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Thermal characteristics and amorphization in plasma spray deposition of Ni-Si-B-Ag alloy

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ABSTRACT

Crystalline-amorphous matrix composites preserve the amorphous material high strength and additionally gains on plasticity. Substituting hard crystalline precipitates with soft ones should even more improve the latter. Therefore, this work was aimed at verifying, whether Ag and Ni-Si-B alloy shows liquid immiscibility and consequently, if they might form crystalline Ag/Ni-Si-B amorphous/crystalline composite. Firstly, a mixture of 95 wt% of Ni-Si-B (1559-40) and 5 wt% of Ag powders was arc-melted in argon and cooled at copper plate. The solidification process was documented by IR mid-wave camera and Time/Temperature graph. The microstructure of the ingot was studied using a scanning electron microscope (SEM) and light microscope (LM). Secondly, the powders mixture was plasma sprayed on a cooled copper plate. The cross-section microstructure and the phase composition of the plasma spray deposit were analyzed with a transmission electron microscope (TEM), scanning electron microscope (SEM) and X-ray diffractometer (XRD). The thermal characteristics of the plasma sprayed deposit and the Ni-Si-B powder were analyzed using differential thermal analysis (DTA) and compared. The results show that the melted Ag and Ni-Si-B powders form immiscible liquids at high temperatures used both during arc-melting and plasma-spraying. The proved that that the plasma spraying enables production of a Ni-Si-B/Ag composite with high strength Ni-based matrix with dispersed in it fine soft Ag-FCC flake-like particles.

1. Introduction

Amorphous alloys are considered for use as structural materials because they have outstanding attributes such as high strength, elasticity, excellent wear resistance [1] and special electric [2] and magnetic properties [3]. Nevertheless, the rapid formation of localized shear bands, especially upon uniaxial tension, causes brittleness of the metallic glasses [4] seriously limiting their eventual applications. It was already proved that the crystalline-amorphous matrix composites preserve the unique amorphous materials strength and gains on elasticity. However, control of the fraction of the former in the latter during their production pose a serious problem.

A number of methods can be used to produce metallic glasses and glass-matrix composites. These include melt spinning [5], high-pressure die casting [6], water quenching [7] and suction casting [8]. However, massive elements could be obtained only from alloys characterized by high glass forming ability. Manufacturing massive amorphous matrix composites containing crystalline phases caused by immiscibility can therefore be very difficult or impossible using the methods mentioned above [9]. This problem can be eliminated using plasma spraying, which provides

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Table 1
Specification of 1559-40 powder.

Particle size, µm	Chemical composition, wt.%				
	C	Si	B	Fe	Ni
53–150	≤0.06	3.0	2.9	0.2	balance

a high quenching rate of molten alloy (typically 10^5–10^7 K/s) [10] and is particularly useful for manufacturing relatively thick coatings on elements of various shapes and sizes.

Ni-Si-B-based alloys present a good glass forming ability, good mechanical properties [11,12] and wear-resistance [13]. At the same time, it is known that the introduction of Ag to Ni can cause immiscibility in the liquid state [14] opening possibility of obtaining composite having silver crystallites immersed in the amorphous nickel based matrix.

Therefore, the aim of this work was to determine whether Ni-Si-B alloy and Ag form liquid immiscibility and, whether such mixture enables the glass transition of the nickel based liquid under plasma spraying conditions. The former task was achieved by arc meting of both material and chilling melted drops on a copper plate.

2. Experimental

The precursors used for producing the alloys were Ni-Si-B-based commercial 1559-40 grade argon atomized powder manufactured by Höganäs (particle diameter 53–150 µm) and 5 wt% of water atomized Ag powder (particle diameter <63 µm) made by INMET. The specification of the 1559-40 powder is presented in Table 1. The powders in the as-received state were observed using a scanning electron microscope (SEM) and particle size distributions were determined.

Next, the mixture of these powders containing 95 wt% of 1559-40 and 5 wt% of Ag (referred in the text as 1559 + Ag) was arc-melted in a titanium gettered argon atmosphere. The 2 g ingot was re-melted in the arc furnace and observed with an MWIR FLIR SC7650 camera, while it cooled on a copper plate. The sample-to-camera distance was 200 mm. The process was observed through a high transmission CaF_2 window. The room temperature was 25 °C when the measurements were taken. Two regions of interest (ROI) were selected in areas of the sample that would ensure that the narcissus effect would be avoided and the influence of reflection of electrode (ROE) would be eliminated. Analysis of the microstructure and chemical composition of the arc-molten ingot was performed using a JEOL 6610 SEM with an Oxford X-Ray microanalyser.

