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Analysis of the Surface Matrix of Copper Cable in Jointing as the Effect of Increasing Current and Heating on Fire Application

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ABSTRACT

This research aims to analyze the surface matrix of copper cable in jointing as the influence of increasing current and heating on fire experiments. The investigation makes it easier to observe parts of the material of the surface matrix changes of copper cable in jointing as heating increases. The study observed the material surface of general requirements for electrical installations (PUIL) jointed cables and standard NYA ø 1.5 mm^2 cables at current load of 50 A and 110A using HIROX digital microscope, XRF (X-ray fluorescence), Raman spectroscopy, and fluke infrared thermometer (FLIR). The study results showed that the PUIL sample jointing heat cable reached 201°C and 1087°C, respectively, with a heat standard cable of 25.6°C. The copper cable will melt when it reaches overheating of 1080°C, causing the deformation of the cable's cross-sectional area, which is observed in changes in the surface matrix of the burned cable structure. This research can be used to investigate the causes of fires and the maximum heat application on the cables.

Keywords: Copper Cable, Fire Experiment, Overcurrent, Overheating, Surface Matrix

ABSTRAK

Penelitian ini bertujuan untuk menganalisis matriks permukaan kabel tembaga dalam penyambungan sebagai pengaruh dari peningkatan arus dan pemanasan pada percobaan kebakaran. Penelitian ini memudahkan untuk mengamati bagian-bagian dari material perubahan matriks permukaan kabel tembaga dalam penyambungan seiring dengan peningkatan pemanasan. Studi ini mengamati permukaan material persyaratan umum untuk instalasi listrik (PUIL) kabel yang disambung dan kabel standar NYA ø 1,5 mm^2 pada beban arus 50A dan 110A menggunakan mikroskop digital HIROX, XRF (fluoresensi sinar-X), spektroskopi Raman, dan termometer inframerah fluke (FLIR). Hasil studi menunjukkan bahwa sampel PUIL penyambungan kabel panas mencapai 201°C dan 1087°C, masing-masing, dengan standar panas kabel sebesar 25,6°C. Kabel tembaga akan meleleh saat mencapai pemanasan berlebihan sebesar 1080°C, menyebabkan deformasi pada area penampang lintang kabel, yang diamati dalam perubahan matriks permukaan struktur kabel yang terbakar. Penelitian ini dapat digunakan untuk menyelidiki penyebab kebakaran dan aplikasi panas maksimum pada kabel.

Kata Kunci: Arus Berlebih, Eksperimen Kebakaran, Kabel Tembaga, Matriks Permukaan, Pemanasan Berlebih

1. Introduction

The investigation of the fire relied on the appearance of the surface of the remaining electrical cable from the fire, such as damage and melting on the burned cable, to determine the initiation of the cause of the fire. The fact that there is an overcurrent in the cable is proof that the cable was electrified during the fire [1]. Therefore, the cable that caused the fire must be evaluated in depth. Whether or not there is an overcurrent influence on the cable has a strong influence on the fire investigation process. Researchers have attempted to determine the specific conditions for fires caused by excessive heat in electrical cables [2].

Copper cables are widely used in electrical installations because of their high electrical properties and low cost. However, copper-based cables' mechanical properties and conductivity have reached their limits and become the most dangerous obstacle to further application in circuits and high-power cables in household installations [3]. Overheating provides a sufficient change in the melt from microheterogeneity to homogeneity. This can be reflected in the transformation of sensitive properties of structures, such as surface tension, kinematic viscosity, density, and electrical conductivity [4].

