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Thermal and Mechanical Characterizations of Improved Polyimide Insulation for High voltage Applications

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Abstracts - Insulation failures linked to poor thermal stability and less tensile strength have drawn in power transformers, power cables, aerospace industries and electrical and electronic circuits. The concerns have developed regarding the thermal stability, mechanical breakdown strength and the safety of polyimide insulations(PI) in electrical high voltage engineering. Several polyimide composites are selected for evaluation in the laboratory tests. The selected composites of polyimides are made in the laboratory through a roll ball milling process. Thermos-gravimetric analysis(TGA) and Tensile strength tests is performed by using a universal testing machine (UTM) in accordance with American society for testing and materials (ASTM D412). In this study these tests are performed in the high voltage laboratory at NUST University in Islamabad.

Keywords – Polyimide Insulations, Thermal stability test, Tensile Strength, TGA, UTM.

1. Introductions:

Various types of insulating material are used for insulation propose in electrical power system. Every insulator has their own properties of insulation in electrical power system but due to the outstanding thermal, mechanical and electrical behavior of polyimide insulation, it is one of the best insulator used for high voltage electrical and electronic applications. [1] [2] [3] [4].

Polyimide composite are used in laboratory for the testing purpose to check its thermal electrical and mechanical behaviors for different temperature ranges up 480^{o}C for high voltages. Due to Light weight (136 sq ft/lb [28 m2/kg] for 1 mil) over a wide-ranging of temperature of polyimide films gives a good thermal,

electrical, chemical and physical behavior for high voltage electrical insulation. The phenomena for manufacturing of cable insulation for different voltage ranges and also for high voltage direct current (HVDC) the polyimide are being used. The evaluation of polyimides is done in laboratory for the usage of high voltage applications. Polymers has high breakdown toughness at high temperature under electrical strain. This study is about the electric field strength of polyimide and also discuss the breakdown field strength. At room temperature the nanocomposite polyimides are conventionally utilize as insulating material with the dielectric field strength at range of of 10^6–10^9V/m. [5].

The high voltage power transfer is consisting of metal hosing, electrical conductive coils which is covered by a polyimide insulating material and lubricants (transformer oil). Transformer hosing is full of oil and the coils are immersed in this tank. The composite of stabilizing compounds of insulating material which gives chemical and thermal stability. [6].Nanocomposite material having positive effect that with stand high temperature and provides resistance to high voltage electrical environment. [7]

The silver nano-composite polyimides are also use for the packaging purpose. The nanoparticle comes in the study to improve the polyimide structure like: Ag, Au, TiO2, and ZnO and properties such as thermal, mechanical and electrical. [8]

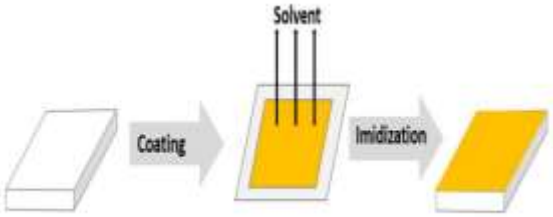

Figure: 1.1 Coating on the solid surface.

In electromagnetic coil industries the polyimide is extensively used for insulation due to high temperature endurance and high mechanical properties. The information comes in the knowledge that the number of stresses applied to polyimide electromagnetic coil's insulation, with stand these stresses and monitoring polyimide insulation strength. PI operating temperature is 240 °C and expected operating lifetime is 20,000 hr (2.3years) before facing the electrical breakdown according to the ASTM D2307. [9] [10]

1.1 Experimental test with high temperatures and weight loss:

The TGA and DSC were performed in nitrogen and oxygen environment at the flow rate of 20 mL·min^{-1}. With the heating rate of 20 K·min−1 and temperature of polyimide is from 450◦C to 750 ◦C to observe the thermal stability. The total weight loss of polyimide is 45.2% at 627 ◦C. SiO2 and Mg(OH)2 were selected as composite polyimides. [11].

