Bonded Multi-layer Materials - The Materials of the Future

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Abstract

Multi-layer materials composed of various metallic or metallic-and-ceramic layers, and also from materials with modified surfaces may have various physico-chemical, electric and mechanical properties. This is why a great progress in the production of these materials is expected.

To develop the optimum methods for bonding these materials, the following physico-chemical problems must be mastered, among other things: activation of sparingly wettable surfaces, draining of electric charge in bonding dielectric layers, reduction of the temperature of bonding or minimizing of the heat leakage zone in bonding magnetic layers, as well as the simultaneous sintering of different metallic and ceramic layers.

The article deals with the anticipated methods of producing multi-layer materials and the expected progress in the sphere of their bonding techniques.

Keywords: laminar materials, bondability, sinterwelding, laser, electron beam, plasma.

1. Introduction

In many domains of technology the materials must fulfil various functions. Materials to be used for the production of process equipment, in addition to mechanical strength must be resistant to high-temperature corrosion and must have good heat abstraction properties. Laminar materials in microelectronic elements, store sets and sensors, apart from magnetic and electric properties must also be resistant to thermal and mechanical stresses and - at least in some places - they must feature good heat conduction. The multi-layer materials produced by plasma methods, vacuum evaporation, CVD and PVD methods, ion implanting and Sol-Gels techniques fulfil various functions provided that they have been properly bonded both inside and outside.

A proper use of the methods of bonding will be of essential importance in the future, both in the production of laminar materials and joining them together.

Techniques requiring a high concentration of heat (laser, plasma and electron beam) will find a wide application in the bonding of multi-layer materials; already now these techniques are unrivalled in some applications such as bonding a multi-layer material made up from Au, Ni, Fe, FeNiCo. Vacuum soldering and diffusion bonding, presently applied to join nitride (AlN and Si_3N_4) and oxide (Al_2O_3, ZrO_2) layers to metals, will become more and more popular.

Combining into one process the layer depositing techniques and the modern bonding methods may produce multi-layer materials which will fulfil a number of various functions.

In the future, the investigation into the process of bonding multi-layer materials should embrace both the conducting and semiconductor layers and the magnetic and dielectric ones.

The following problems must be solved: activation of the sparcely wettable surfaces (AlN, Si_3N_4, BN, SiC-Si) during bonding, draining of electric charges when bonding dielectric layers, development of low-temperature methods for bonding magnetic and semiconductor materials. Research work should be aimed at the development of new methods such as friction bonding, with the use of ultrasounds, and the resistance bonding of ceramic conductors.

2. Anticopated process in developing basic multi-layer materials, and their production methods

Multi-layer materials which fulfil various functions are presently applied in microelectronics, biomedicine, in the construction of machines and special technological equipment. Fig. 1 shows the anticipated progress in the development of multi-layer and multi-phase materials in the aircraft industry, whereas Table 1 specifies the basic groups of multi-layer materials and the expected production methods.

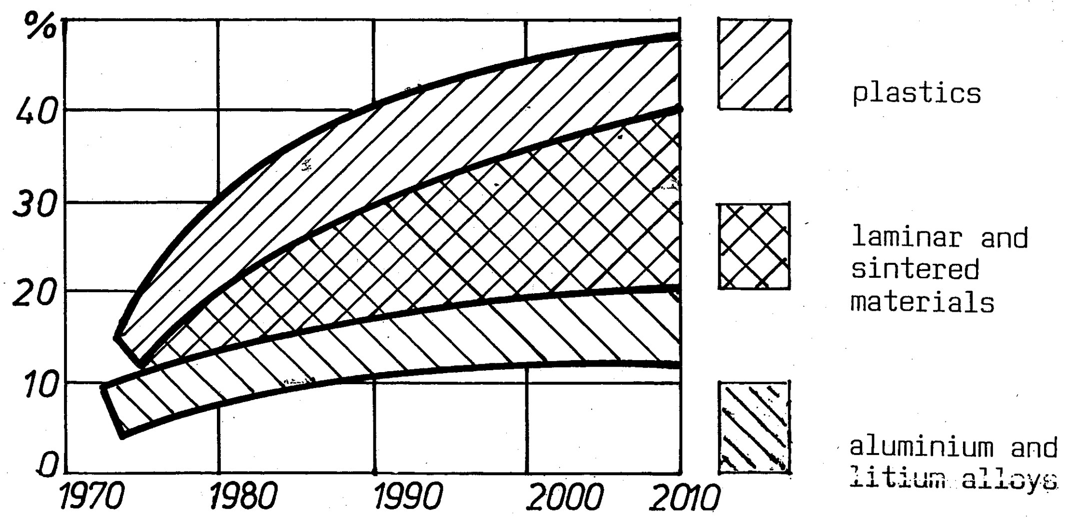

Fig. 1. Anticipated development of multi-layer materials in the aircraft industry.

