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G.S. Bektasova[1], K.M. Issina[1*], G.T. Imanzhanova[1], L.I. Kveglis[1], N. Kantai[1], A.I. Nedobitkov[2], A.B. Sadibekov[2]

[1]*Sarsen Amanzholov East Kazakhstan University, 070020, Ust-Kamenogorsk, Kazakhstan;*
[2]*D. Serikbaev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan*
[*]*Corresponding author's e-mail: gyka1983@mail.ru*

Study of the copper structure samples externed to extreme influences

This work is devoted to the study of changes in the crystal structure, chemical and phase composition of copper samples subjected to extreme effects of temperature, pressure and electromagnetic fields. With the help of X-ray diffraction, as well as microanalysis, it was revealed that the plastic deformation of copper wires in the car power supply system leads to the formation of a superconducting Cu_2O phase. This is the reason for the rapid ignition of the car, as it leads to a sharp increase in the magnitude of the electric current and temperature in the plastic deformation zone of copper wires. During explosion welding of copper samples, the Cu_2O phase appears on their surface, which has superconducting properties. This significantly changes the electrophysical properties of copper samples. In metallurgical processes during the smelting of copper products, there is a possibility of the appearance of a superconducting Cu_2O phase. When modifying a copper melt with hardening additives, the superconducting Cu_2O phase makes it possible to obtain fracture-resistant copper products with high electrical conductivity. Plastic deformation of a copper foil 30 mkm thick by a magnetic field generated by a current of 180 kA leads to the formation of a texture and rupture of the foil. This has been detected using X-ray diffraction, as well as optical and scanning electron microscopy.

Keywords: copper samples, ignition zone, plastic deformation, explosion processing, deformation by electromagnetic wave flow.

Introduction

In recent years, with the continuous development of science and technology, the number of new high-power electrical appliances used in people's daily lives is growing. This increases the requirements for the structure and properties of products in the electrical industry.

The formation of copper oxide particles in copper wiring under extreme impacts in copper wire is described in articles [1, 2]. The following works [3–8] are devoted to the study of the current overload of copper conductors, accompanied by a current pulse and plastic deformation. The possibility of high temperature superconductivity in a copper conductor, with the formation of Cu_2O, is discussed in [9]. In the technique [10], a diffractometric method for studying copper conductors with melting was first proposed based on the detection of Cu_2O. The same is reported by the authors of [11].

The purpose of our work is to investigate structural and phase changes in various copper samples subjected to extreme effects of high temperatures, mechanical loads and electromagnetic fields, which make it possible to increase the strength and electrical conductivity of copper products.

To achieve this goal, the process of current overload in the electrical system of cars was investigated. For this, fragments of copper conductors subjected to current overload [3–8] were studied, which made it possible to establish changes in the crystal structure and chemical composition. Similar experiments were carried out to study the surface of a copper cylinder subjected to an explosion, as well as when copper foil was compressed by a magnetic field. The magnetic field has a significant effect on metals: it can set the metal in motion, cause plastic deformation and heat the metal. When a strong pulsed, field interacts with a metal conductor the first interesting effects appear in the range of 0.1–1 MOe.

It is necessary to increase the strength of copper products that are exposed to electromagnetic fields. Near 400 kOe, the diffusion of the magnetic field becomes nonlinear, and the magnetic pressure exceeds the yield strength of most metals [11].

Since copper has rather low yield strength, it is necessary to increase the strength of copper products by introducing hardening additives into it during smelting. Known strengthening additives dramatically reduce the electrical conductivity of copper [12].

Material and methods of research

The sections of the conductors of the electrical system of the car, subjected to current overload and having signs of residual plastic deformation, were studied, since, according to [7, 8], it is these signs that indicate an electric arc process, accompanied by a pulsed field, and causing the car to ignite.

For the study, copper conductors seized from the scene of a car fire were used. Fragments of damaged copper conductors were filled with epoxy resin in a standard holder, which were then ground and polished as shown in Figure 1.

