Surface & Coatings Technology 268 (2015) 99–107

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Influence of spraying parameters on cold gas spraying of iron aluminide intermetallics

N. Cinca [a,b,*], A. List [a], F. Gärtner [a], J.M. Guilemany [b], T. Klassen [a]

[a] Helmut Schmidt University, University of the Federal Armed Forces Hamburg, Germany
[b] Centre de Projecció Tèrmica, Universitat de Barcelona, Barcelona, Spain

ARTICLE INFO

Available online 2 August 2014

Keywords:
Coatings
Cold gas spray
Intermetallics
FeAl

ABSTRACT

Cold spraying was used to build up coatings of ordered Fe40Al intermetallics, which are a kind of alloys which are being proposed for high temperature applications. The spray experiments were performed with chemically ordered powder feedstock of different size distributions to study influences from impact velocities. Stainless steel and Ti grade 1 substrates were used to investigate influences of the mechanical and physical properties of the substrate material. While coatings on stainless steel are mostly dense with good cohesion, those on titanium show some cracks perpendicular to the coating substrate interface. That might be due to the larger difference in the thermal expansion coefficients between the titanium substrate and the iron aluminide. Regarding the influence of spraying parameters, it has been found for both substrate materials, that when spraying the first layers, a uniform almost linear decrease in the coating thickness is observed when increasing the spraying distance. By increasing the number of spray layers, the increase in thickness asymptotically approaches a saturation limit. Thicker coatings were obtained on stainless steel substrates than on Ti substrates.

1. Introduction

During the last decades, iron aluminides, as well as other transition metal aluminide compounds, have become promising for high temperature applications due to their high Al content; their good resistance to sulfidizing and chlorine environments has also been reported. In many terms, they have been proposed as substitutes of superalloys but still some drawbacks have to be overcome for their expanded use in structural components. In terms of coatings, one of the primary users of high-temperature coatings is in the gas turbine engine industry for commercial and military aircraft, industrial power generation and marine applications. One possible application of FeAl-based coatings could, therefore, be for the protection against oxidation of external and internal surfaces of turbine blades and vanes to fight oxidation and hot corrosion. Other applications would include turbines for coal gasification combined cycle power plants, components of fast breeder reactors, and superheater tubes in the incinerator of waste to energy plants.

Cold spraying (CS) of ordered iron aluminides is a great challenge due to the low plasticity that these intermetallic compounds exhibit at ambient temperatures. In order to avoid their brittleness, CS was so far only applied to high energy milled fine crystalline Fe(Al) solid solution powders that are presumably more suitable for cold spraying [1–3]. By subsequent heat treatments of the coatings, chemically ordered structures are obtained, even for other aluminides [4–6]. Directly processing chemically ordered alloys by CS of gas atomized powders would open up more cost effective and environment-friendly routes.

With respect to preserve feedstock properties, cold spraying in general has advantages over thermal spray processes. For intermetallic compounds, it is expected that their chemically ordered crystalline structure could be retained in the whole deposit, instead of having ordered and disordered areas as it is obtained by HVOF-spraying of either atomized or ball-milled powders [7,8]. By the solid state impact in cold spraying, the oxidation during coating formation is also minimized. That is particularly of high interest since the aluminium depletion usually encountered at particle boundaries by using conventional techniques is detrimental for the high temperature oxidation resistance.

For avoiding the inherent brittleness of equiatomic FeAl compounds, and to allow for plastic deformation of the spray material in CS leading to bonding, a composition of Fe–40 at.% Al was chosen to serve as feedstock in the present study. Such material accepts deviation from the ideal composition by the accommodation of vacancies, which increases the diffusion rates at high temperatures making the material softer [9, 10]. In CS of ductile materials, inter-particle and particle–substrate bonds are obtained, if local thermal softening is predominant over work hardening, causing shear instabilities at the interfaces [11,12].

Yield strength dependence with temperature shown for bulk polycrystalline FeAl is observed to either decrease slowly with increasing temperature (fine-grained material) [13] or be independent of temperature (large-grained material) [14] from room temperature to some intermediate temperature (~367 to ~650 °C), before decreasing rapidly

* Corresponding author at: c/ Marti i Franques 108028 Barcelona.
E-mail address: ncinca@cptub.eu (N. Cinca).

