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# THE ACQUISITION AND INVESTIGATION OF SUBMICROCRYSTAL STRUCTURE MATERIALS IN EXPERIMENTS ON LOADING OF METAL SPHERES BY SPHERICALLY CONVERGING SHOCK WAVES

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Methods of explosive loading of solid metal spheres by spherically converging shock waves with pressures up to 200 to 1000 GPa and durations of 0.5 to 1.5 μs on conserved samples have been developed. Results of analyzing the changes of microhardness, macro- and micro-structures, and residual-oriented microstresses along the radius of the copper compressed core are presented. In the material layer adjacent to the vacuum cavity, the essential grinding of a grain (by 2 to 3 orders relative to the initial one) due to the high-rate crystallization of the melt in the stress waves has been revealed.

## 1. INTRODUCTION

The acquisition and investigation of stable submicroscopic materials with grain sizes from 0.1 to 10 μm are of interest in the field of superplasticity phenomena.[1-3]

Present static setup parameters,[1-4] are insufficient for the acquisition and realization of the superplasticity state in high-strength refractory materials such as tungsten and its alloys.

The method of obtaining submicrocrystalline materials described in this work does not have the drawbacks of static compression techniques and can be applied to obtain the required submicrostructures with new physical-chemical and thermal-physical properties in a wide class of metals and alloys, including high-strength and refractory materials. Our studies include:

- a description of the loading conditions, allowing the recovery of metal samples, which have undergone loading by spherically converging shock waves, pressures up to 200 to 1000 GPa, with durations of the load impulse from 0.5 to 1.5 μs;
- an investigation of changing the macro- and micro-structures, as well as microhardness, along the radius, including the layer of material being formed by the loading and having the submicrocrystalline structure;
- an estimate of the temperature stability for the discovered submicrostructure and kinetics of annealing the defects produced by the shock-wave action.

## 2. CONDITIONS FOR EXPLOSIVE LOADING AND CALCULATED PARAMETERS OF THE LOAD IMPULSE

Loading of solid metal spheres with initial diameters equal to 64 mm was carried out by the spherical converging shock waves, while applying the load impulse upon the metal sphere surface.

Numerical computations of the wave process in the compressed sphere and the heavy case have been performed according to the program VOLNA-81[5] and SPRUT-D[6] in the hydrodynamic approximation (HD), as well as in the plasto-elastic one (PE). The size of the cavity being formed in the sphere center, has been computed using two criteria for the spall fracture: the model of the instant spall (MIS)[7] and the kinetic model of the spall fracture (KMSF).[8]

To describe the thermodynamic properties of the metal, we used several different equations of state, including that of Reference 9, taking into account melting and vaporization of the metal in the stress waves. Location of the vaporization and melting regions in the central zone of the metal core is also calculated.

## 3. BASIC RESULTS OF THE CONSERVED SAMPLE INVESTIGATION

After loading the solid sphere and cooling it to room temperature, the samples became thick-wall spherical shells. The exterior diameter of the sample was increased, but in the center a high-vacuum cavity was formed. The cavity surface for materials without polymorphous transformations was smooth, although small drops of the crystallized melt were observed. The samples were used to analyze the change of microhardness, macro- and microstructures by means of optical microscopy and TEM.

In Figure 1 the change of microhardness with radius is shown in one direction.

An increase of microhardness was observed, while the radius decreased in the external layers of the compressed core where the material that was subjected to the increasing plastic deformation in the front of the converting wave remained in the solid phase. There was considerable evidence of deformation in the microstructure, such as lines of slipping twins, in various directions, whose concentration increased with radius. Further, the curve of the $H_\mu(R)$ dependence reaches a plateau. In this region, corresponding to a microhardness increase by more than two relative to the initial microhardness, there was a high density of twins, in various directions. Further along the radius the microhardness is rather quickly and sharply decreased, and its level appears to be close to the initial one. Under the shock wave loading, the material in this region turned into the liquid phase, and the crystallized melt did not undergo further plastic deformation.

Recrystallized material with extremely fine grains has been observed in the layer with 2 to 3 mm thickness close to the center. Such a submicrostructure, with the grain size ≤ 1 μm, could be formed as a result of the high-rate crystallization of the melt under its spraying upon the walls of the cavity, which was formed in the process of the solid sphere loading.

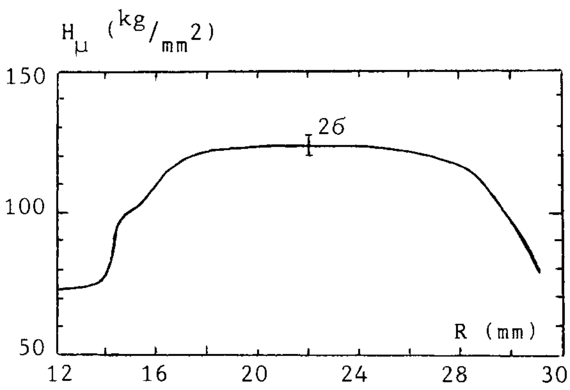


FIGURE 1
Change of microhardness in the material, after explosive loading of the copper core, along the radius

## 4. CONCLUSIONS

Conditions of explosive loading are described, together with the computed parameters of the load impulse, generated by spherically converging shock wave loading of copper spheres. The main results of the recovered sample investigation, include the analysis of the microhardness changes along the radius, macro- and microstructures, and the residual oriented microstresses. The submicrocrystal material formation, connected with the high-rate crystallization of the melt, has been revealed in the material layers adjacent to the central vacuum cavity. In conclusion we note, that the results, analogous to those described for copper, have been obtained for a number of other materials, including high strength refractory materials.

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