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Effect of Immersion in Water and Composition of Fly Ash Filler on Performance of the Insulator Material of Silicone Rubber

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Abstract: The duration of immersion in water and the composition of the filler material affects the performance of silicon rubber insulation material. This has been proven in studies that have been conducted on high voltage engineering laboratory, University of Hasanuddin. The objective of this study was to determine the effect of immersion time in the silicon rubber filled with fly ash. Besides this, another goal is to get the effect of fly ash filler material composition of the value of the relative permittivity, hydrophobic contact angle value and the value of the percentage change in the mass of silicon rubber insulators. This study uses a filler of coal fly ash with a variation of the mass of the silicon rubber composition of 0, 10, 20 and 30% (with code FFA 0, 10, 20 and 30%). Materials testing and test developed and implemented with the ASTM standard. The test results showed that the soaking time and the variation of the mass of filler material composition will worsen silicon rubber insulator material is shown by the increase relative permittivity value, increasing the value of the percentage change in mass and decrease the value of the contact angle.

Key words: Silicone rubber, fly ash, filler, immersion, insulator material

INTRODUCTION

Isolation is the nature of the materials that can be separating two or more adjacent conductors so that no leakage currents or in the case of high voltage gradient, no occur flashover. So insulator is a material that is used to isolate parts of the voltage. Isolator used on any electrical equipment, especially high-voltage equipment, is a major cost components needed to make the equipment. The use of insulation must be economical but does not reduce ability it or need to find an alternative to the new insulating materials and the price is low and sufficiently available in the market.

Insulators in electric power systems play an important role as a separation device between portions voltage with no voltage as well as retaining and sustaining the wire channel. In general, insulators used in electrical systems in Indonesia ranging from medium voltage, high voltage and extra-high is made of ceramic and glass insulators.

But lately, there is a change and the development of insulating materials is very fast as the outside post insulators for high voltage equipment. The emergence of polymeric materials in insulation materials high voltage has replaced material traditional insulation made of ceramic and glass that used is increasingly unprofitable due to the mass density ceramic and glass are large, fragile and losisnya getting bigger, causing increasingly high cost of construction and maintenance of electric power network.

Polymer insulator has advantages in dielectric properties, volume resistivity, thermal properties, mechanical strength and light weight (Gencoglu, 2007; Jung and Kim, 2009; Fernando and Gubanski, 2010; Lau and Piah, 2011). In addition to the polymer insulator has a water-repellent, even able to recover and move to the hydrophobic nature of the layer of pollution causing pollution join hydrophobic coating. Hydrophobic properties and the ability to transfer it to a layer of pollution is very useful for outdoor insulators for electric plug in moist, wet or rain will not prevents the formation of continuous water layer so that the conductivity of the surface of the insulator remains low (Manjang *et al*., 2015).

One of the polymer material used as an insulator material is silicon rubber. Silicone rubber is the insulating material which is resistant to high temperatures, crosslinking is obtained through the process of vulcanizing. One type of silicone rubber that has been popular in the use of high voltage insulators on outdoor installation is Room Temperature Vulcanized (RTV) silicone rubber. Usually used to coat the surface of the

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ceramic insulator or in the construction of an isolator is typically used to make the fins of the insulator core made of ceramic. RTV silicone rubber is composed of Polydimethylesiloxane (PDMS) and fillers such as silica or aluminatyhydrate. PDMS layer, fillers, catalysts and materials is intended to improve bonding to the surface of the polymer insulator.

Despite the various advantages of silicon rubber insulators but the material is a synthetic material that is generally susceptible to climate, pollution and exposure to high electric field. The influence of inertia and high rainfall could lead to erosion of the surface of the polymer insulator including silicon rubber. Partial pressure difference between the materials and environmental conditions allows the absorption of water. The amount of water is absorbed and the speed of the process of absorption depends on the outside air humidity and ambient temperature. This phenomenon is called polarization effects macroscopic interface that will worsen the dielectric properties of the insulator (Karner and Ieda, 1991). Besides, it also caused a decrease in surface properties which can be seen by the disappearance of hydrophobicity, the occurrence of cracks and erosion increasingly intense insulator surface followed by an increase in the surface leakage current which can shorten the life of the insulator.