Figure 1. Fragments of copper conductors subjected to current overload and prepared for research

The holder with conductors was examined in an Xpert PRO X-ray diffractometer (U = 40 kV, I = 30 mA CuKα) and a scanning electron microscope with a microanalyzer.

Figure 2 shows images of fragments of a sample of a copper cylinder torn apart by TNT.

Figure 2. Fragments of a copper cylinder torn apart by TNT

Figures 3 *a*, *b* show fragments of a copper foil sample before and after the magnetic field destruction test. The micrograph (Fig. 3 *a*) shows traces of rolling; this confirms the x-ray diffraction image below.

a *b*

Figure 3. Fragments of a sample of copper foil before (*a*) and after (*b*) the magnetic field destruction test. The micrograph (*a*) shows traces of rolling, which confirms the X-ray diffraction picture

Results and discussions

Figure 4 shows a picture taken in a scanning electron microscope from a section of a copper wire subjected to current overload and removed from a burned-out car. It can be seen how cracks appeared in the plastically deformed section of the copper wire, from which drops of liquid copper were formed. The drop is shown in a separate Figure 5.

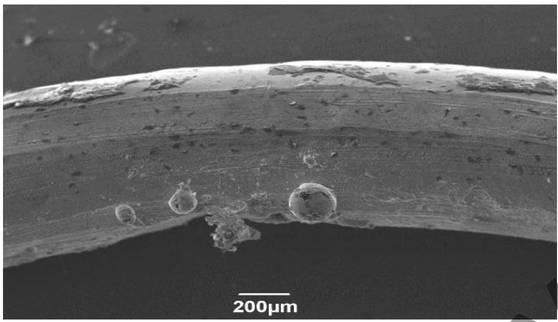

Figure 4. Ball melting on the bends of the deformed conductor [5]

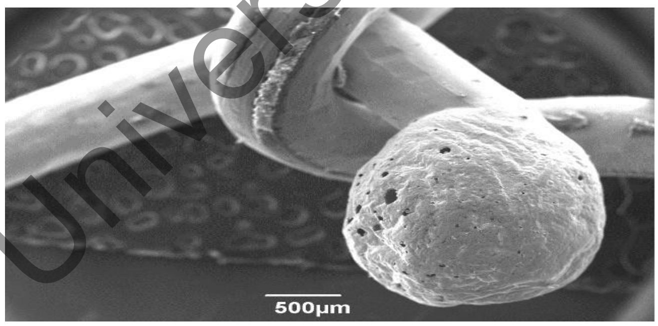

Figure 5. Ball melting of the end of the copper conductor [5]

X-ray fluorescent energy spectra were obtained from such a drop (Fig. 6 and Table 1). The drops contain mainly copper and oxygen (Table 1). The temperature exceeding the boiling point of copper (10830C) arose in the bending zones, that is, in the zones of mechanical load transferred to these wires during plastic deformation [5]. Since the flow of mechanical energy per unit time during plastic deformation in a localized zone was too large, the energy turned into heat. As a result of heating the copper conductor, the insulation ignited, which was intensified due to the electric arc process that arose due to the formation of a superconducting Cu_2O layer in the surface layer of copper wires with an increase in their temperature.

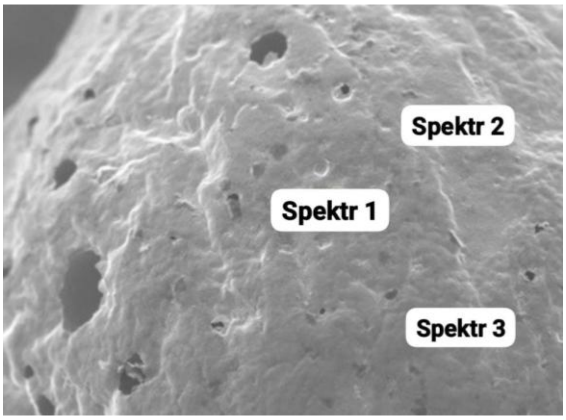

Figure 6. Image of the areas where X-ray spectral analysis was carried out [5]

Table 1

Ball Reflow Spectra

O	Al	Si	Cu	Total
12.24	1.45		86.31	100.00
17.24	3.84		78.93	100.00
4.69	3.06		92.24	100.00
9.22	6.15		84.63	100.00
14.32	1.30	0.82	83.56	100.00
9.38	3.16		87.46	100.00
17.24	6.15	0.82	92.24	
4.69	1.30	0.82	78.93	

X-ray diffraction revealed the presence of a superconducting Cu_2O phase in drops that appeared in the damage zones of copper conductors (Fig. 7*a*).

