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Analyzing the deformation of copper conductor from a fire impact

Didik Notosudjono*[1], Tatang Kukuh Wibawa[2], Bagus Dwi Ramadhon[3]
[1]Electrical Engineering, Pakuan University Bogor, Indonesia
Pakuan St. PO Box 452 Bogor 16143, tel/fax: (0251) 8312206 ext 51/(0251) 8312206
[2]Institut Sains dan Teknologi Nasional (ISTN) Jakarta
Moh Kahfi St. II, Srengseng Sawah, Jagakarsa, RT.13/RW.9, Srengseng Sawah, Jagakarsa, Jakarta Selatan, Daerah Khusus Ibukota Jakarta 12630, tel: (021) 7270090
[3]Brawijaya University, Veteran St., Ketawanggede, Lowokwaru, Malang, Jawa Timur 65145, tel/fax: (0341) 551611, (0341) 575777/(0341) 565420
*Corresponding author, e-mail: dnotosudjono@gmail.com[1], tatang_kukuh@yahoo.com[2], gussygoosee@gmail.com[3]

Abstract

Fire is an oxidation reaction of the three elements (fuel, oxygen, heat) that can result in loss of property, injury, even death. Electricity potential that may results on fire is the short circuit current that occurs on the equipments and electrical installation cables. The remaining wires at the first fire location are subject to fire damage and can cause electrical short circuit. The purpose of this study is to analyze the short-circuit electrical deformation of copper cable using SEM EDS and MICRO XRF instrument. Based on the study result, there is a dominant change of oxygen elements in single cable and fiber sample causing fire that is 35.96% and 21.24%, those values are higher than Oxygen on a burned short-circuited cable that is 19.54% and 12.1%. The microstructure of the cable that causes fire looks like irregular clumps whereas the burned cable looks like a clump of clumps.

Keywords: *copper cable structure characteristics, copper deformation, electrical short circuit, micro-XR, SEM-EDS*

1. Introduction

Indonesian DKI Jakarta's fire department (Damkar) data released recapitulation of every fires occurred in 2017 in Jakarta that rounds up to 1.471 occurrences. From every burned object in 2017, households occupy the highest with a total of 505 buildings and fires caused by electricity reached 927 cases. From this data, it can be shown that in every day, 3 fire cases caused by electricity occurred. Short circuit is always the main cause of the fires, even though there are some cases that a criminal activity could be the cause. The purpose of this study is to analyze whether or not the fire that occurred in buildings or houses is purely caused by short circuit or intentional factor which leads to the fire. With fire development and smoke propagation, some factors, such as high-temperature, smoke, carbon monoxide, electrical fire left burning copper wire beads melt or melt marks used to identify physical evidence is an important cause of the fire [1], one of the identifications of its role indistinguishing the high-temperature fire, electrical fires caused by short circuit has a key role [2].

The capability of electrical cable and its safety mechanism related to fires is that everything inside including switches, MCB, Electric Dashboard and other circuit breakers are generally completely burned out, leaving only copper wires as a proof. These copper wires don't reach their melting point which is at 1.083˚C, visually still intact, and only a few wires suffered damage from fire. This indicates that only these copper wires remain in the fire location [3]. As the temperature increases, the metal grains are growing [1, 4]. Thus, by observing the microstructure, the heating process can be analyzed. Different holding time for metals, the microstructure of its size has a huge impact. In addition, increased its water jet fire undercooling, the wire will have an impact on the microstructure of metal [5].

The internal organization of Copper wire is the face-centered cubic crystal, after annealing crystal easily become ~~a~~ equiaxed grains. General microstructure of copper wire was small equiaxed grains, the original equiaxed elongated along the deformation direction, but was

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fibrous tissue, without the power of the copper wire is annealed organization. In the normal power state, the copper wire still obvious orientation, only to stress the annealing temperature is 200-280˚C and under a certain time, the direction will disappear. Recrystallization annealing temperature is between 600-700˚C [1].

Fire can occur when there are three elements: combustible, oxygen and heat. Fire is an oxidation reaction of the three elements (fuel, oxygen, heat) which results in loss of property, injury, even death [6]. Electrical causes can be identified by various events such as short circuit, electrical overload, loose contact, errors in the material usage or in the electricity installation, and electrical equipment defects [7].