The results suggest that filler were added to the silicone rubber material with a specific composition can alter the properties of silicon rubber. So, many researchers who conducted the optimization of material that can be mixed with silicone rubber, especially in terms of filler material that is concentrated in Silica (SiO_2) (Stevenson *et al.*, 2001), Alumina (Al_2O_3) (Zha *et al.*, 2014), titanium dioxide (TiO_2) (Madidi *et al.*, 2013) and Magnesium oxide (MgO) (Jeong *et al.*, 2010).

One source of filler material is coal fly ash that contains chemical elements, among others, Silica (SiO_2), Alumina (Al_2O_3), Ferrous Oxide (Fe_2O_3) and Calcium Oxide (CaO), also contains elements of other enhancements that Magnesium Oxide (MgO), Titanium Oxide (TiO_2), Alkaline (Na_2O and K_2O), Sulfur trioxide (SO_3), Phosphorus Oxide (P_2O_5) and carbon. So, that in this study, coal fly ash is used as a filler in silicone rubber polymers. With the hope to look at the feasibility of coal fly ash as filler in silicone rubber.

In this research, there are some parameters which is used in the observation of the characteristics of polymer insulator that determine the value of permittivity relative, the value of the contact angle of hydrophobic and the percentage of water absorption in insulating materials by providing treatment concentration filler coal fly ash different and immersed in a container for 30 day. Thus obtained difference value relative permittivity, hydrophobic contact angle value and the value of the percentage of water absorption in polymer insulator before and after immersion in progress.

MATERIALS AND METHODS

Research diagram: This research study follows the model diagram shown in Fig. 1 (experimental procedure flowchart). The material used in this study is a kind of silicone rubber RTV 683 (Jaya and Berahim, 2012) and coal fly ash obtained from PT Semen Tonasa, South Sulawesi. Fly ash has been examined the value of its chemical content by using XRF (X-ray fluorescence), the result are SiO_2 = 40.16%; Al_2O_3 = 19.48%; CaO = 8.35%; Na_2O = 2.4%; MgO = 3.8%; P_2O_5 = 0.15%; SO_3 = 1.33%; K_2O = 1.75%; TiO_2 = 1.3%; Cr_2O_3 = 0.05%; MnO = 0.29%; Fe_2O_3 = 20.22%; CoO = 0.06%; SrO = 0.12%; ZrO_2 = 0.06%;

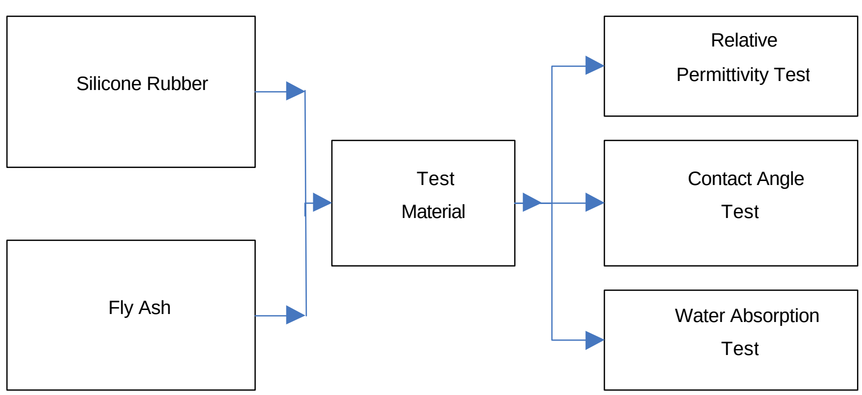

Fig. 1: Experimental procedure flowchart

BaO = 0.19%; Pr_6O_{11} = 0.05%; Nd_2O_3 = 0.08% (Kitta *et al*., 2016). Chemical compounds most widely percentage are SiO_2 and Al_2O_3.

Making material test: In this study measures the manufacture of test specimens was conducted by vulcanization Room Temperature (RTV) which prepare silicon rubber as much as 40 and add fly ash appropriate percentage desired, mixing fly ash and silicon rubber into one by using a mixer, put the mixture in a vacuum until the conditions are not void, adding a catalyst to the mixture of fly ash and silicon rubber. Put all the mixture into the mold. Wait until it dries. Once dry fill material into the oven with a temperature of 80°C until the mass of the test material of saturated.