1.2 Samples preparation Tensile Strength:

PI films is preparing by using the spin coating of poly amic acid (PAA). Glass and Si/SiO2 is used as substrate material then the improved polyimide insulation is prepared. The prepared PI films presented the high toughness and tensile strength of up to 194.71 MPa, of elongation up to 130.13%, and glass transition temperature of 400 ◦C. [12].

1.3 Mechanical properties:

The strain hardening rate is decrease with the increase in temperature. But some cracks are available in the samples at 20 ℃ and these crakes are deep and wider at increasing the temperature from 250℃. [13]

2. Methodology:

The phenomenon of making polyimide insulation samples in the laboratory is being discussed. And there experimental testing procedure of TGA and tensile strength test using UTM according to ASTM D412 to find out the thermal stability and mechanical breakdown strength of each polyimide samples. All these test are performed in High voltage laboratory at NUST University Islamabad.

The Polyimide/Zinc oxide (PI/ZnO) thin films are processed in a solution using Tetrahydrofuran (THF) and formic acid (Sigma-Aldrich, USA) as the solvent due to its ability to dissolve polyamide effectively. Polyamide and Zinc Oxide micro fillers in powder form is mixed with the help of roll ball milling process. To ensure good dispersion of the powder mixture, the 15gm mixture of PI/ZnO to 50 ml formic acid is added in small quantities and stirred on a hotplate magnetic stirrer for approximately 3 hours at a speed of 850 rpm. After stirring, the solution is degassed and bubbles are removed from the solution using a sonicator at room temperature for 8-10 minutes. Glass Petri dishes are used as a substrate for casting the solution, and after drying on room temperature for a few minutes, the casted solution is then placed in an oven at 80º C for 45 minutes until the solvent is completely evaporated. Finally, the films are peeled off from the glass Petri dish after a cold-water bath. The diameter and thickness of the samples are measured with the help of Vernier caliper is found to be 80mm and 0.01mm respectively. The prepare samples is given bellow at different composition of PI/ZnO 0%,5%,10%,15% & 20% respectively.

Figure 2.1 Polyimides Samples

3. Experimental Procedure:

TGA is a process of thermal analysis of the specimen is used for the analysis of mass measured over the time as the temperature change. The physical phenomena of this measurement is provides the information, such as phase transition, absorption and desorption. The chemical facts are that the thermal decomposition and solid-gas reactions. (e.g., Oxidation & Reduction). The following are the general procedure for the testing and techniques of polyimide insulation.

3.1 Static thermos-Gravimentry or Isothermal:

In this technique weight of specimen is noted at constant temperature, as a function of time.

3.2 Quasistatic thermos-Gravimetry: In this method sample is heated to constant weight at each of series of increasing temperatures.

3.3 Dynamic thermogravimetry: In this procedure sample is heated in an atmosphere whose temperature is varying at linear rate. This technique is generally used [14].

4. Results and Discussions:

4.1 Thermal stability test result using TGA

In the thermos-gravimetric analysis the specimen of polyimide is heated in a given environment with the air flowing towards the specimen at a controlled rate. The changes in weight of polyimide insulation is recorded as a function of temperature. The temperature is linearly increased for an initial weight of the polyimide insulation (i-e 2mg is known) and the changes in weight of the polyimide is recorded as the function of temperature at different time interval. As a result, the graphs are generated according to the weight changes against the temperature which is called Thermos-Gravimetric curve or thermos Gram.