The consequences of poor electrical installations include inappropriate cables, excessive current, poor grounding systems or even not having a grounding system, which can cause the cables to catch fire easily [5]. Cable quality that is below standard and cable connections that do not follow established rules can cause damage to the cable due to environmental factors, including temperature [6], humidity and impact/squeezed loads, as well as being hit by nails which cause the insulator to tear and result in a short circuit [7], which is not detected by the safety circuit because the current is still below the tolerance limit so that in a short period it can cause high-temperature sparks, namely around 3850°C which can melt the insulation [8] and burns where the melting point of polyvinyl chloride (PVC) insulation is (75 - 110)°C while the burning point is (435–557)°C. Previous research has also shown that improper electrical cable connections can result in significant overheating [9]. However, it can be seen after the characterization process that the electrical cable can withstand overheating even after exposure to external fire [10]. This depends on the duration and intensity of fire exposure and the cable construction and materials [11]. The material residue of copper cable was often recovered from forensic locations and determined the initial circumstances of the fire's origin.

Previous research on the identification and analysis of copper cable matrices due to overheating has been widely carried out, including analyzing the electrical conductor surface of copper cables using Sem, microstructure and mechanical properties of the wire also on Cu-Al using SEM [12], the influence of process parameters on surface quality and copper bond quality also with SEMEDS [13], investigation of Cu-P structure by overheating [14], which is based on the cable surface morphology. Meanwhile, surface analysis with XRF was previously also carried out for chemical trace analysis to detect sharp force trauma in fresh conditions and burnt bones [15], investigation of the impact of autoclave curing on the mechanical properties, heavy metal stabilization, and anti-microbial activity of green geopolymer composites [16].

Mechanical and microstructural characteristics of Cu–Sn–Zn/Gr metal matrix composites processed by powder metallurgy for bearing materials [17], Experimental investigation of the feasibility of industrial waste into conversion resources for dome slag [18], and the effect of chemical treatment on the physical and thermal stability of Hibiscus Tiliaceus Bark Fiber (HBF) as composite reinforcement [19]. Several analyses of a surface matrix using a HIROX digital microscope have been carried out, such as morphometric analysis of cut marks [20], the study of silicone elastomer surfaces [21], and 3D surface acquisition from a comparison of two microtopography equipment when measuring cultural heritage materials [22].

From various surface analyses of the copper cable matrix in jointing, nothing has been analyzed regarding the influence of overcurrent and overheating of the copper surface matrix cable in jointing as a fire application using a digital microscope and Raman spectroscopy. Therefore, it is necessary to develop a new method for analyzing the surface of the copper cable matrix in jointing, as the effects of overcurrent and overheating are scientific information in the investigation. The results of this research will guide forensic examiners/investigators as a guide to analyze the fire evidence.

2. Method

2.1. Materials

The copper cable utilized was NYA type, featuring PVC insulation with a diameter of ø 1.5 mm^2 (046620.3 Eterna CU/PVC 1.5 mm^2 450/7500 NYA), as depicted in Figure 1. The cable underwent in situ experiments with the following variations: Sample A (PUIL jointed standard cable, temperature maintained at 25.6°C for 30 minutes), Sample B (PUIL jointed cable exposed to normal heating reaching 201°C for 30 minutes), and Sample C (PUIL jointed cable subjected to severe heating resulting in burn damage reaching 1087°C for 4 minutes), as shown in Figure 2.

The evaluation instrument used a HIROX microscope (2500 –USA), X-ray fluorescence (XOS HD Prime - USA), Raman analyzer (Rigaku – USA), flux infrared thermometer (FLIRTG165-X MSX thermal Imaging camera-USA), and digital Camera (Vidicon-Japan).

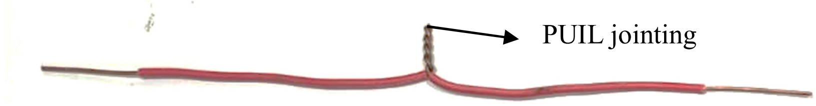

Figure 1. NYA copper cable in PUIL jointing.

2.2. X-ray Fluorescence (XRF) Analysis

Each sample is positioned inside the sample chamber. Subsequently, the coating type is adjusted and applied to cover the sample. Analysis is then conducted using photon wavelengths. The results are displayed on the screen and subsequently saved.

