

The Study of Degdradation Cable Isolation of PVC (Polyvinil Chloride) : A Comparison of Isolation Cable Between Short Circut and Open Flame

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Abstract
Research about The study of degdradation cable isolation of PVC (Polyvinil Chloride) : A comparison of isolation cable between short circut and open flame was carried out. The purposes of this research are i) to know degradation process of cable isolation from melting to be short circut occurring and ii) to know comparison of fire cable due to overload or open flame. This research is experimental laboratory whereas cable "NYA" size 1x1.5mm used as sample. Subsequently, samples are divided as: i) normal sample (without electric current) (as well as reference); (ii) samples were flowed by using Electrical current 16, 25 dan 35 Ampere, respectively; iii) Sample was flowed by using electrical current until short circuts occurred, and iv) Sample was burned by open flame. All samples were characterized with FTIR, SEM-EDS and XRD, respectively. The results showed that: i) FTIR Data. FTIR Spectra of *short* cable significantly changing compared to normal cable isolation. It means, flowing electric current to the cable caused temperature of cable will be increased, it may initiated oxidation occurred at functional group of esther which was existed in cable isolation; ii) SEM EDS Data. Supply of electron into cable caused overheating at cable, whereas degradation process for cable isolation occurred. The continuity of degradation will result pyrolisis (carbonization) at surface of isolation. Therefore SEM image proved that increasing of electron supply at degradation process will be accelerating pyrolisis process; and iii) XRD Data. Increasing current electric will be increasing intensity of carbon (number of carbon atoms increased) and decreasing intensity the number of oxygen atoms (number of oxygen atoms increased). All of data indicated when open flame happened at cables so the number of oxygen will be increased, whereas carbon has been burned. Based on all data concluded whereas degradation process of isolation cable by giving overload of electrical current it clearly showed that significantly differences with cable isolation of open flame. It may be concluded that the burning cable isolation of open flame was caused by degradation functional group. On the other side cable of open flame, the number of carbon will be decreased.
Keywords: analysis, cable, PVC isolator, and degradation.

1. Background

Fire is a phenomenon that often we hear, both in print and electronic media. Fire is an event or accident that can result in loss of life and considerable material losses. Number of fires each year is always increasing, it can be seen from the data that in 2014 the number of fires 117 cases, in 2015 rose to 165 cases. From the results of the investigation that for 2015, the number of cases of fire that is generally the cause is a short circuit to 75%, 18% human negligence, the remaining element of intent. (Data obtained from annual reports of cases Forensic Laboratory Branch 2015). From the definition of a fire is the rapid oxidation is accompanied by the release of energy and light (Charter, 1985) while the broad definition that fire is a stand-alone exothermic reaction phase involving solids, liquids, or gases that are usually associated with the oxidation of the fuel by the oxygen in atmosphere emitting energy in the form of heat and light (Jay, et al., 2008). Fires can occur if there are three elements, namely a combustible material, oxygen, and sparks (Setiabudy, 2009). Good electrical installations must use the cable installation according to the standard ISO / SPLN as NYM cables with PVC insulation. Insulator PVC is a kind of isolation characteristics in accordance with the needs of household electrical installations and meet the requirements and standards. PVC also has several advantages, which are lighter, have better mechanical properties, dielectric loss smaller and higher volume resistivity, and one of the most important is the relatively rapid production process and production costs are cheaper. While PVC also has the disadvantage of low heat resistance so easily damaged melted and charred at high temperatures (Almanda, 2014).

PVC insulation system has been widely used in electrical appliance, it is possible in addition to its good and economical price at the time of production. PVC cable isolation are very susceptible to heat, even at the time of the fire due to short circuit, then the isolation that became the first fuel that exist around the cable. So that the electrical fire in the main fuel for the achievement of the fire triangle is the isolation (Dudun, 1998). High voltage cable isolation systems and accessories subjected to various pressures during the time of service so that the insulation degradation and damage therefore many research efforts to understand the degradation of the insulation. Some researchers are trying to explore the process of degradation before the fire of the cable isolation, such as: a) Analysis of the degradation of insulation resistance of PVC with the provision of flow where the degradation process seen from a decrease in insulation resistance and thermal electric current influence (Andre

Sutomo, 2010), b) Predictions degradation of XLPE cable isolation (Imron Ridzki, 2009), and c) Predicyion of insulation Negration of Distribution Power cables based on Chemical Analysis and Electrical Measurement (Hyvonen petri, Helsinki University of Technology, 2008). Researchers from several publications about the degradation of the cable isolation, almost all researchers have a basic knowledge of electrical, so that the direction toward the publication of more electricity, even degradation implied by the reduction in insulation resistance and leakage current. Therefore, researchers are interested in studying the degradation process more towards the (chemical). Where, according to chemists, in particular polymers that degradation is an event of termination of long chain polymers into monomers by the influence of heat, temperature, weather, and chemical reactions, so that the process of this study, the researchers tried to see this process as a chemical which degradation isolator cable powered by electrical current to overload for the occurrence of a short circuit as the cause fire. Cable isolation is energized will be analyzed by means of FT-IR, SEM-EDS, X-RD.

2. Research Methods

2.1. The testing procedure degradation process.

The testing procedure is performed for the degradation process is as follows: a) Preparation of a series of closed power flow for testing, b) Replacing the cable to be tested NYA 1x 1.5 mm, c) Setting the load, d) Conducting cable connection with twine, e) Powering electric current, f) Take note of changes in temperature on the wire for approximately 1 hour, and g) Take the cable insulation and separating of copper, h) to examine the cable insulation with FT-IR analyzer test, SEM-EDS, and X- RD, and i) Perform the same test for each sample of cable with varying load (16A, 25A, and 35A).

2.2. Testing Procedures Short Circuits.

The testing procedure is performed for short circuits the process is as follows: a) Preparation of a series of closed power flow for testing, b) Replacing the cable to be tested NYA 1 x 1.5 mm, c) Combining the wiring by lapped, d) Giving load 35A, e) Powering electric current, f) Take note of changes in temperature on the cable occur until the short circuits, g) Take the cable insulation from the junction who experience short circuits, and h) to examine the cable insulation with the analysis of FT-IR, SEM-EDS and X-RD.

2.3. Cable Testing Procedure Burned by Flames

The testing procedure is performed for the process that was burned by the flame are as follows: 1) Setting up the teflon is working, 2) Burning wires "NYA" 1 x 1.5 mm above the teflon until the cable is lit, 3) Turn off the flame on the cable, 4) Separating the cable insulation from copper, and 5) to examine the cable insulation with FT-IR analysis, SEM-EDS and X-RD.