Table 1. Groups of multi-layer materials and expected production methods

Groups of multi-layer materials	Kinds of materials	Expected production methods
1	2	3
Dielectric and conducting materials	conducting layers - metallic (Cu, Ni, Mo, Au) dielectric layers - ceramic (Al_2O_3, AlN, Si_3N_4)	Simultaneous sintering of various layers, sputtering, diffusion bonding

1	2	3
multi-layer sensors	ZrO_2, Al_2O_3, β-Al_2O_3, Cr_2O_3, semiconductors (Si), BN, SiO_2	sintering method, plasma method, EVD, soldering in protective atmospheres
magnetic, dielectric and conducting materials	metal oxides, metals (Si, Cu)	Plasma sintering, vacuum evaporation, diffusion bonding, Sol-Gel method
abrasion-resistant laminar materials	Metals (Fe, Ti, Al), oxides (Al_2O_3, Cr_2O_3), ZrO_2, nitrides (TiN, BN), carbides (SiC, CrC_x, TiC_x), borides and other layers of a complex structure, e.g. composites (WC-CrC_x+Ni)	Plasma methods, CVD and DVD methods-ion implantation, evaporation, and other surface modification methods (by laser or by electron beam)
multi-layer materials resistant to high temperatures (abrasion wear, corrosion, mechanical strength)	Metals (Fe, Cr, Ni, Ti), oxides (Al_2O_3, ZrO_2), nitrides (Si_3N_4, TiN), composites (SiC+Si, Al_2O_3+ZrO_2)	sintering, plasma methods, modification of surface with laser, evaporation, vacuum soldering, etc.)
corrosion-resistant multi-layer materials	Metals (Ti, Cr, Ni, Al, Mg) Oxides (Al_2O_3, ZrO_2), composites	Sintering of layers by plasma methods, surface modification, etc.

1	2	3
Multi-layer materials used in biomedicine	Metals (Ti, Fe), oxides (Al_2O_3, SiO_2), nitrides (Si_3N_4, BN, (TaN)	Plasma methods, surface modification with laser, soldering in protective atmosph.

The various physico-chemical functions which must be fulfilled by materials specified in Table 1 call for the development of special binding methods. The bonding techniques must take into account both the kind of materials to be bonded and their function and shape (Fig. 2).

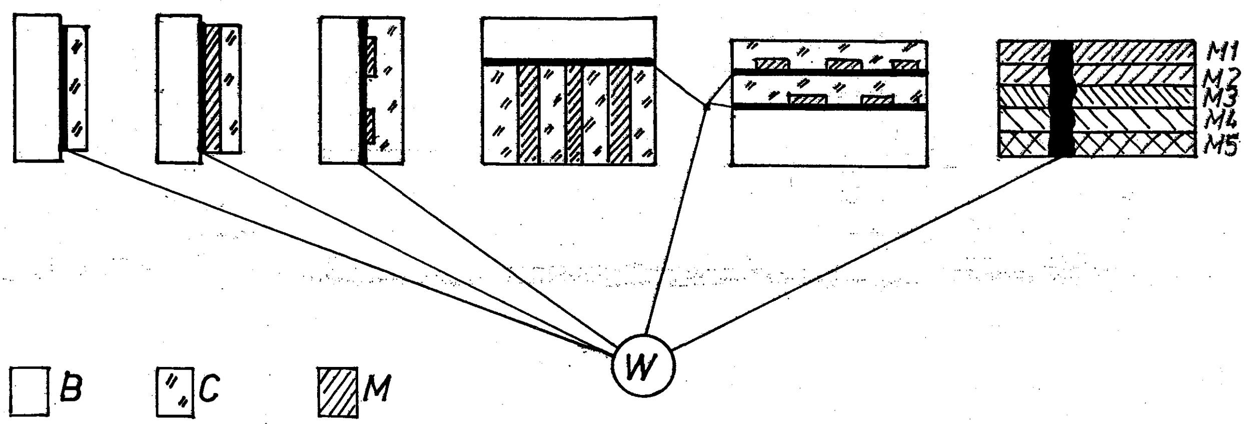

Fig. 2. Various shapes of multi-layer materials to be bonded:
B - base material, c - ceramic layer,
m - metallic layer, w - bonding place.