Test material (a mixture of silicon rubber and fly ash) is made with four compositions (FFA0% = non filler fly ash; FFA10% = 10% filler fly ash; FFA20% = 20% fly ash filler; and FFA30% = 30% fly ash filler). The percentage of filler based on the amount of silicone rubber mass multiplied by the percentage of filler desired.

Capacitance measurement: Capacitance measurement test material aimed to know the dielectric constant of value relative permittivity of a composite silicon rubber. Measures the relative permittivity measurements begins with a measurement module in the form of two metal plates are mounted vertically, connecting two metal plates with a capacitance meter, put the test material between two metal plates and then will appear on the capacitance value of capacitance meter digital screen. The equation for calculating the relative permittivity by Manjang *et al.* (2015):

$$\varepsilon r = \frac{Cl}{\varepsilon_0 A} \quad (1)$$

Where:

C = Capacity capacitor (farad)
ε_r = Relative permittivity
ε_0 = Air permittivity (8.85×10^{-12} F m^{-1})
l = The distance separating the two plates (meters)
A = Cross-sectional area (m^2)

Hydrophobic contact angle measurement: This contact angle measurements using the drop analysis of software Image j. Taking pictures using Sony Xperia C camera to photograph the contact angle on the surface of the test material. The contact angle measurements intended to determine the surface properties of test materials, hydrophobic or hydrophilic. Hydrophobic contact angle reflects the water-resistant properties of test materials, the greater the hydrophobic contact angle, the better the properties of the material to be able to hold the water from getting into the insulating material. For the procedure itself that put the test material on module and then turn on camera. The test material is positioned such that the camera screen is not visible surface of the test materials back (front and back and the surface of the test material overlaps) and the tears in 20 mL on the surface of the test material, turn on the lights as an additional light source so that droplets photographed looks obviously, take pictures of test material with a camera. The camera is equipped micro zoom is set to get an enlarged picture of water droplets to be more focused. Shooting time is done after 2 min of water droplets on the surface of the test material. Furthermore, the test results can be directly inserted into a computer to analyzed using Image J software. Then the contact angle is obtained by the formula (Manjang *et al*., 2015):

$$\text{Contact angle} = \frac{\text{Contact angle left} + \text{Contact angle right}}{2} \quad (2)$$

Measurement of the percentage of water absorption: One of the conditions of polymer insulator material must be resistant to water damage. At different pressure conditions between the material and the surrounding environment, the water that comes out of moisture can penetrate the polymer material. The amount of water is absorbed and the speed of absorption depends on the polymer itself and the circumstances surrounding atmosphere polymer is placed. To simulate the situation we tested the absorption of water by immersion material insulator in the water temperature of 50°C According to the Standard (ASTM D570), the test materials were soaked for 24 h removed from the heater and allowed to stand for 1 min and then the surface is dried with a tissue and then weighed. Weighing and immersion is done 1 day during 30 days. To measure the absorption values of water in each test sample is then used formula based Manjang et al. (2015):

$$M(t) = \frac{m - m_0}{m_0} \times 100\% \quad (3)$$

In cases:

M (t) = Percentage absorption
m = Mass after immersion
m_0 = Mass before immersion

Linear regression: To get the effect of the length of time of immersion and the composition of the fly ash filler material on silicon rubber is used in the form of mathematical analysis of linear regression method.

RESULTS AND DISCUSSION

The measurement results: In Table 1 are shown the results of measurements of test silicon rubber filled with fly ash in a diverse composition are soaked for 30 days.

Measurement of relative permittivity: Dielectric constant or relative permittivity is a constant flux electrostatic symbolizes the meeting in a material when given electric potential. This constant is the ratio of the electric energy stored in the material if given a potential, relative to a vacuum. By using Eq. 1 can be obtained relative permittivity value at each test material for a certain time in Table 1.

In Table 1 shows the values of the measurement results relative permittivity of the test material which on days 0, FFA0% have value relative permittivity of 1.7, FFA10% by 1.87%, FFA20% by 2.05 and FFA30% by 2.05. The relationship between the value of permittivity relative to the concentration of filler material is linear as shown in Table 2. It is shown by the test material which has the lowest value relative permittivity is FFA0% and test material with the highest value relative permittivity is FFA30%. The concentration of the testers affect the increased bandwidth interfaces and increased polarization of the interface with the polymer filler materials resulting material becomes more easily absorb water, besides the addition of filler concentration also resulted in the emergence of cracks and small holes in the process of making the test material. These phenomena will provide opportunities water molecules accumulates more in.