2.4. Flowchart of Research

2.4.1. Schematic circuit Test Equipment

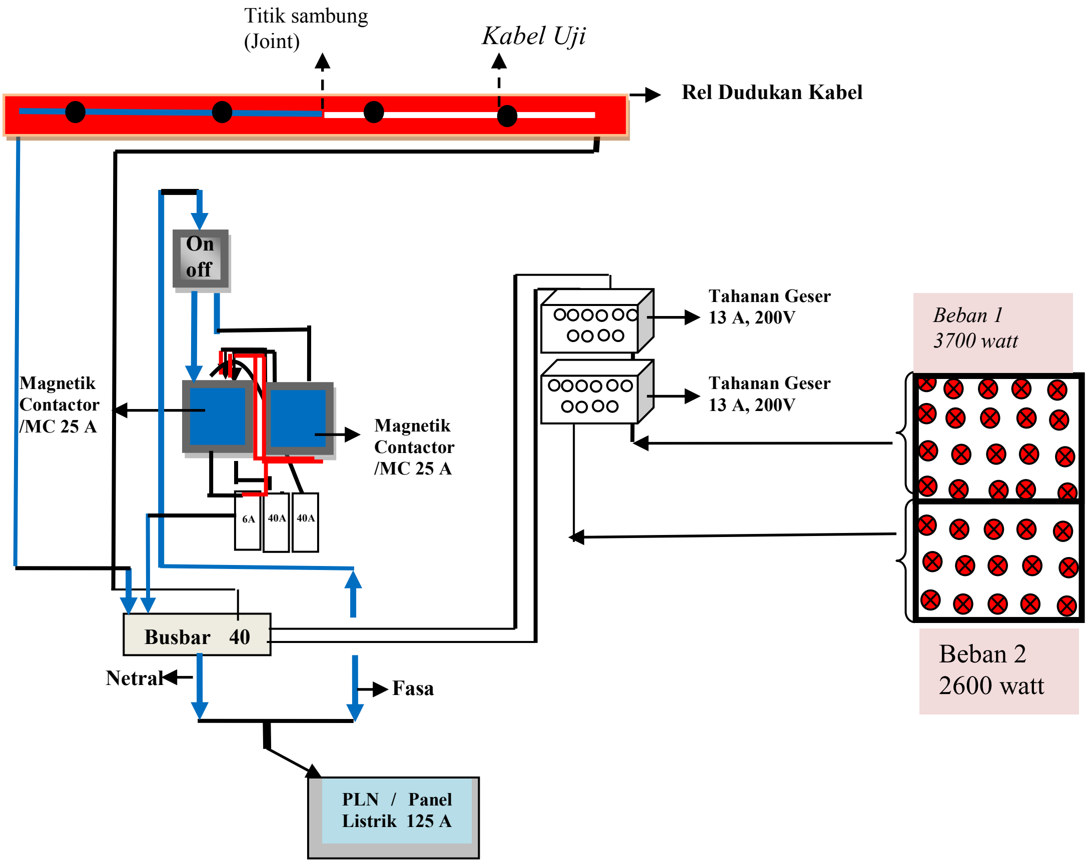
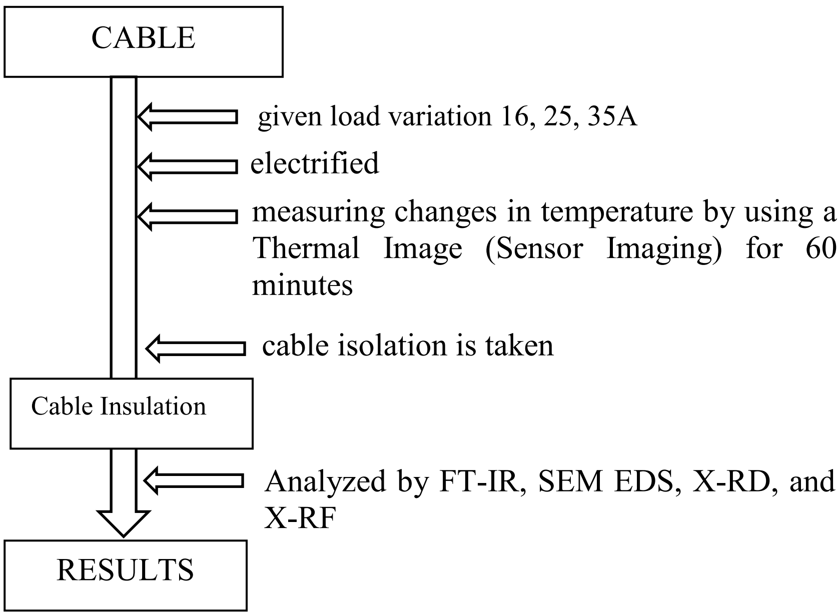
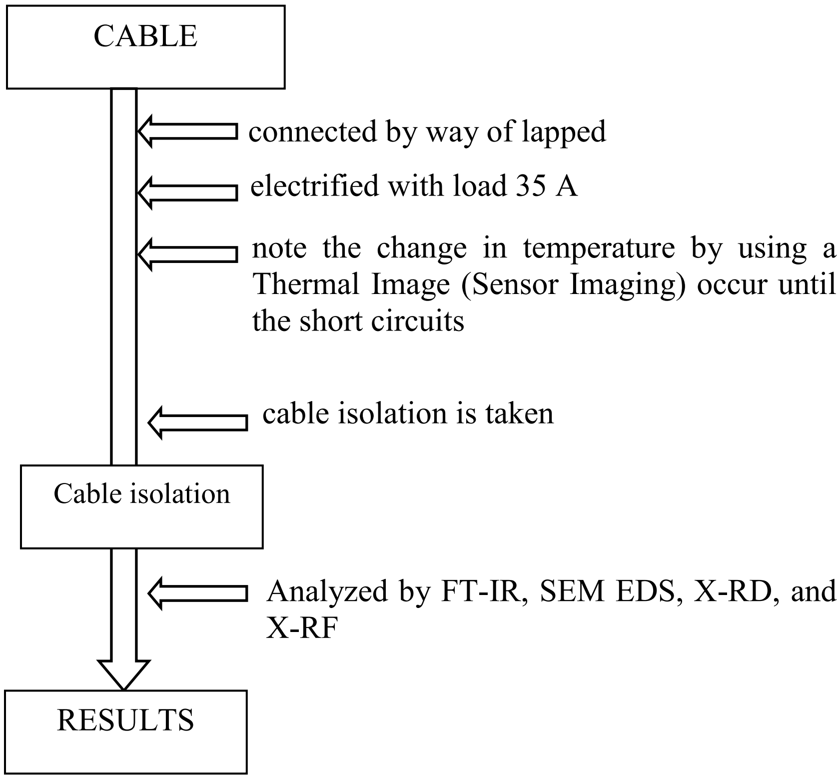


