The Curing Simulation And Prediction Of Shape Distortion Of Thermoset Composite Reinforced With 3d Woven

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Abstract. The general modeling methodology for thermoset composite reinforced with 3D woven is described. In this study the focus is on the curing simulation and prediction of shape distortion for thermoset composites in ABAQUS with user subroutines. The procedure of homogenization and determination of effective properties of a thermoset composite reinforced with 3D woven for the rubbery and glassy state of the matrix is also described in detail. Depending on the thermoset polymer type, the different cure reaction formulations are implemented. The temperature expansion and chemical shrinkage tensors at each time step are set depending on the degree of cure and the glass transition temperature. Curing model with piecewise constant elastic modules is used. The model takes into account the shape distortion of the part due to chemical shrinkage and thermal expansion of the material. Curing simulation and prediction of shape distortion results for U-shaped part for Kamal-Sourour reaction type is presented. The effective properties of the composite reinforced with 3D woven for the rubbery and glassy states of the matrix are obtained.

1. Introduction
Polymer composite materials (CM) are widely used in various fields. Recently, there has been a significant increase in the research and development of composite reinforced with 3D woven preforms, in particular, to develop Gas Turbine Engine fan blades and housings (LEAP, GE9X engine blades) [1]. The 3D woven composites are highly resistant to delamination and impact due to reinforcement out-of-plane.

Nomenclature

| CM   | composite material |
| UD   | unidirectional     |
| UC   | unit cell          |
| i,j  | axis of the orthogonal coordinate system |
| Eij  | effective Young's modulus |
| vij  | effective Poisson's ratios |
| Gij  | engineering shear strain |
| <>   | denotement of averaging |
There are many methods and some software for 2D textile composite manufacturing modelling. However, there is dearth of similar engineering methods and software for 3D textile composites. In particular, the literature describes the use of averaging techniques to obtain elastic properties, coefficients of linear thermal expansion and chemical shrinkage for UD fiber laminates based on...
micromechanical approach [2]–[4]. 3D woven composites with various textile architecture require the development of new averaging techniques.

Also, various manufacturing defects may appear during the manufacturing process, in particular, unplanned part shape distortion as a result of curing of the thermoset matrix. The mechanical behavior of UD fiber laminates and 2D woven composites as a result of curing is well studied and presented in many publications.

Numerical implementation of the model for prediction of the degree of cure, the associated heat and temperature increase of undiluted polymer resin is presented in [5]. J. Zhang, Y. C. Xu and P. Huang studied the influence of temperature cure cycle have on the temperature and degree of cure gradient [6]. In [7], [8] numerical discretization methods of the kinetics equations for adhesives are described. J. Magnus Svanberg and J. Anders Holmberg an approach for prediction of shape distortion for different constitutive models is presented [9]. J. Magnus Svanberg and J. Anders Holmberg analyzed results of the kinetics equations for adhesives are described. J. Magnus Svanberg and J. Anders Holmberg an approach for prediction of shape distortion for different constitutive models is presented [9]. Modeling of residual strains for the pultrusion of composite beam is described in [10]. In [11] M.V. Kozlov et al. consider the main causes of shape distortion, conduct a comparative analysis of mathematical models of curing and offer mechanical contact between the part and the tool, which changes during the solution. M.V. Kozlov et al. using the constitutive relations of CHILE (cure hardening instantaneously linear elastic) and Svanberg models modeled the influence of tool on the shape distortion [12].

The overall goal of our work is development of modelling approach for manufacturing process of composite materials with 3D woven preforms and a thermosetting matrix. It includes integrated techniques and algorithms with wide possibilities for automation and solving optimization problems. Now we propose to use a complex of CAE solutions, including commercial packages ANSYS CFX (or ANSYS Fluent), ABAQUS and proprietary FORTRAN and Python codes. In this paper a general modelling strategy for thermoset composite reinforced with 3D woven and in more detail results of the thermoset composite curing simulation and prediction of shape distortion are presented. The issue of homogenization and determination of the effective properties of CM with 3D fabric reinforcement is considered.

2. General approach description

Now our approach the manufacturing modelling of 3D woven composites includes the following main steps:

1) Creating of geometrical and finite element models of unit cell (UC) for a dry undeformed 3D woven.
2) Determination of the effective elastic properties of UC for a dry undeformed 3D woven.
3) Draping and compaction simulation of textile on a tool surface with using effective properties from step 2.
4) Dividing the textile into the finite number of regions where shear strain obtained in step 3 belongs to given range.
5) Shear strain averaging for regions obtained in step 4.
6) Application of shear loading obtained in step 5 to the dry undeformed UC.
7) Determination of the permeability tensor components for deformed UC from step 6.
8) Modelling of textile preform impregnation for part with different permeability regions.
9) Homogenization and effective property’s determination of the composite material for the rubbery and glassy matrix state for deformed UC obtained in step 6.
10) Transient heat transfer and cure kinetics modelling for part using effective elastic properties from step 9.
11) Residual stresses and strain determination for part, prediction of part shape distortion.

