New possibilities for solid-phase joining of difficult-to-weld aircraft materials using nanolayered foils

Ustinov A (1), Falchenko Iu (1), Melnichenko T (1), Petrushinets L (1)
(1) E.O.Paton Electric Welding Institute of NASU

Introduction

Wide application of modern materials based on composites and intermetallics in aviation is considerably restrained by absence of technologies for producing their permanent joints. Application of traditional fusion welding technologies for these purposes leads to degradation of such material properties in the fusion zone. Joining such materials without melting (in the sold phase) is difficult, because of their high strength: at exposure to high pressure with heating it is difficult to achieve plastic deformation in the regions adjacent to contacting surfaces, that is required for establishing physical contact between them and activation of diffusion processes. Application of interlayers based on ductile metals provides a partial solution of the problem. However, chemical inhomogeneity forms in the joint zone that lowers the joint strength and its corrosion resistance. The work considers the possibility of ensuring the necessary conditions for realization of the process of diffusion welding of difficult-to-weld materials using interlayers with nanolayered structure.

Method to produce nanolayered foils

Nanolayered foils (NF) based on reacting elements were produced by the method of their layer-by-layer deposition. Used for this purpose was the method of electron beam evaporation of elements in the vacuum chamber from two evaporators, separated by impermeable shield, above which the substrate was positioned, which was fastened to a vertical shaft. At substrate rotation it successively moved from one to the other evaporator that led to successive formation of layers based on one or the other element [1].

Fig. 1 gives an example of cross-sectional microstructure of NF produced on the base of Ti/Al system. It is seen that thicknesses of Ti and Al layers are characterized by nanometric scale, and their interfaces are quite narrow that is indicative of absence of diffusion interaction between the layers during their deposition. This conclusion is in agreement with the results of XRD and TEM investigations.

Performed investigations showed that variation of element evaporation intensities and of substrate rotation speed allows varying in broad ranges element ratio in the foil and their layer thicknesses (from 10 to 1000 nm) (modulation period), and specified foil thickness can be obtained by changing process duration, from 10 up to 200 μm. Absence of limitations in electron beam evaporation of metals allows producing NF based on various systems, such as, for instance Ni/Al, Ni/Ti, Ti/Co, Ti/Cu, Cu/Al, etc. This enables not only variation of foil structure, but also changing its composition.

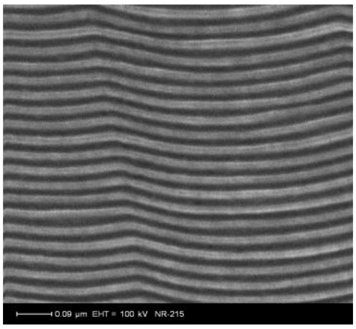

Fig.1. TEM image of cross-sectional microstructure of Ti/Al NF. Dark bands correspond to layers of titanium (17 nm thickness), light ones – to those of aluminium (25 nm).

NF properties

It is known that if during NF production the reaction interaction between the layers does not take place, then slight increase of foil temperature activates the processes of their diffusion interaction. In the work XRD, TEM and DTA techniques were used to study the structural and phase transformations which are realized in NF at their continuous heating. It turned out that irrespective of foil composition, phase transformations start at relatively low temperatures and run by multistage kinetic scheme with formation at the initial stages of the process, of intermetallic phase based on metal, the atoms of which are less mobile in the metal forming the adjacent layers. Further temperature rise leads to formation of intermetallics with a higher concentration of the second element. It is established, for instance, that in the case of Ti/Al NF of equiatomic composition, transformation runs predominantly, by the following scheme: $Ti+Al \rightarrow Al_3Ti \rightarrow Al_5Ti_2 \rightarrow Al_2Ti \rightarrow TiAl$ and is over at heating up to 650 ^{0}C [2]. Intermetallic formation is accompanied by intensive heat evolution that is manifested in the form of exothermal peaks on DTA diagrams.

At NF application as interlayer in welding, it is subjected not only to heating, but also to uniaxial compression. Considering that application of uniaxial compression induces not only compressive, but also tangential stress components in the interlayer, HF deformational behaviour under the impact of tensile stresses at continuous heating was studied in this work. It is seen (Fig. 2) that NF deformational behaviour changes during its heating under continuously applied tensile stresses: there exist two temperature ranges, in which the foil is plastically deformed at relatively low stress level. Foil plastic flow in the low-temperature range is associated with superplasticity induced by foil phase transformations, and in the high-temperature range - by its structural superplasticity.

