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GFPR composite, wood-fiber-polyester resin composites, homogenization methods, Digimat software

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THE POSSIBILITY OF USING WOOD FIBER MATS IN PRODUCTS MANUFACTURING MADE OF POLYMER COMPOSITES BASED ON NUMERICAL SIMULATIONS

Abstract

In this work the calculations for predicting the properties of wood fiber mats – polyester resin composite using numerical homogenization method were performed. For this purpose, the microstructural strength properties were calculated using DIGIMAT FE commercial code. In addition, for comparative purposes a calculation of polyester resin – glass fiber composites was conducted. This allowed to compare the properties of two types of compositions. In addition, the obtained strength properties were used to simulate the work of product made of these composites. This study was performed using the Ansys commercial code. Usability of the polyester resin – wood fiber mat composite and knowledge of its properties will allow to find a correct application of this composite type and can provide an alternative way to other polymeric resin reinforced by mat.

1. INTRODUCTION

The polymer composites based on natural fibers are widely used in manufacturing of products from many areas of life. Increasingly, due to the care for environmental purity, the natural fibers can replace other fibers (for example: glass fibers) in production of composites, in the areas of life where it can be done because of their strength and economical or aesthetic reasons.

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Natural fibers are used to produce the composites on the basis of phenolic, epoxy, polyester, vinyl ester and thermoplastics resins (Thakur & Thakur, 2014). The resins used to manufacture the natural fibers reinforced composites have a polymer structure modified to make it more polar in nature, making it more hydrophilic, and therefore it could interact or bond better to the OH groups on the surface of the natural fibers (Aziz, Ansell, Clarke & Panteny, 2005). Synthetic resins are widely used, for example, as a component of paints and adhesives joints too (Kubit, Bucior & Zielecki, 2016; Zielecki, Kubit, Kluz & Trzepieciński, 2017).

Among many natural fibers the cellulose fibers are primarily important. The composites based on natural cellulose fibers find applications in a number of fields ranging from automotive to biomedical. Natural cellulose fibers have been frequently used as the reinforcement component in polymers to add the specific properties in the final.

A large share of the market among cellulose fibers are WPC composites. A large proportion of wood waste has been used for years. On a wide scale, in the production of polymer products the wood particles or even sawdust are used. The share of wood fibers is smaller due to higher manufacturing costs (Campilho, 2015). The wood fibers have been used for many years in the production of polymer composites on the basis of polymers such as PVC, ABS, PP or PA. However, there are short fibers up to 1–2 mm from softwood and 3–7 mm from hardwood (Rowell, 2013). Such fibers are used in construction, automotive, aerospace industries, household products and furniture, mainly to manufacture interior components (Ho, Wang, Lee, Ho, Lau, Leng & Hui, 2011). Major processing technologies include extrusion and injection molding (Ho, Wang, Lee, Ho, Lau, Leng & Hui, 2011; Klyosov, 2007; Kutnar & Muthu, 2016).

The manufacturing of composites based on long wood fibers is limited. Long wood fibers are mainly used in manufacturing of reinforcing road mats so-called anti-erosion which are used in the construction of motorways and expressways, primarily to reinforce shafts, high slope slopes and road embankments. These mats provide high water permeability, can stabilize the substrate humidity, exhibit sufficient mechanical strength and biodegradability after a short period of time, are characterized by high thermal and acoustic insulation. They help (in the natural way) of settling vegetation (grasses, shrubs) in a new environment, preserving the terrain established in the road project.

The wood fiber geometry, specifically in varied shape of its cross section and the small smoothness of the fibers (the lateral surface is strongly frayed) does not allow the yarn to be made. These fibers are long enough to be used in the production of the mat. Such mats can also be used to reinforce laminates. The work suggest to perform these tests, thanks to the performed numerical analysis of laminates reinforced with wood fiber mat. In order to predict the composites properties, the homogenization methods, among others, are used.