Figure 2.1. Network schemes Test Equipment

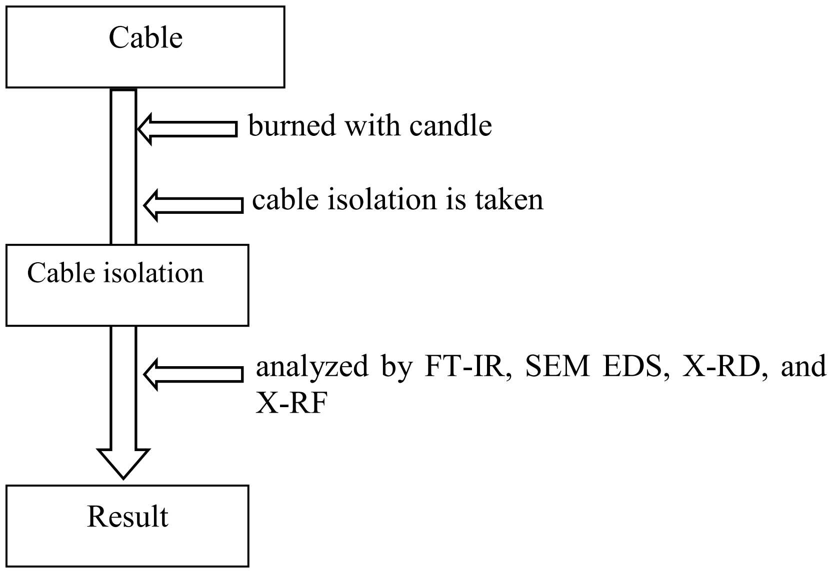
2.4.2. Degradation processes in Isolation



2.4.3. Process Treatment Short Circuits



2.4.4. Combustion Process Cable with Flames



The following table of parameters and conditions of the test sample FT-IR, and SEM EDS

Table 2.1. Sample Test Parameters and Conditions Cables

Types of Tests	Test parameter		Test Equipment
Identifikasi Polimer dengan FTIR	Preparasi	*cutting*	Tensor 27 with Hyperion 2000 FTIR
	Metode	ATR	
Analisa Unsur dengan EDS	Preparasi	Pelapisan dengan Emas	JEOL JSM-6510 LA SEM-EDS
	Electron voltage	20 kV	
	Perbesaran	150 X	

3. Results and Discussion

3.1. Imposition Test Cables

Cable samples used in this study is the cable type "HIS". These samples were obtained from the electronics store that sells a variety of electronic equipment scale and scale house industri.Selanjutnya, the sample used is given by the imposition of excessive load variations (overload) of the cable capacity. As well as their treatment (impact) of the cable in the manufacturing process of short circuits. For reference load variation of temperature increase is done electricity using prisoners and the bulb. The load variations are performed in this study is 10 amperes (A) (equivalent to 2,200 watts (W), 16 A (equivalent to 3,500 W), 25 A (equivalent to 5,500 W), 30A (equivalent to 6,600 W) and 35 A (equivalent to 7,700 W). However, in this study were selected as the sample to be analyzed, namely 16A, 25A, and 35A. While treatment for examination of short circuits do with the load 35A (peak load). the basis of selecting the size variable of the load current is scaled simple household, and a mansion. it is considered in this study is the ability of the insulation that would be degraded by temperature rise caused by an electric current. the reference loading time for each experiment performed just 60 minutes. this was done because the effect of time on the use of cables not so significant to the process of degradation. the temperature measurement is shown in Table 3.1dan 3.2.

Table 3.1. Data Cable test "NYA" size 1 × 1.5 mm

No	Flow Imposition (Ampere/A)	Imposition of time (minutes)	Temperature (ºC)		Information
			Spot 1 inrush	Spot 2 outflow	
1.	0	60	0	0	Without load (N)
2.	10	60	30,5	32,0	Process Degradation
3.	16	60	33,0	36,5	Process Degradation
4.	25	60	37,6	45,4	Process Degradation
5.	30	60	44,0	47,0	Process Degradation
6.	35	60	48,0	53,3	Process Degradation
7.	41	60	65,0	71,0	Process Degradation

Table 3.2 Data Cable test *Short Circuits*

No	Flow Imposition (Ampere/A)	Imposition of time (minutes)	Temperature (ºC)			Keterangan
			Spot 1 inrush	Join	Spot 2 outflow	
1.	35	0	28,3	28,4	28,2	Room Temperature
2.	35	15	35,0	42,5	36,0	Process Degradation
3.	35	30	45,0	97,0	50,0	Process Degradation
4.	35	50	54,0	112,0	55,0	Process Degradation
5.	35	60	54,0	122,0	60,0	Process Degradation
6.	35	75	65,0	141,0	70,0	*Short Circuits*
7.	35	110	75,0	170,0	78,5	*Down*

3.2. Summary Test Results

Identification by the cable isolation with FT-IR and SEM-EDS, can be seen in Table 3.3.

Table 3.3. Sample Test Results Summary Cable with FT-IR with SEM EDS

No	Name sample	Hasil	
		Material Identification with FT-IR	*** Element content with SEM-EDS**
1	Cable Normal	Polyvinyil chloride plasticized with phtalate esther and filler with with sodium carbonate	C, O, Al, Cl, Ca, Cu
2	Cable 16A		C, O, Cl, Ca, Cu
3	Cable 25A		C, O, Al, Cl, Ca, Cu
4	Cable 35A		C, O, Cl, Ca, Cu
5	Cable *Short*		C, O, Al, Cl, Ca, Cu
6	Cable burned from the outside		C, O, Cl, Ca, Cu

Data from sample cable isolation identification using FT-IR instruments are shown in Table 3.4.

Table 3.4. Results of Sample Material Identification Cable with FT-IR

No	Name samples	Number of waves (cm^{-1})	Information
1	Cable Normal	2960, 2927, 2864, 1794, 1725, 1583, 1426, 1278, 1126, 1074, 1040, 959, 875, 842, 782, 743, 705, 624 3442, 3367	Polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*
2	Cable 16A	2960, 2926, 2866, 1802, 1726, 1582, 1426, 1278, 1127, 1074, 1040, 959, 875, 843, 772, 744, 705, 631 3437, 3358	Polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*
3	Cable 25 A	2960, 2929, 2869, 1798, 1726, 1582, 1426, 1279, 1127, 1074, 1041, 959, 875, 843, 776, 744, 705, 620 3444, 3409, 3350	Polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*
4	Cable 35 A	2960, 2926, 2868, 1794, 1726, 1585, 1425, 1279, 1127, 1074, 1040, 960, 875, 844, 778, 744, 705, 628 3442, 3409, 3350	polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*
5	Cable Short	2960, 2920, 2860, 1794, 1726, 1586, 1426, 1278, 1127, 1074, 1040, 959, 875, 844, 782, 743, 702, 620 3442, 3413, 3358	Polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*
6	Cable burned from the outside	2960, 2923, 2868, 1795, 1726, 1587, 1426, 1280, 1127, 1074, 1040, 960, 875, 844, 778, 743, 704, 624 3441, 3412, 3366	Polyvinyl choride plasticized with phthalate ester and filled with sodium carbonat. Referensi Hummel/Scholl no 2021 *Other material*

3.3. Analysis by FT-IR

FT-IR spectra of several different cable isolation reveal some chemical functional groups. FT-IR identification results are shown in Figure 3.1- 3.7. Figure 3.1. is FT-IR from isolation the data cable that is no electricity (Cable Normal). FT-IR spectra in the normal cable obtained the following wave numbers: 2960 cm^{-1}, 2927 cm^{-1}, 2864 cm^{-1}, 1794 cm^{-1}, 1725 cm^{-1}, 1583 cm^{-1}, 1426 cm^{-1}, 1278 cm^{-1}, 1126 cm^{-1}, 1074 cm^{-1}, 1040 cm^{-1}, 959 cm^{-1}, 875 cm^{-1}, 842 cm^{-1}, 782 cm^{-1}, 743 cm^{-1}, 705 cm^{-1}, 624 cm^{-1}.

