INFLUENCE OF THERMOCYCLING ON STRUCTURE AND MECHANICAL PROPERTIES OF THE ALUMINIUM-BORON COMPOSITE MATERIAL

A.V. FILIPOVSKII

G.V. Karpenko Physico-Mechanical Institute,
Academy of Sciences of Ukraine, 5, Naukova St., 290601 Lviv, Ukraine

ABSTRACT

The influence of thermal cycling on structure and strength of composite aluminium-based alloy, reinforced with boron fibres was studied. The tests have been performed on the composite materials made of AlMg6 aluminium alloy. The boron fibres of 140 µm in diameter are used as a strengthening phase. Fibres volume content was 50%. The thermal cycling was carried out in argon in the temperature range from 150 to -196 °C according to two regimes: mild cycle and thermal shock. It is shown that structural changes, taking place in a composite aluminium-boron material during thermal cycling reduce the material strength. The peculiar features of crack initiation and fibres fracture depending on a number of cycles and speed of heating and cooling were studied morphologically. It was established that the most favorable place of crack initiation is a boron shell - tungsten base interface.

KEYWORDS

Composite material, matrix, aluminium, boron fibres, interface condition, thermal cycling, coefficient of linear thermal expansion, thermal stresses, strength, crack.

INTRODUCTION

To a significant degree the strength and life of composite material parts depend upon the compatibility of the physicochemical properties of the components, adhesion, composition, and interface condition. These properties are, as a rule, determining ones in thermal cycling. The differences in the coefficients of linear thermal expansion and in the relaxation capacity of the constituents of a composite material, the formation of intermetallide compounds, and other reasons may cause significant internal stresses. In some cases the internal stresses occurring may lead to formation of cracks in the fibres (Chawla, 1976; Maksimovich et al., 1988, 1990).

EXPERIMENTAL PROCEDURE

The purpose of this work was to investigate the thermal cycling on the structure and strength of an aluminium-boron composite material produced by compacting at increased temperatures of packets composed of unidirectionally reinforced single layers. AlMg6 aluminium alloy (coefficient of linear thermal expansion $\alpha = 22 \cdot 10^{-6}\ ^{\circ}C^{-1}$) was used as the matrix. The reinforcing was with 140 μm diameter boron fibres ($\alpha = 6,3 \cdot 10^{-6}\ ^{\circ}C^{-1}$) produced by vapourgas deposition of boron on 12 μm tungsten wire. The fibre content was 50 vol.%.

Flat specimens (gage length cross section 3 x 1 mm) for mechanical tests and thermal cycling tests (size 20 x 15 x 1 mm) were cut from 1 mm thick plates of the composite by the electrospark method.

The experiments were made in an atmosphere of purified argon by two methods, moderate (20°C → 150°C → 20°C → -196°C →...) and severe thermal shock (150°C → -196°C → ...) with holds of 10 min at each cycle temperature.

In the mild method the container with the specimens was placed in a furnace heated to 150°C. After reaching this temperature and the specified hold container first cooled in air to 20°C and then in liquid nitrogen to -196°C, heated in air to room temperature, and then the cycle repeated. In the severe method the container was transferred from the heated furnace into a bath with liquid nitrogen, then into the furnace, etc. until reaching the required number of cycles.

RESULTS

It was observed (table 1) that even after 10 thermal cycles the strength of specimens thermally cycled using both methods starts to drop. An increase in the number of thermal cycles leads to a further reduction in strength of the composite material. However, after 40-50 thermal cycles the loss of strength is slowed. In the range up to 30 thermal cycles the specimens cycled using the severe method have a lower strength than after thermal cycling using the mild method. After 30 thermal cycles regardless of the method, their strength becomes practically the same.

Table 1. The influence of thermal cycling on the strength of AlMg6- boron composite material.

Number of cycles	0	10	20	30	40	50	100
Strength, MPa (mild cycle)	1185	1080	920	645	550	510	500
Strength, MPa (shock)	1185	950	700	600	540	500	500

DISCUSSION

Analyzing the processes of failure of the composites it may be proposed that the most vulnerable will be the boron fibres, which themselves are already a composite. In the center of the fibre the formation of brittle phases, tungsten borides (WB, W_2B_5 , WB_4) in which microcracks will originate, is possible.

On the basis of the metallographic analysis data it was established that in the original conditions the boron fibres have no cracks. Even after 10 thermal cycles using the mild method cracks appear in them. They originate in the center of the fibre at the tungsten core-boron shell interface (26%), on surface (13%), that is, the crack is directed from the fibre-matrix interface into the fibre, in the boron shell (1%), and also by a mixed mechanism combining all of these cases 7%. A portion of the fibres remained unfailed (43%).