The presence of the superconducting phase [13] increases the current, which leads to an instantaneous increase in temperature, exceeding the melting point of copper (1083 °C). The X-ray diffraction pattern (Fig. 7*a*) shows the diffraction intensities and angles: 111 Cu, 200 Cu, 220 Cu reflections. We also see a weak reflection of the Cu_2O phase (before 111 Cu). The formation of this phase is associated with the process of car ignition.

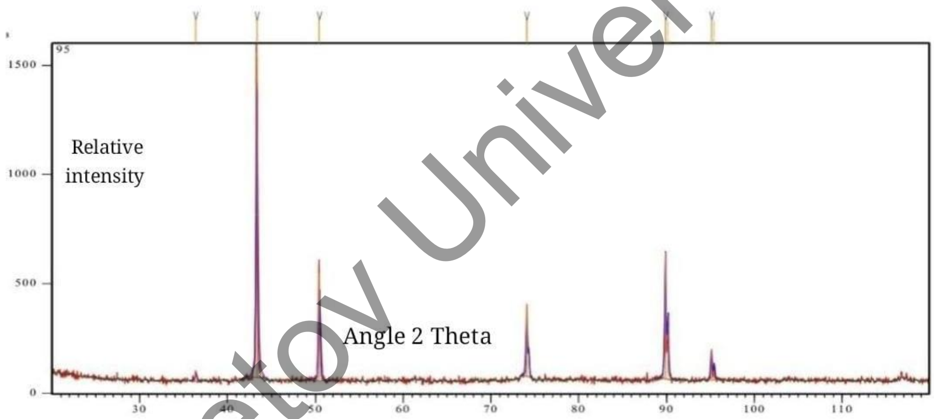

Figure 7 *a*. X-ray diffraction pattern obtained from samples of copper wire subjected to current overload [9]

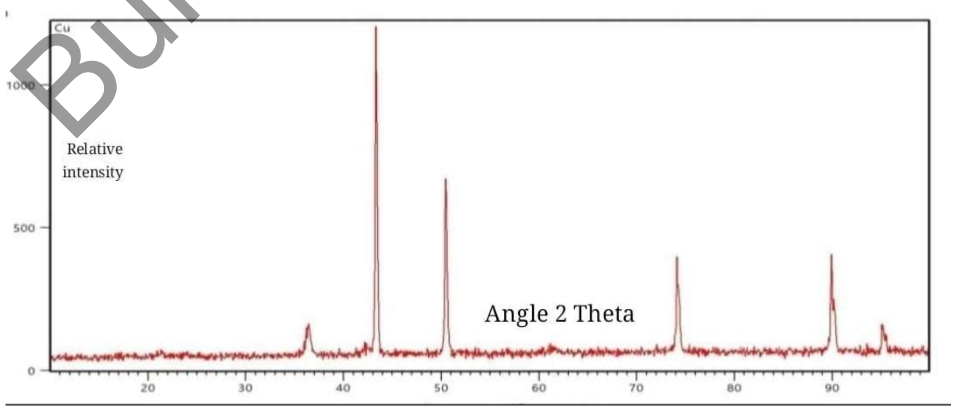

Figure 7 *b*. X-ray diffraction spectrum obtained from a sample subjected to an explosion with TNT

Figure 7 *b* shows an X-ray pattern obtained from a copper sample treated with an explosion, and the interpretation data are given in Table 2.

