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Research paper

The Phenomena of Transformation of Chemical Bond in Tungsten Wire Obtained by Radiation Technology

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Abstract

The results of experimental studies in the field of radiation materials science, in particular, the phenomenon of chemical bond transformation in metal powders subjected to ionizing radiation in producing tungsten wire are presented. The phenomenon of energy conversion of an intracrystalline chemical bond between a material and a complex, including point defects and impurity atoms, leading to a change in the structure of sinter powder crystals, has been established experimentally.

Keywords: *tungsten, wire, gamma radiation, defect, sintering, structure, recrystallization, electric explosion, plasma, pulsed destruction, bond heterodesmicity, vacuum.*

1. Introduction.

The development and use of advanced methods of improvement of technology in powder metallurgy is a priority direction limiting the development of many areas of science and technology. For the formation of high-quality characteristics of materials from powders, a more advanced - a breakthrough technology based on accelerator technique - is proposed. This is especially true for ionizing radiation as a technological tool for obtaining stable properties of powder components in the processing of mineral raw materials. The birth of a new scientific area in the field of high technologies has passed approbation in industrial conditions and has shown that radiation treatment of tungsten powders improves the properties of the final product - wire, and is of considerable interest. The results indicate the possibility of controlling the structure by irradiating polycrystalline powder particles in the technology for producing tungsten wire, which leads to a decrease in the tendency of products to recrystallize and increase the mechanical and physicochemical properties that are inaccessible to macro-technologies. Tungsten wire is characterized by high plasticity, which allows increasing the winding speed of the helix, and imparting specific properties ensures the operation of products under extreme conditions [1, 2].

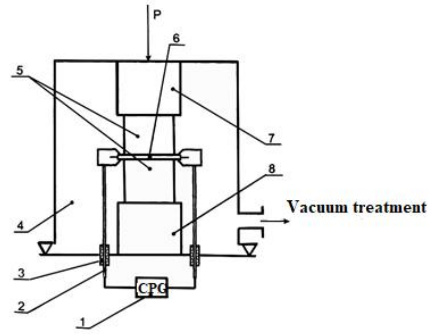
For practical tasks, it is necessary to study the specific features of the mechanism of irradiation on diffusion processes, which ensure the formation of a new structural state in sintered polycrystalline materials under large excitation conditions. The issues of structure defectiveness and its effect on diffusion processes during the formation of physicochemical properties in irradiated samples is one of the most interesting, but unsolved problems of condensed matter physics. Understanding the structure of chemical bonding in irradiated samples is the key to solving problems not only in radiation physics, but also in the production of amorphous metals and their alloys the scientists from many countries are working on. The basis of the chemical bond of metals is determined by the structure of interacting electrons located on the outer shells; therefore, chemical bonds at the interface between solid phases are increasingly being studied. It is known that the mechanism of hardening of metals is considered from the point of view of the theory of dislocation. However, it is appropriate to emphasize here that neither X-ray diffraction nor electron diffraction provide a real picture of dislocations in an atomic crystal. The true nature of changes in the macrostructure in metals and alloys should not be associated with the mechanism of dislocations, but with the nature of changes in chemical bonding under the influence of external factors: temperature, pressure, irradiation, etc.

When describing micro-regions in the melt, as well as building a general theory of metals and their alloys, American scientists use a cluster model of the liquid state of the metal, according to which the molten metal contains micro-regions where the long-range order in the arrangement of atoms is not violated. Clusters were not directly experimentally detected, but when decoding radiographs, interpreting data on thermal conductivity, electrical conductivity, etc. (i.e., indirect methods) a number of scientists state on that clusters do exist. Clusters are located far from each other, so they are not connected with each other, but hard bridges appear with an increase in the concentration of defects between clusters, indicating the presence of heterodesmic structure of the chemical bond during the transition of substances to the condensed state. Numerous studies indicate the formation of clusters under the action of ionizing radiation, both in the finished metal and in its production, however, physical materials science had previously no idea of how this type of communication is transmitted on a microscale, whether it has long-range order, whether affects the basic properties of a metal.