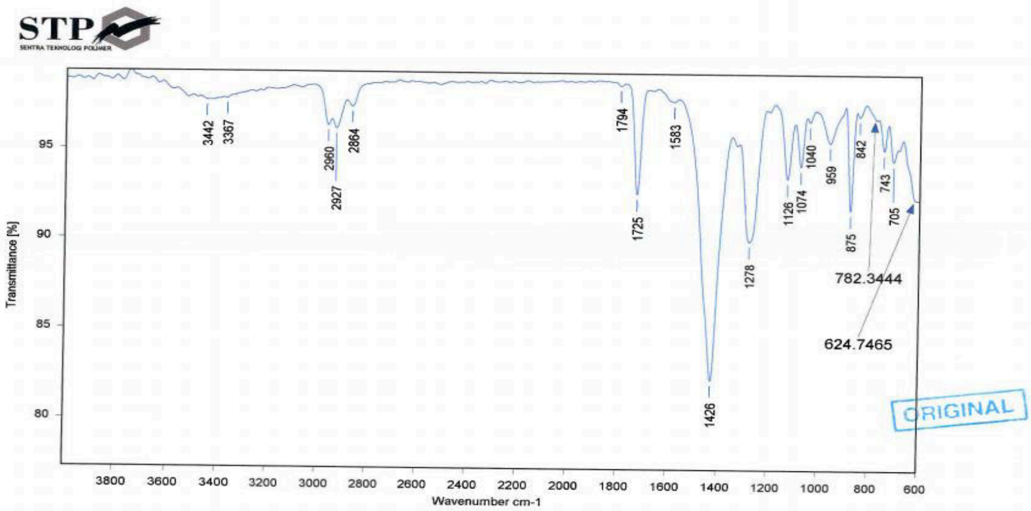


Figure 3.1. FT-IR spectra Cable Normal

Data FTIR of a normal cable is shown in Figure 3.1. The composition of normal cables are polyvinyl chloride, phthalate esters and sodium carbonate filler (commercial cable). Therefore FTIR analysis to ascertain the composition of the cable. Their spectra at 1725 cm^{-1} indicates a carbonyl (C = O) reinforced their spectra overtone at 3442-3367 cm$^{-1.}$ Spectra in the 1300 - 1000 cm^{-1} is the group C-O typical of esters. The spectra were sharp and great at 1426 cm^{-1} indicates a hydrocarbon group (C-H) of CH_2.

This is reinforced by their spectra in the 2960 - 2927 cm^{-1} indicates aliphatic C-H. Their spectra 800-600 cm^{-1} too indicate C-Cl vinyl group. These data indicate that normal cable composed of vinyl chloride, ester, methyl and methylene (aliphatic hydrocarbons), in accordance with commercial data cabling. Furthermore, a normal cable is used as a control material.

The spectra of cables given the current treatment respectively 16, 25 and 35 Ampere (A) shown in Figure 3.2, 3.3, and 3.4. All three spectra show that no significant changes compared to spectra of normal cables. That is, the increase of the flow inside the cable does not result in changes in the functional groups of the cable isolation. Images of FT-IR spectra of cables given current respectively 16, 25 and 35 Ampere (A) is shown in Figure 3.2, Figure 3.3, and Figure 3.4 below.

