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Numerical Modelling of HNT and Rubber Reinforced Epoxy Composites

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Abstract: Metal and metal alloys such as iron and steel start to be replaced by nanocomposite materials with lightness, durability, superior mechanical, electrical, chemical, and thermal properties. The reason for these superior properties is that the matrix-reinforcement interface area increases, and their interactions increase as the dimensions reach the nanometre level. Unique nanocomposite materials are designed and used in many fields, from aviation to electronics, from computers to the food industry. The reasons why these composites are preferred in engineering structures are that they are of high quality and more economical than traditional materials. In this study, Halloysite Nanotube (HNT) and rubber reinforced epoxy composites are modelled, and mechanical properties of these composites are obtained theoretically by numerical methods. Halpin-Tsai Approach and Mori-Tanaka Approach, which are modeling methods developed for composite materials in the literature, are used in modeling.

Keywords: *Composite, modelling, micromechanical analysis, mori-tanaka, halpin-tsai*

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I. INTRODUCTION

Composites are formed by combining at least two different materials. Basically, the reinforcement material or materials are distributed to the matrix base material homogeneously while preserving their physical properties. The matrix phase is responsible for properly transferring the loads acting on the composite to the reinforcement phase while maintaining the geometrical arrangement of the reinforcements.

Various nanoparticle reinforcements with different properties can be used in nanoparticle-reinforced epoxy nanocomposites. Significant changes in material properties can be observed even in a small amount of these additives. Silica, HNT, Carbon Nanotube (CNT), rubber, and aluminum oxide (Al_2O_3) can be given as examples of reinforcements to the epoxy matrix [1, 2].

(HNT) is a nanometre-sized cylindrical form of clay mineral. It is seen in various studies that a more rigid structure is obtained by adding HNT to the epoxy matrix [3, 4]. Rubber reinforcement to the epoxy matrix is discussed in various ways in the literature. It is seen that many engineering properties such as fatigue life, electrical conductivity, and hardness of the reinforcement element have higher values when the rubber reinforcement is small-scale sizes [5, 6] .

Numerical studies are preliminary studies in order to obtain information about composites due to costs such as manufacturing costs, time costs, and testing costs of composite materials. It provides a more effortless and more rapid comparison of the elements intended to form the composite material to be designed and predictability. With this predictability, expensive and very time-consuming manufacturing and testing processes can be used optimally [7, 8].

Some researchers have directly used continuum mechanics in the analytical modeling of composites [9]. However, continuum micromechanics is commonly used to estimate the modulus of elasticity. These microme-

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chanical models can be listed as follows: Strength approach, Voigt upper limit and Reuss lower limit (VR model), Hashin and Shtrikman upper and lower limits (HS model), Halpin-Tsai model (HT model), Hui-Shia model (HS model), Wang-Pyrz model (WP model), Cox model (Shear lag model), and Mori-Tanaka approach [9, 10].

In this study, HNT-reinforced epoxy composite and rubber reinforced epoxy composite are modelled using the Halpin-Tsai approach and Mori-Tanaka approach, and the estimated Young's modulus values of the composites are obtained. For this purpose, the effect of the reinforcement material on the modulus of elasticity is investigated, and composite materials are modelled [11].

II. MATERIALS AND METHOD

Homogenization methods are used to model the mechanical behavior of many engineering materials. In the literature, there are many studies dealing with homogenization methods and composite structure characterization. Numerical models differ in their functions used in constitutive equations. These functions are based on experimental results that determine the mechanical behavior of the material under various loading conditions [12, 13].

In this study, the Halpin-Tsai approach and the Mori-Tanaka homogenization method, which are modeling methods of composite materials, are used.

A. *Halpin-Tsai Approach*

One method used to determine the mechanical properties of composite materials is the Halpin-Tsai method. It is developed as a result of the curve fitting method based on elasticity by Halpin and Tsai [14].

B. *Mori-Tanaka Homogenization Method*

In the Mori-Tanaka approach, the mechanical properties of the materials that make up the composite structure give the mechanical properties of the composite material with closed and analytical form equations [15]. The ability to find an analytical and closed solution in the homogenization of particulate composites makes the Mori-Tanaka method applicable in terms of ease of processing and accuracy. Considering similar studies in the literature, it is seen that the Mori-Tanaka homogenization method is frequently used for particle-reinforced nanocomposite materials [16].

III. RESULTS

Stiffness is called the material property that defines the deformation behavior of a material when a certain load is applied. In the elastic region of the stress-strain graph of the material, the stiffness can be considered concerning the modulus of elasticity when the stiffness of a material increases, the force that must be applied to the new sample to measure the unit strain value at the same value as the previous state of the material will also increase.

