ATOMIC FORCE MICROSCOPY STUDY OF THE Cu-Be ALLOY STRUCTURE

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1. Introduction

Structural analysis of materials is a permanent research problem aimed to achieve the results of new material properties with desirable characteristics for challenging applications. Metals in the solid form are polycrystalline, and consist of an aggregate of many crystals (grains). Typically, the grains of a metal object are very small. The physical parameters of the materials depend on their composition and arrangement of the internal structure according to the technological processes of their preparation. Conventional methods of structural analysis were based on the optical microscopy. The higher level represents the use of scanning electron microscopy (SEM). Currently, the best way for analysis are the physical methods based on the atom interactions. Electrically conductive materials are suitable for the scanning electron tunneling microscopy (STM). The universal technique is the atomic force microscopy (AFM) applicable for analysis of any materials, including biological structures. In this paper, the methods of investigation of Cu-Be alloy structure by AFM are presented. The measurements were made on commercial equipment Cypher AFM from Asylum Research. For the evaluation of the structural parameters, the various modes of measurement where implemented. New methods at interpretation of the collected data for description of the examined material structure are presented.

2. Atomic force microscopy

Since invention of AFM in 1986 [1], the atomic force microscopy became an essential tool for material and biological research. Exhaustive description of AFM and its applications can be found in the publication [2]. Investigation of mechanical properties of the matter is important in many applications. Now, it is possible to find the numerous articles dealing with the AFM applications in various fields of research, biology and medicine including. Of particular interest are works that describe new evaluation methods of AFM technology. Amplitude-modulation atomic force microscopy (AM-AFM) known as tapping-mode AFM, has opened a number of non-destructive evaluation ways with high spatial resolution [3]. The AM-FM mode gets results by operating at two cantilever resonances simultaneously. As the name indicates, the first resonance is used for tapping mode imaging, also known as amplitude modulation (AM), while a higher resonance mode is operated in frequency modulation (FM). At resonance, the cantilever frequency and phase respond sensitively to changes in sample properties. A mechanically driven oscillation is characterized by three parameters, the amplitude, the frequency and the phase lag with respect to the mechanical excitation. AM-FM Mode provides elastic information including storage modulus, Young's modulus, and contact stiffness and viscoelastic information including viscoelastic loss tangent and loss modulus. In AM-FM, the excitation frequency is fixed at the beginning of the experiment, whereas the amplitude and the phase lag of the oscillation provide two channels to explore tip–surface conservative (elastic) and dissipative (inelastic). The quantitative elastic modulus is determined from frequency, amplitude, and phase of the two modes with a contact mechanics model. The relationship of macro and micro elastic modulus is depended on molecular dynamics (MD). The MD simulations of the compression model under the uniaxial strain allows a control of parameters such as strain rate and temperature to better understand the behavior under complex dynamic shock conditions [4].

3. Experimental

Copper beryllium alloys are used for their high strength, good electrical and thermal conductivities, good corrosion and oxidation resistance. There are two groups of copper beryllium alloys, high strength alloys and high conductivity alloys. The wrought high strength alloys contain 1.6 to 2.0% beryllium and approximately 0.3% cobalt. Cu with 1.9 wt% Be is a precipitation hardening alloy that achieves the highest strength in Cu based alloys. The high conductivity alloys contain 0.2-0.7% beryllium and higher amounts of nickel and cobalt. These alloys are used in applications such as electronic connector contacts, electrical equipment such as switch and relay blades, control bearings, housings for magnetic sensing devices, non sparking applications, small springs, high speed plastic molds and resistance welding systems.

In this work, we used the sample of Cu-Be alloy with nominal composition: Be 1.80-2.00%, Co + Ni 0.20% min, Co + Ni + Fe 0.6% max, Pb 0.02% max, Cu + Sum of named elements 99.5% minimum [5]. The alloy solution was annealed at 790 ^{o}C, subsequently precipitation hardened at 315 ^{o}C for 3 hours to achieve maximum attainable hardness. The microstructure (see Fig. 1 a.) consists of equiaxed alpha grains and the cobalt beryllide phase uniformly dispersed throughout the matrix. The strengthening precipitates which result from precipitation heat treatment are not resolved by optical microscopy. Small amounts of equilibrium gamma phase are present in the grain boundaries.

