Material law for numerical analysis of rapid prototype products

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INTRODUCTION

The rapid prototyping is one of the most increasing segment of the engineering scients. In the last decade appeared numerous different method to rapid prototyping. These methods brought many advantages. To manufacturing with these methods we can work much more efficient. The products more accurate, its costs are reduced, and the time of the preparation is shorter. Thanks to these developed, the role of prototypes has increased considerably, especially that of the functional prototypes, the rapid toolings and the small series production .

FINAL ELEMENT ANALYSIS

Nowadays the prototypes appear in a fairly early phase of planning. There are the so-called digital prototypes, which are 3D models used by CAD/CAM/CAE softwares. Through these models the shape can be seen, and we can perform final element analysis on them regarding the possible constraints and loads.

Realising that the demand for functional prototypes and the use of built-in rapid prototypes in small series production and medical science have increased significantly, it became necessary to be able to tell whether the certain model can be used in its real loads conditions. In more complicated cases we have to use final element analysis to carry out this

For the final element analysis we need a 3D CAD model and we have to know the constraints and loads depending on the environment, moreover, we need the material law which, in the case of a linearly elastic model, means that we have to know the Young modulus and the Poisson's ratio. To examine the non-linear behaviour depending on time we have to specify further material properties.

It is important to mention that in the case of a model with unknown material properties the results have to be verified by experiments done on real models, the defined material law can be applied only after this verification.

The main goal of this paper which of the material properties of the rapid prototyping model have to be used for final element analysis. We will concentrate to the linear elastic area(real working area), where we look on constant the Elastic modulus (E) and the Poisson's ratio (υ), none the less those aren't constants.

The basic equation of the final element method is :

$$\underline{K}\,\underline{u}=\underline{F}$$

where $\underline{K}$ is the modified stiffness matrix of the body, $\underline{u}$ is the vector of nodal translations, and $\underline{F}$ is the generalized vector of the loads.

To solve this equation we have to known the real loads, which depend on the environment. We have to known the parameters of the stiffness matrix too. These parameters are depended on the constraints and the material properties. In general case (linear static analysis) is that means the Young modulus (E) and Poisson's ratio (υ).

But now, we have to analyse rapid prototype models. It has to known something about the procedure of the manufacturing of these models. The rapid prototype technologie is builds the solid body layer by layer. This is the main cause, that the material properties are differents in the principal material directions.

MATERIAL PROPERTIES

Isotropical material properties

In the isotropical case the material properties are independent from the directions. The Hooke's law which makes a relative between the stresses and strains. The Hooke's law :

$$\sigma = E\varepsilon$$

where σ the stress, E is the Elastic modulus, ε is the strain.
The shear modulus (G) is determinable by the Young modulus and the Poisson's ratio.

$$G = \frac{E}{2\cdot(1+\nu)}$$

Its shows us that we need two independent constants (material properties) to analyse an isotropical model.

Orthotropical material properties

The orthotropical materials are special type of the anisotropical materials. There are 2 or 3 principal directions, which have different material properties. The generalized Hooke law for orthotropical materials is

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{21} & S_{22} & S_{23} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & S_{66} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix}$$

where ε_1, ε_2, ε_3 are the strains into the 1,2,3 principal directions,
γ_{ij} $(i\neq j)$ represents engineering shear strain
σ_1, σ_2, σ_3 are the principal stresses,
τ_{ij} $(i\neq j)$ are the shear stresses
$\underline{S}_{ij}$ is the stiffness matrix,

$$[S_{ij}] = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}$$

In the stiffness matrix E_1, E_2, E_3 are the Young modulus in 1, 2, and 3 directions respectively
υ_{ij} is the Poisson's ratio for transverse strain in the j-direction when stressed in the i-direction
G_{ij} are the shear modulus in the ij planes
in addition : $S_{ij}=S_{ji}$
These relations showed that there are 9 independent constants need to represent an orthotropical material.

THE EXAMINATION OF A MATERIAL

From the OBJET technology, where the acrylic-based photopolymer used as basic material polymerizes drop by drop, we can presume isotropic material properties.
We would like to decide that material has isotropical or orthotropical properties?

The tensile specimen is standard size, it is 4mm thick and the material it is made of is the above-mentioned acrylic-based photopolymer.
The tensile specimen was manufactured by Varinex Rt. in two building directions.

RESULTS

Fig. 1 shows us the significally differents between the elongations at rupture and the Young moduluses. Since the direction of the tensile was perpendicular to both building directions, it can be presumed that the material may also give a different result when it is built in another direction which is perpendicular to these building directions.

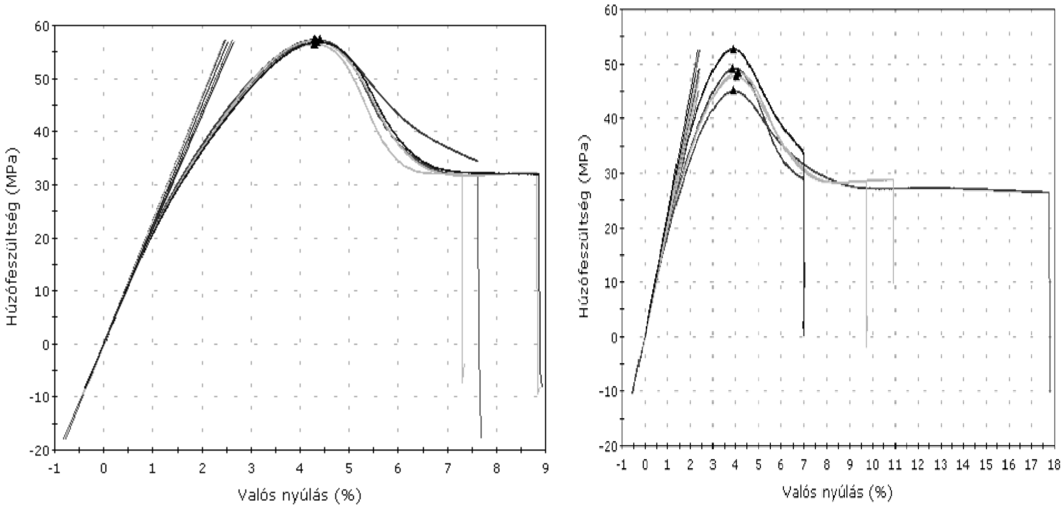

Figure 1: The results of the tensile test in two direction.

REFERENCES

[1] P. Ficzere, L. Borbás, The specification of the material properties of products made by rapid prototyping to be used in finite element analysis. GÉP (in Hungarian), 10-11 (2009) 36.