Electrical fire is described as structure fire that involved some kind of electrical failure or malfunction to ignite a fire that can only be assumed after all possible accidental causes of fire are eliminated by the fire investigator [8]. Copper wires that are widely used in structure wiring and electrical appliances are frequently associated with fire. Electrical overcurrent is a condition where the current flows exceed the acceptable safety standards of that particular conductor, depending on the duration and magnitude of the overcurrent [9, 10].

SEM-EDS (Scanning Electron Microscope Energy-Dispersive X-Ray Spectroscopy) and MICRO XRF (X-Ray Fluorescence Spectrometry) are the supporting instruments of forensic examination that couples each other to examine the elements and compounds on copper wires based on Electron-Based Microscopes and X-Rays.

Until now there haven't been any research that conducts forensic short circuit on a single or stranded copper conductor using a modern instrument like SEM-EDS and MICRO-XRF to analyze the source and cause of the fire so to gives an accurate value of what causing fires in multi-story buildings, industries, or households. Fires only need 16% of oxygen for them to lit up. The air that we breathe contains 21% oxygen, so a fuel is already surrounded with adequate oxygen for them to burn. Some fuels however contain enough oxygen in themselves to burn in an environment without oxygen [11].

This purpose of this study is to analyze the short circuit characteristic on copper wire in fire cases by finding the difference in structure between the short-circuited cable that causes the fire and the other cable that is due to the fire using SEM EDS and MICRO XRF. Researches using SEM-EDS and MICRO XRF will be very helpful for the police to do forensic analysis on a building, industry or a household so it can differentiate whether or not the fire caused by a short circuit or burned intentionally where in most cases before these two instruments were invented, it would prove to be very difficult to determine.

2. Theory of Electric Fires

2.1. Fire Cause due to Electricity

Electricity plays a role as one of the sources that can cause fire. The process in which an ignition occurred can be started from various causes; they are electrical short circuit, electrical overload, or the current leakage from loose contact. Electrical fire is described as structure fire that involved some kind of electrical failure or malfunction to ignite a fire that can only be assumed after all possible accidental causes of fire are eliminated by the fire investigator [8]. When overcurrent occurs, the entire circuit is heated through which the current flows which could then affect the thermoplastic insulator of the conductor and prolong heating of the conductor could lead to fire ignition [12].

Electrical potential that can cause fires is short circuit that occurs on the available electrical installation equipment and components. If the circuit breaker (fuse and MCB) is not working properly, they can cause an increase in temperature on the cable and its isolation which in turns could burn themselves and its surroundings. Other problems that could cause fires are aging, standardization, planning, installation, and operation available electrical installation equipment and components [11].

2.2. Copper Characteristics on Conducting Wire

Copper is an element from periodic table with the symbol Cu, originated from the Latin Cuprum, has an atomic number 29, mass number 63,54, is a metal with reddish color scheme. Copper is a good conductor for heat and electricity. This can be seen on the Table 1. Macro structural Inspection Characteristics from a damaged conductor (melting) caused by various events by the conductor, damage caused by electricity and receiving heat from environment. Figure 1 is derived from research result conducted by US Police Bureau that handles fire cases [13].

Table 1. Physical, Mechanical, Heat Properties of Copper [3]

Physical	Unit
Density	8920 kg / m3
Tensile Strength	200 N / mm2
Modulus of Elasticity	130 GPa
Brinnel Hardness	874 MN m-2
Thermal Expansion Coefficient	16,5 x 10-6 K-1
Heat Conductivity	400 W / Mk