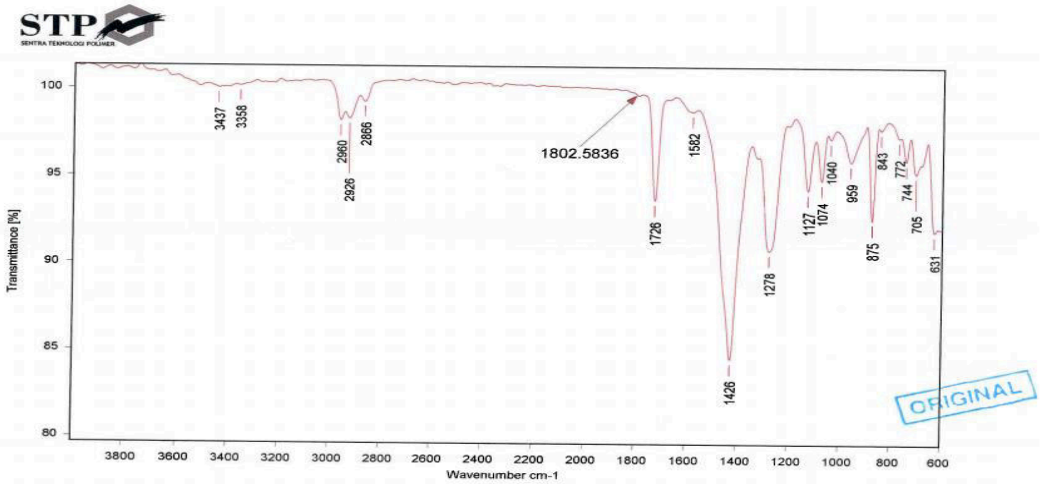


Figure 3.2. FT-IR spectra cable 16A

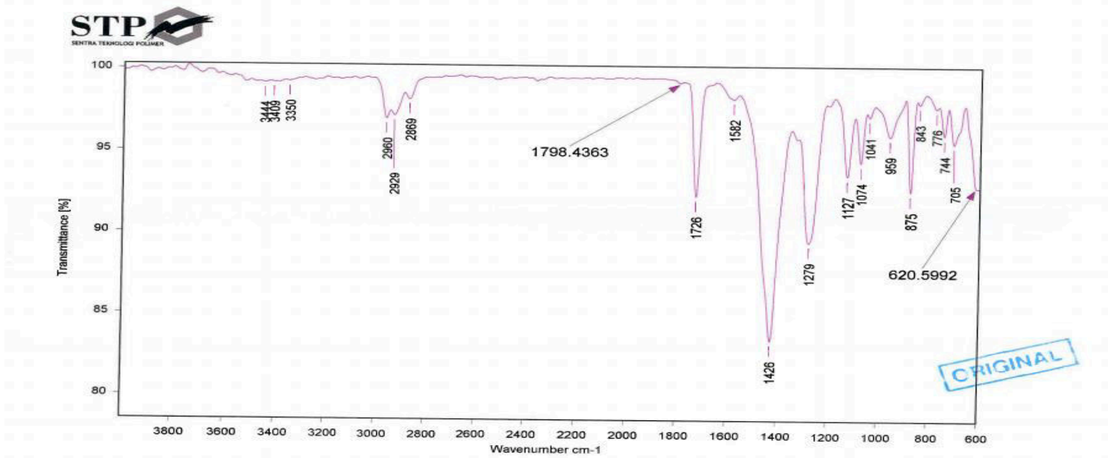


Figure 3.3. FT-IR spectra cord 25A

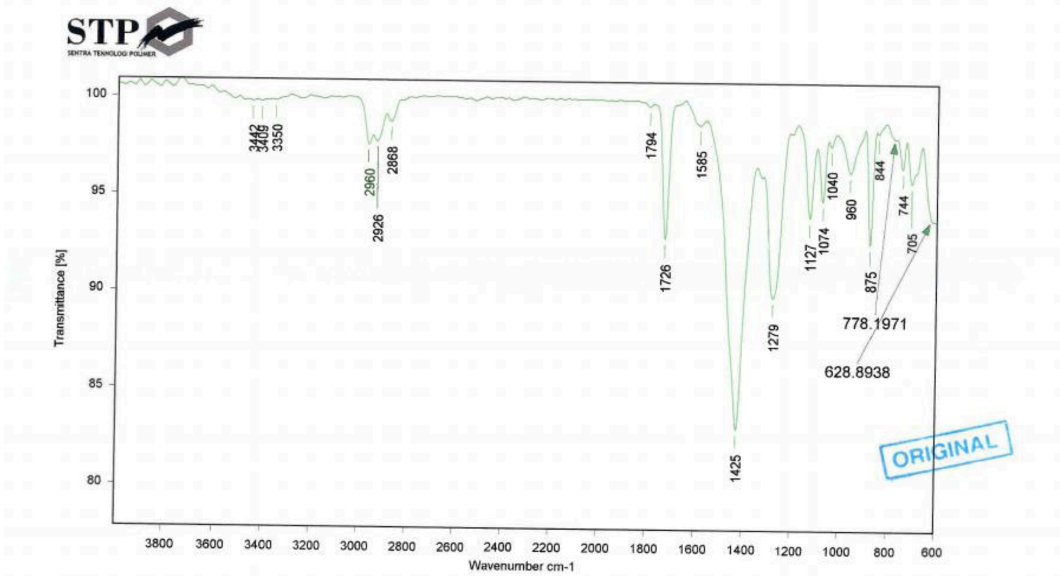


Figure 3.4. FT-IR spectrum Cable 35A

FT-IR spectra data of the cable isolation short (Figure 3.5).

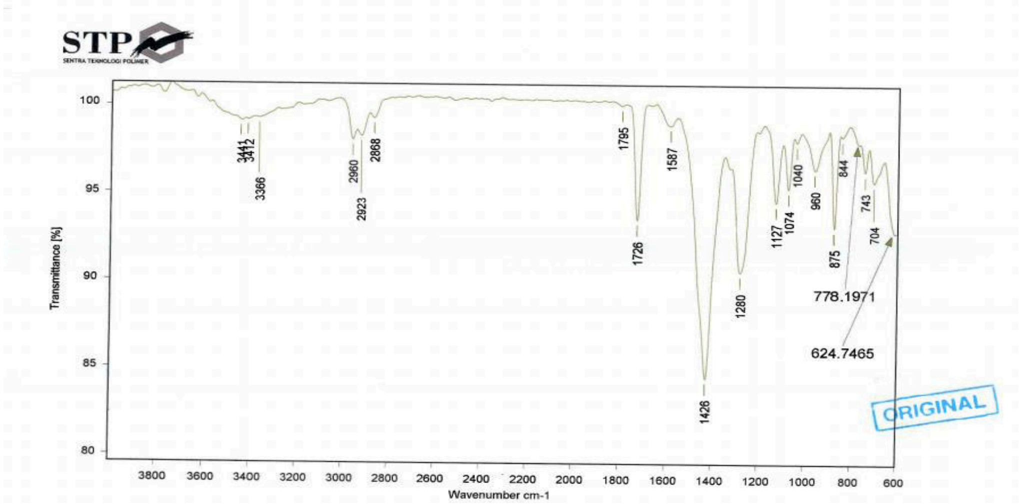


Figure 3.5. FT-IR spectra Cable Short

In the FT-IR spectra of the short cable very significant change compared to the normal cable insulation. Their spectra were widened in 3442 - 3367 cm^{-1} indicated that the ester group of oxidized wires. This was

Chemistry and Materials Research
ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online)
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reinforced by the change in the intensity of the group C=O (1725 cm^{-1}) on a short cable that is lower than the normal cable. Added to the spectra 1278 cm^{-1} (C-O), the intensity is lower than the normal cable. That is, heating electric current in the cable trigger oxidation with the functional groups of ester compound that is inside the cable. The amount of oxidation of the ester group will lead to many forms of oxygen radicals that trigger oxidation process so that the cable fire. While the FT-IR spectral data of the wires burned on the outside (Figure 3.6)

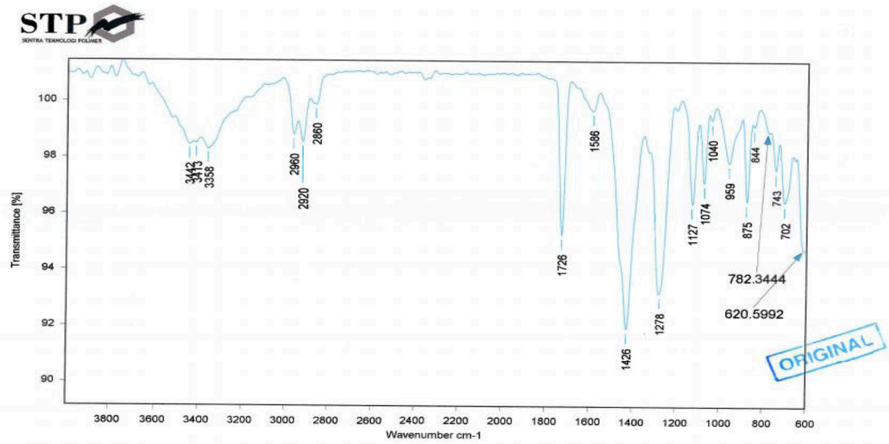

Figure 3.6. FT-IR spectra cord burned from the outside

Where in the wavelength spectra at 3442-3366 cm^{-1} from the cable burned from the outside is widened and a lower intensity than the normal cable. It shows that the functional groups of the cable insulation strengthen their contribution to oxidize carbonyl oxygen of ester functional groups which resulted in a fire. Images of FT-IR spectra of the wires burned on the outside can be seen in Figure 3.6. Combined FT-IR spectra Normal Cables, wires given current load 16A, 25A, 35A, burned from the outside wires short and cable which can be seen in Figure 3.7 below.