Table 2

Diffraction spectrum of a copper sample contain the Cu_2O phase

№	HKL	d/n [A]	2θ [°]	I [%]
1	011	3.01864	29.569	5.1
2	110	3.00		0.3
3	111	2.46471	36.424	100
4	111	2.45		100
5	020	2.13450	42.309	35.3
6	121	1.74281	52.461	1.2
7	022	1.50932	61.367	28.6
8	122	1.42300	65.547	0.0
9	031	1.34998	69.584	0. 3
10	131	1.28715	73.518	22.1
11	132	1.14094	84.931	0.2
12	200	2.12		31
13	222	1.23235	77.374	4.8

From a comparison of the X-ray image interpretation table [14], presented in Figure 7 *a* and 7 *b* and the tabulated values of copper Cu (Table 3) and copper dioxide Cu_2O (Table 3), we see that the same processes occur in the samples of copper wire from a burnt car and an exploded copper sample. By analyzing the chemical composition of an exploded copper sample and comparing the chemical composition of copper wire samples after combustion, we can conclude that in both cases copper dioxide is formed.

Table 3

Diffraction spectrum of Cu_2O

d = 2.08603	43.341	2.086	100.0	111	100	2.088	–0.002	3.613
d = 1.80617	50.489	1.806	20.4	200	46	1.808	–0.002	3.612
d = 1.27697	74.202	1.277	83.3	220	20	1.278	–0.001	3.612
d = 1.08980	89.954	1.090	31.5	311	17	1.090	0.000	3.615
d = 1.04357	95.146	1.044	11.9	222	5	1.044	0.000	3.617

The exploded sample was examined using a JEOL 683 scanning electron microscope with a microanalyzer. A micrograph and an energy dispersive spectrum are shown in Figure 8.

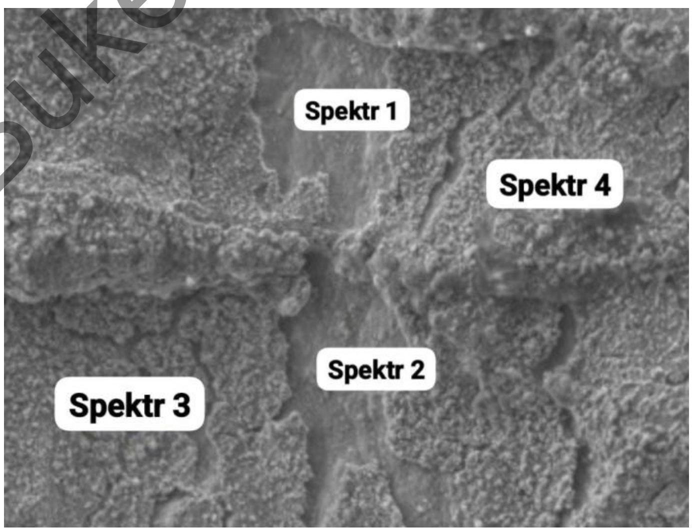

Figure 8. Scanning electron microscopy energy dispersive analysis

Table 4

Energy-dispersive spectrum obtained from the surface subjected to an explosion

O	Al	Cu	Total
1.51	0.30	98.19	100.00
3.39	0.58	96.03	100.00
12.88	0.63	86.49	100.00
15.20	0.60	84.20	100.00
8.25	0.53	91.23	100.00
6.80	0.15	6.91	
15.20	0.63	98.19	
1.51	0.30	84.20	

Table 4 shows that the sample subjected to the explosion contains copper, oxygen and a small admixture of aluminum. During explosion welding, the effect of pressure on metal conductors can lead to an increase in the internal energy of the latter to values that significantly exceed the chemical binding energy in solids. Obviously, at such levels of energy impact, the properties of metals (the behavior of atoms and ions in the lattice), as well as the transport properties of electrons, can differ significantly from those that occur under normal conditions. The change in the binding energy in solids is the result of solid-state synthesis.

It is known that a feature of solid-phase synthesis is the high values of the diffusion coefficients of atoms or ions of the components in the solid phase. Unlike ordinary diffusion, which is determined by the concentration gradients of the components, this type of diffusion is called "deformational atomic mixing" or "ballistic diffusion". A variety of assumptions have been made regarding the mechanism of this process, but there is still no consensus on the mechanism of deformation atomic mixing [15]. Thus, the external pressure gradient leads to the appearance of new phases.

