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АКТУАЛЬНІ ПРОБЛЕМИ ПОЖЕЖНОЇ БЕЗПЕКИ ТА ЗАПОБІГАННЯ НАДЗВИЧАЙНИМ СИТУАЦІЯМ В УМОВАХ СЬОГОДЕННЯ

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Секція 2
Section 2

СИСТЕМИ ПРОТИПОЖЕЖНОГО ЗАХИСТУ

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STUDY OF CHANGES IN THE MICROSTRUCTURE OF COPPER UNDER THE INFLUENCE OF SHORT CIRCUITS AND FLAME TEMPERATURE REGIMES

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Studying the relationship between the microstructure and properties of metals and their alloys exposed to high temperatures and an oxidizing environment is of great importance not only for solving various engineering problems [1], but also for the development of modern fire protection technologies in many industries [2, 3]. In addition, from the point of view of ensuring fire safety, this kind of research is of particular interest, since information on the microstructure of copper wires removed from a burned-out object can be very useful in determining the true causes of fires.

Analysis of the causes of fires shows that fires often occur due to malfunctions in electrical wiring. Practice shows that malfunctions of electrical equipment often occur due to current overload, short circuit and increased resistance of electrical contacts. In order to minimize accidental fires, it is necessary to take timely measures to ensure fire safety. To do this, it is necessary to carefully find out the exact causes of the fire. To find out these reasons, the authors [4] conducted a large number of theoretical and experimental studies. It is shown that the most effective way to study the causes of the fire is a thorough study of the removed electrical wiring, in particular, a study of the microstructure of the copper current-conducting elements of the wiring.

The heat generated by short circuit currents can produce various temperature modes [2, 3] (Table). Studies have shown that copper wires of wiring often melt at high current loads, since under the impact of short circuits the melting point of copper (1083.4°C) is instantly reached. A short circuit can also cause wire breaking due to an occurrence of an electric arc, which, in turn, results in boiling of copper (the boiling point of copper is 2567°C) after which the ends of the broken wire are fused. In certain cases, the current density can reach a value of 60 A·mm^2, which exceeds the nominal current value by more than 10 times. The calculations showed that the short circuit currents that occur in the copper wires can reach values from 80 to 200 A at a current density of 30–60 A·mm^2.

Table Temperature modes of different current loads

***I*, A**	***T*, °C**	
	$S_{cross\text{-}section}$ **= 2,5 mm²**	$S_{cross\text{-}section}$ **= 4,0 mm²**
50	191	98
100	703	331
150	1557	720
200	–	1260

Note:Calculations were carried out for a copper wire with a current load time of 200 s.

The temperature characteristics of fires can vary greatly. The flame temperature of such fires varies from 800°C to 1100°C, depending on the flame zone [2]. In the oxidation zone, the temperature is the highest (about 1100°C), while the temperature in the luminous zone is slightly lower (about 800°C) due to the scattering of heat energy and heated combustion products into the environment. It is not excluded that the copper wires of the electrical system may even melt under the influence of an open flame.

Obviously the said flame temperature modes will also facilitate a change in the microstructure of copper wires. To confirm it, we carried out a series of open-flame experiments, for this a seat of fire was prepared (Figure 1).

The test samples of both the original copper wires (previously not exposed to any impact) and the wires that had previously been exposed to a short circuit are placed above the flame.

The flame temperature in the area of the copper wires was measured by thermocouples, the signals from which were transmitted to the personal computer. The experimental dependence of changes in the temperature modes of the flame on time is shown in Figure 2.

Figure 1 – An experimental installation for testing copper wires with an open flame

