Damping capacity of nanoquasicrystalline Al-Cu-Fe materials

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Abstract. An influence of the grain size of quasicrystalline Al-Cu-Fe materials (QCs) on their damping capacity at the alternate loading has been investigated in the strain amplitude range of \(1 \times 10^{-4}\) and in the temperature range 20..350°C. It has been established that damping capacity of the nanometer-sized QCs at heating is essentially higher than that of submicron-sized ones. Logarithmic decrement of the QCs is found to increase progressively in whole strain amplitude range as temperatures go higher than some threshold value. Possible mechanisms of dissipation of mechanical energy in nanometer-sized QCs at elevated temperatures are discussed.

1. Introduction

It has been earlier established that the decreasing of the grain size in QCs to nanoscale values essentially affects their mechanical behaviour. The effect manifests itself in a nonmonotonic dependence of microhardness on the grain size [1] as well as in the change of an extent of hardening stage in the stress-strain curves of QCs at the decreasing of the grain size [2]. Theoretical considerations [3] suggest that the decreasing of the grain size in QCs may result in the facilitation of processes of both motion and multiplication of dislocations as well as in an exit of the dislocations and phason defects to the grain boundaries. Such processes will facilitate microflow also. Based on this ground one can suppose that damping properties of QCs should also be changed essentially at the decreasing of the grain size down to nanoscale level.

In this connection, the purpose of this work is a study of the influence of the grain sizes of QC Al-Cu-Fe coatings on their damping capacity (capability of material to dissipate a significant amount of mechanical energy as it is subjected to cyclic strain).

2. Experimental procedure

2.1. Materials and coating procedure

Coatings Al-Cu-Fe of thickness in a range 65..110 μm were produced by electron beam evaporation of an ingot in vacuum followed by a vapor condensation on the substrate at the deposition rate of 5 μm /min. QC coatings having different grain size were obtained by the varying of substrate temperature (from 270°C up to 670°C) [1]. Composition of coatings deposited at different substrate temperatures was close to Al_{63}Cu_{24}Fe_{14}. The coating compositions were determined by X-ray fluorescent analysis in an X Unique II unit. The distribution of chemical elements across the coating thickness was measured in an Energy-200 microanalyzer, mounted on the scanning electron microscope CamScan4. Structural investigations were carried out using a DRON-4 X-ray
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tometer with Co-K$_\alpha$ radiation. TEM investigations were conducted by using JEM-2000FXII
electron microscope operated at 200 kV.

2.2. Damping measurements

Damping properties of coating materials (values of the true logarithmical decrement) was evaluated
by calculation procedure [4] using measured amplitude dependencies of decrement of substrate-
coating system ($\delta_i$: $\delta_i = \frac{1}{n} \ln \frac{A_i}{A_{i+n}}$, where $A_i$ and $A_{i+n}$ are vibration amplitudes of the free end of
the sample with coating at the i-th and i+n-th vibrations, $A_i$ is the mean value of amplitude in the
range between the i-th and i+n-th vibrations. Experimental measurements of amplitude dependencies
decrement of substrate-coating system were carried out in a temperature range of 20..360ºC at the
strain amplitude range of 1..12×10$^{-4}$ by using mechano-dynamic analyzer [5]. A flat titanium
specimen of 1.8 mm thickness covered with a QC coating was cantilever fixed at one end and was free
to vibrate at the other end, while it is excited through the base. Used for these measurements was a
free-decay method of flexural vibration at the frequency of 140÷150 Hz.

3. Results and discussion

A typical microstructure of cross section of QC AlCuFe coatings obtained by electron beam deposition
is presented in figure 1. It is seen that the coating is characterized by homogeneous microstructure.
Figure 2 shows X-ray diffraction patterns of coatings, deposited at different substrate temperatures.
All diffraction peaks of coatings deposited at temperature above 400ºC can be indexed using (N, M)
for icosahedral structure [6]. Moreover, XRD patterns of coatings deposited at low temperatures
exhibit peaks of both QC and cubic B2 crystalline phases. Analysis of the diffraction patterns testifies
that the decreasing of substrate temperature leads to the widening of diffraction peaks of icosahedral
phase. The broadening of diffraction peaks can be caused mainly by decreasing of the
crystallite size in the coatings. This conclusion is confirmed by TEM investigation presented in
figure3.

