# Alumina filled silicone nanocomposites for electrical insulation of power rotating machines

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**ABSTRACT**

Silicone resins are widely adopted in outdoor and indoor electrical equipments. One of the main applications includes medium power rotating machines where they are used for the impregnation of rotor and stator windings. Due to the growing demand for compact insulation, the improvement of heat dissipation in such devices has recently become a very important issue and dielectric materials with enhanced thermal conductivity and, at least, unmodified mechanical and electrical properties are needed.

In the present paper, we report results about the preparation and the morphological, thermal, mechanical and electrical characterization of new materials obtained by addition of nano-sized alumina ($Al_2O_3$) fillers to silicone matrix. Their measured physical properties are compared with those of the unfilled matrix, used as a reference, and the influence of the weight concentrations, ranging between 1 wt % and 7 wt % is fully discussed.

**Key Words:** silicone resin, ceramic nanofiller, nanodielectrics.

## 1. INTRODUCTION

The life expectancy of electrical equipment mainly relies on the duration of its insulation materials. As concerns as power rotating machines, the introduction of new technologies such as pulse width modulation (PWM) and the concomitant tendency to the miniaturization of electrical devices have sensibly increased the electrical, mechanical and thermal stresses over the electrical insulation [1] and have thus introduced new issues in the design of electrical machines. In fact, the increased heat generated during operations might reduce the lifespan of the final product, and it is therefore essential to dissipate it as quickly and effectively as possible. One of the main limits is essentially due to the low thermal conductivity of polymers, such as epoxy resin and silicone resin, which are widely used for the vacuum pressure impregnation (VPI) of traction motor windings and it is therefore essential to enhance the ability of the polymer to dissipate excess heat.

It is well known [2] that the inclusion of solid particles, such as ceramics or metals, improves thermal conductivity of resulting composites; on the other hand, the addition of high filler content can deteriorate processability and electrical performances of insulating material. Many efforts are then devoted to the enhancement of thermal conductivity while keeping the other properties of the polymer unchanged.

The use of nanosized particles has been proposed in the recent scientific literature as an alternative to conventional fillers. Taking advantage of the enormous specific surface area strong improvements are noticed as a result of nanoparticles inclusion in polymeric matrices. In recent years, while many results have been published in the literature about epoxy based nanocomposites [3, 4], few data are still available about nano-filled silicone resin [5].

The present study is dedicated to the preparation of silicone composites containing alumina ($Al_2O_3$) nanofillers at different weight percentages and to their morphological, thermo-mechanical and electrical characterization.

## 2. EXPERIMENTAL

### *2.1 Nanocomposite preparation*

A methyl-phenyl-vinyl hydrogen polysiloxane resin was selected as the host matrix and alumina nanoparticles of spherical shape with a diameter ranging between 40-47 nm and a specific surface ranging between 35-43 $m^2/g$ where used as filler. Nanocomposites containing 1, 3, 5 and 7 weight percent of alumina, with respect to the total mass of the silicone resin, were prepared in laboratory, by using combined dispersion techniques, that is mechanical mixing by high speed homogeneizer "*Turrax T25"* at 6500 rpm for 10 min and sonication by ultrasonic processor *"Hielscher UP200S"* at a 50% of maximum amplitude (200W) for about 30 min.

*2.2 Morphological characterization*

Morphological observations were carried out by using a scanning electron microscope (SEM, *"FEI Quanta type 200F"*). Cryogenically fractured surfaces of the samples were gold coated prior to SEM studies to avoid electrostatic charging and were examined at 20-30 KV accelerating voltage. SEM images show a reasonably good dispersion of the nanofillers, characterized by clusters and aggregates of negligible size.

*2.3 Thermo-mechanical characterization*

Thermogravimetric analysis (TGA) was performed by using a *TA Instruments Q-5000* balance. The temperature was ramped at a rate of 10°C/min from room temperature up to 700°C in nitrogen atmosphere; initial thermal decomposition temperature was evaluated at 3% weight loss. The plots of weight loss as a function of temperature show that the addition of nano-sized fillers does not sensibly affect the thermal stability of the composites.

The thermal conductivity $\lambda$ of neat silicone resin and nanocomposites was estimated by modulated differential scanning calorimetry (MDSC), using a *TA Instruments Q-1000 DSC,* according to ASTM E 1952; the composite with 7% wt showed the highest value for the thermal conductivity corresponding to an increase of about 70% with respect to neat resin.

Dynamic-Mechanical Analysis (DMA) was performed by a *DMA-TAQ800* instrument in order to evaluate the storage modulus (E') and damping (tan$\delta$) curves and the glass transition temperature ($T_g$) of the composites. The addition of ceramic particles determines a slight increase in the elastic modulus which, for the 7%wt samples, becomes ~10% higher than the neat resin. On the contrary, $T_g$ values decrease with filler content and reach a minimum for the 7%wt samples, characterized by a $T_g$ value 10°C smaller than the unfilled silicone resin.

*2.4 Electrical characterization*

Plane, disc-shaped, samples were prepared for electrical characterization. The dc volume resistivity ($\rho_v$) was evaluated at 23°C by holding the specimens in a suitable shielded cell and using a stabilized dc source and a picoammeter HP 4140B. Resistivity plots vs filler content show a decrease of $\rho_v$ value with respect to neat resin and invariance with respect to filler loadings. Relative dielectric permittivity ($\varepsilon_r$) and dissipation factor (tg $\delta$) were measured at high voltage and 50 Hz by placing the samples in a dielectric test cell Tettex 2914 and by adopting a Haefely bridge type 470. All dissipation factor values are lower than in the unfilled resin, except for the composite at 7%wt in which an increase of about 40% has been observed; a slight increase is observed for the relative permittivity in the composites at 3%, 5% and 7% wt. Frequency spectra were obtained by means of an impedence analyzer HP 4192A and a suitable test cell Agilent 16451B. In the frequency range [10 Hz÷10 MHz] no relevant relaxation phenomena has been observed and the permittivity and dissipation factor values are nearly independent of frequency. Tests are in progress for the evaluation of the short-term breakdown strength of the composites. Further activity is planned in order to develop a simplified model for the explanation of the main phenomena which have been observed experimentally.

## 4. CONCLUSIONS

In this paper, silicone composites with nano-sized alumina fillers for electrical insulation in medium power traction motor windings were prepared by mechanical mixing and sonication. SEM results revealed a good filler dispersion in the polymer matrix. A sensible increase in thermal conductivity (about 70% with respect to neat resin) was obtained with the 7% wt composites, while leaving the mechanical and electrical characteristics almost unchanged.

## 5. REFERENCES


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