In a parallel experiment the same mixture of powders was plasma sprayed with AP-50 system (F4 plasma torch and a PF-50 powder feeder) by Flame Spray Technologies a water-cooled copper plate (80 mm × 40 mm × 5 mm). The flow rates of the plasma-forming gases were 54 l/min for Ar and 9 l/min for H_2. The carrier gas for transporting powder to the plasma stream was Ar flowing at 4.2 l/min. The current was 530 A, the torch-sample distance 120 mm and the velocity of sample movement 0.3 m/s. The cross-section microstructure of the plasma sprayed deposit was investigated using a JEOL 6610 SEM equipped with energy dispersive

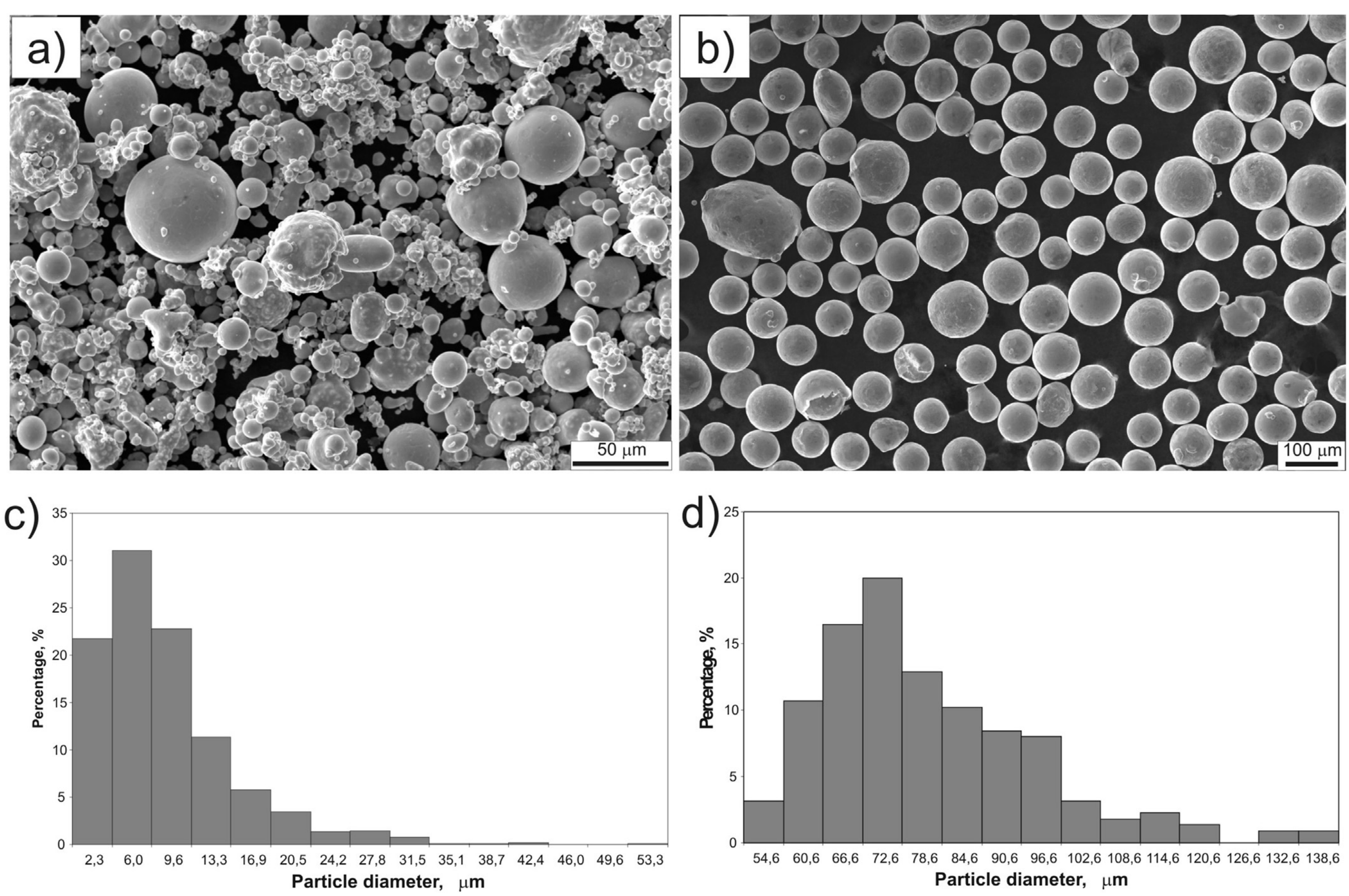

Fig. 1. Powders in as-received state: a) water atomized Ag powder, b) 1559-40 powder, c) particle size distribution of the Ag powder, d) particle size distribution of the 1559-40 powder.