2.3. Hirox Digital Microscope Analysis

Position each sample on a coaster, then configure the image capture, meter, and analyzer in 3D mode. Adjust the settings to focus the 3D multifocus and measure the Spot Height, Volume, and Area. Capture the desired image focus and save it for further analysis

2.4. Raman Spectroscopy Analysis

The Raman spectrometer was calibrated before use, and then the third PUIL sample material cable was placed on top of the Raman ATR and then scanned using a laser beam of a capacity of 1064 nm. All of the data result was recorded and interpreted [23].

3. Results and Discussion

Based on the material data of the samples used in this study, the following table and figure illustrate the relationship between current and heat observed in the fire experiment. Figure 2 displays images captured during the fire experiment using FLIR at 25.6°C, 201°C, and 1087°C.

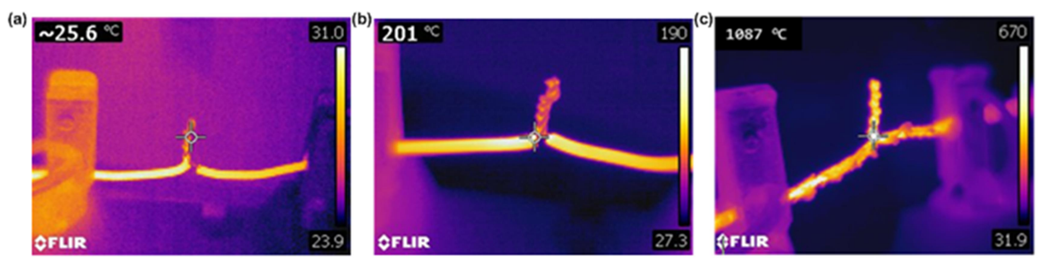

Figure 2. FLIR images of fire experiment: (a) standard PUIL sample of 25.6°C (sample A), (b) B PUIL sample of 201°C (sample B), and (c) C PUIL sample of 1087°C (sample C).

Table 1. Data analysis of copper cable on fire experiment.

Sample	Current (A)	Time (min)	Heat (°C)	
			Input	Joint
A	0	30	23.2	25.6
B	50	30	184	201
C	110	4	1070	1087

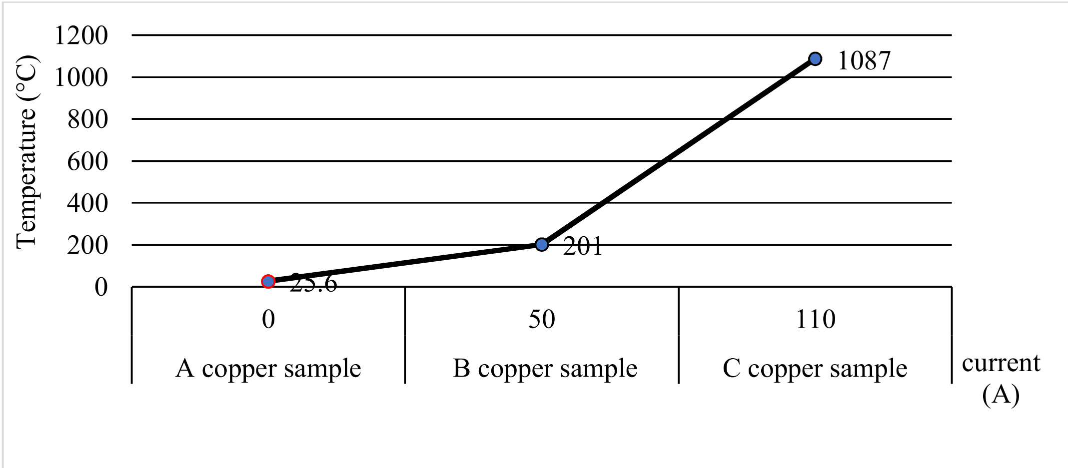

Figure 3. Graph of the relation between current and heat.

In Table 1 and Figure 3, it is evident that the surface matrix heat of copper cable joints increases proportionally with the rise in current and heat. The greater the current strength, the higher the surface temperature of the copper. Variations in current significantly impact changes in conductor temperature, with proximity to the heat source resulting in higher temperatures.

