CYCLIC STRENGTH OF AN Al-Al$_3$Ni COMPOSITE AT STRESSES APPEARING THE FATIGUE LIMIT

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Investigations of the fatigue characteristics of composites as very promising structural materials for use in the new technology are of considerable theoretical and practical interest. The information available in the literature relates mainly to composites based on copper [1, 2], aluminum [3, 4], and plastics [5], reinforced with continuous fibers. Data on the fatigue characteristics of directionally crystallized eutectic composites are scanty. This is due in some measure to the difficulties encountered in the production in considerable quantities of strictly identical composite specimens and to the limited application of such materials in technology.

By studying the system Al—Al$_3$Ni over a limited endurance range (from 4 to 66,417 cycles), using smooth and notched specimens, Hoover and Hertzberg [6] have shown that the number of cycles to failure of the composites decreases with rise in the stress amplitude. From the results of mechanical tests, metallographic examination of the microstructure, and the nature of the distribution of the fatigue crack, these authors concluded that, if (with "whiskers" of micron diameter) the ratio $l/d$ is sufficiently large, composites containing discrete fibers should have a fatigue resistance comparable with that of composites containing continuous fibers.

The object of the present research was to investigate the fatigue resistance of an Al—Al$_3$Ni composite at stresses approaching the fatigue limit and also to study the effect of annealing mechanically worked specimens on their cyclic strength in long-term tests.

![Fatigue Curves](image1)

![Fatigue Failure Diagrams](image2)

Fig. 1. Fatigue curves of the eutectic Al—Al$_3$Ni composite: a) mechanically worked specimens; b) mechanically worked specimens which were subsequently annealed in vacuo at 350°C.

Fig. 2. Diagrams of the fatigue failure of Al—Al$_3$Ni composites at stresses of 7.5 kgf/mm$^2$ (a) and 10 kgf/mm$^2$ (b).


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Fig. 3. General appearance of specimens containing a fatigue fracture: a) development of fatigue crack in the direction of increasing stresses; b) development of fatigue crack in direction of decreasing stresses; c) fatigue fracture along the cleavage boundary of blocks.

Fig. 4. Site of accumulation of "black particles" in fatigue fractures: a) fatigue crack separating the specimen into core and outside; b) cleavage boundary of blocks.

For the tests we used specimens produced by Czochralski's method in graphite crucibles [7] with a crystallization rate of 40 mm/h. The purity of the starting materials was: Al 99.9996% and Ni 99.99%. Threads of the intermetallic compound Al$_3$Ni occupied 10.6% of the volume of the composite material with a ratio $l/d \approx 10^3$. The short-term ultimate strength of the composite concerned was $32 \pm 2$ kgf/mm$^2$.

The cyclic strength was investigated on smooth specimens, the working part of which was 3 mm in diameter. The tests were carried out by the cantilever bending of a rotating specimen held at one end in a grip on a machine designed for the fatigue testing of microspecimens [8], the frequency of stressing being 2800 cycles/min. Diagrams showing the failure of the specimens in relation to the magnitude of the load and the number of cycles were recorded by means of an automatic attachment.

Some of the specimens were annealed in vacuo for 1 h at 350°C to remove residual stresses in the surface layer after mechanical working and possible internal stresses set up during the shaping of the composite. The time of cooling from 350°C to room temperature was 1.5-2.0 h.

The test results are shown in Fig. 1. The band of scatter of the experimental points obtained under conditions of high cyclic stresses indicates a certain inhomogeneity in the unannealed specimens; this is doubtless associated with the methods of production and mechanical working. The scatter of the points diminishes with reduction of load on the specimens. At cyclic stresses of about 7.0 kgf/mm$^2$, the fatigue curve exhibits an inflection which indicates that the stresses are equal or near to the fatigue limit.

Annealing the specimens leads to a small reduction in the fatigue strength in the limited endurance range and to an increase in the cyclic strength as compared with that of unannealed specimens at a large number of cycles (see Fig. 1b).

Failure diagrams of unannealed specimens, typical of the composite material tested, are shown in Fig. 2 for stresses of 7.5 and 10 kgf/mm$^2$. There are known to be three stages in the formation of a fatigue fracture in pure metals and alloys: the first is associated with the strengthening of the most heavily stressed crystals; the second occurs when there is a breakdown in some of the (most highly stressed) crystals; and the third accompanies the propagation of the fatigue crack [9].

It has been found in the present investigation that the development of a fatigue fracture in a two-phase eutectic alloy differs somewhat from that in a single-phase material. Thus, at stresses close to the fatigue limit (7.5 kgf/mm$^2$), an increase in the angle of bending of the specimen is observed in the first stage on the fatigue failure diagram of the Al--Al$_3$Ni alloy (see Fig. 2a); this may be due to weakening of the eutectic alloy. The extent of bending of the specimen and the duration of the stage in specimens of