UPPER AND LOWER LIMITS IN THE ELASTIC PROPERTIES OF LOW-SHRINK SHEET MOLDING COMPOUNDS

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Summary The aim of the paper is to determine the upper and lower limits of the homogenized elastic coefficients for a 27% fibers volume fraction Low-Shrink Sheet Molding Compund (LS-SMC) based on a homogenization method as well as to compute four averages of the Young's and shear moduli of various LS-SMCs with different fibers volume fractions. A comparison between these limits and the experimental data is presented. These averaging methods show that for a 27% fibers volume fraction LS-SMC, the arithmetic mean of the computed Young's and shear moduli give close values to those determined experimentally.

INTRODUCTION

The most obvious mechanical model which features a multiphase composite material is a pre-impregnated material, known as prepreg. In the wide range of prepregs the most common used are Low-Shrink Sheet Molding Compounds. A Low-Shrink Sheet Molding Compound (LS-SMC) is a pre-impregnated material, chemically thickened, manufactured as a continuous mat of chopped glass fibers, resin (or matrix), filler and additives, from which blanks can be cut and placed into a press for hot press molding. The result of this combination of chemical compounds is a heterogeneous, anisotropic composite material, reinforced with discontinuous fibers [1]. A typical LS-SMC material is composed of the following chemical compounds: calcium carbonate, chopped glass fibers roving, unsaturated polyester resin, low-shrink additive, styrene, different additives, pigmented paste, release agent, magnesium oxide paste, organic peroxide and inhibitors in various volume fractions. The matrix system plays a significant role within a LS-SMC, acting as compounds binder and being "embedded material" for the reinforcement. To decrease the shrinkage during the cure of a LS-SMC prepreg, filler have to be added in order to improve the flow capabilities and the uniform fibers transport in the mold. For materials that contain many compounds, an authentic, general method of dimensioning is difficult to find. In a succession of hypotheses, some authors tried to describe the elastic properties of SMCs based on ply models and on material compounds [2-4]. Theoretical researches regarding the behavior of heterogeneous materials lead to the elaboration of some homogenization methods that try to replace a heterogeneous media with a homogeneous one [5]. The aim is to obtain a computing model, which takes into account the microstructure or the local heterogeneity of a material.

APPLICATION

In the case of a LS-SMC composite material which behaves macroscopically as a homogeneous elastic environment, is important the knowledge of the elastic coefficients. For this material is preferable to estimate these homogenized coefficients between an upper and a lower limit. Since the fibers volume fraction of common LS-SMCs is 27%, an ellipsoidal inclusion of area 0.27 situated in a square of side 1 is considered. The plane problem will be considered and the homogenized coefficients will be 1 in matrix and 10 in the ellipsoidal inclusion. We have considered the function $f(x_1, x_2)$ being 10 in inclusion and 1 in matrix. To determine the upper and the lower limit of the homogenized coefficients, first the arithmetic mean as a function of x_2-axis followed by the harmonic mean as a function of x_1-axis must be computed. The lower limit is obtained computing first the harmonic mean as a function of x_1-axis and then the arithmetic mean as a function of x_2-axis. Since the ellipsoidal inclusion of the SMC structure may vary angular up to ± 30° against the axes' centre, the upper and lower limits of the homogenized coefficients will vary as a function of the intersection points coordinates of the ellipses, with the axes x_1 and x_2 of the periodicity cell. We considered both resin and filler system as a distinct phase compound which can be called replacement matrix, so that a LS-SMC can be regarded as a two phase compound material. The Young's modulus of the replacement matrix can be estimated computing the harmonic mean of the basic elastic properties of the isotropic compounds. For the whole LS-SMC structure, the Young's modulus has been determined using the rule of mixtures. The upper limit of the homogenized coefficients can be estimated computing the quadratic mean of these basic elastic properties taking into account the compounds volume fractions. The lower limit of the homogenized elastic coefficients can be estimated computing the harmonic mean of the basic elasticity properties of the isotropic compounds. Intermediate limits between quadratic and harmonic means are given by the arithmetic and geometric means. The longitudinal elasticity moduli for the replacement matrix and for the entire composite have been computed. We have used following functions to compute the upper limit of the homogenized coefficients:

