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Original Research Article

Considering influence of microstructure morphology of epoxy/glass composite on its behavior under deformation conditions—digital material representation case study

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ABSTRACT

Digital Material Representation (DMR) concept in application to numerical investigation of the two different types of epoxy/glass composite morphologies under loading conditions is addressed within the paper. First, two algorithms for reconstruction of digital microstructures based on metallography investigations are developed. Then, material properties of the investigated epoxy matrix and glass fillers are evaluated based on an in-situ tensile test as well as nano-indentation, respectively. At this stage a numerical investigation is also extended by series of experimental tensile tests to understand basic mechanisms occurring during deformation of the two different types of glass particles fillers. Finally, an example of practical application of the developed digital microstructure model for multi scale calculations of the epoxy/glass composite under loading is presented.

1. Introduction

Epoxy resin-based thermosetting composites are one of the most widely used insulating materials in medium- and high-voltage applications. Insulation of components of the power grid such as breakers, switches, instrument transformers, dry transformers, bushings or insulators is most often made of epoxy due to its very good dielectric properties, thermal and chemical resistance, low mechanical creep and good adhesion to metals. In such applications metal parts like conductors,

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windings, cores or shields are usually overcast in an epoxy resin. Due to substantial difference in coefficients of thermal expansion of an epoxy resin and overcast metals high mechanical stresses can occur in the epoxy structure. They can be caused by changes of the temperature during manufacturing process as well as under exploitation conditions in the field. This may lead to epoxy cracking and debonding of epoxy-metal interface what may further result in the failure of the device. In order to reduce the difference in thermal expansion, epoxy resins can be mixed with various fillers [1,2,3]. One of popular fillers used in epoxy resin-based systems are silica (glass) particles [4,5]. They reduce the thermal expansion coefficient and have a positive impact on other parameters like mechanical stiffness or thermal conductivity. But their addition has also a negative impact on the brittleness of the epoxy composite material.

The brittleness is one of the biggest disadvantages of epoxy resin-based systems and there are constant endeavors to increase the cracking resistance of these composite materials [6,7]. Therefore, in order to deeply analyze the influence of fillers, their type, distribution, size and shape, on the fracture strength of epoxy composites the numerical models taking into account direct influence of their microstructure morphologies should be developed.

One of the approaches that can be used to solve that issue is to develop numerical model based on the Digital Material Representation (DMR) concept [8,9]. Such models combined with CAE (Computer Aided Engineering) systems will allow to take into account the microscopic morphology of epoxy composites on their macroscopic properties and eventually will result in further development of epoxy insulation systems.

2. Digital material representation concept

The major concept of the DMR approach is microstructure reconstruction of the investigated materials with an explicit representation of its morphological features as well as interactions between them. That way a numerical model can predict not only averaged influence of microstructure on its macroscopic response during loading but can also take into account all kinds of local heterogeneities. Local inhomogeneous material behaviour is crucial, especially when mentioned problems of composite failure under high stress conditions are investigated.

Development of the reliable numerical model based on the DMR concept is usually composed of three major steps. The first is attributed with a geometrical reconstruction of the investigated composite microstructures [9,10]. Shape, position, distribution as well as volume fraction of the filler materials in the matrix have to be accurately recreated. Digital microstructures are often created as exact replicas with numerical processing of real microstructure images (optical, electron or tomographic) both in 2D and 3D spaces [11,12,13]. During such investigation series of valuable quantitative information on morphological aspects of subsequent features can also be obtained and used to support generation of DMRs [14]. At this point these experimental methods are still quite expensive and require applications of series of data analysis techniques. That is why numerical methods e.g. cellular automata [15], Monte Carlo [16] or recently Nurbs [10] are more often used to provide synthetic microstructures that statistically recreate material morphology in a fast and efficient way. Then, the second step in DMR model development, is focused on a proper material data acquisition [9]. Realization of typical macroscopic plastometric tests like compression or tension may no longer be an option for composite materials. Properties of each particular component type are required in the case of DMR model development, what forces utilization of more advanced testing methods including an in-situ deformation or a nano-indentation. Finally, when reconstructed microstructure morphology is filed with physical properties, the model has to be incorporated into a software responsible for handling calculation of material behaviour under loading conditions based on e.g. finite element method. This step involves development of proper discretization techniques like finite element mesh generation, see e.g. [17].

Realization of mentioned three stages of the DMR model development for the investigated epoxy resin, with two different types of glass particle fillers, is presented in the following chapters.

3. Reconstruction of microstructure morphology

Two kinds of composite microstructures with epoxy resin matrix and the same volume fraction of glass particle fillers were investigated within the present work. In the first case, the filler material in the form of spherical 5-8 μm glass particles was produced by emulsification process and then introduced into the liquid epoxy. This resulted in an uniform size and shape of particles distributed within the epoxy resin matrix, as can be observed in Fig. 1.

In the second investigated case, the crumble type glass particles, were manufactured by typical grinding method of high-purity quartz through specific finer mesh followed by an air separation to remove any mineral residuum. As a result, highly inhomogeneous shapes of glass particles were obtained as seen in Fig. 2.

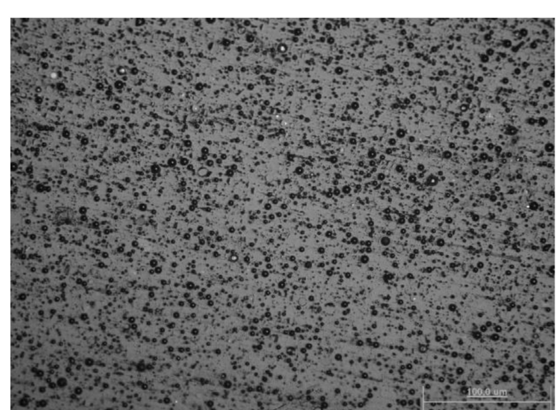

Fig. 1 – Investigated spherical type glass particles distributed within the epoxy resin matrix.