MODIFICATION OF Al-Si EUTECTIC ALLOY STRUCTURE BY ALLOYING WITH Nb ATOMS UNDER COMPRESSION PLASMA FLOWS IMPACT

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Aluminium alloy matrix composites attract considerable attention due to their low density and low cost. Transition metals, such as Ti, Zr, Hf, V, Nb and Ta constitute a group of alloying additions to Al that show particular promise for developing creep-resistant, thermally stable Al-based alloys due to formation of Al_3M (M=Ti, Zr, Hf etc.) intermetallides /1/. Such trialuminides possess high melting temperature, low density, high elastic modulus, high thermal and oxidation resistance /1/. A large number of investigations were carried out in the field of synthesis of bulk aluminium matrix composites reinforced by metals trialuminides. At the same time many applications require good exploitation properties only of the materials surface layer. In this case techniques providing synthesis of composites in the surface layer are of interest /2/. Treatment of a coating/substrate system by high energy particles ($\geq 10^6$ W/cm^2) is one of such techniques that allows alloying the surface layer of a substrate with coating elements /2, 3/. Such treatment provides enough energy for melting the coating and the surface layer of a substrate. Convection in the melt leads to mixing and homogenization of elemental composition in the melted layer. A high cooling rate results in the formation of a disperse structure having submicron or nanocrystalline grains and phases. This approach was used to form the surface composite layer reinforced by intermetallic particles on the basis of Al_3Nb in the Al-Si piston eutectic alloy and was realized by subjecting Nb coated alloy samples to compression plasma flows (CPF) treatment.

The samples used were made of a eutectic silumin alloy (12.9 % Si; 3 % Mg; 0.7 % Cu; 0.4 % Ni; 0.1 Fe %; at.%, Al - balance). The niobium coating was formed using cathodic arc vapour deposition with the following process parameters: the arc current was 190 A; the bias voltage was -120 V. The coating deposition time was 10 min (the corresponding coating thickness was 4 μm).

Compression plasma flows were obtained using a gas-discharge magneto-plasma compressor of compact geometry powered with the capacitive storage of 1200 mF, operating at the initial voltage of 4 kV. Nitrogen was used as a plasma-forming gas. The pressure of a plasma-forming gas was 400 Pa. The discharge duration amounted to 100 μs. Treatment of the formed Nb/silumin system was carried out by three pulses to provide homogeneity of the mixed layer. The density of heat flux (Q) absorbed by the surface layer (registered by calorimetric measurements) varied in the range of 9-19 J/cm^2 per pulse.

Phase composition of the samples was investigated by the X-ray diffraction analysis (XRD) in CuKα radiation using a Rigaku Ultima IV diffractometer. Surface and cross-section morphology as well as element composition were analyzed by means of scanning electron microscopy (SEM) using a LEO1455VP device equipped with an energy-dispersive X-ray Röntec detector. Microhardness of the samples was tested by means of a Wilson Instruments 402MVD microhardmeter with a Vickers indenter under the load ranging from 0.25 to 2 N.

Impact of plasma pulses with the “coating/substrate” system leads to melting of the coating and substrate surface layer, liquid-phase mixing and subsequent crystallization under conditions of a fast cooling rate (10^5 - 10^7 K/s) /3/. The data of the phase composition analysis showed that plasma impact led to melting in the Nb/silumin system, mixing of components and as a result – the formation of Al_3Nb phase with $D0_{22}$ structure (Fig. 1). Q increase led to the growth of Al_3Nb diffraction lines intensity. Thus one can conclude that growth of intermetallide volume fraction in the analyzed layer occurs.