So far, there has not been a direct experimental method for determining the fraction of each type of chemical bond in a real crystal, although it was stated a priori that, on a microscale in metal crystals, along with a metal type, a covalent form is possible. This was explained by the fact that the crystalline state complicates getting rid of the imperfection of the crystal, anisotropy of properties, chemical heterogeneity and surface phenomena. The use of high-voltage pulsed discharges as a tool for destruction (sputtering with an explosion of conductors) provides new possibilities in the study of changes in chemical bonding in the structure of metal and alloys [3, 4]. Experimental studies have shown that, with an increase in the number of radiation defects introduced, conditions for the accumulation of many vacancies — clusters — are facilitated, and regions with a stronger bond are observed that do not collapse during melting and represent not macro, but macro-volume. The difference in the electron density redistribution in space of excited atoms near the nuclei from the original redistribution of this density in the neutral atoms forming this bond can be determined by electrofusion spraying of conductors in the form of a foil or wire in vacuum [5].

The study of the behavior of thermodynamic functions under phase transformations in solids was carried out on an experimental setup made on the basis of the T1220 hydro-pulse press using its high-voltage unit. The electrical circuit included a current pulse generator (CPG) with stored energy up to 30 kJ, a capacitor bank with a capacity of 200 μF and an operating voltage of 10 kV, as well as conductive rods with clamps the conductors were fixed with. The maximum amplitude of the discharge current was 60 kA, the inductance was 0.1 μG, the pulse repetition rate did not exceed 450 pulses per hour, the current density was more than 106 - 107 A/cm^2, the pressure after the explosion was 0.1 MPa.

As a result of the research carried out on the explosive evaporation of a conductor in the form of a wire, a pattern has been established for the formation of a stronger chemical bond in liquid-crystalline materials as compared to the original one. The experimental procedure was as follows: in a vacuum chamber 4 (Fig. 1) on a working table 8 of the lower flange (Fig. 2) between two samples 5 made of glass or ceramics a metal conductor in the form of a wire 6 was placed (Fig. 3), which tight coupling was provided by the force of the punch 7.



1 - current pulse generator; 2 - high-voltage input; 3 - insulator; 4 - vacuum chamber; 5 - glass or ceramic samples; 6 - metallic conductor; 7 - punch; 8 - working table

Fig. 1: Diagram of the experimental unit

Vacuum was created in chamber 4 (about $3 \cdot 10^{-4}$ Pa), and then a high-voltage pulse (10 kJ energy, discharge period $\tau \le 30$ μs) was applied to wire 6 from the pulse current generator 1 through the high-voltage input 2; the conductor evaporated, and the subsequent condensation of vapors between the two samples ensured the formation of a liquid metal layer.

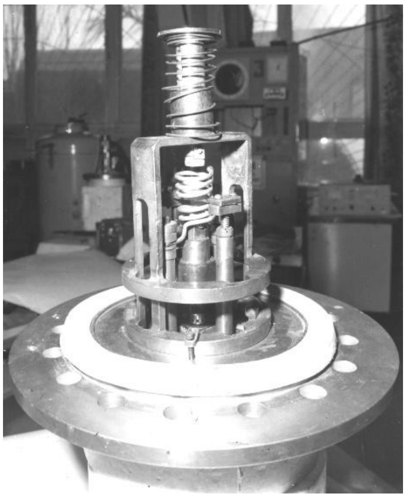


Fig. 2: Lower flange of the vacuum chamber with a mandrel

For an electrical explosion of a conductor, a mode of energy release is characteristic, with an active resistance close to critical, which must be taken into account during the research. It is known that the transfer of the energy of an electric discharge pulse to a crystalline conductor at high operating voltage is accompanied by a skin effect, which causes attenuation of electromagnetic waves mainly in the surface layer.

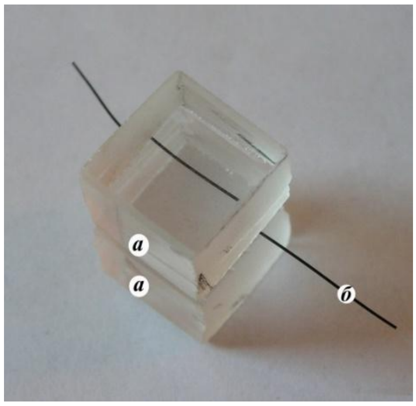


Fig. 3: Glass samples (a), with a metal wire (b) between to be sprayed by high-voltage discharge

In addition, on the path of electrons in the skin layer, the increasing magnetic field lines provide for the conductor contraction, causing constrictions across and its destruction with the formation of plasma and melt in a short section of length, which is not acceptable for studying the structure. Experimentally, a mode was selected that made it possible to avoid shunting of the blasting conductor, and for complete overheating and subsequent evaporation, a mild processing mode was used with a discharge time of 30-100 μs and with stored energy at the current pulse generator capacitor exceeding 2 times the evaporation energy of the conductor.