Comparison the manufacturer published microstructure (Fig. 1a) with actual microstructure of the sample images were made on an optical microscope (Fig. 1b) and SEM (Fig. 1c). At seven times magnification in comparison to Fig. 1a, there are visible signs of microcrystalline grain edges. Weak observable areas with dimensions in several μm include the cobalt beryllide phase. Strengthening precipitates are tiny dots clearly visible on the SEM image.

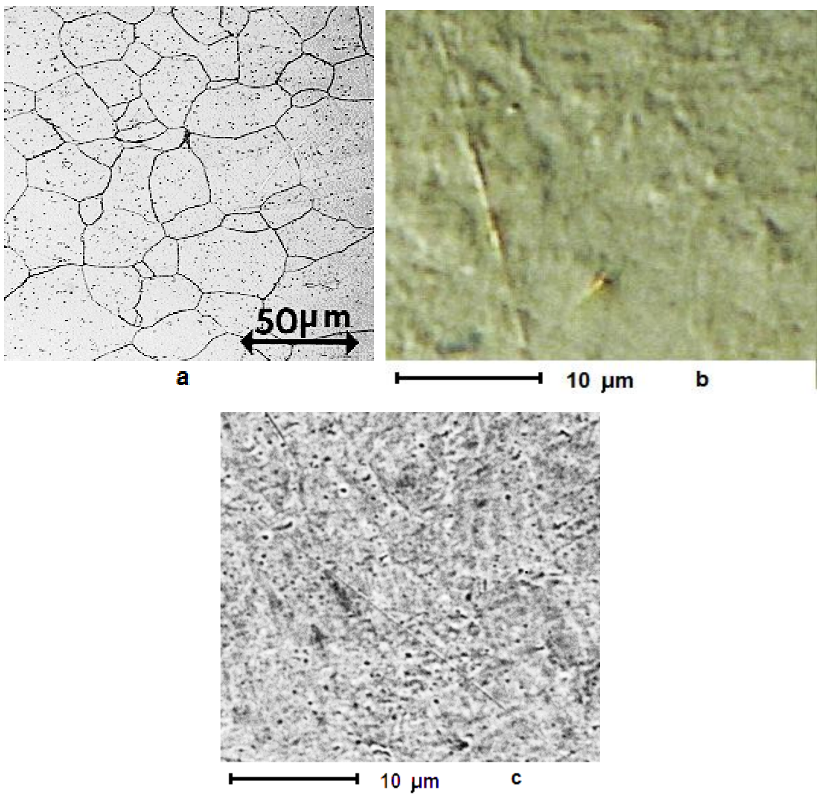

Fig. 1: *Metallographic structure of CuBe alloy: a. macrostructure by [5], b. an optical microscopy image, c. SEM image.*

Measurement results from AFM are shown in Fig. 2. The structure is nine times magnified in comparison with the SEM. Fig. 2 shows the surface of Cu-Be sample of size 3.5 x 3.5 µm in all assessment modes. Cobalt beryllide phase area (in the center of the image) has size approximately 1.2 x 1.5 µm. Strengthening precipitates are contrasting formations with dimension at the level of tens µm. By comparing of these images, there is deduced suitability of various evaluation modes to identify the structure details. The most appropriate assessment is based on elasticity modulus (Fig. 2d). Fig. 3 shows the profile of elasticity modulus across the precipitate. This characteristics suggests mechanical inconsistency of these particles. On the contrary, the cobalt beryllide phase has a mechanical properties little different from the base material. This is documented by the elasticity modulus map from

