

## Interface Discharge Behaviour at Polypropylene Nanocomposites and Silicone Rubber under AC Voltage

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**Abstract**—Polypropylene has a great electrical property and may be used as primary insulating material in electrical power cable. In cable accessory, the field distribution is often distorted since the very complicated physical structure, which makes interface discharge between PP and cable joint insulation easy to happen. Polymer based nanocomposites has recently received a lot of attentions, which can offer a better insulation property than the neat polymer. In order to improve the electrical property of the PP/SiR interface, nano-sized MgO filler has been adding into PP matrix to form the so-called PP/MgO nanocomposites. The interface discharge behavior between the nanocomposites and the SiR have been studied. Obtained results showed that with the increase in the nano-particle content from 0 wt% to 5 wt%, the interface breakdown strength firstly increases but then decreases. A proper content of 3 wt% nano-sized MgO adding can improve the interface breakdown strength by a fact of 3.5. It is suggested that the interface breakdown strength can be enhanced through the adding of nano-sized MgO.

**Keywords**- Polypropylene; Nanocomposites; Silicone Rubber; Interface Discharge

### I. INTRODUCTION

Cable accessory is an important part of a cable system, which is also the weakest point along a cable route. In recent years, power cables have been widely used thanks to its advantages of less land occupation, high reliability and low electromagnetic radiation. They have been an indispensable part of modern power system. It has been demonstrated in numerous articles that interface discharge along cable accessory tends to occur because of its strong distortion of electric field, which leads to the breakdown of interface and thereby inducing insulation failure to the cable system [1]. Consequently, with the purpose of operating the cable safely, it is of great necessity to investigate the interface discharge behavior within a cable joint or a cable terminal.

Over the years, a lot of contributions have been published to clarify the electrical insulation performance within the cable accessory, for instance, it was reported that with the increase of interfacial smoothness, the discharge voltage was increased [2]. It was also revealed that with the increase of the interface pressure, partial discharge could be strengthened [3]. Majid et al. proposed a theory on electric field distribution along the interface and the method of breakdown strength calculation, arguing that the interfacial

breakdown strength is governed by the discharge inception stress of the air-filled cavities [4].

Nowadays, with the development of PP insulated power cable, the insulation property at PP/SiR interface has drawn a lot of attentions [5, 6]. It has been generally accepted that the interface discharge is still a drawback for the cable joint. Polymer based nanocomposites has received a plenty of sights from researchers as the electrical property of polymer material could be improved by the adding of nano-sized inorganic particles. In this paper, PP/MgO nanocomposites have been prepared to test the effect of nano-filler adding on interface discharge performance at PP/MgO and SiR. Obtained results showed that the interface breakdown strength can be promoted if proper content of nano-filler is added into the neat PP. This information is helpful for the development of new material for cable application.

### II. EXPERIMENTAL SETUP

#### A. Sample Preparation and Electrode Arrangement

The PP/MgO nanocomposites was prepared by thermal press method. By adding 50 nm MgO particle into Isotactic PP (PPH-T03) (Sinopec Beihai company, China) with weight content of 1 wt%, 3 wt% and 5 wt%, the nanocomposites were therefore made as test samples. As regards to the Silicone Rubber sample, high temperature vulcanized silicone rubber (110) (Ximei Silicone Materials, China) were employed. The length and width of the samples were 8 cm and 5 cm, while the thickness was 5 mm. As shown in Fig. 1, a pair of point to plane electrode system was used for electrode configuration. The PP nanocomposites and SiR samples were kept at a physical pressure of 0.12 MPa. The electrodes were formed by attaching 55  $\mu$ m-thick aluminum foil on the surface of PP/MgO. The point electrode was featured with an angle of 30°. The interval between the point and the plane electrode was 4 mm.

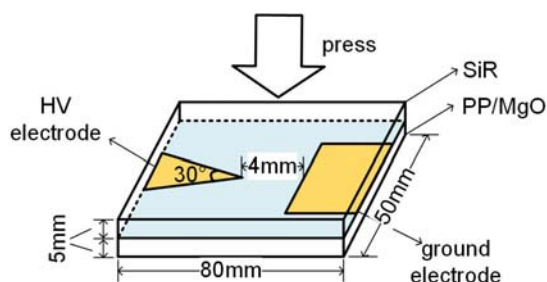


Fig. 1. Schematic diagram of the sample position and the electrode arrangement.

### B. Test Circuit and Procedure

The test circuit is shown in Fig. 2. A high frequency current transformer (HFCT) was used to measure the discharge current and a high speed AD convertor was used to collect the data. A charge-coupled device (CCD) camera was used to monitor the propagation of interface discharge channel. Before the test, the sample surface was cleaned with ethyl alcohol and was dried at 40°C for 1 hours. The experiment was conducted at room temperature with relative humidity of 45%. By applying AC voltage with 20 kVrms of 50 Hz between the electrodes, surface discharge was initiated and the discharge current was measured until the insulation interval was breakdown. The PRPD features during the discharge propagation process were extracted and the statistics of discharge magnitude were obtained.