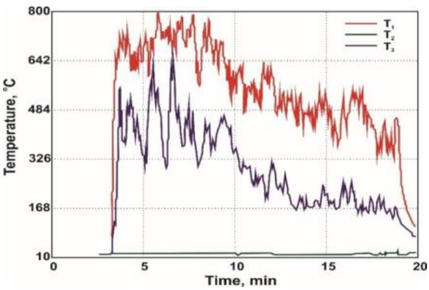
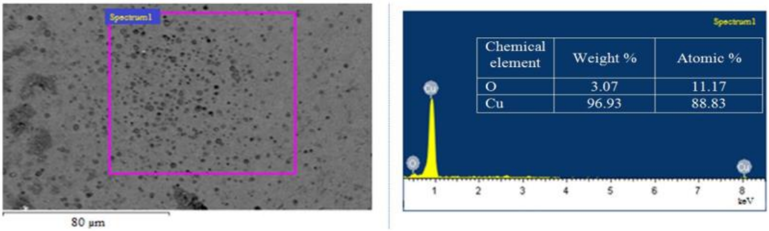
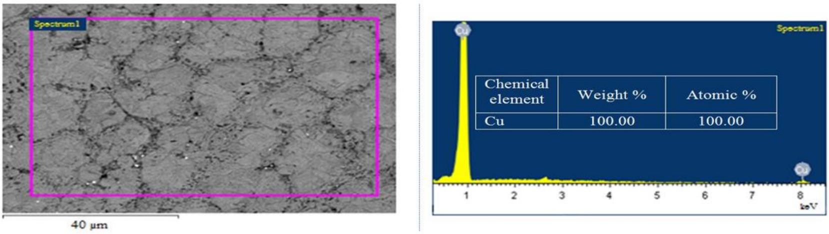


Figure 2 – Flame temperature modes versus time: **T₁**– temperature near copper wires; **T₂** – ambient temperature; **T₃** – temperature over flame

The image of the microstructures of the original copper wire samples visualized by SEM and EDX results is shown in Figure 3. On the SEM image of the crosswise microsection (Figure 3(*a*)) rounded grains of almost the same size (average linear intercept (L) is ~15–20 µm, equivalent ASTM grain-size number (G) is no. 8 [4]) are barely noticeable. However, grains in lengthwise microsection already are clearly visible (Figure 3(*b*)); furthermore, these have a slightly elongated shape oriented in the direction of wire drawing. In certain parts of the surface of lengthwise microsections, there are grains whose sizes (L = ~30 µm, G = no. 7–6) exceed the average size of most grains.



(*a*)



(*b*)

Figure 3 – SEM images showing the areas where the EDX analysis was applied on samples of the original copper wire: (***a***) crosswise microsection, (***b***) lengthwise microsection (the arrow indicates the direction of wire drawing). To the right of the SEM images, the relative signals of copper and oxygen are shown

For the completeness of the experiment, three fire development scenarios were considered. The first - melting of conductors occurred as a result of short-circuit currents. The second - melting formed under the action of an open flame. The third – there was a complex action of current and open flame.

After short circuit impact, local spherical formations (beads), indicating fast crystallization of once melted parts of the copper wire, are found out in the SEM image. Such beads along with pits were discovered on surfaces of both crosswise and lengthwise microsections. It should be noted that due to a short circuit, these formations are localized in places where an electric arc was formed, which caused copper to boil.

When exposed to an open flame, the fine-grained microstructure of the original copper wire turns into coarse-grained. In this case, the linear sizes of the grain increase by about 10 times. Apparently, grain growth results from the diffusion phenomena which accelerate with an increase in temperature. This applies equally to the crosswise and to the lengthwise microsections.

It is very interesting to see the microstructure of copper wires, which, before these were in an open flame, were affected to a short circuit. In this case, the fine-grained microstructure with local spherical inclusions (beads and pits) turns into a special coarse-grained microstructure in which the boundaries of oxidized grains are clearly observed.

Although the linear sizes of the grains formed in the second and third fire scenarios are almost identical, nevertheless the flame produced with the third fire scenario mode is able to more effectively oxidize the grains on their boundaries.

The copper wire samples that were exposed to short circuits and different temperature modes of the flame, were explored by a scanning electron microscope equipped with an EDX spectrometer. This allowed to study the effect of various external factors on the change in the microstructure of copper wires. It was found that when exposed to open flames, the fine-grained microstructure inherent in the original copper wire turns into coarse-grained. During the short circuit, local spherical formations (beads and pits) appear on the surface of the copper wire, resulting from the instant boiling of copper caused by the electric arc. The effect of an open flame on copper wires that have previously been undergone short circuit impact results in the fact that their fine-grained microstructure containing local spherical inclusions turns into a kind of coarse-grained microstructure with oxidized grains on their boundaries.

The information obtained from studying the microstructure of copper wires taken from a burned-out object can be very useful in solving problems related to determining the true causes of fires.

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