Samples of copper foil subjected to magnetic field pressure as a result of the passage of a high frequency current were examined for structural changes. The X-ray diffraction interpretation spectrum obtained from a section of a copper foil sample compressed by an electromagnetic wave (Fig. 3 b).

Using X-ray diffraction had studied of areas the torn sample. It was shown that the lattice parameter of copper can change both upward and downward. The lattice parameter of copper can vary depending on the localization of deformation, which clearly exceeded the yield strength of copper. As a result of the impact of an electromagnetic wave, as a stream of charged particles, the copper foil broke. The dependence of the energy flux of the current magnetic field on the magnitude of the alternating current is given by the expression [16]:

$$W_M = \frac{LI^2}{2},$$

W = current magnetic field energy; L = inductance; I = current in conductor.

Using X-ray diffraction and optical microscopy (Fig. 3*a*), it was found that compression of a copper foil 30 mkm thick by a magnetic field created by a current of 180 kA leads to its plastic deformation and the formation of texture [17].

Thus, studies of changes in the crystal structure, chemical and phase composition of copper samples subjected to extreme effects of temperature, pressure and electromagnetic fields have shown the possibility of mechanochemical reactions that change the crystal lattice of the material of copper samples and the appearance of new phases.

With the help of X-ray diffraction, as well as microanalysis, it was revealed that the plastic deformation of copper wires in the car power supply system leads to the formation of a superconducting Cu_2O phase. This is the reason for the rapid ignition of the car, as it leads to a sharp increase in the magnitude of the electric current and temperature in the plastic deformation zone of copper wires. Plastic deformation of a copper foil 30 mkm thick by a magnetic field generated by a current of 180 kA leads to the formation of a texture and rupture of the foil. This has been detected using X-ray diffraction, as well as optical and scanning electron microscopy.

During explosion welding of copper samples, the Cu_2O phase appears on their surface, which has superconducting properties. This significantly changes the electrophysical properties of copper samples. In metallurgical processes during the smelting of copper products, there is a possibility of the appearance of a superconducting Cu_2O phase. When modifying a copper melt with hardening additives, the superconducting Cu_2O phase makes it possible to obtain fracture-resistant copper products with high electrical conductivity. The electrical resistivity of pure copper is $1.7\cdot10^{-2}$ Ohm*mm^2/m. When modified, it can increase up to 35 %, which significantly worsens the properties of electrical copper. Due to the fact that Cu_2O is formed in the reaction mixture during the smelting of copper products, the electrical resistance of the material is significantly reduced.

Conclusions

1. During plastic deformation of copper wires located in the power supply system of the car and subjected to current overload, the formation of the superconducting Cu_2O phase occurs at a high speed, which leads to ignition of the insulation and ignition of the car.

2. During explosion welding of copper samples, the Cu_2O phase appears on their surface, which has superconducting properties.

3. Using X-ray diffraction and optical microscopy, we found that compression of a copper foil 30 mkm thick by a magnetic field created by a current of 180 kA leads to its plastic deformation, texture formation and rupture.

4. It was found that in copper samples under conditions of extreme energy exposure, a superconducting Cu_2O phase can form, which affects the electrical properties of copper samples.

Acknowledgments

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Г.С. Бектасова, К.М. Исина, Г.Т. Иманжанова, Л.И. Квеглис, Н. Кантай, А.И. Недобитков, А.Б. Садибеков