The limitations encountered with the use of analytical homogenization methods require additional calculation methods. Therefore, in recent years numerical methods of direct calculation of effective material data have become increasingly numerous and significant (Bendsøe & Kikuchi, 1988). Most of these methods are only developed with respect to the linear strain range – the range of small deformations. Due to the growing calculating power of computers, several methods have been developed to predict the nonlinear behavior of composite material. Numerical calculations can be performed in 2D space, where discretization is most often used to divide the area into triangles. This solution allows to calculate the values that appear in the cross section of material. However, there are some constraints resulting from the specificity of the solution to the problem (e.g. flow direction only penetrating the modeled surface, etc.) (Abdulle, 2013). Due to the advancement of computer technology in most recent years, more simulation packages are equipped with the ability to solve 3D problems. Discretization usually consists in dividing the area into tetrahedrons finite elements (FE). Such modeling is devoid of the fundamental limitations of 2D technology but is much more demanding in terms of memory and computing power. One of the main types of FE used in microstructural calculations are Voxel finite elements (Doghri & Tinel, 2006). This type of finite element is a regular, incompatible set of brick elements. Each element is assigned to the phase material where its center is located. It is targeted for advanced RVE where discretization is difficult to reproduce the shape of matrix and analyzed inclusions (e-Xstream engineering, 2016).

2. CALCULATIONS

In the presented work, the standard properties of wood fiber and polyester laminate were considered. Numerical analyzes were carried out to predict the suitability of this type of fiber in production of composite products.The strength analysis was performed taking into account the properties of the composite, which were defined by homogenization methods. The strength analysis was made for the assumed geometric model of the product. The example of seat model, used in public transport vehicles, were analysed. The results of the strength calculations were compared with the results obtained for the fiberglass laminate on the base of the same resin.

2.1. Calculation of polyester resin – glass fibre variant of composite

Stage I

The first analysis was performed for polyester resin – glass fiber composite, especially for OCF M8610 glass fiber mat grade. This type of mat has been the subject of many research papers (Kim & Macosko, 2000; Dominguez & Rice, 1983; Hedley, 1994; Frącz, Janowski & Ryzińska, 2017). The first phase calculations were done for beam roving (thickness of 140 μm) from S glass fiber (Tab. 1). An RVE size of 0.075 mm x 0.075 mm x 0.075 mm was assumed in the calculations, taking into account parallel arrangement of the roving fibers (Fig. 1). Preliminary calculations were performed for the composition of glass fiber-air (wt. glass fiber content was approx. 99.98%), which allowed calculation of the yarn properties (Tab. 2), directly used to build the glass mat model.

Tab. 1. Properties of S-glass fiber used in calculations

Property	Unit	Value
Fiber diameter	μm	15
Density	kg/m^3	2490
Young's modulus	MPa	85500
Poisson's coefficient	–	0.22

a) b)

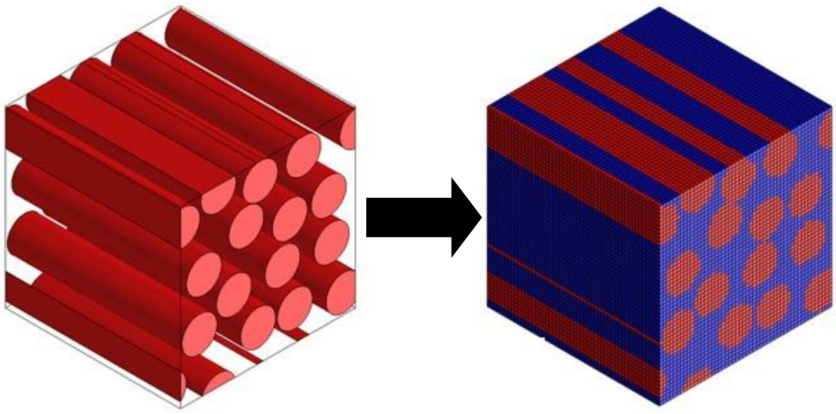

Fig. 1. Visualization for beam roving S glass fiber: a) location of fibers in RVE b) RVE after discretization of 125 000 Voxel FE (Voxel size for single cell 0.0015x0.0015x0.0015 mm)

Tab. 2. Mechanical properties of beam roving calculated by means of Digimat FE

Property	Unit	Value
Density	kg/m^3	1892.69
Young's modulus E1	MPa	130834
Young's modulus E2	MPa	123067
Poisson's coefficient v12	–	0.2699
Poisson's coefficient v21	–	0.2539
Kirchhoff's modulus	MPa	47407

Stage II

During the second stage of the calculation for the glass mat saturated with polyester resin the roving bundle data (obtained from a prior analysis) and polymer matrix data were implemented (Tab. 3). The beam diameter of yarn equal to 140 μm was assumed as the mean value (Kim & Macosko, 2000). The volume fraction of the glass mat in the composite was also determined (11.97 %), and a random fiber orientation in the plane (the orientation type in Digimat FE software: Random 2D) was defined. Based on the geometric data of glass mat, the representative RVE with dimensions of 1.8 x 1.8 x 1.8 mm was generated (Fig. 2), which was discretized by 2 125 364 voxel type FE – (size of a single voxel: 0.014x0.014x0.014 mm) and then the calculations of composite properties were made, whose results are summarized in Tab. 4. The results of the calculations are in accordance with the results contained in the publication (Trevino, 1991).