http://dx.doi.org/10.1016/j.surfcoat.2014.07.070
0257-8972/

with further increases in temperature. Afterwards, studies on both polycrystals and single crystals showed that a peak in the yield stress existed in the range 402–600 °C for iron-rich FeAl [15], which is even more pronounced for higher strain rates. This behavior is known as a yield strength anomaly, which is also presented by other aluminides, that is, their strength increases rather than decreases with temperature [16, 17]. For iron-rich alloys (≤45 at.% Al), the yield stress exhibits a minimum at~227 °C and a maximum at~402 °C before declining rapidly with further increasing temperature [18]. The peak can be, however, obscured in fine-grained materials because the grain boundary contribution to the yield strength decreases with increasing temperature, thus offsetting the increasing lattice strength. All these facts might hinder the occurrence of adiabatic shear instabilities required for a suitable bonding [8]. Nevertheless, preliminary work showed that there was a narrow parameter window for successfully depositing Fe–40 at.% Al intermetallic alloy by cold spraying [19]. In this work, the processing parameters were changed to evaluate the effect of individual particle deposition onto stainless steel substrates. Since it has been reported that the mechanical behavior of intermetallics is very strain-rate sensitive, the present work aims to evaluate effects of substrate material properties and particle sizes on coating formation. In contrast to conventional thermal spray processes, the influence of the substrate material is known to be very important in CS. The mechanical properties play an important role on the adhesion of the first coating layer, and can also influence the deformation during following particle impacts. Regarding the influence of particle size, smaller particles are easier to accelerate and attain higher impact velocities on the one hand. On the other hand, smaller particles reach lower impact temperatures due to faster cooling in the expanding nozzle regime, allowing for less thermal softening and restricting the occurrence of adiabatic shear instabilities. Furthermore, the critical velocity increases with decreasing particle size [11].

2. Experimental procedure

In this study, commercially atomized FeAl powder (Mecachrome, France) with particle size of −51 + 17 μm was used as feedstock material to be sprayed onto #1200 ground AISI 304 stainless steel and titanium grade 1 substrates; the feedstock was sieved in the range of 25–38 μm and 45–53 μm. Fig. 1a shows a SEM micrograph of the free surface of the gas atomized Fe–40 at.%Al feedstock powder. The powders are spherical and the size distribution contains only few amounts of fine particles with sizes < 10 μm. Fig. 1b shows the XRD pattern of the as received powders, exhibiting the typical superlattice lines corresponding to the chemically ordered structure.

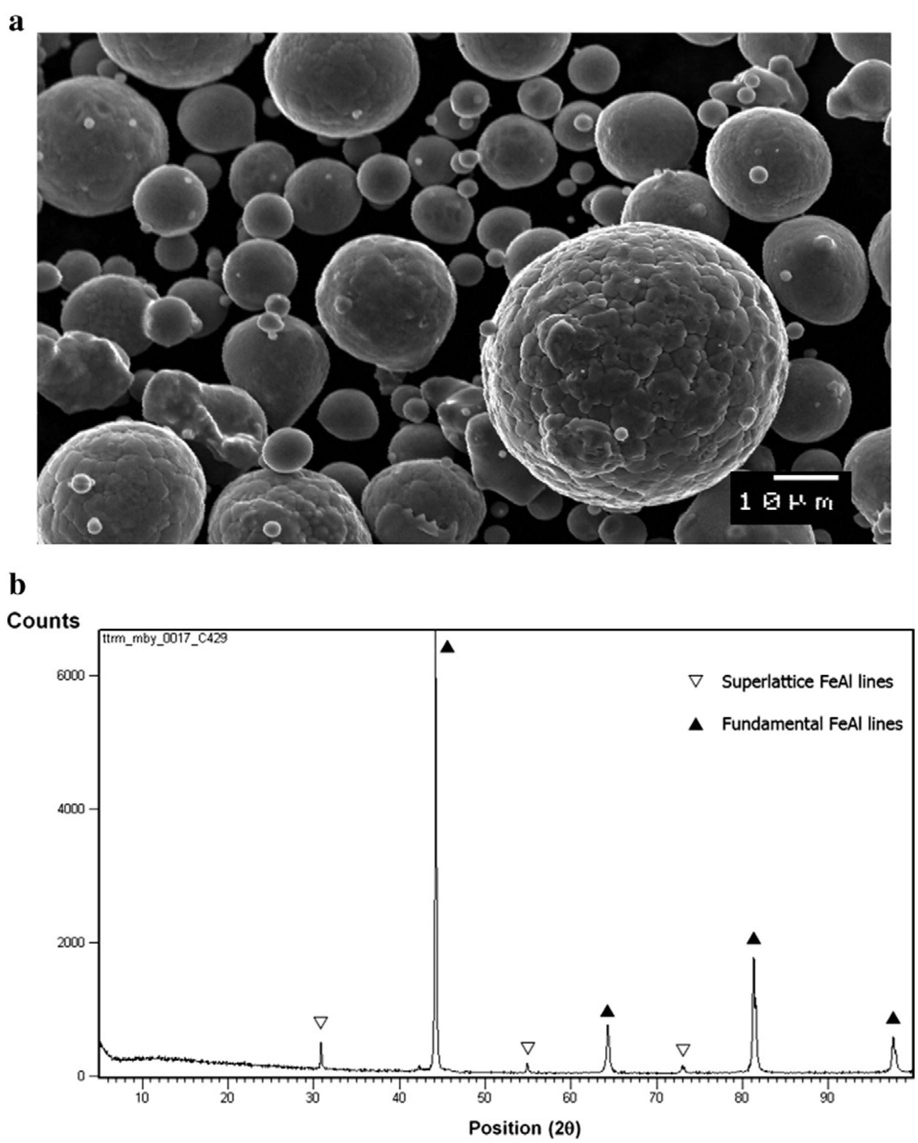

Fig. 1. (a) Morphology and (b) X-ray diffraction of the gas atomized Fe–40 at.% Al powder feedstock.