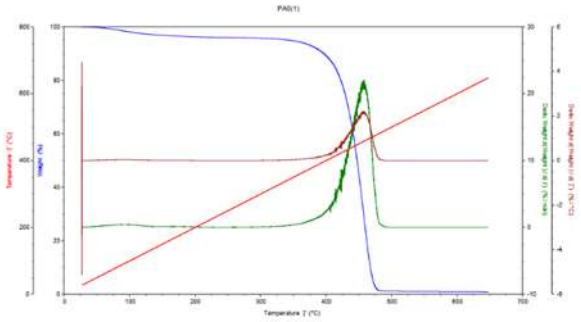

Figure 4.1 weight verses temperature of sample 1

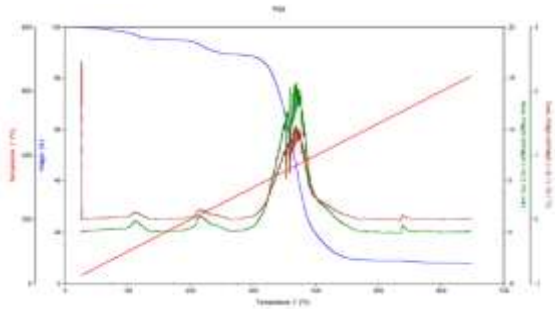

Figure 4.2 weight verses temp0erature of sample 2

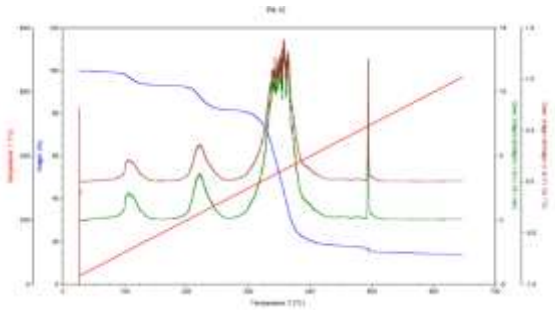

Figure 4.3 weight verses temperature of sample 3

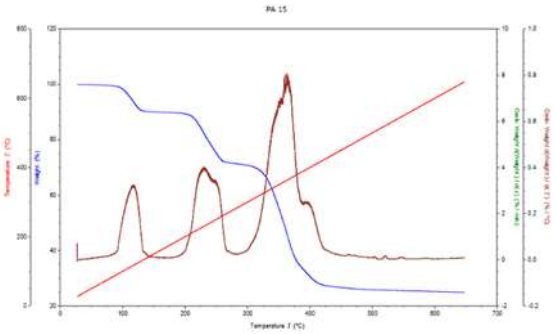

Figure 4.4 weight verses temperature of sample 4

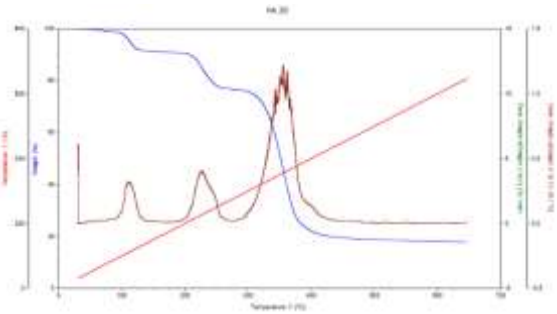

Figure 4.5 weight verses temperature of sample 5

The above given figure4.1,4.2,4.3, &4.5 display the results of the composite polyimide samples during TGA. These tests are performing at each samples individual at linearly increase temperature from 20°C to 650°C. During the tests of sample 1,2,3,4 &5, the weight loss occurred 48% at 450°C, 60% at 380°C, 55% at 350°C, 40% at 360°C and 58% at 360°C respectively. From those tests we conclude the result that, the sample 4 give best result compare to other at high temperature of 360°C. Because at 360°C the 40% weight loss occurred. So at this temperature the sample 4 is more stable at high temperature.

4.2 Mechanical breakdown/Tensile strength test results

The test is preformed according to ASTM D412 by using UTM. Due ASTM D412 the minimum average tensile strength for polyimide or rubber polyimide is 82.5 MPA [15].The dumbbell shape specimen is used for mechanical properties to be measured such as tensile strength of polyimides. The area of the sample is 25.80mm^2, where the length and width is 10mm and 2.58mm respectively. The below figure show the samples for tensile strength test.

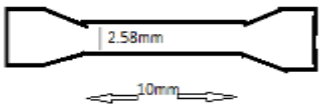

Figure. 4.6 Sample for tensile strength

The same specimen is used at different compositions of PI/ZnO, which is being discussed in chapter 3 for the tensile strength test. By using UTM to take each composite polyimide sample to perform the tensile strength tests according to ASTM D412.