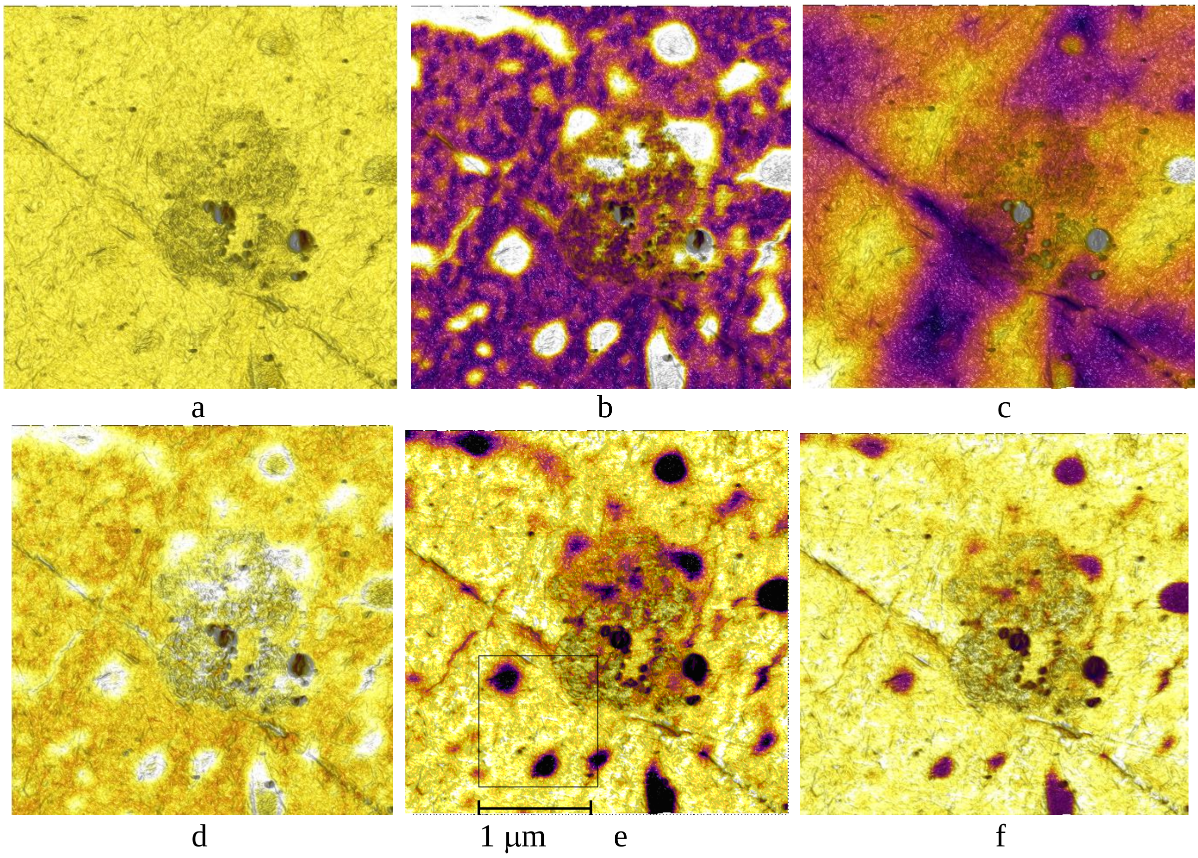

Fig. 2: *Images of 3.5 µm x 3.5 µm Cu-Be surface area from CYPHER AFM in various measurement modes: a. amplitude, b. phase, c. z sensor, d. dissipation, e. elasticity, f. identation.*