In this study, 1% HNT, 2% HNT, 5% rubber, and 10% rubber reinforced by weight epoxy composites are modelled separately with both the Halpin-Tsai approach and the Mori-Tanaka homogenization method. Material properties used in homogenization processes are given in Table 1.

TABLE 1
MATERIAL PROPERTIES OF EPOXY, HNT, AND RUBBER

	Elasticity Modulus [GPa]	Aspect Ratio
Epoxy	3	-
HNT	140	166.6667
Rubber	0.1	1

As a result of the modeling, the elasticity modulus values of the designed materials are obtained. Results are presented in Figures 1 and 2.

The elasticity modulus of materials obtained with the Mori-Tanaka homogenization method is presented in Figure ??. As can be seen from Figure1, the HNT additive tends to increase the elastic modulus of the epoxy composite, while the rubber additive tends to decrease. The Mori-Tanaka homogenization method yields the moduli of elasticity for 1% HNT, 2% HNT, 5% rubber, and 10% rubber-doped epoxy composites as 3.1297 GPa, 3.2608 GPa, 2.6913 GPa, and 2.4172 GPa, respectively. With the addition of HNT to the epoxy matrix, the modulus of elasticity increased by 4.3233% and 8.6933%, respectively. With the addition of rubber to the epoxy matrix, the modulus of elasticity decreased by 10.29% and 19.4267%, respectively.

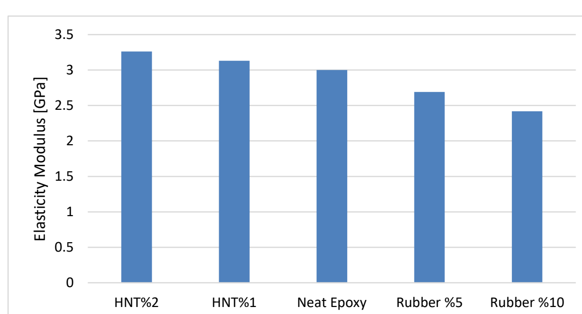

Fig. 1. The elasticity modulus of materials obtained with the Mori-Tanaka homogenization method

The elasticity modulus of materials derived from the

Halpin-Tsai approach can be seen in Figure 2. Figure 2 shows that the HNT additive to the epoxy matrix increases the epoxy composite's elasticity modulus, and the rubber additive has the opposite effect. The Halpin-Tsai approach shows the moduli of elasticity for 1% HNT, 2% HNT, 5% rubber, and 10% rubber-doped epoxy composites as 3.1924 GPa, 3.3706 GPa, 2.7319 GPa, and 2.44 GPa, respectively. With the addition of HNT to the epoxy matrix, respectively, 6.4133% and 12.3533% increment is observed. With the addition of rubber to the epoxy matrix, the modulus of elasticity dropped by 8.9367% and 18.6667%, respectively.

In their study, Sheng et al. compare the Halpin-Tsai and Mori Tanaka models of polymer/clay nanocomposites and found that both models showed similar trends. In contrast, the Halpin Tsai model gives stiffer results. They note that acceptable data for effective stiffness are obtained with the Halpin-Tsai model. Still, the Mori-Tanaka models obtain the best reinforcement results with a large aspect ratio [17]. Another study pointed out that the Halpin-Tsai method gives possible results at low volume fraction values [18].

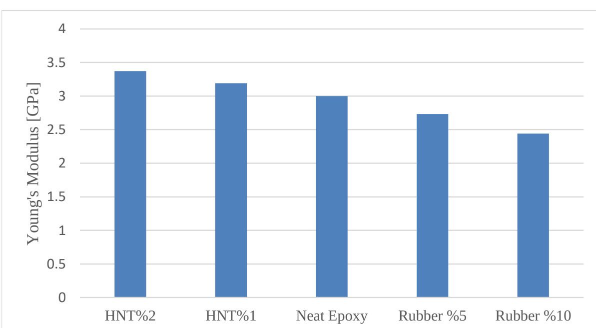

Fig. 2. The elasticity modulus of materials obtained with the Halpin-Tsai approach.

When the results of this study are compared with the studies in the literature, it is also observed that the addition of HNT by weight to the epoxy matrix increases the elasticity modulus of the epoxy composite and rubber addition by weight to the epoxy matrix reduces the modulus of elasticity of the epoxy composite [19, 20].

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IV. CONCLUSION

This study aims to predict the effects of reinforcement elements on the mechanical properties of the composite matrix by numerical modeling methods. For this purpose, models are made with Halpin-Tsai, and Mori-Tanaka approaches, and results are obtained. In the light of the obtained values, it is observed that HNT reinforcement increases the elastic modulus of the epoxy composite. In contrast, rubber reinforcement decreases the elastic modulus of the epoxy composite. To conclude, it can be said that in cases where material stiffness is desired, it is preferable to use HNT-reinforced epoxy composites.

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