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# Mechanical and Electrical Characteristics of Polymeric Insulators Manufactured from Castor Oil Resins

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**Abstract:** The use of polymeric materials in high voltage applications is considered especially interesting in the electrical and industrial materials sectors. In this context, the purpose of this paper is to describe the electrical and mechanical characteristics of new polymeric insulators manufactured with novel polyurethane-type insulating resins derived from the castor-oil plant (Ricinus communis). Electrical tests were conducted with alternating voltage in the industrial frequency, while the mechanical tests involved the application of flexural and compressive stresses. These new insulators, which are part of an extensive ongoing research effort on this raw material deriving from a plant common in Brazil, where the climatic conditions for its cultivation are excellent, show an excellent potential for end products with competitive prices. This paper also describes the end results of aging by accelerated weathering and the manufacturing process of these insulators, which have proved to possess suitable characteristics as electrical insulators.

## Introduction

Polymeric insulators have been competing steadily with ceramic insulators in electric power system applications, currently representing 60 to 70% of all new insulator installations in the United States [1].

This preference for polymeric insulators in detriment to the traditional ceramic ones is justified by several important characteristics [2], among them:

- light weight,
- higher mechanical strength to weight ratio,
- resistance to vandalism,
- better performance in the presence of heavy pollution under wet conditions, and
- comparable or better withstand voltage than porcelain or glass insulators.

In addition, the use of polymeric in place of ceramic insulators eliminates enameling and cementing defects, cracking caused by the propagation of structural micro-cracks or internal stresses, and deficiencies in the characterization and stability of the raw material's physicochemical characteristics.

This paper describes the electrical and mechanical characteristics of the new polymeric insulators manufactured with novel polyurethane-type insulating resins derived from castor oil (scientific name: *Ricinus communis*).

The physicochemical characteristics of these resins, pure and with fillers, are described in [2] and [3]. The specimens were classified in all the tests according to the material used in their fabrication, as:

- RI 1 or RI 2: pure resins (without fillers) ;
- RI 1C1 or RI 2C1: resins RI or RI 2 with silica and carbon black in the mass proportion of 10:2:0.2, respectively;
- RI 1C2 or RI 2C2: resins RI or RI 2 with mica in the mass proportion of 10:2.

The main difference between these two resins is that resin RI 1 costs twice as much and has twice the mechanical hardness of resin RI 2, although they and their composites have similar electrical characteristics [2].

## Experimental procedures

### Preparation of the insulator specimens

Manually molded, conventional support-type polymeric insulators were used as test specimens. For the insulators produced with pure resins, the process began with the weighing of the polyol on a semi-analytic scale, to which the pre-polymer was added in the mass proportion of 1:1, in the case of resin RI 1, and of 1:1.75 in that of resin RI 2. After these two components were mixed for about 2 min, the mixture was placed in a glass chamber and subjected to a vacuum of $1.10^{-4}$ mbar for 3 min to extract air bubbles. The resin thus prepared was poured into silicone molds and left there for about 6 hours, after which it was removed from the molds.

The silica and mica fillers used in the insulators were first oven-dried for 20 min at 150°C and allowed to cool in the oven for 2 hours. They were then mixed with the polyol for about 3 min, using an electric mixer to homogenize the mixture. Subsequently, this mixture was also subjected to a vacuum of $1.10^{-4}$ mbar for 5 min before the pre-polymer was added in the abovementioned proportions. From that point on, the process was similar to that described for pure resin.

### Electrical and Mechanical testing procedures

#### Electrical tests

In order to determine the withstand voltage of the polymeric insulators under service conditions, alternate 60 Hz sinusoidal voltages were applied simultaneously on four test specimens. These voltages were increased at a uniform rate of 500 V/s, from 0 volts up to the breakdown of one of the insulators or even of the air. During these tests, the temperature and relative humidity were kept at 23°C and 52%, respectively.

It should be noted that all the electrical tests were conducted on specimens in two conditions – non-aged and aged – in a critical accelerated process of 5,000 hours, simulating approximately 3.5 years of natural aging. The aging tests were carried out with an *Atlas Weather-Ometer*, from the Atlas Electric Devices Company [4], with an acceleration factor equal to six.

#### Mechanical flexural and compressive tests

The Instron Corporation, model 5500R, serial # 7010, universal mechanical testing machine with a 25 ton capacity and a data acquisition system based on Merlin Version 4.0 software were used for the mechanical flexural and compressive tests.

In order to reproduce the same service conditions as those to which polymeric insulators are subjected, a testing device was prepared for use in the flexural tests, as shown in figure 2.

For this device, a system was built to fix the insulators with screws, ensuring high resistance during testing. This system required metal inserts with standard screw threads in the specimens, the upper insert with a 12mm diameter thread and a 25mm depth and the lower with a 16mm diameter thread and a 50mm depth. Channels were machined on the external surfaces of the inserts to improve adherence on the polyurethane resins.

A conventional load cell was used for the compressive tests.