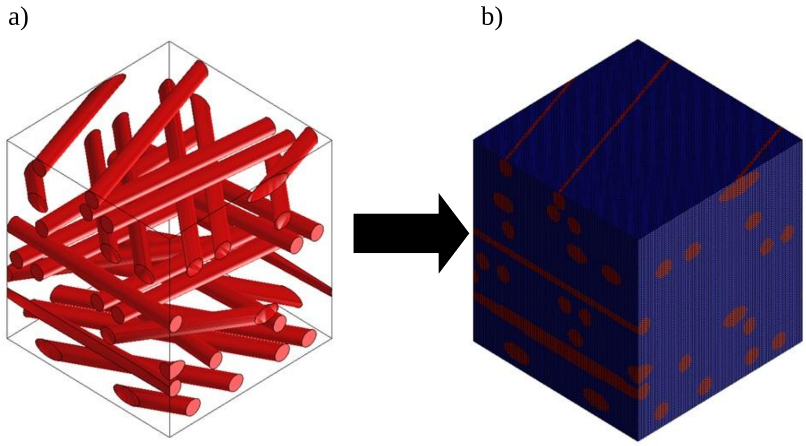

Fig. 2. Visualization of yarn: a) orientation of glass mat saturated with polyester resin, b) RVE glass mat with polymer matrix after discretization

Tab. 3. Properties of polyester resin [13]

Property	Unit	Value
Density	kg/m^3	1200
Young's modulus	MPa	4000
Poisson's coefficient	–	0.4

Tab. 4. Properties for calculated composition: glass mat – polyester resin

Property	Unit	Value
Density	kg/m^3	1282.83
Young's modulus E1	MPa	9745.89
Young's modulus E2	MPa	9568.16
Young's modulus E3	MPa	6586.12
Poisson's coefficient v12	–	0.3298
Poisson's coefficient v21	–	0.3238
Poisson's coefficient v13	–	0.4174
Poisson's coefficient v31	–	0.2821
Poisson's coefficient v23	–	0.4231
Poisson's coefficient v32	–	0.2913
Kirchhoff's modulus G12	MPa	3059.64
Kirchhoff's modulus G23	MPa	1857.91
Kirchhoff's modulus G13	MPa	1849.61

2.2. Calculation of polyester resin – wood fibre variant of composite

The basic properties of wood fiber in the analyzed composite were established on the basis of literature (Autodesk Moldflow Insight, 2013) (Tab. 5). Polymer matrix data were implemented from previous analysis (Tab. 3).

Tab. 5. Properties of wood fiber used in calculations

Property	Unit	Value
Fiber diameter	μm	100
Density	kg/m^3	2000
Young's modulus	MPa	10000
Poisson's coefficient	–	0.3

For the correct comparative analysis, the same parameters for fiber content and RVE dimensions (Tab. 6.) were chosen, relative to the previous analysis. Visualization for polyester resin – wood fiber composite is presented in Fig. 3.

Tab. 6. The input data for micromechanical analysis of polyester resin – wood fiber mat composite, using Digimat FE

Fiber volume content	11.97%
RVE dimensions	1.8 x 1.8 x 1.8 mm
The type of fiber orientation	Random
Type of FE elements	Voxel
Number of FE elements	2 125 364
Size of a single voxel	0.014x0.014x0.014 mm