Экстремалды әсерлерге ұшыраған мыс үлгілерінің құрылымын зерттеу

Мақала температураның, қысымның және электрмагниттік өрістердің экстремалды әсеріне ұшыраған мыс үлгілерінің кристалдық құрылымының, химиялық және фазалық құрамының өзгеруін зерттеуге арналған. Рентген сәулелерінің дифракциясының, сонымен қатар микроталдау анықтағандай, автомобильдің электрмен жабдықтау жүйесіндегі мыс сымдарының пластикалық деформациясы асқын өткізгіш Cu_2O фазасының пайда болуына әкелетіні айқындалды. Бұл мыс үлгілерінің пластикалық деформация аймағында электр тогының шамасы мен температураның күрт жоғарылауына әкеліп соғатындықтан, автокөліктің жылдам тұтануына себепкер болады. Мыс үлгілерін жарылыс дәнекерлеу кезінде олардың бетінде асқын өткізгіштік қасиеті бар Cu_2O фазасы пайда болады. Бұл мыс үлгілерінің электрфизикалық қасиеттерін айтарлықтай өзгертеді. Металлургиялық үрдістерде мыс өнімдерін балқыту кезінде асқын өткізгіш Cu_2O фазасының пайда болу мүмкіндігі бар. Мыс балқымасын қатайтатын қоспалармен өзгерткен кезде, Cu2O асқын өткізгіш фазасы жоғары электр өткізгіштігі бар сынуға төзімді мыс өнімдерін алуға мүмкіндік береді. Қалыңдығы 30 мкм мыс фольгасының 180 кА тогы әсерінен пайда болған магнит өрісінің пластикалық деформациясы фольга құрылымының түзілуіне және жарылуына әкеледі. Бұл рентгендік дифракция, сондай-ақ оптикалық және электронды микроскопия көмегімен анықталды.

Кілт сөздер: мыс үлгілері, тұтану аймағы, пластикалық деформация, жарылыспен өңдеу, электрмагниттік толқын ағынының деформациясы.

Г.С. Бектасова, К.М. Исина, Г.Т. Иманжанова, Л.И. Квеглис, Н. Кантай, А.И. Недобитков, А.Б. Садибеков

Исследование структуры медных образцов, подвергнутых экстремальным воздействиям

Статья посвящена исследованию изменений кристаллической структуры, химического и фазового состава медных образцов, подвергнутых экстремальным воздействиям температуры, давления и электромагнитных полей. С помощью дифракции рентгеновских лучей, а также микроанализа выявлено, что пластическая деформация медных проводов, находящихся в системе электропитания автомобиля, приводит к образованию сверхпроводящей фазы Cu_2O. Это является причиной быстрого возгорания автомобиля, поскольку приводит к резкому возрастанию величины электрического тока и температуры в зоне пластической деформации медных проводов. При сварке взрывом медных образцов на их поверхности возникает фаза Cu_2O, обладающая сверхпроводящими свойствами. Это существенно изменяет электрофизические свойства медных образцов. В металлургических процессах при выплавке изделий из меди существует возможность появления сверхпроводящей фазы Cu_2O. При модифицировании медного расплава упрочняющими добавками сверхпроводящая фаза Cu_2O позволяет получать стойкие к разрушению изделия из меди с высокой электропроводностью. Пластическая деформация медной фольги толщиной 30 мкм магнитным полем, созданным током 180 кА, приводит к формированию текстуры и разрыву фольги. Это обнаружено с помощью дифракции рентгеновских лучей, а также оптической и растровой электронной микроскопии.

Ключевые слова: медные образцы, зона возгорания, пластическая деформация, обработка взрывом, деформация потоком электромагнитных волн.

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Information about authors

Bektasova, G.S. — Associate professor of the Department of Physics and Technology, Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan; e-mail: bektasovags@mail.ru, ORCID 0000-0002-6746-4964

Issina, K.M. — 5th year student "Nuclear Physics", Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan; e-mail: gyka1983@mail.ru

Imanzhanova, G.T. — Senior lecturer, Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan; e-mail: kuba_6164@mail.ru

Kvenglis, L.I. — Professor of the Department of Physics and Technology, Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan; e-mail: kveglis@list.ru. ORCID: 0000-0002-6850-354X

Kantai, N. — Engineer of the national laboratory, Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan; e-mail: nurgan85@mail.ru

Nedobitkov, A.I. — Cand. Sci. (Eng.), Senior Research Center of Excellence of the D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan; e-mail: a.nedobitkov@mail.ru. ORCID: 0000-0003-4605-9668

Sadibekov, A.B. — Research engineer, D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan; e-mail: ajdarsadibekov@gmail.com, ORCID: 0000-0002-2932-7029