

# Nanosilica-toughened epoxy resins

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Surface-modified silica nanoparticles are available as concentrates in epoxy resins in industrial quantities for nearly 20 years. Meanwhile, they are used in many epoxy resin formulations for various applications like fiber-reinforced composites, adhesives or electronic components; even in space vehicles like satellites. Some of the drawbacks of “classic” epoxy toughening using elastomers as a second phase, like lower modulus or a loss in strength can be compensated by using nanosilica together with such tougheners. Apparently, there exists a synergy as toughness and fatigue performance are increased significantly. This work intends to provide an overview regarding the possibilities of nanotoughening with silica, the industrial applications of such epoxy resin formulations and the most recent research results. Furthermore an overview of other material improvements achieved by the modification of epoxy resins with nanosilica is given.

Keywords: epoxy resin ; silica nanoparticles ; toughening ; fatigue ; nanotoxicity

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## 1. Introduction

An short overview of epoxy resin properties, suitable tougheners and nanomodifications followed by an introduction into nanosilica and it's use in epoxy resins.

## 2. Epoxy Resins Modified with Silica Nanoparticles

- Toxicological Aspects of Silica Nanoparticles in Epoxy Resins

Overview regarding the many investigations performed in vitro and in vivo with silica nanoparticles, all concluding that they are harmless regarding toxicological aspects but should always be handled in a safe matrix like an epoxy resin.

- Property Improvements of Epoxy Resins by Silica Nanoparticle Modification

Major material properties of cured epoxy resins are improved by the addition of silica nanoparticles. This depends of course on the chemical nature of the epoxy resin, the curing agent used and the addition level of nanosilica. Detailed information and links to even more detailed investigations are provided.

- Toughness Increase of Epoxy Resins by Nanosilica Modification and Mechanisms

The improvement of epoxy resin toughness as function of nanosilica addition level is investigated and the underlying toughening mechanisms are explained in detail.

- Synergy Between Elastomeric Tougheners and Silica Nanoparticles: Further Property Improvements

The synergie found between nanoscale toughening and macroscale elastomeric tougheners is investigated. Apparently it is related to the morphology of the cured resin rather than to the chemical nature of the elastomeric toughener. Links to all relevant recent studies

## 3. Improving Epoxy Resin Applications with Silica Nanoparticles

- Adhesives

The toughness and fatigue performance of structural epoxy adhesives can be improved by the use of silica nanoparticles in the adhesive formulation. Of course this is related to the adhesive formulation and the nanosilica addition level - many details are provided

- Stereolithography (SLA)

The property improvements of UV-curable epoxy resin formulations (mainly based on cycloaliphatic epoxies) achieved by the use of nanosilica are reported.

- Coatings

Currently nanosilica is not used in relevant coating applications, hence the few studies available are mentioned.

- Electronic Applications

A very interesting field of application, in which nanosilica-modified epoxy resins are used widely. Examples of applications and the property improvements achieved are given.

- Fiber-Reinforced Composites

By far the largest application area currently for epoxy resins modified with nanosilica. They offer many advantages compared to unmodified systems as well as to other modifications, hence many examples are given and many links to very detailed investigations are given

### **Conclusions and Outlook**

Taking into account the price/performance ratio of nanosilica-modified epoxy resins, their widespread use within several industrial applications is more than justified and they will show a significant further growth.

The most promising area for future epoxy resin formulation and subsequent epoxy resin property improvement is the combination of nanosilica with other modifications, i.e. elastomeric tougheners, graphene, macroscaled fillers - just to mention a few.

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