the original ingot in the form of parallelepipeds with approximate dimensions 15 mm × 10 mm × 2 mm. These