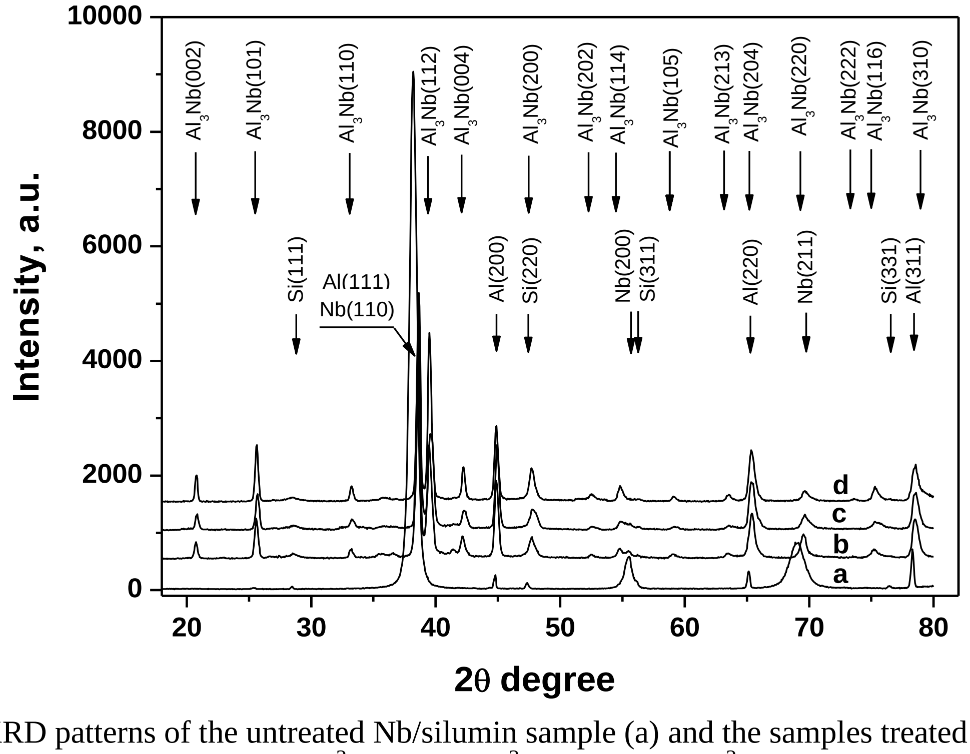

Fig. 1. XRD patterns of the untreated Nb/silumin sample (a) and the samples treated by CPF at Q=9 J/cm^2 (b), 13 J/cm^2 (c) and 19 J/cm^2 (d)

The lattice parameters of Al_3Nb derived from the diffraction pattern were less than those of the standard (a=0,3848 nm and c=0,8615 /4/). Q increase led to diminishing of Al_3Nb lattice parameters. At Q=19 J/cm^2 they were equal to a=0,3807 nm and c=0,8554 nm. It is known that in Al_3M compound part of Al atoms can be substituted by Si atoms, thus leading to diminishing lattice parameters /5/. It is seen in Fig. 1 that Q increase also resulted in diminishing Si diffraction lines intensity. Thus, some part of Si atoms can take part in precipitation from the melt of Al-Nb intermetallic phase which can be identified as $(Al,Si)_3Nb$. Si atoms can also form an oversaturated solid solution on the aluminium basis crystallized under conditions of a high cooling rate, thus resulting in the shift of Al diffraction lines to the region of greater diffraction angles. The difraction peak of small intensity at the position of $2\theta=32.8^o$ in the treated sample can be attributed to AlN or NbN phase.

The investigations of treated sample cross-section morphology showed considerable inhomogeineity of the alloyed layer structure after CPF treatment at Q=9 J/cm^2 and 13 J/cm^2 (Fig. 2). It can be caused by big difference in melting temperatures of Al-Si alloy and niobium.