The most common point of crack origin in fibres in thermal cycling is the boron shell-tungsten core interface.

In the original condition the core and the surface layer of the boron fibres are in compression while a large portion of boron fibre is loaded with significant tensile stresses (Vega-Boggio and Vingsbo, 1977), which eases crack origin at the interface.

A somewhat smaller quantity of originating cracks is on the surface of the boron fibres. They rarely occur in the boron shell.

With an increase in the number of thermal cycles new cracks appear and old ones grow, intersecting the whole fibres. The following types of failure of fibres are observed:

- cracks intersect the fibre through the tungsten core (44%);

- cracks pass through the fibre without reaching the tungsten core (18%);

- a crack develops within a fibre without reaching the core of the fibre-matrix interface (2%);

- the fibre fails according to a mixed mechanism (11%);

After 20 thermal cycles 75% of the boron fibres had failed. After passage through the whole fibre crack development slowed at the fibre-matrix interfaces, that is, retarding of microcracks at the interfaces was observed (Mileiko and Anishchenkov, 1980). Changes were not revealed in the matrix. Therefore relaxation of the thermal stresses in the composite material causes failure of the fibres.

An increase in the number of thermal cycles to 30 leads to even more damage of the fibres with 80% of them failing.

With an increase in the thermal cycling time, the number of failed fibres and the degree of their damage grow. There is also a reduction in the strength of the composite material.

As the result of thermal cycling according to the severe method the composite material was strongly damaged. After 10 thermal cycles the damage of the material correspond to that after 20 mild thermal cycles. The character of failure of the fibres does not change. A further increase in the number of thermal cycles is accompanied by some damage of the composite material. However, after 30 thermal cycles the number of failed fibres and the degree of their damage are practically the same as after 30 mild cycles. Consequently the cooling rate has a significant influence on the structure of the composite material only at the beginning of thermal cycling while subsequently this effect drops. After 30 cycles the curves of the relationship of the strength of the composite material to the number of thermal cycles practically coincide. After 50 cycles thermal cycling was stopped.

In both methods of thermal cycling the greatest number of cracks occurred at the tungsten core-boron shell interface. Failure of the composite material obviously occurs in two successive stages. First under the action of thermal stresses the brittle boride phases fail. They accept the first thermodynamic overloads and are their "extinguishers" in a certain time range. During the second stage the fibre fails. It should be noted that during occurrence of the first stage of failure in one fibre the adjoining one may fail completely as the result of the presence in it of larger defects of a different type.

CONCLUSIONS

Therefore thermal cycling by either of the methods used leads to a reduction in the strength properties of composite materials. The maximum drop in strength occurs during the first 20-30 load cycles (more intense in the severe method). Subsequently the drop in strength decreases and even after 40 load cycles using both the mild and severe methods the loss of strength is slowed. The main source of origin of primary cracks is the fibres themselves and their core (brittle boride phases). In connection with this it is necessary to change the constituents of the reinforcing fibres and the method of their preparation.

REFERENCES

Chawla K.K. Thermal fatigue damage in Borsic-Al (6061) composites (1976). Journal of Materials Science, 11, N 8, p.p. 1567-1569.

Maksimovich G.G. (1974). Micromechanical Investigations of the Properties of Metals and Alloys, Naukova Dumka, Kiev.

Maksimovich G.G., Filipovskii A.V., Mikheev D.I. et al.(1988). The influence of temperature on the structure and mechanical properties of a magnesium-boron fibre composite material. Mekh. Komp. Mater., N 3, p.p. 468-471 (in Russian).

Maksimovich G.G., Filipovskii A.V., Mikheev A.I. and Tarasenko I.V. (1990). The strength and feature of failure of an aluminium-boron composite material subjected to thermal cycling. In: Summaries of Papers for the Seventh All-Union Conference on the Mechanics of Polymer and Composite Materials, Yurmala, April 17-20. p. 109, Zinatne, Riga (in Russian).

Mileiko S.T. and Anishchenkov V.M. (1980). Features of the fatigue failure of fibre composites with a metal matrix. Mekh. Komp. Mater., N 3, p.p. 409-417 (in Russian).

Vega-Boggio I. and Vingsbo O. (1977). Radial cracks in boron fibres, Mat. Sci., 12, N 12, p.p. 2519-2524.