The flexural and compressive tests speeds were set, respectively, at 10mm/min and 5mm/min for an average testing time of 300 seconds.

## Results

### Electrical tests

After aging, all the insulators were visually inspected to check for alterations in color, internal and/or external cracks, microcracks and strains. The great majority of insulators showed only, as in [2], color alterations from light to dark yellow, with no visible type of strain or cracking.

The results of the electrical tests before and after the accelerated aging test are shown in figure 1.

Considering the environmental conditions of the electrical tests before and after aging, which were performed on different days, and the fact that the flashovers occurred in the air, the variations between the results obtained lie within the measurement tolerances, with RMS withstand and peak voltage values of around 80 kV and 100 kV, respectively.

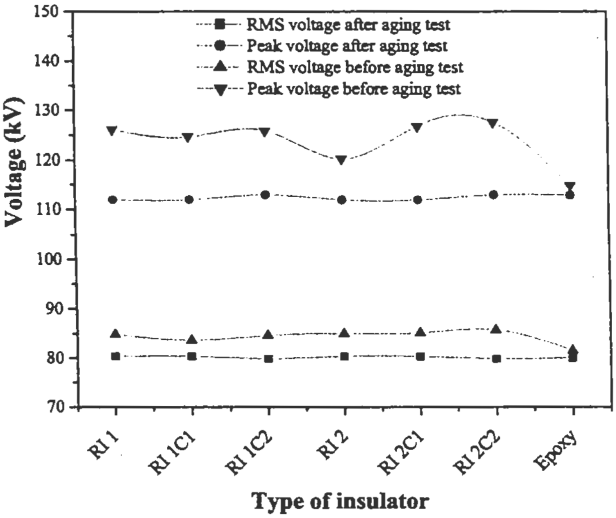


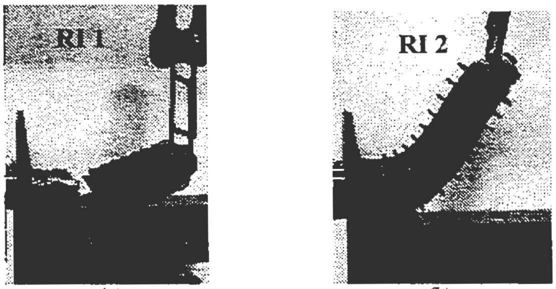

**Figure 1:** Results of the electrical tests on the insulators before and after the accelerated aging tests.Mechanical tests

### Behavior of the insulators under compressive loads

The results of the mechanical tests were classified as ductile or fragile for each type of mechanical breakdown, according to [5]. It should be noted that, in the ductile breakdown mode, the material strained before breaking while, in the fragile mode, material breakdown occurred with practically no strain and no incipient failure before breaking.

The support-type insulators produced with the RI 1, RI 1C1 and RI 1C2 resins under flexural loading presented a fragile type breakdown similar to that of commercial epoxy insulators, as illustrated in figure 2(a) for the RI 1 insulator.

On the other hand, the insulators produced with the RI 2, RI 2C1 and RI 2C2 resins presented ductile breakdown under flexural loading, as shown in figure 2(b) for the RI 2 insulator.



(a) (b)

**Figure 2**: Mechanical flexural test on insulators produced with: (a) RI 1 resin; and (b) RI 2 resin.

The specific strain value of the insulator in the device developed for this test (*S.d.*) is given in mm and the results of the test are shown in table 1.

The mean value and standard deviation of the flexural test on the insulators produced with the RI 1 resin were, respectively, 5.46 kN and 0.85 while, in the case of the insulators produced with the RI 2 resin, these values were 3.25 kN and 0.31, respectively.

The characteristic curves of the flexural test on the insulators produced with the RI 1 and RI 2 resins are given in figure 3(a) and 3(b), respectively.

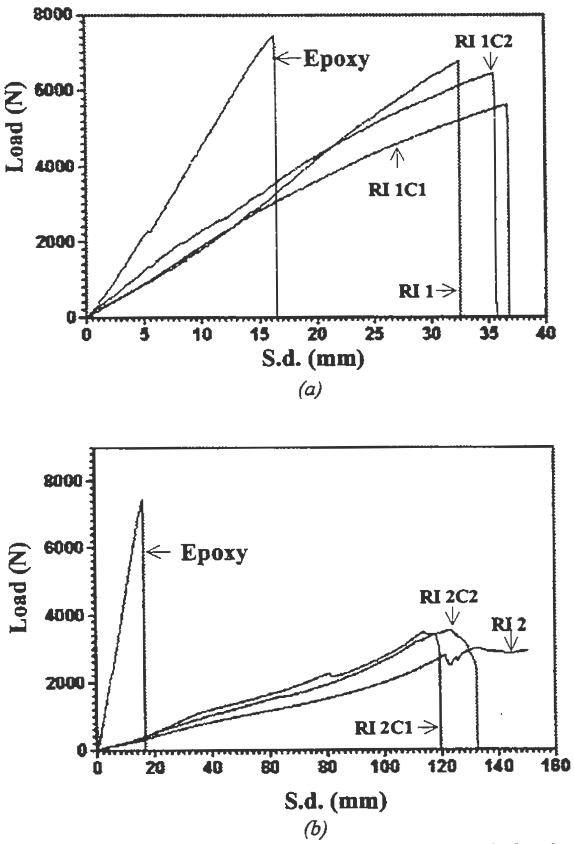



**Figure 3**: Flexural load vs. specific strain of polymeric insulators in the device developed for this test (*S.d.*), with metal inserts, and produced with (a) RI 1 resin; and (b) RI 2 resin. The epoxy insulator was used as reference.