During the 30 days of immersion obtained the increase of relative permittivity value as a result of the effect of a much larger percentage of water absorption in the material so that each test material reaches the maximum value of the relative permittivity. On day 30, the values of the test material is as follows: FFA0% has a relative permittivity value by 4.89, FFA10% by 6.3, FFA20% by 6.31 and FFA30% by 6.65. Those values reflect the relationship between the composition of the fly ash filler in silicon rubber with a relative permittivity value of the test substances on the 30th day is linear as shown in Table 2.

In Table 3, the relationship between the soaking time with a relative permittivity value of a composite silicon rubber are shown. Where the relationship to the test material FFA0, 10, 20 and 30% are linear which means that the longer the immersion time, the values of relative permittivity getting bigger.

The observation that shows the increase in value relative permittivity of silicon rubber material when filled fly ash, it can be hypothesized that there has been no perfect polymerization of silicone rubber when reacted with a hardener. The presence of filler fly ash has made the test material becomes more rigid that there has been a cementation process in the test material. Cementation process is due to the element of water reacting with fly ash filler. The water is then reacted with fly ash through the cementation process. The observations also found that during the mixing of filler, silicone rubber and hardener, there has been hot. This occurs because there is a hot cementation process between water and fly ash. Thus, as a result of the presence of fly ash filler, silicon rubber polymerization becomes imperfect and this makes

Table 1: Results of testing the test materials

		Days												
Characteristic	Code of Test Material	0	1	2	3	6	9	12	15	18	21	24	27	30
Relative Permittivity														
	FFA0%	1.7	2.39	2.46	2.64	3.1	3.42	3.65	4.05	4.27	4.48	4.61	4.75	4.89
	FFA10%	1.87	3.21	3.5	3.55	3.91	4.45	4.26	5.13	5.34	5.51	5.85	6.08	6.3
	FFA20%	2.05	3.52	3.8	3.87	4.33	4.76	4.41	5.29	5.14	5.45	5.9	6.08	6.31
	FFA30%	2.05	3.45	3.79	3.92	4.33	4.82	5.03	5.47	5.69	5.86	6.26	6.49	6.65
Hydrophobic contact angle (°)	FFA0%	103.5	90	74.8	67.3	69.2	74.8	79.7	78.6	86.5	77.3	86.7	81.9	77.2
	FFA10%	102.3	95.2	92.9	87.9	64.3	68	87.4	84.6	79.5	87.5	84.5	77.6	83
	FFA20%	99.7	90.2	86.1	87.2	64.4	73.5	80.9	83.9	79.6	84.8	78.1	77.4	79.5
	FFA30%	98.5	91	85.6	85.7	64.5	66.6	80.3	78.8	84	82.8	78.3	83.2	79.8
Percentage of water absorption (%)	FFA0%	0	0.73	0.91	0.99	0.98	1.06	0.94	1.02	1.14	1.1	1.11	1.02	1.06
	FFA10%	0	0.31	0.37	0.5	0.69	0.8	0.95	0.94	1.04	1.15	1.25	1.35	1.36
	FFA20%	0	0.36	0.37	0.51	0.67	0.8	0.96	0.93	1.09	1.21	1.32	1.43	1.43
	FFA30%	0	0.27	0.36	0.42	0.65	0.78	0.92	0.94	1.09	1.25	1.33	1.43	1.49

Table 2: Relationship the characteristics of silicon rubber with composition of fly ash

	Days 0			Days 30		
Characteristics	Equation	R^2	Result	Equation	R^2	Result
Relative Permittivity	y = 0.123x+1.61	0.893	linear	y = 0.529x+4.715	0.762	linear
Hydrophobic contact angle	y = -1.76x+105.4	0.975	linear	y = 0.43x+78.8	0.054	No linear
Percentage of water absorption	y = 0	-	linear	y = 0.136x+0.995	0.846	linear

x is composition of fly ash

Table 3: Relationship the characteristics of silicon rubber with time of immersion