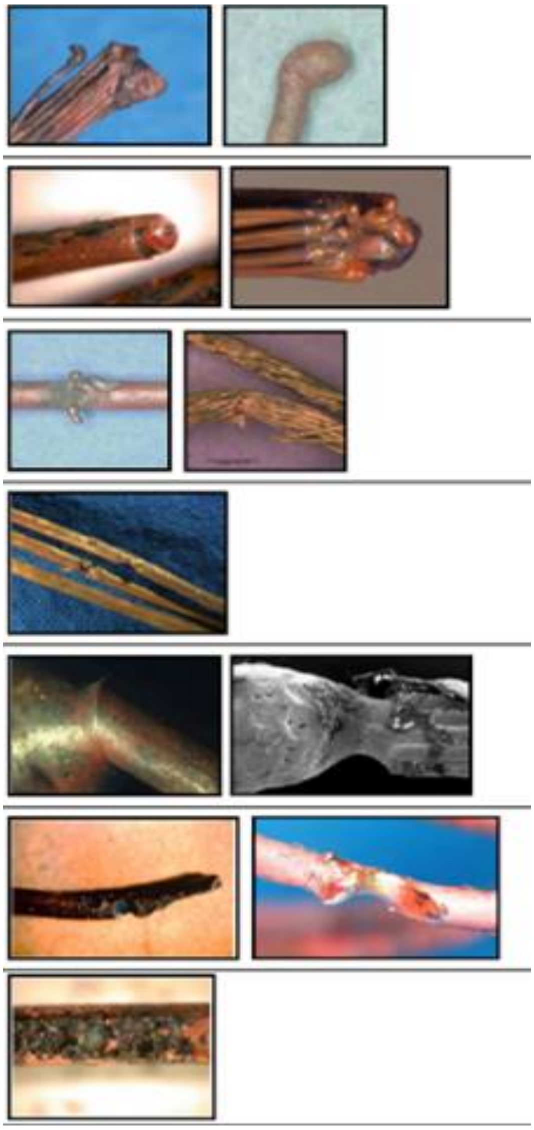

Figure 1. Macro Structural Inspection for conductor [16]

Delplace and Vos (1983) characterised the internal electrical damages with the presence of beads on the copper conductor, abrupt changes in cross sectional appearance of the wires, and also damage on adjacent conductors or metal cable shielding [14]. Liu *et al.* [15] also added that the inner PVC insulator layer experienced a lot of damage in internal heating. Examination of beads and globules frequently utilised for determination of electrical as the source of fire but many researchers, i.e. Levinson [16], Babrauskas [17] and Wright *et al.* [18] agreed that the examination solely based on the external appearance of beads and globules was not a reliable indicator on the cause of their formation.

2.3. Electrical Fire Cause

The flow of electric current may cause heat to a conductor. This heating mechanism can be either conductive or inductive. Conductive heating is a direct heating process with DRH (Direct Resistance Heating) where direct heat occurs due to current flowing through electric conductor having certain resistance. Those heating cause losses to existing electrical equipment conductor losses, dielectric conductor.

On an inductive heating, heat is obtained from current flow on a conductor. The current comes from the inductive electricity that occurs outside the heating plane. Inductive heating is always related with an ever-changing magnetic field. Inductive heating can be depicted in transformator where the heating surface acts as a secondary coil [11].

In every fire cases, a fire investigator is required to determine the cause of fires. Therefore, it is important for a forensic investigator to have an in-depth investigation on the copper wires as to conclude whether or not a fire could have due to faulty electrical appliances or by the exertion of flame due to other consequences. This work was conducted to study the morphological features of the cross section of copper wire due to external flame and eletrical means [19].

2.4. Scanning Electron Microscope and Energy Dispersive X-Ray Spectroscopy

Scanning Electron Microscope (SEM) is one of the electron microscopes that use electron beams to draw the surface shape of the analyzed material. The working principle of this SEM is to draw the surface of an object or material with a reflected electron beam with high energy. SEM-EDS has the ability to provide information directly about topography (sample surface texture), morphology (shape and size), composition (sample compilers), even crystallization information (atomic arrangement of samples).

Using SEM, Gray *et al.* [20] observed numerous square and rectangular pockmarks on FCABs. Erlandsson and Strand [21] found copious voids in the cross sections of arc beads. A study by the Tokyo Fire Department revealed that even arc beads formed in the air at 1000°C contained voids, albeit smaller and more likely to be near the surface of the FCAB. On the other hand, large voids have been observed deeper inside FRABs [22]. Lee *et al.* [23] found that the spacing between the dendrite arms reflected the ambient temperature where the beads solidified; thus, the dendrite arm spacings of FCABs were smaller than those of FRABs. As seen in Figure 2, there are several important signals generated by SEM. From the inelastic reflection, secondary electron signals are obtained. From the elastic reflection, backscattered electron signal is obtained. Those signals are described in Figure 2.