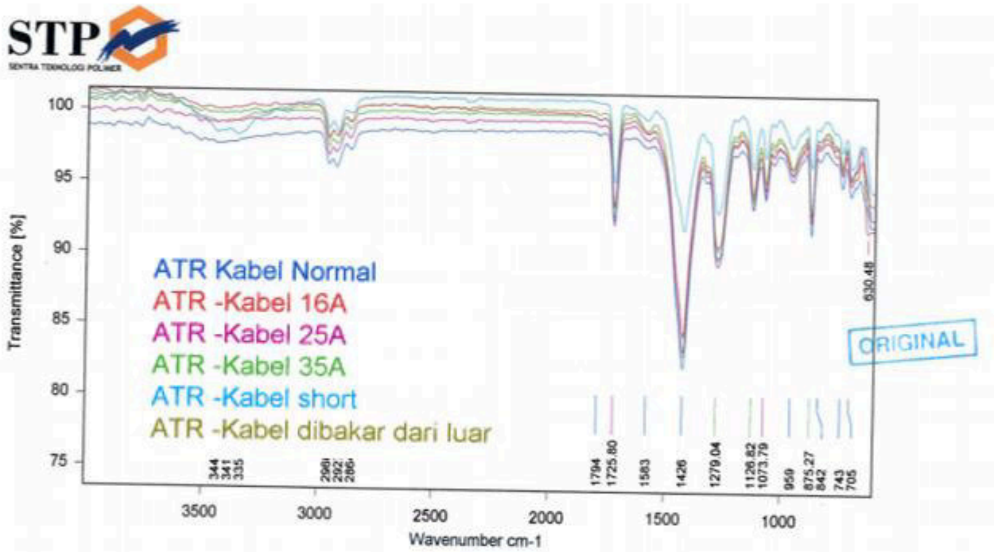

Figure 3.7. Combined FT-IR spectra with Normal Cables, wires 16A, 25A cables, wires 35A, Short cables, wires burned from the outside.

From the combined data of FT-IR can be concluded that treatment with the administration of the current load variation, does not significantly affect the change of constituent functional groups cable isolation. But in the process of short circuits and combustion from the outside give different spectra compared to the normal cable isolation. It is possible the supply of oxygen produced as a result of short circuits and combustion from the outside. The oxygen reacts with the carbonyl group of the ester. This was evidenced by the wide peak at 3442-3358 cm^{-1}. This means that the presence of oxygen allows the carbonyl group of the oxidized lead to a radical on he oxygen and carbon from the functional group. Radicals of oxygen and carbon into fuel for burning.

Chemistry and Materials Research
ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online)
Vol.8 No.12, 2016

3.4. Results Analysis with SEM EDS

Data from sample identification using an instrument cable isolation SEM EDS can be seen in Table 4.4.

Table 4.4. The element analysis results with SEM EDS Cable Samples

No	Sampel Name	The content of element (% Mass) *					
		C	O	Al	Cl	Ca	Cu
1	Cable Normal	49.14	18.60	1.33	20.99	5.53	4.41
2	Cable 16A	44.27	13.60	-	30.47	8.49	3.17
3	Cable 25A	53.37	21.98	1.95	15.65	3.80	3.26
4	Cable 35A	43.69	13.31	-	31.56	8.84	2.60
5	Cable Short	44.02	14.14	0.22**	21.06***	15.62	4.94
6	Cable burned from the outside\	42.75	13.61	-	31.62	9.03	2.99

* Semi-quantitative, the average yield on the three areas of measurement
** Found only in one area of the three areas observed
*** Found in two areas of the three areas observed

From Table 4.4. it can be concluded that the elements C and O in the sample tends to decrease. It is possible that the process of oxidation or heating lead to breaking of C = O groups so that the carbon and oxygen involved in the combustion process. While elements Cl tends to grow. It is possible the release of Cl element of the C-Cl bond yield Cl_2. Photos of SEM morphology of normal cable isolation is shown in Figure 3.8. Normal cable has a surface that looks flat, there is no buildup of pores and smooth and no visible disability or cracker. SEM results from normal cable is shown in Figure 3.8a.

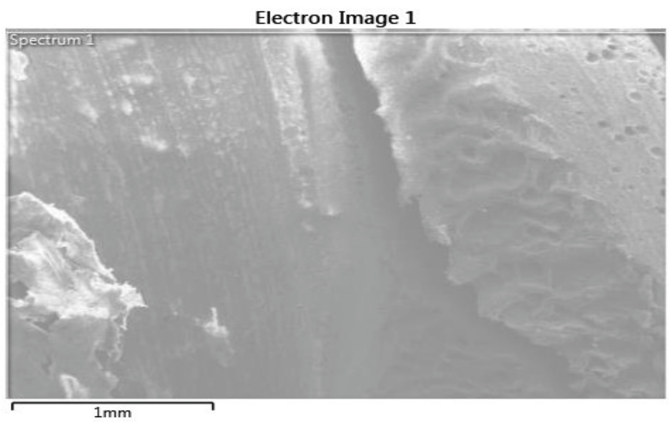

Figure 3.8a. SEM image of a normal cable

Normal cable is energized (weighted) respectively 16, 25 and 35A shows that the surface of the wires crimped and a defect (crack) on the surface, this is caused by their pyrolysis process due to the heat generated by electric current (Figure 3.8, 3.9, and 3.10). The greater the electrical current flow in the cable, the cable isolation surface is getting disability forming crack.

The contribution of electrons into the cable result in excessive heat on the cable, causing the degradation process in cable isolation. Forward degradation continues to produce pyrolysis (authoring) on the surface of the insulation. Thus SEM photograph proves that the size of the current (supply electrons) in the degradation process, the more speed the process of pyrolysis. This can be seen in isolation morphology Figure 3.8b (16A), 4.9 (25A), and 4:10 (35A).