**Table 1**: Results of the flexural test on the polymeric insulators with inserts.

| Type of insulator | Maximum breakdown load (kN) | Duration of test (s) | D.e. (mm) |
|---|---|---|---|
| RI 1 | 6.79 | 197.49 | 32.92 |
| RI 1C1 | 5.65 | 222.30 | 37.05 |
| RI 1C2 | 6.48 | 217.53 | 36.26 |
| RI 2 | 3.03 | 902.35 | 150.39 |
| RI 2C1 | * 3.48 | 720.95 | 120.16 |
| RI 2 C2 | * 3.54 | 796.84 | 132.81 |
| Epoxy | 7.46 | 101.15 | 16.86 |

Note: The breakdown load of these insulators could not be determined because the inserts of the elastomeric material became unglued as a result of the great strain.

## Behavior of the insulators under compressive loads

The mechanical compressive tests were first performed on polymeric insulators without inserts. The curves of these tests, for the insulators containing RI 1 resin, are given in figure 4. This figure also shows that the breakdown load of the epoxy insulator is higher than the universal testing machine used here, which is 250 kN.

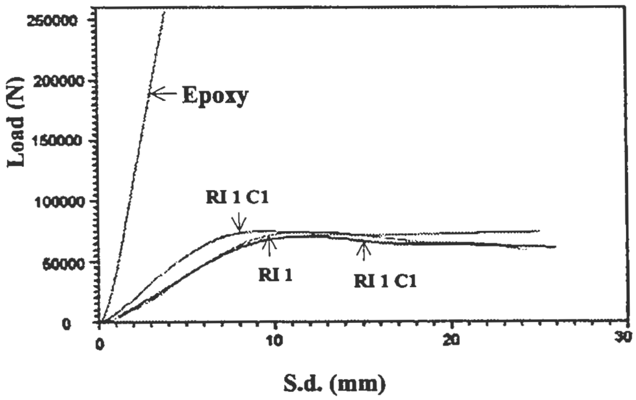



**Figure 4**: Compressive load vs. specific strain of polymeric insulators in the testing device (*S.d.*), without metal inserts, and produced with RI 1 resin. The epoxy insulator was used as reference.

Owing to the substantial plastic strain they were subjected to and the low hardness of the RI 2 insulators, the tests were also repeated on insulators with inserts. In this case, the resulting curves were similar to the previous ones, indicating that the metal inserts failed to increase the strength of the insulators in the compressive tests. The reason for this was that the inserts were positioned at the ends of the insulators and had no base to provide greater support.

It should also be noted that the nominal compressive load for insulators produced with the polyurethane resins studied here should be obtained up to a specific strain, defined as a design specification. To exemplify this, table 2 lists the compressive load values of insulators with a strain (insulator under test) of 2.0mm.

**Table 2**: Compressive load of insulators with metal inserts.

| Type of insulator | Specific strain of the insulator in the testing device [mm] | Compressive load [kN] |
|---|---|---|
| RI 1 | 2.00 | 4.64 |
| RI 2 | 2.00 | 7.41 |
| Epoxy | 2.00 | 114.95 |

## Conclusions

The accelerated aging test caused only color alterations in the insulators, owing to the fact that the double bonds in the chemical composition of the resins employed underwent an oxidation process when subjected to high temperatures [6].

The results of the electrical tests revealed no change in the performance of the insulators subjected to accelerated aging, demonstrating RMS withstand voltages of around 80 kV and peak voltages above 100 kV.

In the mechanical tests, most of the insulators produced with the polyurethane resins studied here reached the point of breakdown with lower flexural and compressive loads than the breakdown loads of the epoxy-type insulator used as reference. The insulators produced with R1 2 resin failed the tests owing to ungluing of the inserts.

However, since all the insulators passed the artificial aging and electrical tests, the results of the mechanical tests were the differentiating factor in the final and conclusive analysis of the insulators developed in this study. Hence, it was concluded that: the insulators produced with the R1 2 resin and its composites RI 2C1 and RI 2C2 are inappropriate for application as electric insulators, and the other insulators produced with the RI 1 resins, RI 1C1 and RI 1C2, are applicable as electric insulators for use in internal environments and for temperatures below 70°C, albeit with some restrictions regarding their mechanical load withstand strength.

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