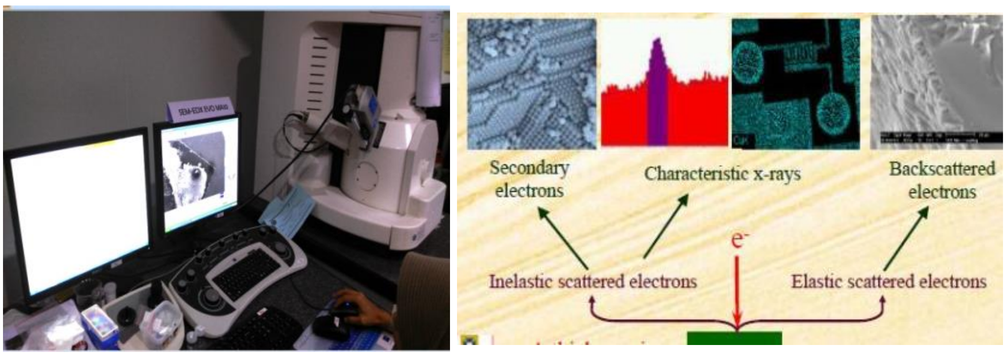

Figure 2. Important signals generated by SEM

2.5. Scanning X-RAY Fluoroscence (XRF)

The XRF method is widely used to determine the elemental composition of a material. Because this method is fast and does not damage the sample, this method is selected for field and industrial applications for material control. Depending on its use, XRF can be generated not only by X-rays but also other primary excitation sources such as alpha particles, protons or high energy electron sources. Figure 3 shows the X-Ray Fluoroscience Scanning Device.

Figure 3. Scanning X-Ray fluoroscence equipment

3. Research Methodology

This study was conducted only for NYM (single) and NYMH (Fiber) size 1.5 mm^2, with simulation in PLN Puslitbang's Cable and Low Voltage Laboratory, simulated using load addition (overload) to short circuit the connector of NYM and NYMH cable that causes fire. The samples from the simulation in the lab PLN Puslitbang's Cable and Low Voltage Laboratory are then inspected using SEM EDS and MICRO XRF in Polri Bareskrim's Forensic Laboratory. Research only limited to find the structural characters on a short-circuited copper cable or fire source by checking the cable structure which covers topographic sample, morphology, and composition. The analytical method used in this study was scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDS). SEM/EDS is a reliable and reproducible technique that produces images of high resolution as well as an X-ray spectrum that represents an elemental fingerprint of that product [24].

4. Analysis and Discussion

The morphologies and compositions of the dried samples were investigated using field-emission Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) [25]. In the fire simulation, maximum fire flash over temperature measurements using FLIR proves that the melting points of copper wire 1083˚ Celsius is still above the the maximum fire temperature that is 1015˚ Celsius as seen on the Figure 4.

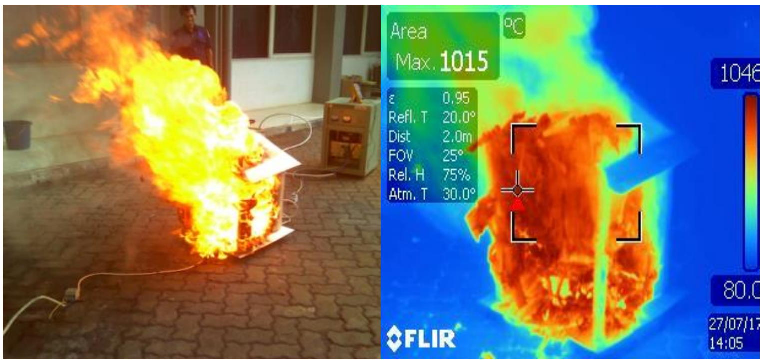

Figure 4. Thermal imaging of FTIR tool on a mock house with electrical cable installation inside set on fire (flash over)

According to the simulation result with copper wire on the fire case caused by a short circuit on the electrical cable installation, and analyzed using SEM-EDS and MICRO-XRF instrument. It can be seen that there is a deformation on the copper wires caused by the fire. MICRO-XRF examination result on the dominant element shows that the difference between a cable causing the fire and burned one is the composition of copper on the burned NYM cable is, at 93.05%, much lower than the NYM Cable which causes the fire, at 97.8195%. While burned NYM fiber cable at 92.46% copper composition against 97.8195% on the NYM fiber cable which causes the fire. The difference can also be seen on the element of calcium where the burned single NYM cable at 4.968% is higher than the NYM cable causing the fire at 0.3205% calcium composition. For the NYM fiber, the burned is at 4.9165% and the causal NYM fiber cable is at 1.315%. More details can be seen in Figures 5 and 6.