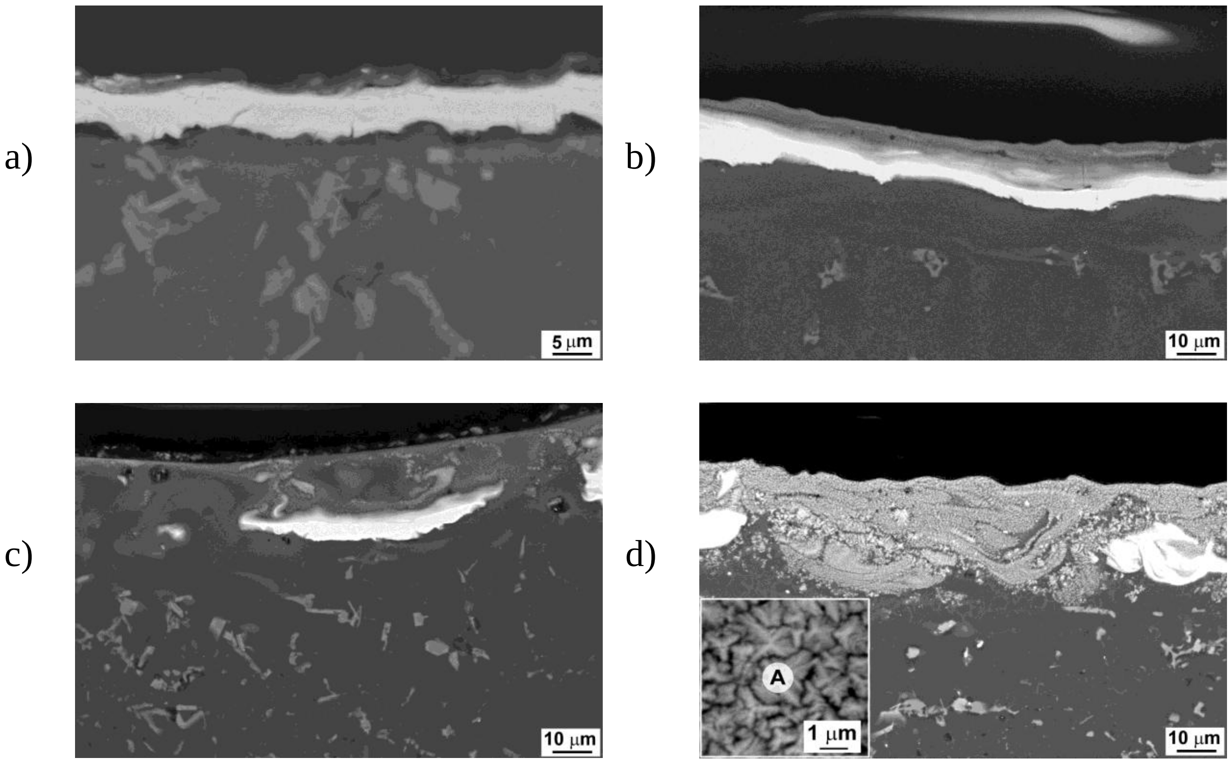

Fig. 2. Cross-section morphology of the untreated Nb/silumin sample (a) and the samples treated by CPF at Q=9 J/cm^2 (b), 13 J/cm^2 (c) and 19 J/cm^2 (d)

The growth of the energy absorbed by the surface layer leads to the increase of the melted layer thickness (Fig. 2) and to the growth of the melt existence time. The increase of the melt existence time provides more uniform distribution of Nb atoms in the melt due to the growth of convection processes duration. Increase of Q up to 19 J/cm^2 allows forming the surface composite layer with more homogeneous niobium distribution (Fig. 2d). This treatment regime provided highest volume fraction of $(Al,Si)_3Nb$ phase according to the data of the phase analysis (Fig. 1).

$(Al,Si)_3Nb$ precipitates synthesized under plasma impact grew in the form of dendrites due to high undercooling. The size of intermetallide precipitates can reach 2 μm. Composition of the dendrite (in the area enriched with niobium) corresponds to $Al_{84}Si_{10}Nb_6$ (point A in the Fig. 2d) according to the data of energy-dispersive analysis regardless of the other alloying elements with a negligible concentration. This composition differs from that of $(Al,Si)_3Nb$ stoichiometry assuming that Si atoms can substitute Al atoms only in $D0_{22}$ lattice. The formation of lattice with defects under conditions of a high-cooling rate or low resolution of microanalysis can be the cause of such a difference.

The surface layer microhardness after treatment with Q=19 J/cm^2 appears to be constant at all indentation depths (1.8-5.6 μm) and is equal to 2.5±0.3 GPa. Additional investigations showed that silumin microhardness after CPF treatment with Q=9-19 J/cm^2 varied in the range of 1.4-1.7 GPa. Such increase can be attributed to the formation of more disperse structure (grains refinement, the formation of dispersed Si crystals and Al(Si, Mg, Cu, Ni, Fe) supersaturated solid solution. Thus, additional microhardness growth in case of Nb alloying is caused by dispersion hardening with trialuminide particles.

The findings showed that plasma impact with Nb/silumin samples resulted in the formation of a composite surface layer containing a supersaturated aluminium solid solution and disperse intermetallic phases on the basis of Al_3Nb compound. The synthesized composite layer possessed a high hardness value (up to 2.5 GPa).

References

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