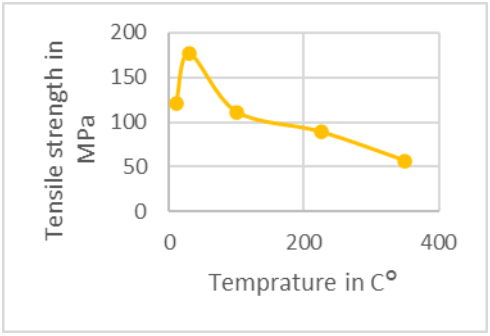

Figure 4.7 tensile strength vs temp of sample 1

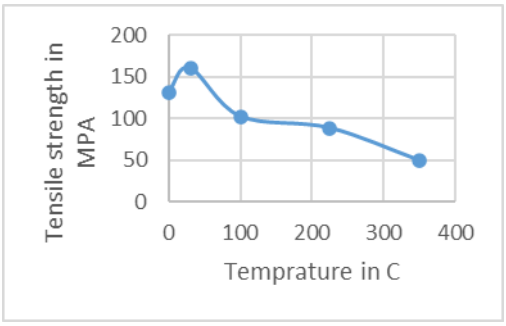

Figure 4.8 tensile strength vs temp of sample 2

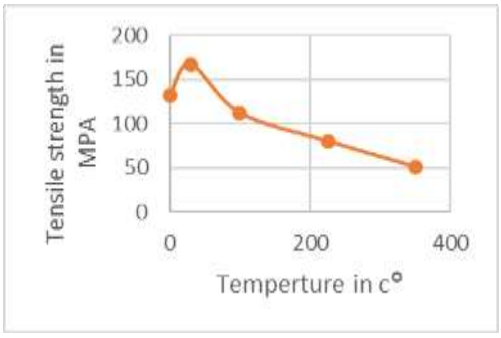

Figure 4.9 tensile strength vs temp of sample 3

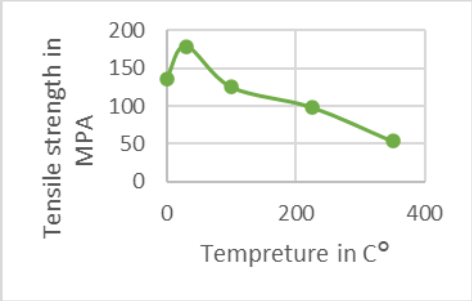

Figure 4.10 tensile strength vs temp of sample4

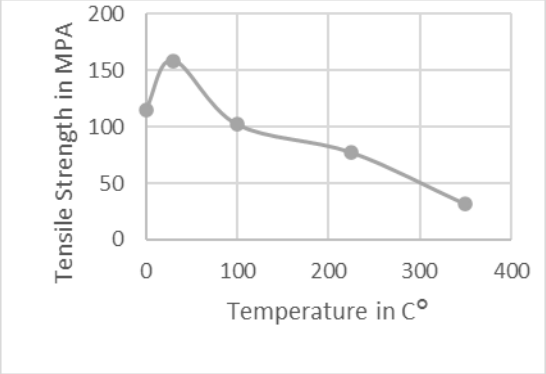

Figure 4.11 tensile strength vs temp of sample 5

The mechanical properties of polyimides are tested through UTM and according to ASTM D412. Taking different composition samples individually and perform the test during the different temperature ranges from 0°C to 400°C of each samples. The average tensile strength for sample 1,2,3,4 & 5 is 110.75 MPA, 106.37MPA, 109.11MPA, 118.1MPA and 96.68MPA respectively. But here the samples 4 give a better tensile strength for 360°C.

5. Conclusion and Future Recommendations:

For high voltages electrical equipment's, the electrical insulation thermal stability is very important for its service life during operation. The poor thermal stability and low tensile strength of any insulation make it unsuitable for high voltage applications. The thermal stability of improved polyimide insulation (PI/ZnO) is excellent. The 15% PI/ZnO micro-composite polyimide insulation is selected for high voltage application because of its high stability up to 360°c. The result for 15% PI/ZnO micro-composite average tensile strength is better from other compositions at for 350°c and weight loss 40% of its original weight. The future work is to search another composition polyimide to with stand more highest temperature and tensile strength.

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