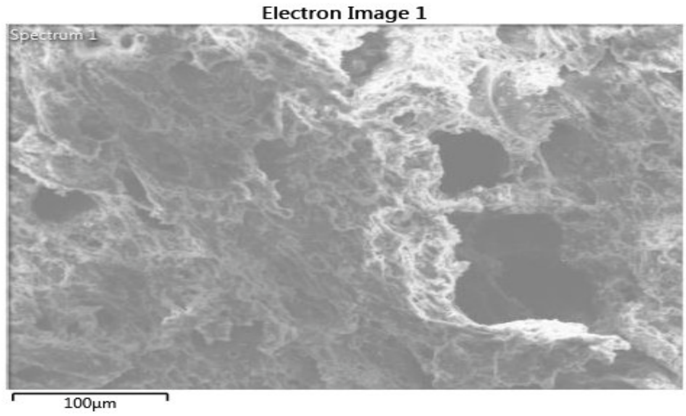

Figure 3.8b.Foto SEM image of a current-carrying cables 16A

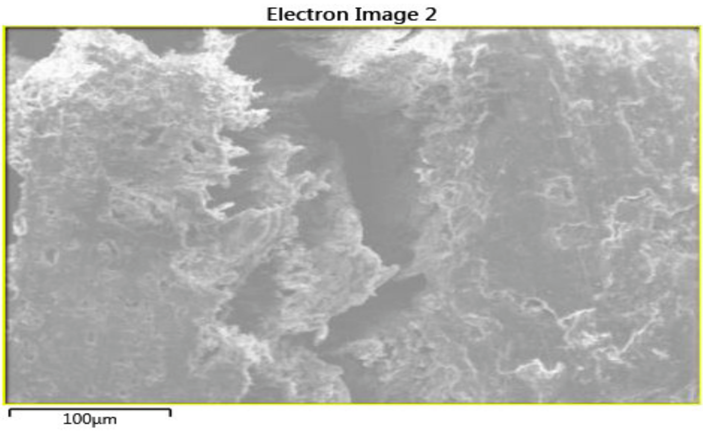

Figure 3.9. Foto SEM image of a current-carrying cables 25A

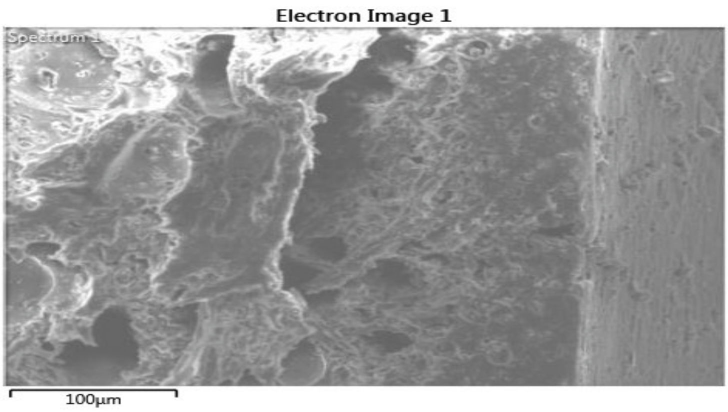

Figure 3.10. FotoSEM dariIsolasi current-carrying cables 35A

The cables have short show pore surface insulation very different significantly compared with normal insulation (Figure 3.11). In short cable isolation surface has occurred pyrolysis (authoring) evenly. It can be seen from defects in the insulation surface (surface wrinkled) and pore buildup. This data proves that the cable insulation is much more experienced short circuit defects.

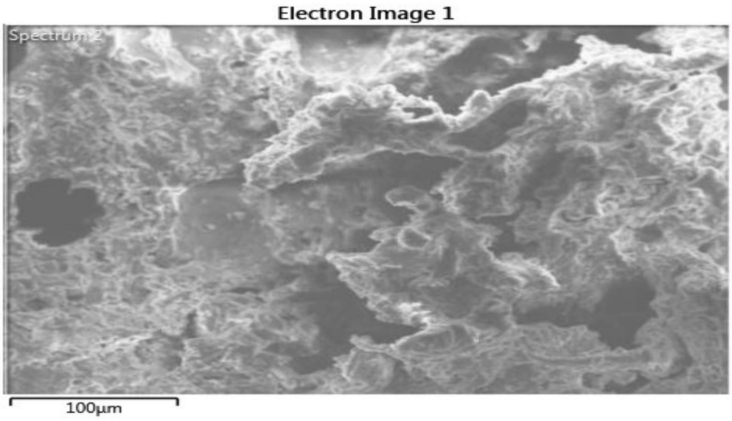

Figure 3.11. SEM photos of the Cable Short

The SEM images of the cable isolation is burned out is shown in Figure 3.12.

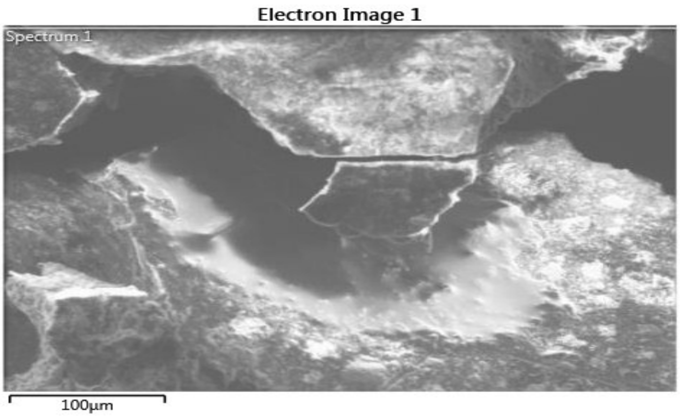

Figure 3.12.Foto SEM image of Cable Burned Outside

Burning effect of the cable isolation is clearly visible on the surface of the wires that occurrence of defects in various places. However flawed uneven, and terzonasi. This is because the burning of the outer insulation. In the process of fire, the carbon element of the cable insulation becomes a major fuel ongoing process of fire. So the establishment of authoring (pyrolysis) is not so significant.

Figure 3.8 The isolation of morphology (16A), 3.9 (25A), and 3.10 (35A), can be clearly seen that the degradation is due to the heat generated by the load current. The greater the load currents, temperatures are increasing. With the increase in the temperature of the degradation processes that result in pyrolysis will be even greater on the surface. It can be seen in Figure 3.8 morphology (16A), 3.9 (25A), 3.10 (35A) in which the defect rate is increasing.

3.5. Results of X-Ray Analysis Difraction (X-RD)

Diffractogram of a normal cable is shown in Figure 3.13. In general, normal cables are amorphous. Peaking at 2Θ (29,97^o) indicates the presence of carbon (C). While the peak in 2Θ (7,19^o) indicates the presence of oxygen. The oxygen comes from the possibility of carbonyl (C = O) (Figure 3.13).