Using the method of electroexplosive destruction, which provides a high rate of conversion of electrical energy into mechanical work, it was possible to establish that the impact of a high-voltage pulse on an electric current with a density of about 107 A/cm^2 for $\approx 3 \cdot 10^{-5}$ s and with an operating voltage of 10 kV on a tungsten wire of 45 mm long and a diameter of 14.5 microns, obtained by industrial technology, leads to its complete destruction due to explosive boiling, and the resulting liquid metal layer causes coupling - welding of samples. Due to the high heating rate of the metal conductor (106 - 107 K/s), it is possible to eliminate the effect of phase transitions under its high-voltage electric discharge spraying.

The direct experiment allowed proving the spatial inhomogeneity of electrons in the metal and taking a "photograph" of the electroexplosive destruction of tungsten wire obtained by radiation technology (Fig. 4), which was destroyed in separate areas and did not ensure the formation of a welded joint using the method of exploding conductors.

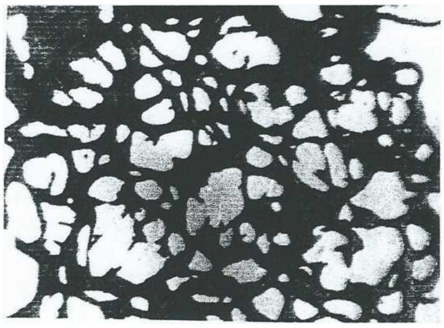


Fig. 4: Picture of the electric explosion destruction of a tungsten wire obtained by radiation technology. 150x magnification.

The picture clearly shows the core with a stronger localized chemical bond, which does not conduct electric current due to the absence of conduction electrons, and certain structural groups of atoms in a crystal connected to each other in the form of island formations - clusters. Moreover, cluster groups (from two to hundreds of atoms) are held by covalent chemical bonds, and the nature of the structure formation is determined by the binding energy between the interacting particles of the dispersed phase, forming a structure in the form of a spatial framework. It follows that in the process of irradiating a material, the high-energy potential of the electron shells changes dramatically, and, in particular, electrons with free spins are responsible for the formation of a chemical bond. For a sufficiently high concentration of defects in the metal-dielectric structure, the effect is due to the spatial localization of charge carriers. These results are consistent with the work by Anderson P.W. stating that an increase in the lattice by 12% leads to an increase in the proportion of covalent bond in a metal sample [6].

Thus, the phenomenon of energy conversion of an intracrystalline chemical bond between a material and a complex, including point defects and impurity atoms, has been established. As a result of the restructuring of the crystal lattice under the action of ionizing radiation, the formation of the heterodesmic structure of the sintered polycrystalline powders is observed, which is manifested in the local erosion of the metallic conductor during its electrical explosion in vacuum in the form of an energy grid. The mechanism linking the energy and crystal-chemical aspects contributes to the transformation of the binding energy, as well as the stability of the properties and structure of products obtained in powder metallurgy. The high defectiveness of the structure allows conducting self-construction of the structure and obtaining products with physicochemical and mechanical properties not available for modern industrial production.

Practical use of the considered method opens up great prospects for the study of structural changes in radiation-chemical technology. Based on experimental research, it is possible to say unequivocally why metal alloys or pure metals have greater resistance when heated and melted than in the initial state - due to the formation of a heterodesmic structure, that is, the localization of electrons, and not only due to an increase in the amplitude of thermal vibrations and ions.

The phenomenon of the formation of a heterodesmic structure is also true for explaining the mechanism for increasing the hardness and elasticity of Damascus steel, thanks to a special thermomechanical treatment. The ability of alloys to acquire, in the process of crystallization, their typical internal structure, which simultaneously provides hardness, toughness and elasticity, strongly depends on the multiple mechanical (forging or rolling) effects on the workpiece and the thermal (quenching or tempering) processes. Similarly to radiation treatment of powders, a steel workpiece heated in a furnace, being subjected to mechanical stress - forging while cooling, leads to an increase in the defect structure of the material due to dislocations and, accordingly, changes in the state of chemical bonding. Due to this, the cooled steel sample acquires extremely small grain sizes and higher operational characteristics.

2. Summary

It was experimentally possible to prove that metals and alloys obtained from powders by radiation technology have a heterodesmic chemical bond structure at the macroscale, which is manifested in the local erosion of the conductor during its electrical explosion in vacuum, and the nonconducting core has the form of a volume network.

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