# DAMAGE PROPAGATION OF COMPOSITE MATERIAL REINFORCED BY RANDOMLY-DISPERSED PARTICLES

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*Summary* The principal objective of this work is to study the macroscopic damage propagation behavior in a composite, taking into account the randomness of the orientation of the reinforcements. A general purpose FE program MECORAP (MEchanics of COmposites reinforced by RAndomly dispersed Particles) has been developed. An analysis of the effect of the microstructure on the strength and damage resistance of the material can be a basis for the improvement of a material's durability and performance.

## MULTISCALE ANALYSIS PROCEDURE

In this paper, we propose a multiscale analysis procedure. This procedure is divided into four stages, which are implemented sequentially. Fig. 1 outlines the detailed relationships among the four stages.

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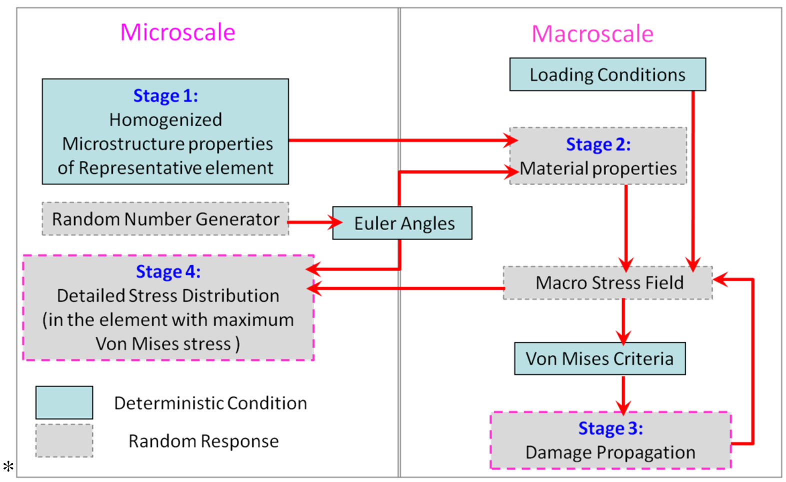


**Figure 1.** Multiscale analysis procedure.

Consider a three-dimensional (3D) composite specimen and divide it into many unit cells. Each unit cell is reinforced by a cylindrical particle, the orientation of which is characterized by three Euler angles, $\alpha$, $\beta$ and $\theta$. As shown in Figure 1, the random variables in this problem are the three Euler angles for each unit cell. Obviously, such composites show marked inhomogeneity and anisotropy. Here, we choose the one with all three Euler angles equal to zero ($\alpha = \beta = \theta = 0°$) as the representative volume element (RVE), and label the local $x'y'z'$ coordinates on it. All the unit cells can be represented by the RVE through the rotation from the local coordinates to the global coordinates. By changing the radius and the height of the cylinder, we can represent the effects of the morphology of the reinforcement on the mechanical properties of the composite. The damage propagation at the macroscopic level and the stress analysis at the microscopic level can be obtained from the following computational process.

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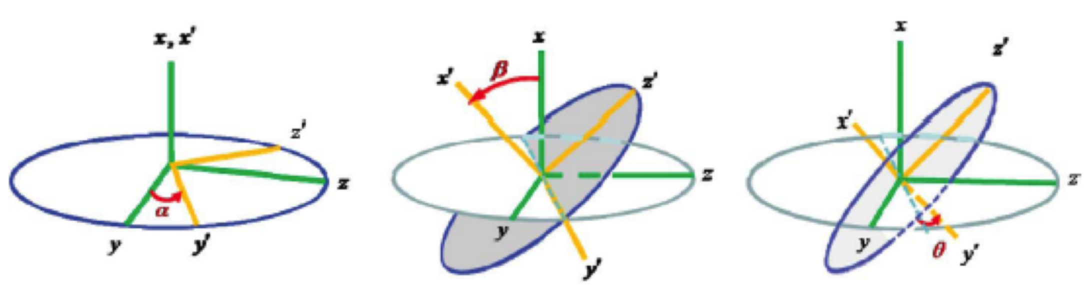


**Figure 2.** Three Euler angles: $\alpha$, $\beta$, $\theta$.

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At the first stage, we calculate the homogenized stiffness matrix for the RVE microstructure based on finite element (FE) analysis. As verification, the properties of the cylindrical particles are set equal to those of the matrix and the computed 'composite' properties reduce exactly to those of the 'isotropic' material, as expected. As shown in Figure 1, the purpose of the second stage is to obtain the stiffness matrices for all the unit cells through the Euler angles [1-2]. One may carry out the transformation from a given Cartesian coordinate system to another by means of three successive rotations performed in a specific sequence. The Euler angles are then defined as the three successive angles of rotation (cf Fig.2) [3]. Then, the damage propagation analysis is performed at the macroscopic level. The von Mises criterion is employed to determine whether damage occurs or not. The damage was modeled by using the element elimination technique. This means the elements of which the von Mises stress exceed a critical value, namely the von Mises strength, are considered as damaged elements, and the Young's modulus of these elements is set to be zero. As a consequence, the stresses in the entire specimen are redistributed. The specimen is then analyzed with a new set of stiffness matrices to determine if any further failure is induced. At the microscopic level, we further explore the microstructural stress distribution for any element. The microscopic stress distribution depends not only on the microstructure but also on the macroscopic stresses obtained in Stage 3. This is one reason why a multiscale analysis is needed here.

## DISCUSSION AND CONCLUSION

MECORAP is a general purpose finite element code which was developed for the analysis of composites reinforced by randomly-dispersed particles. Most commercial codes seem to be ineffective in dealing with this kind of composite, in that creating the material properties for all unit cells is too complicated, while MECORAP makes it possible to perform not only the stress analysis but also failure analysis. Fig.3 shows the distribution of the von Mises stress. It should be noticed that the distribution is very random, not uniform, which is different from the case for homogenous material.

Generally speaking, a composite material is a natural choice to enhance material properties, such as sustainability and durability. Our simulation results show that composite materials can mitigate and arrest the damage propagation effectively and prolong the material's lifetime. Actually, we realize that one may choose the reinforcement and the matrix, and also one may design the reinforcement and the matrix for required mechanical properties and performance.

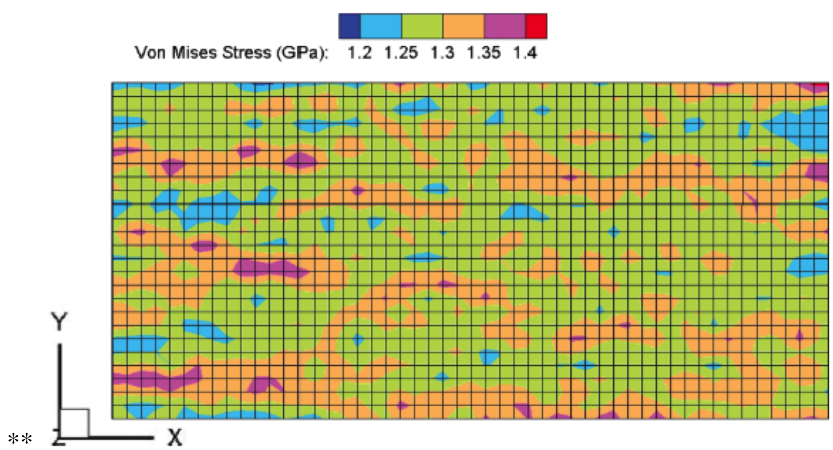


**Figure 3.** Multiscale analysis procedure.

## References

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[3] Goldstein H., Poole C., and Safko J.: Classical Mechanics. Addison Wesley 2001.