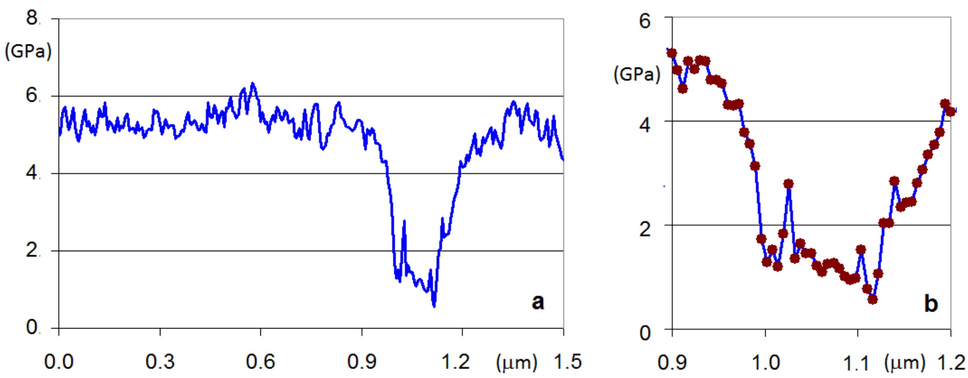

Fig.3: *The profile of elasticity modulus across the precipitate particle (a) and detail (b).*

part of the sample surface, which is shown in Fig. 4. The precipitants are the dark spots and the cobalt beryllide phase is the obscure area in right top corner of the image. Fig. 5 shows the SEM map of alloy elements distribution. The Be is missing due to its small atomic number.

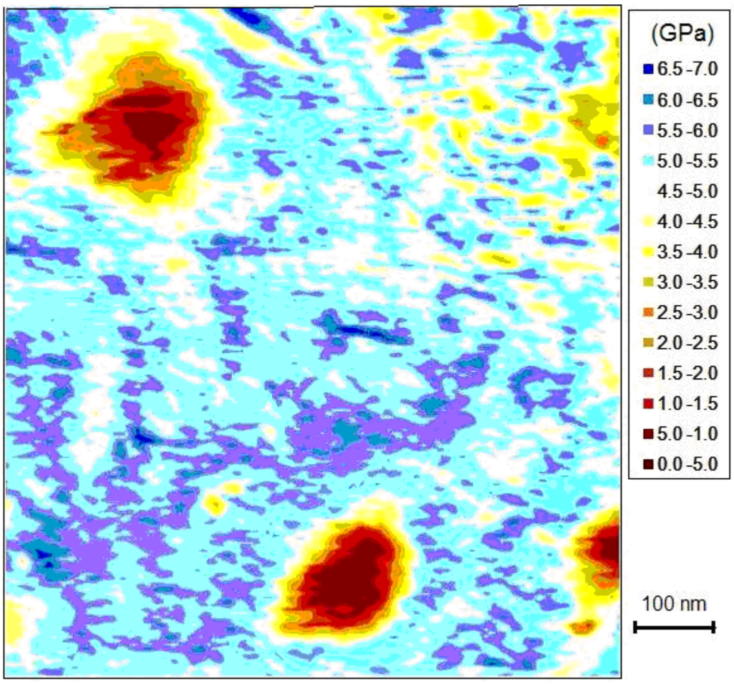

Fig.4: *Map of the cobalt beryllide phase and precipitants (the area marked in Fig.2 e).*

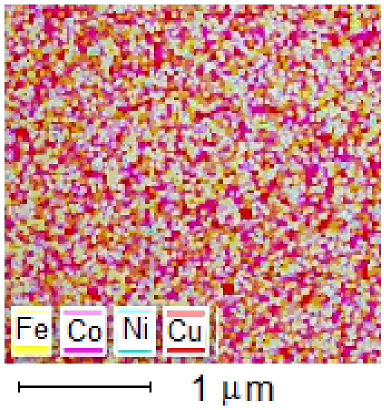

Fig. 5. *SEM surface analysis.*

4. Conclusion

AM-FM technology of AFM offers a comprehensive range of material analyses on the nanometer level. Various modes evaluation of atom force interactions allow to obtain complex material characterization. The result of this work is the observation that the strengthening precipitates in Cu-Be alloy have contrasting mechanical properties compared to the rest of the material.

Acknowledgement

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