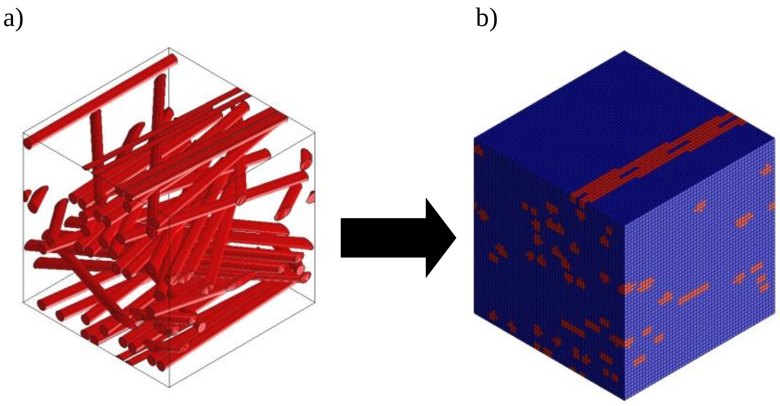

Fig. 3. Visualization for polyester resin – wood fiber composite: a) location of fibers in RVE b) RVE after discretization

The results of performed calculations are summarized in Tab. 7.

Tab. 7. The calculated properties of polyester resin – wood fiber mat composite

Property	Unit	Value
Density	kg/m^3	1295.76
Young's modulus E1	MPa	4512.58
Young's modulus E2	MPa	4610.48
Young's modulus E3	MPa	4507.64
Poisson's coefficient v12	–	0.3812
Poisson's coefficient v21	–	0.3895
Poisson's coefficient v13	–	0.3982
Poisson's coefficient v31	–	0.3977
Poisson's coefficient v23	–	0.3887
Poisson's coefficient v32	–	0.3801
Kirchhoff's modulus G12	MPa	1630.67
Kirchhoff's modulus G23	MPa	1597.50
Kirchhoff's modulus G13	MPa	1587.73

Moreover, additional calculations were performed to increase the percentage volume content of wood fibers in the polymer matrix: by about 24% and 36%. As it can be seen (Fig. 4.) by increasing the fiber contents in the polymer matrix, the Young's modulus does not increase linearly.

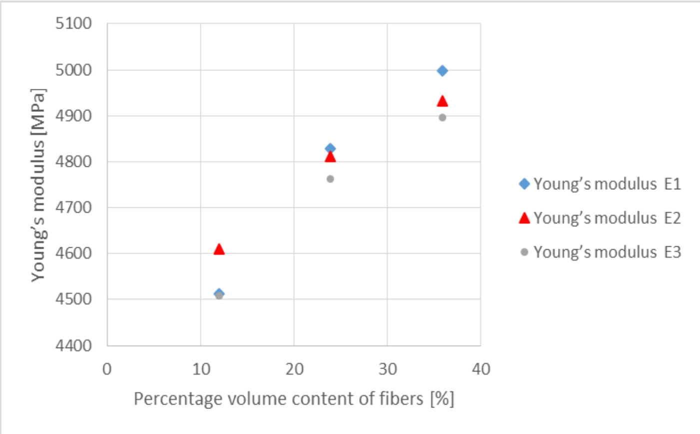

Fig. 4. The predicted Young's modulus for variable volume content: 12%, 24% and 36% of wood fiber

2.3. Strength analysis of product for reinforcement variants

The results of property calculations for heterogeneous composites make it possible to perform advanced numerical analyzes, taking into account the behavior of products made of composites under loads. For this purpose, load simulations of a car seat used as equipment in public transport vehicles were conducted. Numerical analysis was performed for three variants of reinforcement: a) polyester resin without reinforcement, b) polyester resin with glass fiber mat, and c) polyester resin with wood fiber mat. During the simulations, due to computational difficulties related to the composite model, only a single reinforcement layer was taken into account. The thickness of the real fabric layer was 0.96mm. The thickness of the real mats layer was 1.5mm. The geometric model of the seat (610 x 458 x 565 mm, thickness of 3mm) was designed by means of NX9 software. It was assumed that the seat would be equipped with a metal connector attached to the vehicle floor by means four screws. The complete seat model was imported to Ansys ver. 14.5 commercial code to carry out behavior numerical analysis under load. The analysis was performed in terms of static loads. The boundary conditions (Fig. 5), i.e. the load assumed by the seat surface (F_1 = 1000 N) and the force acting on the bearing surface (F_2 = 300 N) were introduced. Between the bottom of the car seat and the upper surface of the metal connector a displacement of 0.5 mm was allowed, which represented the clearance resulting from the assembly of components (the seat and the connector) using screws. The lower surface of the connector was fixed. The next step was to introduce the composite properties for the three reinforcements variants to the software. Due to the anisotropic properties of the mats and fabrics, calculations by means of the Ansys code were carried out in the local coordinate systems of the seat and backrest. They were carried out in order to take into account the material properties of properly oriented reinforcement. It was assumed that the screws and connector were made of steel.