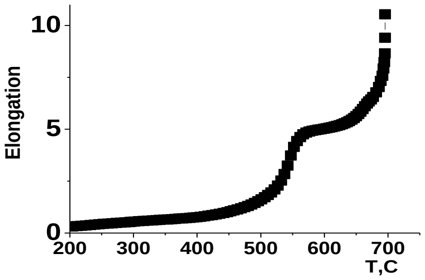

Fig.2. Temperature dependence of TiAl NF elongation at its heating under continuously applied stresses (4 MPa).

It is clear from the obtained results that owing to high plasticity of the foil, NF placing in the joint zone can provide the conditions required for establishing physical contact between the surfaces being welded without high pressure application. More over, high diffusion mobility of atoms in the joint zone will promote welding at lower temperatures and soaking time. Considering that NF composition can be selected close to that of materials being welded, such interlayers will not lead to a change of chemical composition in the joint zone.

Solid phase welding

The work deals with cases of NF application as interlayers in welding of difficult-to-weld materials based on intermetallics and metal-base composites.

Welding of TiAl intermetallic

Ti/Al NF were used to produce permanent joints of TiAl-based alloy in the solid phase. Conditions for producing TiAl alloy joints were established by variation of joint zone heating temperature and applied pressure. Fig. 3 gives an example of cross-sectional microstructure of this alloy joint produced at the temperature of 1200^0C, pressure of 10 MPa and soaking time of 20 min. One can see that a microstructure similar to that of initial material, forms in the joint zone.

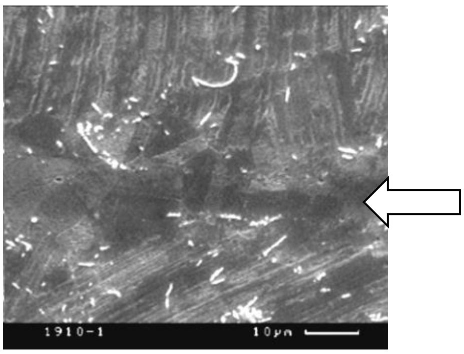

Fig. 3. Cross-sectional microstructure of TiAl alloy welded joint (joint zone is marked by an arrow).

Welding of Al-Al_2O_3 composite

Ni/Al и Cu/Al NF were used for joining Al-Al_2O_3 composite. Fig. 4 shows cross-sectional microstructure of the zone of composite joint produced through Cu/Al interlayer at welding temperature of 500 ^{0}C, pressure of 44 MPa and soaking for 20 min. One can see that the joint zone has no defects, and its structure is similar to that of the base material.

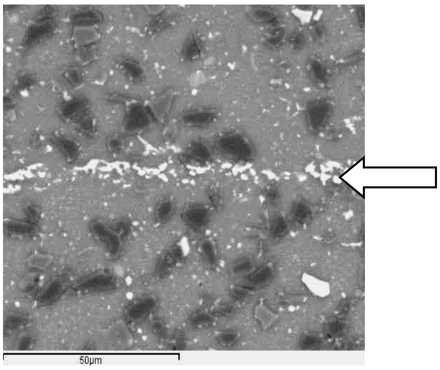

Fig.4. Cross-sectional microstructure of Al-Al_2O_3 composite welded joint (joint zone is marked by an arrow).

Mechanical testing of welded joints of TiAl intermetallic and metal-matrix composite showed that their strength is close to that of the initial material.

Developed approach was verified in the case of welding thermal protection three-layer honeycomb panels from thin foils of Ni-Cr based alloys produced by powder metallurgy method. Microstructure and strength properties of permanent joints of Ni-Cr based alloys produced through nanolayered interlayers based on Cu-Ti and Al-Ni systems are analyzed in the work. Effectiveness of application of nanolayered foils for fabrication of complex structures at their solid-phase joining is shown.

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References

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Biosketch

Prof. Anatolii Ustinov is the Head of Department of Vapour-Phase Technologies of Inorganic Materials of the E.O. Paton Electric Welding Institute of NASU. In the last few years he focus his attention on producing from vapour phase nanostructured materials, studies their properties and practical application.

Contacts

E.O.Paton Electric Welding Institute of NASU, 11 Bozhenko str., Kiev, 03150, Ukraine; Phone +380 44 200 61 80; E-mail: ustinov3@yandex.ua.