![Figure 1. Typical SEM micrographs of cross section of Al-Cu-Fe coatings. Symbols I and II denote titanium substrate and QC coating, respectively.](image1)

![Figure 2. XRD patterns of Al-Cu-Fe coatings deposited at different substrate temperatures. Diffraction peaks of QC structure are indexed using the (N, M) indices [6]. Other peaks belong to cubic B2 phase.](image2)
Statistical analysis of dark field images obtained in reflections of icosahedral phase allows the size distribution of grains in coatings deposited at different substrate temperatures to be determined (figure 3). Average sizes of grains in coatings deposited at temperatures 670ºC, 430ºC and 270ºC are 580 nm, 270 nm and 30 nm, respectively. It is seen that the size distributions at different temperatures are similar and they shift to smaller sizes at the decreasing of substrate temperature. It should be noted that microstructure of coatings deposited at temperature of 270ºC is characterized by nanoscale grain sizes.

Figure 4 presents dependencies of true decrement of QC Al-Cu-Fe materials having different grain sizes in a temperature range of 20...360°C. It is seen that coatings having submicron-sized grains exhibit decrement which is almost independent of temperature. It can be caused by the fact that the damping due to the dislocation motion in such QCs is not significant in whole temperature range investigated. At the same time, the temperature dependence of damping becomes more distinct at the decreasing of the grain size (figure 5). Significant change is observed for the coatings having nanoscale (below 100 nm) grains. In the case, temperature dependence of the decrement of the QC material becomes to be threshold: the decrement exponentially grows with temperature when it is above 250°C. It should be noted that such behaviour is observed in whole range of strain amplitudes. Observed level of damping capacity of nanoQC-based coatings remains unchanged even after long-term cyclic loadings at elevated temperatures and multiple heating-cooling cycles.

Such behaviour testifies that mechanism of microflow and damping in the QCs changes at the decreasing of the grain size. One can suppose that dominate role in energy dissipation in nanoQC-based materials play processes of grain-boundary relaxation (generation and motion of grain-boundary dislocations, accumulation of phason defects into grain boundaries, etc.). A possible influence of small amount of cubic phase in the nanoQC-based materials on the grain-boundary processes is also of special interest. The supposition on the dominate role of the grain boundary relaxation in energy dissipation in nanoQC-based material is confirmed by the fact that the process requires thermal activation and occurs only at the achievement of certain temperature (threshold temperature dependence on the damping). Moreover, the value of true decrement of the coating material has only a weak dependence on the strain amplitude. The behavior is not typical for...
dislocation mechanism of mechanical energy dissipation (e.g. Granato-Luke model) where the
dependence has exponential character.

It is known, that the use of damping materials as coatings on structural elements subjected to cyclic
deformation and to resonance loading enables one to augment significantly their service life and to
reduce noise [7]. At the same time, the materials for coatings should have a high level of strength
properties (high Young’s modulus, hardness, wear resistance and endurance limit) in addition to high
damping capacity [8]. From practical standpoint, the use of nanoQCs as material for damping coatings
may be of special interest due to the fact that QCs possess a unique combination of such properties as:
high hardness, high Young’s modulus, and low friction coefficient, superplasticity at elevated
temperatures, good corrosion resistance, and thermal expansion coefficient comparable with that of
metals.

4. Conclusions
It is established that the decreasing of the grain size in QCs to nanoscale value allow to enhance
essentially their damping capacity at elevated temperatures. Such behaviour is supposed to be related
to change of the mechanism of energy dissipation in the materials. Thermal dependence of damping
capacity in nanoQC-based material is found to be threshold: the damping essentially grows with
temperature when it is above 250°C. At the same time, it is established that the damping capacity of
nanoQC material has only a weak dependence on the strain amplitude in the temperature range of
20...300°C.

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