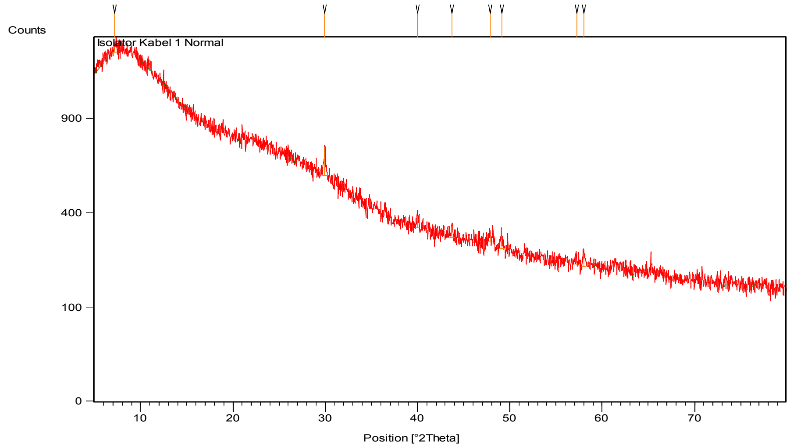

Figure 3.13. Diffractogram X-RD with Isolator Cable Normal

Diffractogram each from cable isolation with loading current treatment 16, 25 and 35A indicate each peak in 2Θ (29,91 (Figure 3.14), 29,74^o (Figure 3.15) and 29,72^o (Figure 3.16). In the third picture can be seen that with the increased load currents then tend to increasing carbon intensity (the amount of reduced carbon atoms) and oxygen diminishing intensity (the amount of oxygen atoms increases). However, there are significant differences in the diffractogram of the wires burned on the outside (Figure 3.16). Carbon peak is not visible and peak oxygen on 2Θ (7,19^o) larger and weaker as well as the intensity is lower than the normal cable. That is, the carbon element is reduced but the elements oxygen increases. This indicates that in the event of a fire in the cable, the amount of oxygen continues to grow while the carbon was burned.

At figure 3.17, we can see that diffractogram produced from the burnt wires, wherein the carbonyl group still exist however, carbon is no longer found. In theory the fire triangle that one of the elements is fuel, and it is carbon. For the process of fires that carbon as a fuel supplier. From the images below 3.17, it is seen that the carbon contained in the cable isolation is not appear again, very different from the figure sample cable 3:14, 3:15, 3:16. That is, if there is a fire caused by an electric current, the carbonyl group is reduced and carbon fixed, whereas if the electric cables are burnt (not causes kebakran) then group fixed carbon discharged while.

Figure difragtogram with the addition of current treatment at 16, 25 and 35 Ampere (A) along with the cable burned from the outside seen in the figure below.

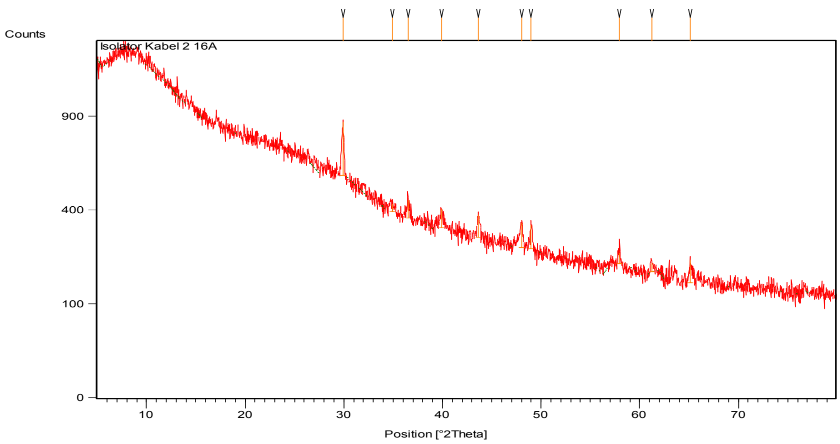

Figure 3.14. Cable Isolator 16A diffractogram

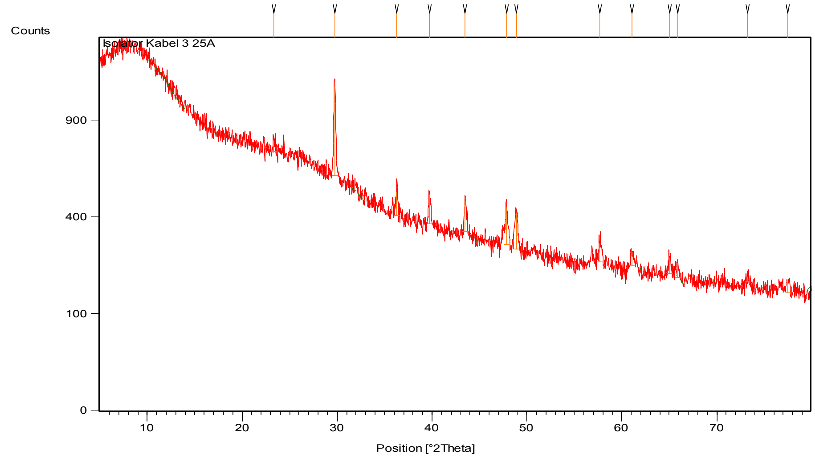

Figure 3.15. Cable Isolator 25A diffractogram

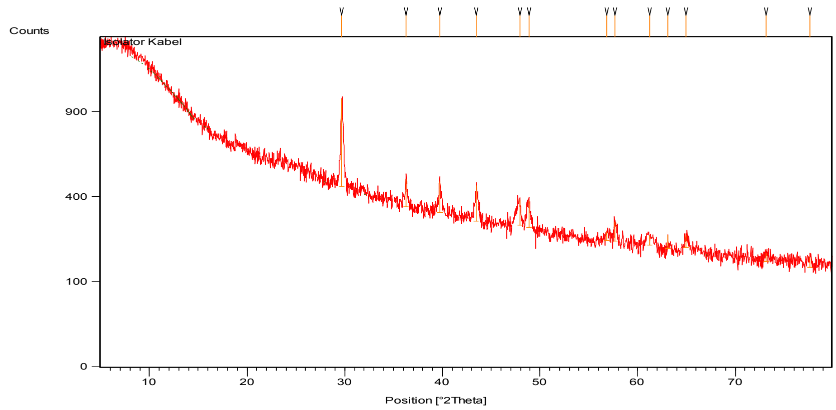

Figure 3.16. Spekrum X-RD with Cable Isolator 35A

Here diffractogram burnt cable insulator from the outside seen in the figure 3.17 below.

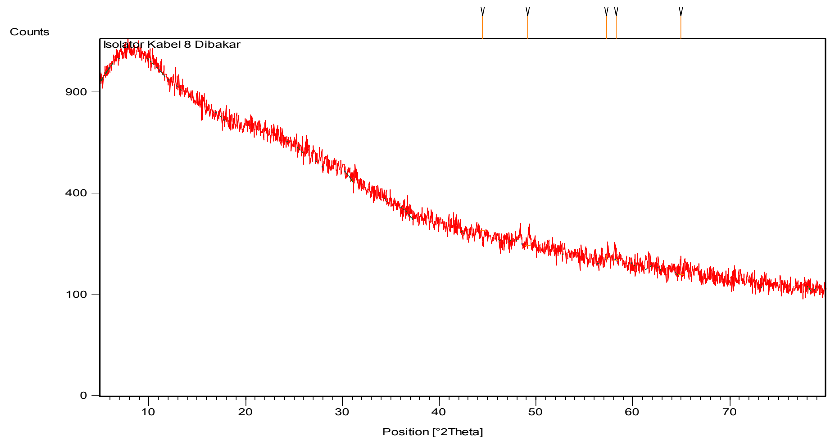

Figure 3.17. Cable Isolator Burned diffractogram of Affairs

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