The components shown in Fig. 2 and made up exclusively of metallic layers may also be produced from various ceramic layers. The inter-layer adhesion, a specific and quite difficult problem, is also dependent on the bondability of the layers.

3. Research work aimed at the mastering of bonding processes and methods

As has been said under 2, the number of layers which are to fulfil various physico-chemical functions, is great; the layers presented there have various chemical composition and different properties and, consequently, different bondability. The basic problem which should be solved in a complex way is the bondability of dissimilar materials.

Bondability is certainly a function of the structure of materials to be bonded, the condition of their surfaces, their ability to produce alloys, and their oxidability. The knowledge of these properties does not, however, suffice if one wants to bond a number of materials, having different properties, into one component part. In such cases one should take into account the ability of materials to be bonded to produce common chemical compounds, their ability to the mutual diffusion of atoms or ions, and differences in their heat expansion coefficients.

Wettability of materials to be bonded is another essential feature. Should any of these properties be not know for various new ceramic layers, it should be found by way of appropriate measurements. The basic problem, however, is the complex utilisation of these properties of materials to be bonded, and determination of their bondability. One of the possible ways of determining that feature is the use of the extreme wetting angle for materials to be bonded.

It may be assumed that bondability is a function of the wetting angle θ. Attempts to mathematically describe the relationship for a dozen or so pairs of metals and ceramic layers (Al_2O_3-Ti, Al_2O_3-Fe, Al_2O_3-Mn, AlN-Al, Al_2O_3-Cu, SiC-Fe) have led to obtaining function: $\beta = 100 \, \mathrm{Exp}\,(-0{,}05\,\theta)$.
Practically it means that for the low values of θ (excellent wettability), bondability β is high and - for the adopted 0...100 scale - it is from 50 to 100; for high values of θ, bondability amounts to ≤ 20. Another way of determining bondability is to use

the relationship presented in the form of function :

$$\beta = f\,(/-\Delta G/ . \Delta x \; . \; \Delta\alpha^{-1})\; k \qquad (1)$$

where $/-\Delta G/$ is Gibb´s free energy

Δx - is mutual diffusiveness of the ions or atoms of materials being bonded,

$\Delta\alpha$ - is the difference in the linear expansion coefficients for materials to be bonded,

k - are the constants which characterise the condition of surfaces and the pressure.

Making use of the physico-chemical properties of various materials being bonded one can determine, by the computer method, their bondability β . With the bondability scale from 0 to 100, it turns out that the bondability of Al_2O_3 to Ti, Al_2O_3 to Mn and Si_3N_4 to Ti is very good and that it amounts to approximately 80. On the other hand, bondability of Cu to Al_2O_3, Mo to Al_2O_3 and AlN to Cu is poor, amounting to only 10. The examples quoted above are only an initial attempt to determine bondability. In the future one should try to determine that property for other materials, using a more unambiguous relationship.

The determination of bondability is vital not only because the number of bonded materials grows constantly, but also due to the fact that various techniques will be used to bond multi-layer materials. In addition to the already known methods such as soldering in hydrogen atmosphere (Fig. 3) and in a vacuum, diffusion bonding (Fig. 4) and friction bonding, other techniques must be mastered too, including laser, plasma and electron beam bonding, compression bonding, as well as bonding with the use of electrostatic field, resistance welding and sinter-welding. Figs. 5 and 6 give the examples of the structures of bonded multi-layer materials and the attempts to apply these methods.