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$$\varphi(x_1) = \int_{-0.5}^{0.5} f(x_1, x_2) dx_2 = 1, \quad for \quad x_1 \in (-0.5; \ -0.45) \cup (0.45; \ 0.5), \tag{1}$$

$$\varphi(x_1) = \int_{-0.5}^{0.5} f(x_1, x_2) dx_2 = 1 + 9.45\sqrt{0.2025 - x_1^2}, \quad for \quad x_1 \in (-0.45; \ 0.45). \tag{2}$$

To compute the lower limit, we have considered $\psi(x_2)$ the harmonic mean of the function $f(x_1, x_2)$ against x_1:

$$\psi(x_2) = \frac{1}{\int_{-0.5}^{0.5} \frac{1}{f(x_1, x_2)} dx_1} = 1, \quad for \quad x_2 \in (-0.5; \ -0.19) \cup (0.19; \ 0.5), \tag{3}$$

$$\psi(x_2) = \frac{1}{\int_{-0.5}^{0.5} \frac{1}{f(x_1, x_2)} dx_1} = \frac{1}{1 - 3.42\sqrt{0.0361 - x_2^2}}, \quad for \quad x_2 \in (-0.19; \ 0.19). \tag{4}$$

The upper limit is obtained computing the harmonic mean of the function $\varphi(x_1)$:

$$a^+ = \frac{1}{\int_{-0.5}^{0.5} \frac{1}{\varphi(x_1)} dx_1} = \frac{1}{\int_{-0.5}^{-0.45} dx_1 + \int_{-0.45}^{0.45} \frac{dx_1}{1 + 9.45\sqrt{0.2025 - x_1^2}} + \int_{0.45}^{0.5} dx_1}. \tag{5}$$

The lower limit will be given by the arithmetic mean of the function $\psi(x_2)$:

$$a_- = \int_{-0.5}^{0.5} \psi(x_2) dx_2 = \int_{-0.5}^{-0.19} dx_2 + \int_{-0.19}^{0.19} \frac{dx_2}{1 - 3.42\sqrt{0.0361 - x_2^2}} + \int_{0.19}^{0.5} dx_2. \tag{6}$$

RESULTS

Typical elasticity properties of the LS-SMC isotropic compounds and the composite structural features in case of a 27% fibers volume fraction LS-SMC are presented as input data in the theoretical approach. For the unsaturated polyesther resin, following data have been used: Young's modulus: < 7 GPa; shear modulus: < 5 GPa; volume fraction: 30%. For glass fibers: Young's modulus: < 80 GPa; shear modulus: < 50 GPa; volume fraction: 27%. For filler: Young's modulus: < 60 GPa; shear modulus: < 30 GPa; volume fraction: 43%. The longitudinal elasticity moduli for the replacement matrix and for the entire composite have been computed. We noticed that the Young's modulus for the entire composite is closer to the experimental value unlike the Young's modulus for the replacement matrix. This means that the rule of mixtures that we have used give better results than the inverse rule of mixtures. The results show that the upper limit of the homogenized coefficients decreases with the increase of angular variation of the ellipsoidal inclusion unlike the lower limit which increases with the increase of this angular variation. Quadratic, arithmetic, harmonic and geometric averaging methods of Young's and shear moduli of various LS-SMCs with different fibers volume fractions have been determined. These used averaging methods show that for a 27% fibers volume fraction LS-SMC, the arithmetic mean of the computed Young's and shear moduli give close values to those determined in simple tensile tests.

CONCLUSIONS

The results suggest that the environmental geometry given through the angular variation of the ellipsoidal domains can lead to different results for same fibers volume fraction. This fact is due to the extreme heterogeneity and anisotropy of these materials. The upper limits of the homogenized elastic coefficients are very close to experimental data, showing that this homogenization method give better results than the computed Young's modulus of the composite determined by help of the rule of mixtures. The proposed estimation of the homogenized elastic coefficients of Low-Shrink Sheet Molding Compounds can be extended to determine elastic properties of any multiphase, heterogeneous and anisotropic composite material.

References

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