Characteristic	Code of test material	Effect of immersion for 30 days		
		Equation	R^2	Result
Relative permittivity	FFA0%	y = 0.090x + 2.375	0.941	Linear
	FFA10%	y = 0.112x + 3.058	0.924	Linear
	FFA20%	y = 0.114x + 3.409	0.917	Linear
	FFA30	y = 0.096x + 3.449	0.872	Linear
Hydrophobic contact angle	FFA0%	y = 0.226x + 76.05	0.059	Nolinear
	FFA10%	y = -0.129x + 82.08	0.019	Nolinear
	FFA20%	y = 0.059x + 76.77	0.004	Nolinear
	FFA30	y = -0.058x + 79.63	0.005	Nolinear
Percentage of water absorption	FFA0%	y = 0.010x + 0.803	0.235	Nolinear
	FFA10%	y = 0.035x + 0.369	0.908	Linear
	FFA20%	y = 0.038x + 0.356	0.931	Linear
	FFA30	y = 0.042x + 0.292	0.952	Linear

x is days

the relative permittivity of the silicon rubber when the fly ash filler in these compounds is high relative permittivity of the pure silicon rubber (FFA0%). It can be concluded that the effects of fly ash filler in silicon rubber cause a rise in the relative permittivity insulating material.

Hydrophobic contact angle measurement: In accordance with the procedure outlined in hydrophobic contact angle measurement methods, the obtained results as Table 1.

It can be seen that each sample before immersion (day 0) has a contact angle ranges from 103.5°-98.5°, which FFA0% amounting to 103.5°, FFA10% by 102.3°, FFA20 by 99.7° and FFA30% by 98.5°. The test materials value are >90° so classified are water repellent (Hydrophobic) (Adamson, 1982). The addition of filler result in a decrease in the contact angle, the greatest value is FFA0% and the smallest is FFA30%. But, the condition of decline is still classified as >90° so that they are hydrophobic. The relationship between the composition of the fly ash with a hydrophobic contact angle values is linear as shown in Table 2 that the value of R square of 0.975.

However, when seen in Table 2 where results of equations derived from linear regression to the relationship between the composition of the fly ash with value relative permittivity of silicon rubber on the 30th day is not linear. It is based on the value of R^2 of 0.054.

Fillers are added to the silicon rubber is to increase resistance to cracking and erosion caused by atmospheric ambient pressure and the possibility of high thermal loading when applied as a post insulator outside. For surface itself after being added to the filler did not experience a significant difference with the other, so that the value of the contact angle is still relatively hydrophobic.

Based on previous research by simply adding silica sand as filler resulted in a decrease in contact angle due to the nature of SiO_2 which absorbs water. Silicon rubber which is known to have a methyl group is free to rotate, where the methyl group that has the water-repellent properties. In the fly ash are SiO_2 and Al_2O_3 values are assumed to hinder the movement of a methyl group to the surface of the test material FFA 10, 20 and 30% so that the contact angle decreased. Can be seen after the diffusion process, the contact angle of each test substances decreased, reaching the lowest value of 77.2° on FFA0% which is where the conditions are classified in wet conditions most of which time the concentration of water is absorbed more and more the value of the contact angle will decrease, but there are conditions where an increase in the contact angle during immersion due to the hydrophobic nature of the sample recovery.

FFA 10% experienced a faster recovery capability than the other but the contact angle value is lower than the initial contact angle. From the test data in Table 1 shows a composite silicon rubber (filler fly ash) used in this study are partially wetted until day 30. The contact angle value ranged from 79.5°-83.2° which can be considered to be partially wetted.

In Table 3, the relationship between the soaking time with a hydrophobic contact angle value of a composite silicon rubber (silicon rubber mixed with fly ash) are shown. Where the relationship to the test materials FFA0, FFA10, 20 and 30% are not linear where the value of R-square (R^2) for FFA0% by 0.059, FFA10% by 0.019, FFA20% by 0.004 and FFA30% by 0.005.

Water absorption of composite silicon rubber: Water absorption rate and its relation to changes in the dielectric properties is done by testing based on ASTM standard D570 with methods as well as on the research methodology section measuring the percent of water absorption within a certain time period is constant. By using Eq. 3 can be obtained a large percentage of water absorption in each sample for 30 days of immersion which can be seen in Table 1.

In Table 1, we can see how the water absorption characteristics at each test material with a variety of filler different as indicated by the high percentage of absorption of water each day for 30 days of immersion, the variation of filler in each sample is encoded namely: FFA0, 10, 20 and 30%.