From the Micro-XRF graphic below, it can be seen that there is a significant difference on a single copper cable causing the fire and due to fire by seeing the single copper cable due to fire element percentage is 93.057% which is lower than the one causing the fire 97.8195%. From the analysis, the graphic will be very useful for the police or the authority to determine the whether the cause of fire in a building, industry or a household is purely caused by short circuit or intentional.

According to analysis result using Micro-XRF instrument with the graphic result, there is a significant difference between the stranded cable due to fire which is 92.746% and the one that causes the fire which is 96.9885%. The calcium element on the stranded NYM cable use to fire is 4.916% which is higher than the one causing the fire which is at 1.3215%.

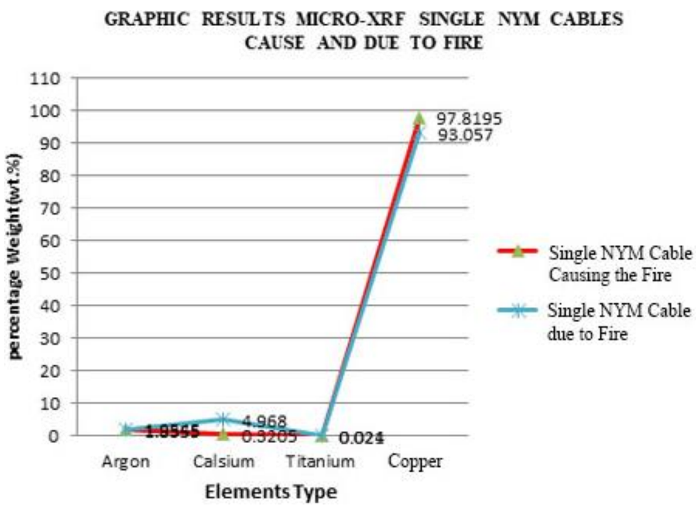

Figure 5. Micro-XRF Result NYM single cable

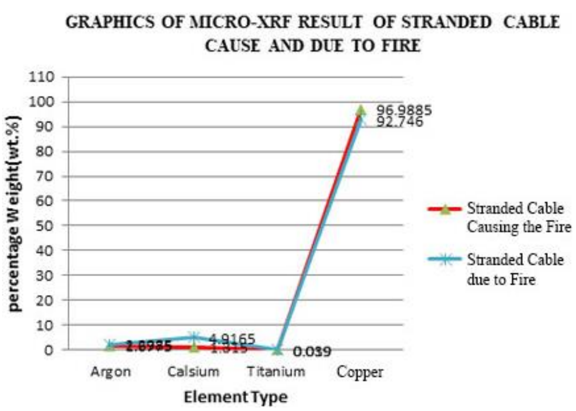

Figure 6. Micro-XRF Result on NYM fiber cable

Forensic analysis of the single NYM cable from Figure 5 is not much different from stranded NYM cable from Figure 6, research result shows that stranded copper cables causing the fire is higher than the one due to fire despite the overall value is lower for stranded cables but it can be a basis for the police or the authority to determine the cause of the fire.

Examination using SEM-EDS result on dominant element composition between the cause and effect of fire on the cable shows that the amount of Oxygen on the NYM cable which causes fire, at 35.69%, is much higher than the burned NYM cable at 19.54%. While Oxygen elements on NYM fiber which causes fire, at 21.24, is also much higher than the burned NYM fiber at 12.1%. Figure 7 shows that the cable which causes the fire has more oxygen than the burned one.

From the forensic analysis using SEM-EDS it can be affirmed that the oxygen percentage could be an indicator for the cause of fire. The percentage of oxygen both on the single and stranded cable which causes the fire is higher than the ones due to fire. This will also be helpful for the police to determine the fire cause if it happens on a building, industry, or household accurately using the difference in oxygen percentage. As seen in Figure 8, oxygen element on NYM Stranded cable sample causing the fire is 21.24% which is higher than the one due to fire 17.7%. This shows that the short-circuited cable causing the fire has more oxygen than the one due to fire while the copper element of the stranded cable causing the fire is 38.04% which is lower than the stranded cable due to fire.