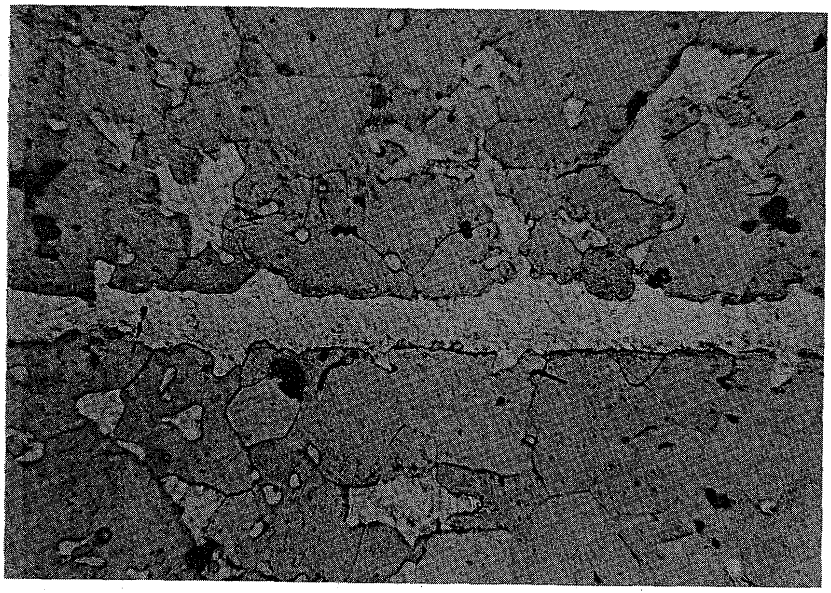

Fig. 3. Microstructure of layers sintered at 760°C, soldered in a hydrogen atmosphere. Magnification 400 x; bonding agent AgCu 28, sinter FeCu.

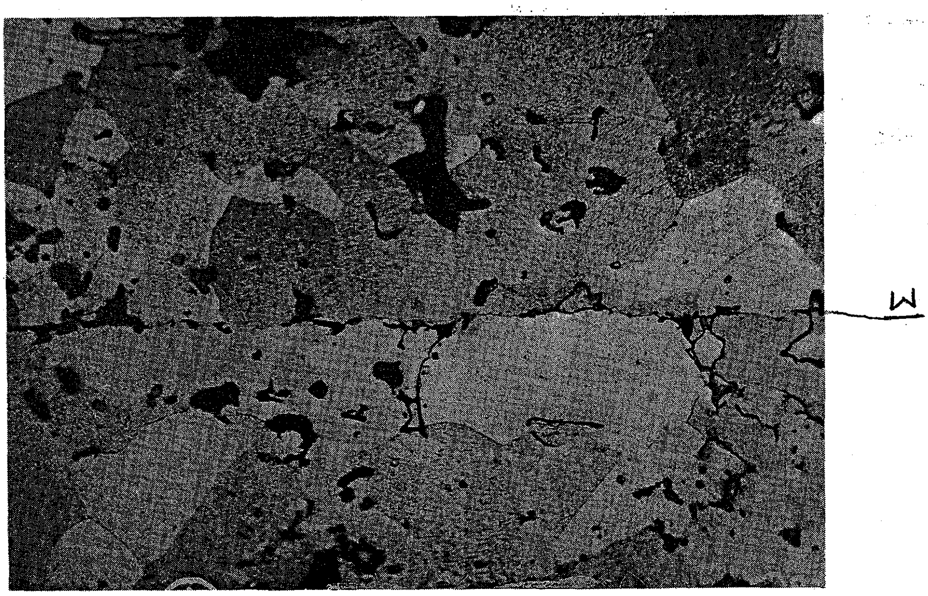

Fig. 4. Microstructure of diffusion-bonded sintered layers. Magnification 800 x, sinter FeCu, interface (W).