It can be seen that each sample before immersion (day 0) has the value of the percentage of water absorption was 0% because there is no soaking and for the first visible value percentage of water absorption ranges from 0.73-0.27 % which FFA 0% by 0.73 %, FFA10 % by 0.31 %, FFA 20% by 12.36 % and FFA 30% by 12.27%. At the beginning of immersion is seen the addition of filler result in a decrease in the percentage of water absorption of the test material, where the greatest value is FFA0% and the smallest is FFA30%. However, when seen in Table 1 where on the 30th day the value of the percentage of water absorption of test material change patterns, i.e., the value maximum is FFA30% and the smallest value is FFA0%. The percentage of water absorption of the test material on the 30th day is linear. It is based on the value of R^2 of 0.846 as shown in Table 2.

Table 1 shows the percentage of water absorption in the test material FFA0%. The relationship between the percentage of water absorption is linear wherein when the longer soaking the amount of water permeating into the test material is increasing but when it reaches the point of saturation, the rate of absorption of water is becoming a constant. This is seen in FFA0% at day 15 and 30 in which the value of the percentage of water absorption was 1.0 and 1.1% with a value of not >1 % for 15 days (Manjang *et al*., 2015). Compared with other samples, FFA0% has a water absorption percentage of at least 30 days soaking with water absorption percentage of 1.06% within 30 days of immersion. For the test materials filler fly ash, FFA10% is a material that is at least absorb water that is equal to 1.36% during 30 days of immersion and the longest saturation is FFA30% with the percentage of water absorption 1.49% which with increasing filler, the ability of water absorption the greater it is. Not yet achieved the diffusion rate constant (steady-state) in samples of fly ash filler because there are impurities. Where in the fly ash contained as much as 40.16% SiO_2 and Al_2O_3 by 19.48%. Based on several studies in which the silica sand has water absorbing properties. Can also on research (Manjang *et al*., 2015) that the filler was found impurity Na_2O, K_2O and Fe_2O_3 which is soluble in water. And the fly ash are also content as much as 2.4% Na_2O, K_2O as much as 1.75% and as much as 20.22% Fe_2O_3. Where it can be seen that the fly ash filler material is also an important role in the calculation of the percentage of water absorption by the polymer insulator silicone rubber.

In Table 3, the relationship between long soaking with percentage of water absorption composite silicon rubber (silicon rubber mixed with fly ash) are shown. Where the relationship to the test material FFA0% is not linear with the R^2 value of 0.235. And for FFA10%, FFA20 % and FFA 30 % is linear which means that the longer the immersion time, the percentage of water absorption relative value to increase.

CONCLUSION

During the 30 days immersion test material composite silicon rubber (silicon rubber mixed with fly ash) is obtained the results of the research is influence of long time the effect of immersion in the water and the influence of fly ash filler composition. Where is found about soaking time and variation of the composition of filler material mass will worsen silicon rubber insulator material that is shown by the increase relative permittivity value, decrease the value of the contact angle of hydrophobic and increasing the value of the percentage of water absorption. Long immersion causes the absorption of water on a composite of silicon rubber increases thereby increasing linearly relative permittivity value, where value of composite of silicon rubber increases. The highest value of relative permittivity achieved by the composition of the fly ash 30% (FFA30%) on immersion for 30 days equal to 6.65. While the value of the lowest permittivity achieved by the test material with 0% the mass of fly ash (FFA0%) is equal to 4.89. The addition of the coal fly ash resulting in the contact angle values decreased but the decrease was not significant and was still in a condition in which the hydrophobic contact angle values are formed is still >90°. Water absorption in composite silicon rubber cause hydrophobic contact angle value has decreased but in a certain time values obtained contact angle increased but not in excess of the point before the immersion, this is due to the hydrophobic nature of the recovery capabilities of silicone rubber. Contact angle of maximum achieved by the test material with a composition of 10% fly ash (FFA10%) in immersion for 30 days at 83°. While the value of the contact angle achieved by the lowest test material with 0% fly ash (FFA0%) is equal to 77.2°. The test results show that the water absorption on the soaking and the filler composition variation increases the mass of the test material (composite of silicon rubber). The highest percentage of water absorption is achieved by the test material with fly ash 30% (FFA30%) in immersion for 30 days in the amount of 1.49%. While the lowest percentage achieved by the test material with 0% fly ash (FFA0%) is equal to 1.06%.

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