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Formation of bulk nanocrystalline and amorphous alloy with controllable microstructure and magnetic properties by plasma spray deposition.

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Nanostructured and amorphous materials exhibit unique and enhanced chemical, mechanical, and magnetic properties [1,2]. The industrial applications of these materials rely on their successful consolidation into bulk body while preserving their structures. Nanostructured and amorphous coatings without grain growth can be formed by plasma spray deposition [3-5]. In this case the microstructure of the bulk coating can be tuned from full amorphous state to composite with nanocrystalline particles in the amorphous matrix, and finally into nanostructured state accompanying with the magnetic properties changes. It was found [6] that the desired magnetic properties of $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ bulk alloy (zero magnetostriction, high initial and maximum magnetic permeability, etc.) can be achieved by formation of coating with certain amorphous/crystalline phase ratio. In the present work, the role of the plasma spray deposition regimes in the control of microstructure and magnetic property of the bulk coating, the mechanism for the nanocrystalline and amorphous structure formation, and the relation between the microstructure and magnetic properties are discussed.

Bulk coatings with 1mm thickness were fabricated using a powder obtained from an amorphous $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ ribbon. The details of the plasma spray deposition processes were reported elsewhere [5]. The investigations of structure and magnetic properties of bulk samples were carried out by X-ray diffraction, electron microscopy and correlation magnetometry. The amorphous/crystalline phase ratio was estimated using the technique of magnetic phase analysis. The phases were identified on the basis of their Curie temperatures T_C and saturation magnetizations M_0.

It is known the plasma coatings are forming by agglomeration of splats formed by the impact, spread and solidification of individual particles. The particles may be fully or partially melted. The power of the electric arc, P, determines the temperature and velocity of sprayed particles, and the substrate temperature, T_s, determines the quenching rate. It is found that the structure and magnetic characteristics (saturation magnetization, M_0, exchange stiffness constant, D, local magnetic anisotropy field, H_a, FMR linewidth, DH, coercive field, H_c) of the alloy remain unchanged if $P < 20$ kW and $T_s < 150^oC$.

It is observed that the relaxation heat treatment causes an essential and non-monotonic changes of integral magnetic characteristics of bulk coating. Figure 1 shows the changing of permeability and coercivity of $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ amorphous coating during annealing (t = 30minute).

The results of thermomagnetic analysis of the annealed coating indicates that the initial alloy can be characterized as a heterophase system in which phase1 with T_C~260°C comprises 90% of the volume and the phase 2 with T_C~530°C comprises 10%. The Curie temperatures of these phases are different and consequently chemical short-range order in these phases is different. It is found that the appearance of dispersed inclusions of phase 2 in phase 1 was stimulated by increasing of substrate temperature. At T_{an}~300°C the nanocrystalline phase inclusions with T_C~330°C arises. Temperature of alloy crystallization is 540°C. It can be noticed that as T_{an} increases the volume fraction of phase 1 (Y_1) decreases and Y_2 (phase 2) increases so that in region $400 < T_{an} < 450^oC$ $Y_1 \approx Y_2$, and if $T_{an} = 500^oC$ the Y_2 is much larger than Y_1. The values of Bloch constant, B, saturation magnetization, M_0, and spin-wave stiffness, D were determined from low temperature measurement of magnetization M(T). It is found that value of M_0 remains unchanged with increasing of T_{an} up to 700 °C. The increase in D value with $T_{an} > 400^oC$ indicate that the volume fraction of nanocrystalline phase increases.

Information on local magnetic anisotropy field H_a (contain a contribution of internal stresses) was obtained from investigation of approach magnetization to saturation law [7]. Figure 2 shows the dependencies of H_a for magnetic phases of bulk coating on annealing temperature. The main magnetic phase is characterized by lower internal stresses and a lager value of correlation radius (the clusters comprising magnetic phase).

The results of magnetic measurements lead to the conclusion that the plasma spray deposition with the optimal regimes allows obtaining bulk nanostructured or amorphous $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ alloys with similar physical properties compared with the ribbon having the same composition. The relaxation annealing of the $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ bulk coating leads to a phase transition in this alloy in the precrystallization temperature range. The magnetic properties of the coating are correlated with changes in the microstructure.

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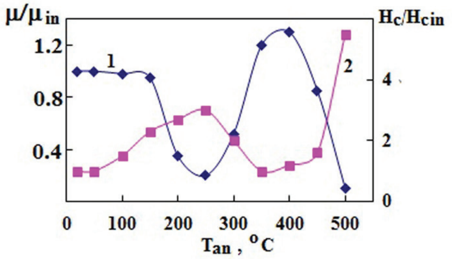

Fig.1. The relative change of permeability (1) and coercivity (2) of $Co_{58}Ni_{10}Fe_5B_{16}Si_{11}$ bulk coating during annealing with t = 30 minute.

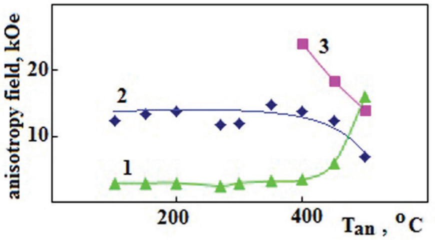

Fig.2. The dependencies of local magnetic anisotropy field for magnetic phases with T_C~260 °C (1), 530°C (2) and 330°C (3) on annealing temperature .