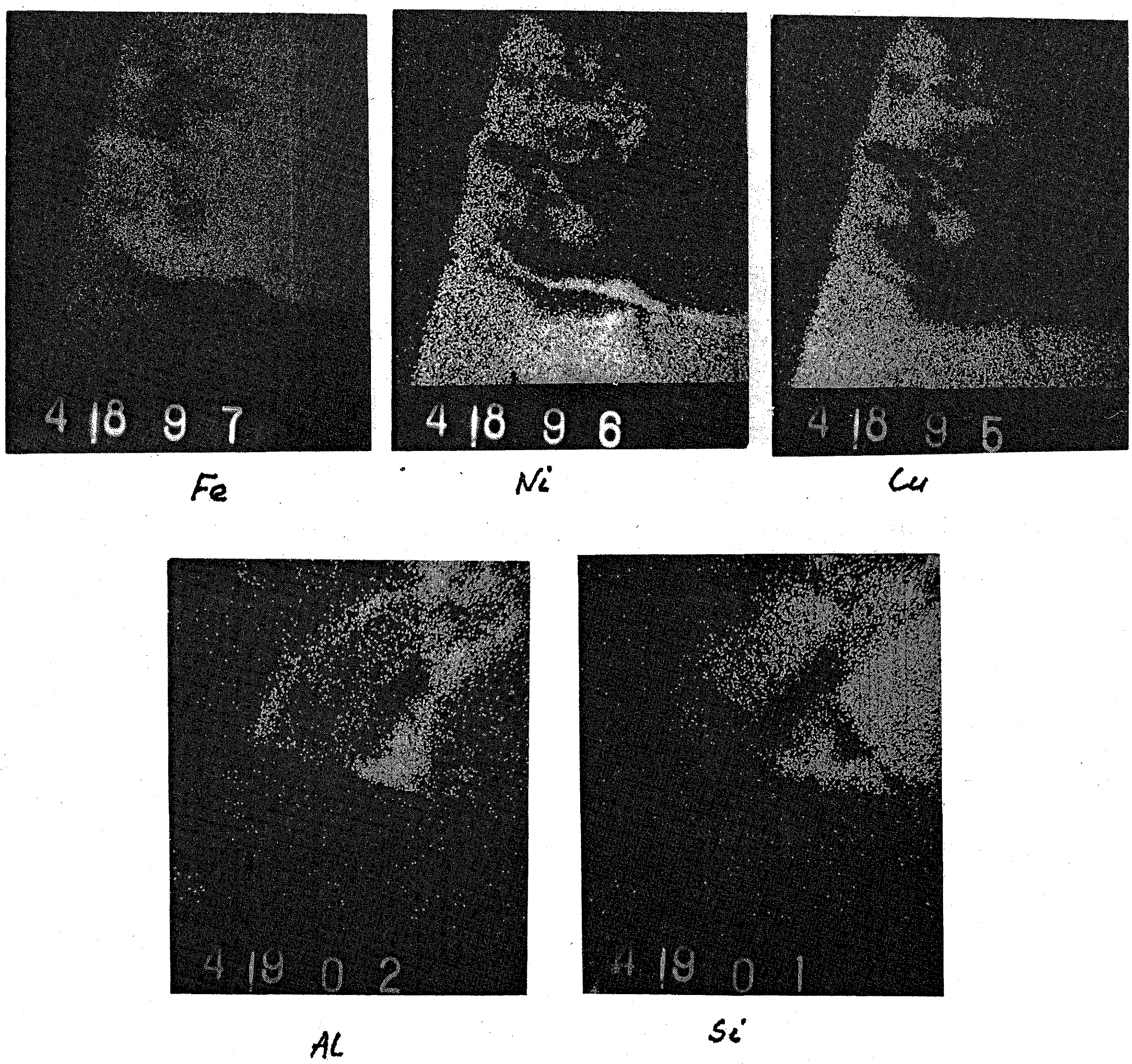

Fig. 5. Surface distribution (SEM) of Al, Si, Fe, Ni and Cu in a multi-layer joint of Cu-Ni-Fe alloy to glass, obtained by means of electron beam method.

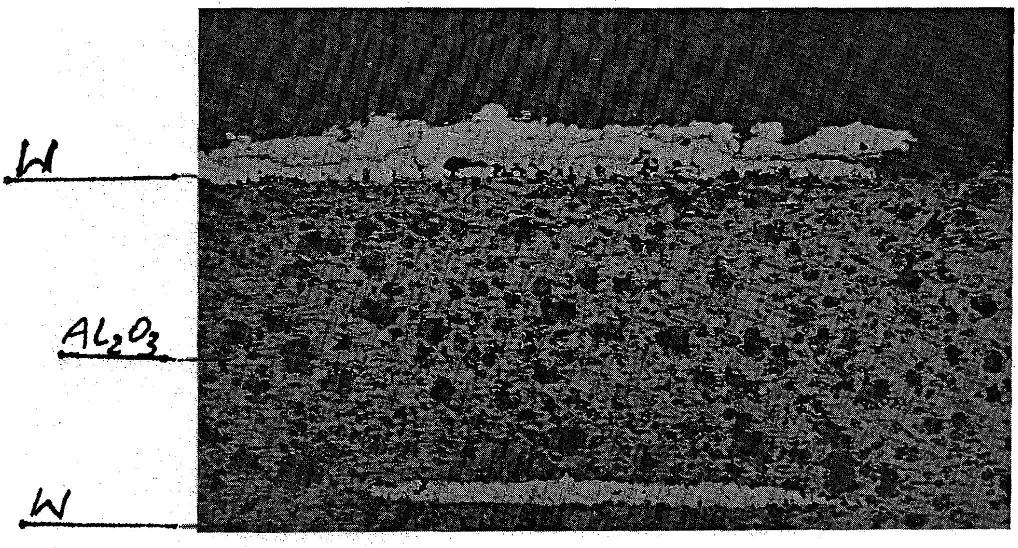

Fig. 6. Microstructure of Al_2O_3-to-W bond obtained by the sinterwelding method. Magnification 250 x, ceramic layer (Al_2O_3), metallic layer (W).

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