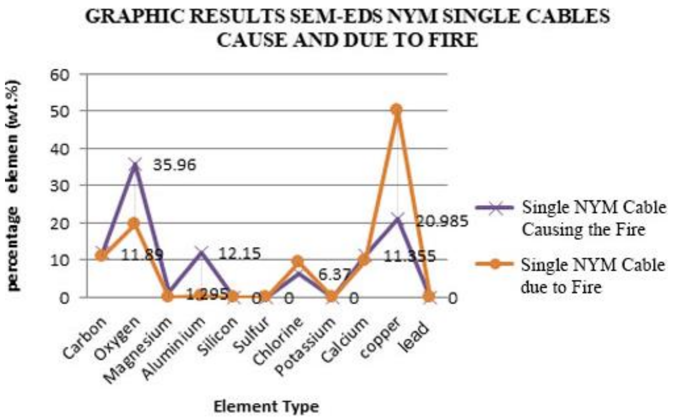

Figure 7. SEM-EDS result on single NYM cable cause of fire and burned of Fire

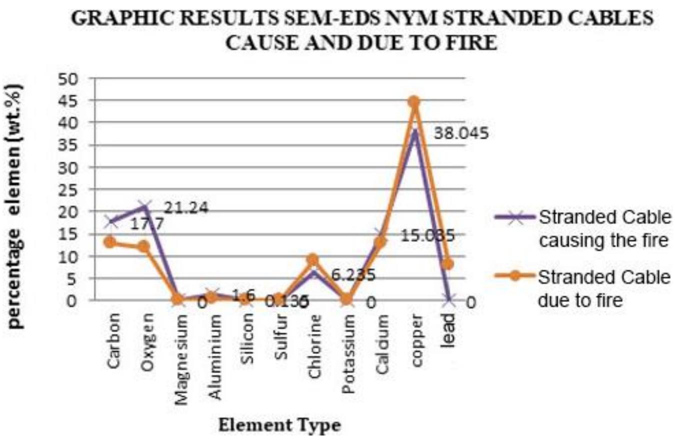

Figure 8. SEM-EDS result on NYM fiber cable cause of Fire and due to fire

On Figure 9, as a result from morphology sample inspection using Micro XRF and SEM-EDS on a NYM single cable causing the fire, it can be seen its tight microstructure and other black elements attachment. The shape of the cable which caused the fire looks like irregular clumps with the conductor severely damaged while the cable effected by the fire takes shape of blobs in group.

Analysis result also conducted on the NYM single cable burned from the fire as seen on Figure 10, from morphology analysis, it can see that the microstructure looks like subtle bubble that protrudes the surface unlike the NYM single cable that causes the fire. The microstructure of the single NYM cable and the fire-causing fibers appear to be tightly structured, while the fires appear to resemble the fine bubbles that protrude the surface of the cable.

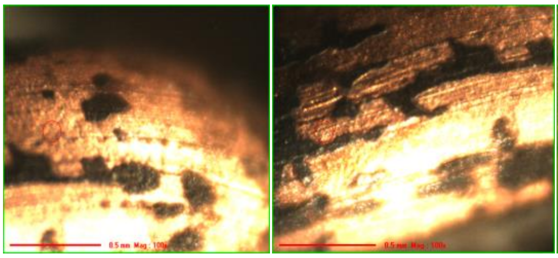

Figure 9. NYM Single Cable cause of fire

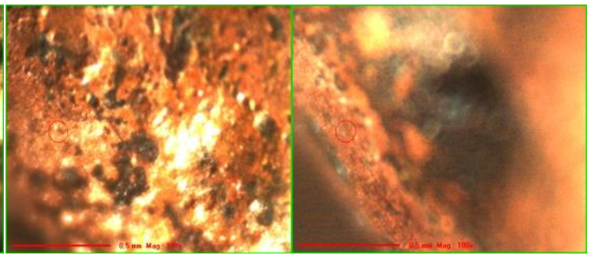

Figure 10. Single NYM cable effected by fire

5. Conclusion

Based on the MICRO-XRF result on dominant element composition between the cable that causes fire and the due to fire, on the copper composition, the burned cable contains 93.057% copper composition while the causal cable contains 97.8195%. For NYM Fiber cables, the cable due to fire contains 92.4%, a lower value than the fiber cable causing the fire which contains 96.9885%.

Based on the SEM-EDS on determining the element composition, the composition of Oxygen on the NYM single cable which causes the fire is 35.96%, a higher value than NYM single cable due to the fire at 19.54%. For the Fiber cables, the composition of Oxygen on the causal cable is 21.24%, a higher value than the fiber cable due to the fire at 12.1%. The microstructure of the cable causing the fire looks like irregular clump with a severe damage on its conductor while the cable that is burned looks like a blob in group.

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