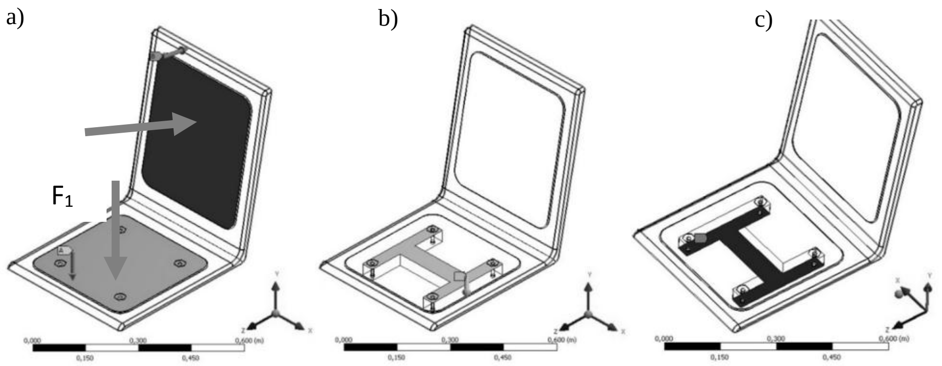

Fig. 5. Boundary conditions and loads: a) forces applied to seat surface and backrest, b) fixed displacement between lower seat surface, and connector, c) lower restraint surface

In the performed simulations of seat load, the comparison criterion was the maximum deflection of the backrest. As shown in Fig. 6 the greatest amount of deflection was found, which is evident in the case of the resin without reinforcement. For the composites reinforced by glass mat and wood mat, deflecttions of 80 mm and 150 mm were obtained. For the chair without reinforcement the largest deflection was 160 mm.

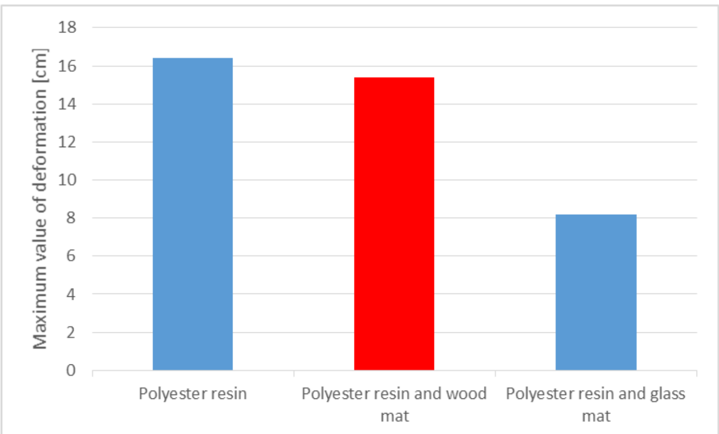

Fig. 6. The maximum deflection of seat backrest for three variants of material

3. RESULTS ANALYSIS

The results of load simulation for the model of passenger seat (for two types of composite: with wood and glass fiber reinforcement) show that the hypothetical using of wood fiber mat affects only slightly the reduction of seat backrest deflection compared to pure polyester resin. In the case of glass fiber mat the deflection can be reduced up to approx. 100% compared with a product made without reinforcement.

An increase in the percentage of wood fibers in the analyzed composite improves slightly the composite stiffness. An increase of the fiber percentage from 12% to 36% vol. content causes a growth of Young's modulus value about 5%.

4. CONCLUSIONS

The mechanical properties of wood mats – polyester resin composites (WPC) were predicted using numerical homogenization methods. For this purpose it was important to introduce the strength and geometry data of the fiber and matrix.

The use of numerical homogenization methods during strength calculations by means of Digimat commercial code allows to take into account the actual geometry data and properties of components in composite structure.

Two-step calculations for wood and glass mats saturated with polyester resin must be performed: one for beam roving, and subsequently for the representative area of mats saturated with resin.

In the case of numerical homogenization, an additional significant step was the design of RVE that reflected the heterogeneous structure of the composite. Appropriate sizing of RVE and voxel FE mesh allow to receive very high compliance between the results of the calculated grammage of glass mat composite and literature data.

In the case of taking into account the only mechanical properties, neglecting ecological and economic aspects the using of wood mat-polyester resin composites will be ineffective.

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