3.1. HIROX Digital Microscope Characterization

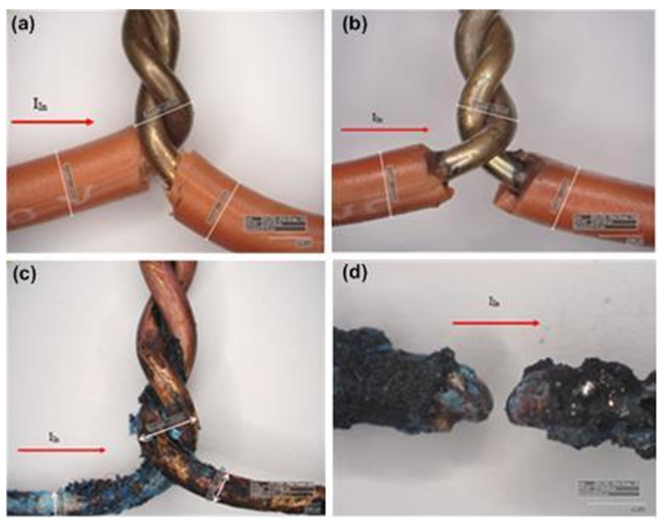

Figure 4. Hirox digital microscope images with 20 times magnification : (a) standard PUIL sample of 25.6°C (sample A), (b) PUIL sample of 201°C (sample B), (c) PUIL sample of 1087°C (sample C), and (d) PUIL sample of 1087°C in burnt.

Figure 4(a) shows the macro analysis of A sample of PUIL in jointing using Hirox with 20x magnification. It appeared that the inside of the insulating sheath was still intact (there are no signs of the pyrolysis process). At the same time, there was no soot on the cable core; it showed a heat transfer value of 0 A current for 30 minutes of 25.6°C (maximum operating temperature value) as PVC insulation in it can endurance heat transfer to reach normal conditions so that there were no signs of pyrolysis (carbonizing process). Figure 4(b) showed B PUIL in a jointing sample using Hirox with 20x magnification. It appeared that the inside of the insulation was still intact, but there were differences (there were signs of pyrolysis and carbonizing process), as the cable core already had soot. This indicated a heat transfer process of 50 A for 30 minutes at 201°C (maximum operating temperature value) because PVC insulation was still resistant to increasing heat, indicating that the pyrolysis process did not occur. Figure 4(c) shows a D sample of PUIL in jointing using HIROX with 20 x magnification. It appeared that the inside of the insulating sheath was still intact, but there were differences (there were signs of pyrolysis and carbonizing process). At the same time, the cable core already had soot; this showed the heat transfer process from 110 A current for 4 minutes of 1087°C (heat value for melted copper cables) so that the partially burned PVC insulation material sticks to the copper conductor cable core. It caused the copper cable to melt when it reached overheating 1080°C. It caused the deformation of the cross-sectional area of the cable, which is observed in changes in the surface matrix of the burned cable structure following Figure 4(d).

3.2. XRF Characterization

Table 2. XRF data of the copper cable element.

Element	Sample A (standard cable, 0 A, 25.6°C) (%)	Sample B (50 A, 201°C) (%)	Sample C (110 A 1087°C) (%)
Al	24.32	4.46	4.81
Ca	0.64	2.54	7.71
Cl	4.98	2.87	12.89
Cu	61.50	87.60	65.07
K	1.05	0.74	0.04
P	1.40	0.67	0.52
S	1.16	0.42	8.44
Si	4.95	0.70	1.01