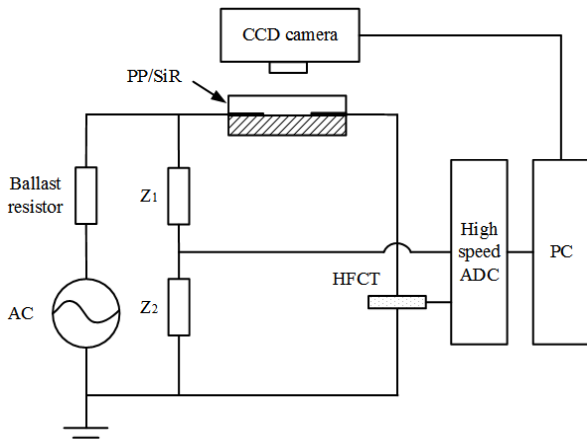


Fig. 2. Schematic diagram of the test circuit.

### III. RESULTS AND DISCUSSION

A group of typical interface discharge behavior is shown in Fig.3 by taking the neat PP and SiR as an example. Interface discharge will happen when the high frequency AC voltage was applied between the point to plane electrode. It was found that the average time for the interface breakdown of untreated PP/SiR was about 40 s, during such a time period three stages could be found, i.e. (a) discharge initiation, (b) discharge channel propagation and (c) breakdown. The characteristics of the three stages monitored

through the CCD camera is shown in Fig.3. Normally, in the stage (a), the discharge pulses are sparse and relatively low. After that, the discharge magnitude and discharge repetition rate increase in stage (b) compared with the former stage (a). Stage (a) lasts for a relatively short time with a typical period of ~15 s, and stage (b) has a time of about 20 s in general. As regards to the stage (c), the breakdown happens between the electrodes that a discharge arc appears with remarkable light emission and heat, the insulation interval is therefore short-circuited with the permanent loss of insulation property of the interface. Some other features that need to be noticed are those at stage (a) no obvious discharge phenomena could be observed.



Fig. 3. An example of interface discharge at PP and SiR.

Fig.4 show the effect of nano-filler content on the time to breakdown for both neat PP and PP/MgO nanocomposites. It can be observed that the time to breakdown is about 40 s with neat PP. With the increase of the nano-filler content from 0 wt% to 3 wt%, the time grows to about 140 s, which means that the breakdown strength is improved by a factor of 3.5. However, a further increase in the nano-filler content induces a decrease in the breakdown time which infers that the dielectric strength at the interface is reduced. It has been claimed in our early research that interface discharge between the PP and SiR is related to the surface trap distribution as well as surface roughness. At the initial stage, the discharge is associated with surface trap depth. Deep surface trap results in a difficult initiation of the discharge. At the propagation stage, the discharge is dependent primarily upon the surface roughness, large roughness leads to fast propagation of discharge channel and thereby accelerating the breakdown phenomena. In order to explain the test results shown in Fig. 5, surface roughness of the test samples have been measured by using a mechanical surface roughness measurement equipment, and the results are shown in Fig. 6.

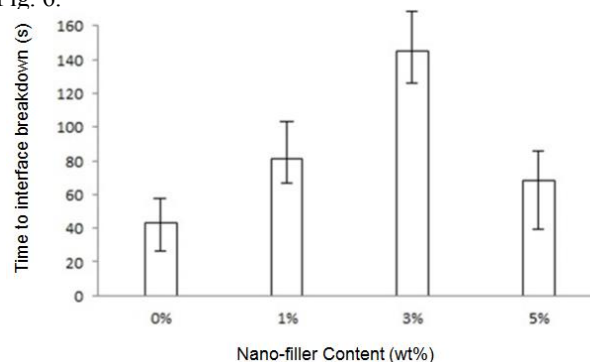


Fig. 4. Relation between the time to breakdown and the nano-filler content.

It can be obtained in Fig.5 that with the growth of the nano-filler content the average roughness of the nanocomposites initially decreases then appears to increase. The roughness of the neat PP is about 160 nm, but with a 3 wt% MgO particle adding the composites holds an average roughness of about 70 nm, which is much smaller than the neat one. A further increase in the nano-particle adding will contribute to an increase in the average roughness, finally to about 90 nm with 5 wt% MgO adding. It is then argued that the variation in the time to breakdown should be attributed to the change in average roughness caused by the adding of MgO particles.

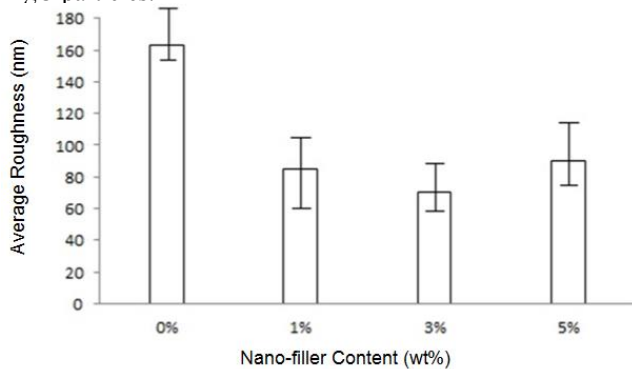


Fig. 5. Relation between the average roughness and the nano-filler content

#### IV. CONCLUSIONS

This work focuses on the influence of nano-particle adding on the interface discharge behaviour between PP and SiR. The main conclusions are summarized as follows,

1. With the increase of the nano-filler content from 0 wt% to 3 wt%, the time to breakdown increase from 40 s to 140 s. With a further increase in the nano-filler content from 3 wt% to 5 wt%, the time decreases from 140 s to 70 s.

2. With the growth of the nano-filler content from 0 wt% to 5 wt%, the average roughness of the sample decreases initially then tends to increase.

Our test results indicate that with the adding of proper content of nano-filler, the interface dielectric property between PP and SiR can be improved. Such a finding is helpful for the development of materials for cable insulation.

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