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# A Kinetics Study on Electrical Resistivity Transition of *In Situ* Polymer Aging Sensors Based on Carbon-Black-Filled Epoxy Conductive Polymeric Composites (CPCs)

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Sensors based on carbon-black-filled bisphenol A-type epoxy conductive polymeric composites (CPCs) have been prepared and applied to monitor thermal oxidation aging of polymeric materials. Thermogravimetric analysis (TGA) is applied to characterize weight loss of epoxy resin in the aging process. By using a mathematical model based on the Boltzmann equation, a relationship between the electrical resistivity of the sensors based on epoxy/carbon black composites and aging time is established, making it possible to monitor and estimate the aging status of polymeric components *in situ* based on a fast and convenient electrical resistance measurement.

**Key words:** Conductive polymeric composite, degradation, *in situ* sensors, electrical resistivity, Boltzmann equation

## List of Symbols

- $p_c$ Percolation threshold
- $C$ Relative weight of epoxy resin matrix
- $W$ Real-time weight of epoxy resin
- $W_0$ Initial weight of epoxy resin
- $t$ Aging time
- $k$ Reaction constant
- $n$ Exponent in power equation for weight of epoxy resin
- $E_a$ Activation energy in degradation of epoxy resin
- $T$ Aging temperature
- $R$ Gas constant
- $\rho$ Electrical resistivity of CPCs
- $\rho_0$ Initial electrical resistivity of CPCs
- $\rho_\infty$ Electrical resistivity of CPCs with infinite aging time
- $x$ Weight ratio of carbon black
- $\alpha$ Exponent in electrical resistance alteration around percolation in Liang's theory[13]
- $t_c$ Induction time, corresponding to aging time needed for a change of $\log \rho$ from $\log \rho_0$ to $(\log \rho_0 + \log \rho_\infty)/2$
- $\Delta t$ A constant in the Boltzmann equation

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## INTRODUCTION

Previous research has indicated that polymeric insulation system breakdowns account for up to 40% of failures of motors, aircraft, and electrical generators. Environmental conditions including heat, light, and oxygen usually facilitate thermal oxidation and decomposition of polymeric materials,[1] contributing to mechanical weakening of polymer insulation materials. In addition, unforeseen operational conditions, including excessive load and reduced/blocked cooling, further accelerate degradation of polymeric insulators and significantly increase the risk of their unexpected breakdown. Therefore, to detect ongoing failures for predictive maintenance, effective monitoring methods for real-time thermal oxidation aging status of polymeric components are desired and required by