Table 2 shows XRF data analysis of the copper cable element that the main composition of the matrix that made up the core of the electrical cable was copper metal which can be seen from the percentage of A sample (standard sample current 0 A, heat 25.6°C) of 61.50% and the elements other elements with varying constituent percentages were 24.32% Al, 0.64% Ca, 4.98% Cl, 1.05% K, 1.40% P, 1.16% S and 4.95% Si. Sample B (current 50 A, heat 201°C) had a percentage of 87.60% copper and the elements 4.46% Al, 2.54% Ca, 2.87% Cl, 0.74% K, 0.67% P, 0.42% S, and 0.70% Si. Sample C (current 110 A, heat 1087°C) had an increasing temperature of 5 times that reached 886°C. The XRF data showed the C sample indicated a decrease of copper composition by 65.07%, but the Cl composition increased by 100%, and the elements 4.81% Al, 0.64% Ca, 4.98% Cl, 1.05% K, 1.40% P, 1.16% S and 4.95% Si. The data experiment showed that the increasing significance of heat reaching 1087°C caused the copper cable to break and burn. According to XRF data, it can be seen that the increasing heating of the cable to 1087°C affected the additional Cl composition on the surface matrix of copper cable in joining because of the high temperature and degradation of the PVC insulation due to the influence of high heat, the cable core conducts on the cable protector until the PVC decomposes into HCl which adheres to the surface of the Cu cable matrix [24].

3.3. Raman Characterization

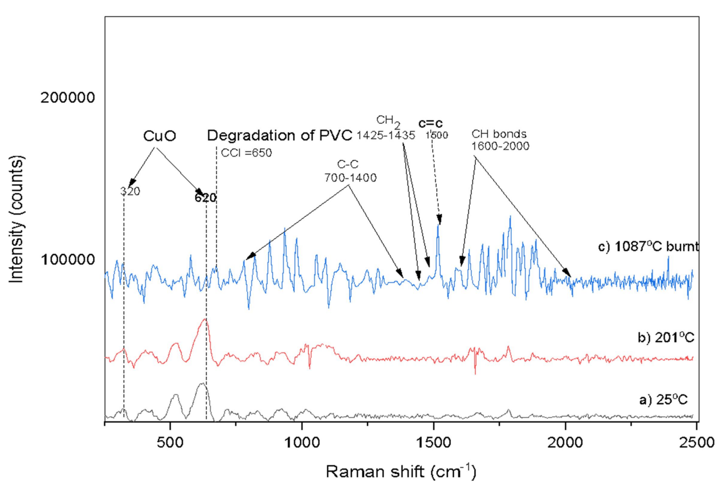

Figure 5. Raman spectrum of copper cable from three samples.

Figure 5 reveals that the third sample contains CuO, as evidenced by absorption peaks at 320 and 620 cm^{-1} wavelengths. Sample C, subjected to maximum heat, led to the melting of the copper cable, consistent with the theory that copper melts at temperatures exceeding 1080°C, resulting in pyrolysis of the protective PVC cable and subsequent combustion. Sample C demonstrates PVC degradation through Raman spectrum analysis, revealing evidence of PVC pyrolysis. Specifically, PVC components adhered to the surface of the copper cable matrix. Notably, absorption peaks at 650 cm^{-1} suggest the presence of CCl, while absorption in the range of 100-1400 cm^{-1} indicates the presence of C-C bonds, and absorption at CH bending short bonds appears at 1600-2000 cm^{-1}. PVC degradation is further evidenced by absorption at 1500 cm^{-1}, indicating the presence of C=C polyene double chains, and absorption at 1425-1435 cm^{-1}, indicating the appearance of short-chain CH_2 (a byproduct of the pyrolysis process).

4. Conclusion

Analysis of the surface matrix of copper cable in jointing type NYA ø 1.5 mm^2 insulation of PVC as the effect of increasing current and heating on fire application using Hirox digital microscope, XRF, and Raman spectroscopy showed the significant changes on the surface of Cu cable in jointing at the heating of 1087°C, characterized by broken and burnt of the jointing cable. The increasing of current and heat above the threshold of 1080°C and the degradation of the PVC insulation, XRF data obtained the increase of Cl element to 12.89%, Hirox digital microscope showed deformation of the cross-sectional area of the cable, and Raman data explained the surface changes in the copper cable core with the appearance of absorption at 1500 cm^{-1} indicating the presence of C=C polyene double bond and absorption at 650 cm^{-1} indicating CCl absorption as the effect of PVC degradation on the copper cable surface.

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