3. Homogenization procedure and effective properties determination

To determine the residual strains and stresses, it is necessary to obtain the effective properties of the 3D-woven composite material (Fig. 1) after impregnation for various states of the matrix during the curing cycle.
Since the yarns of the reinforcing preform are composed of filaments, the effective properties of the threads for the rubbery and glassy states of the matrix are first calculated. In general, reinforcing fibers are not isotropic. Glass fiber is isotropic, carbon fiber is orthotropic. In this study, the filaments and matrix were assumed to be isotropic, with the same material properties in all directions. The UC for homogenization is shown in Figure 2. The volume fraction of filaments was taken to be 76% for both matrix states.

Figure 2. Finite-element model of the UC of the CM (filament and matrix).

The effective constitutive relations for an orthotropic heterogeneous medium in the orthogonal coordinate system \(0X_1X_2X_3\) have the form [13]:

\[
\begin{align*}
E_1^* \langle \varepsilon_{11} \rangle &= \langle \sigma_{11} \rangle - v_{12}^* \langle \sigma_{22} \rangle - v_{13}^* \langle \sigma_{33} \rangle \\
E_3^* \langle \varepsilon_{33} \rangle &= -v_{31}^* \langle \sigma_{11} \rangle - v_{32}^* \langle \sigma_{22} \rangle + \langle \sigma_{33} \rangle \\
G_{12}^* \langle \gamma_{12} \rangle &= \langle \sigma_{12} \rangle; \quad G_{23}^* \langle \gamma_{23} \rangle = \langle \sigma_{23} \rangle; \quad G_{31}^* \langle \gamma_{31} \rangle = \langle \sigma_{31} \rangle
\end{align*}
\]  

The equations (1) contain 12 effective elastic constants \(E_1^*, E_2^*, E_3^*\) – effective Young’s modulues; \(v_{12}^*, v_{23}^*, v_{31}^*, v_{21}^*, v_{32}^*, v_{13}^*\) – effective Poisson’s ratios; \(G_{12}^*, G_{23}^*, G_{31}^*\) – effective shear modules; effective Young's modules and effective Poisson's ratios are related by the equalities:

\[
E_1^* v_{21}^* = E_2^* v_{12}^*; \quad E_2^* v_{32}^* = E_3^* v_{23}^*; \quad E_3^* v_{13}^* = E_1^* v_{31}^*
\]  

Therefore, the number of independent elastic constants for a macroscopically orthotropic heterogeneous medium is 9.

To determine the unknowns, six problems are solved in the finite element formulation for each state of the matrix. The statement of all tasks is shown in Figure 3.
Figure 3. Applying boundary conditions to a UC.

In tasks 1-3 (Fig. 3), we calculate the average tensors of microstresses and microstrains, averaging the stresses and strains obtained at the nodes, respectively. Next, using the system of governing equations (1) and the relationship between Young's modules and Poisson's ratios (2), we find expressions for determining the effective Young's modules and Poisson's ratios (3):

\[
E_i^* = \frac{\langle \sigma_{11}^{(1)} \rangle - \sigma_{12}^* \langle \sigma_{22}^{(1)} \rangle - \sigma_{13}^* \langle \sigma_{33}^{(1)} \rangle}{\langle \varepsilon_{11}^{(1)} \rangle},
\]

\[
E_2^* = \frac{-\sigma_{21}^* \langle \sigma_{11}^{(2)} \rangle + \sigma_{22}^* \langle \sigma_{22}^{(2)} \rangle - \sigma_{23}^* \langle \sigma_{33}^{(2)} \rangle}{\langle \varepsilon_{22}^{(2)} \rangle};
\]

\[
E_3^* = \frac{-\sigma_{31}^* \langle \sigma_{11}^{(3)} \rangle - \sigma_{32}^* \langle \sigma_{22}^{(3)} \rangle + \sigma_{33}^* \langle \sigma_{33}^{(3)} \rangle}{\langle \varepsilon_{33}^{(3)} \rangle};
\]

\[
v_{32}^* = \frac{\langle \sigma_{33}^{(2)} \rangle - \sigma_{31}^* \langle \sigma_{11}^{(1)} \rangle / \langle \sigma_{11}^{(1)} \rangle - \sigma_{32}^* \langle \sigma_{22}^{(1)} \rangle / \langle \sigma_{11}^{(1)} \rangle}{\langle \varepsilon_{33}^{(2)} \rangle};
\]

\[
v_{23}^* = \frac{\langle \sigma_{22}^{(3)} \rangle - \sigma_{22}^* \langle \sigma_{11}^{(1)} \rangle / \langle \sigma_{11}^{(1)} \rangle - \sigma_{23}^* \langle \sigma_{33}^{(1)} \rangle / \langle \sigma_{11}^{(1)} \rangle}{\langle \varepsilon_{33}^{(3)} \rangle};
\]

\[
v_{13}^* = \frac{\langle \sigma_{11}^{(3)} \rangle - \sigma_{11}^* \langle \sigma_{22}^{(2)} \rangle / \langle \sigma_{33}^{(2)} \rangle - \sigma_{13}^* \langle \sigma_{33}^{(2)} \rangle / \langle \sigma_{33}^{(2)} \rangle}{\langle \varepsilon_{33}^{(3)} \rangle};
\]

\[
v_{31}^* = \frac{\langle \sigma_{33}^{(2)} \rangle - \sigma_{32}^* \langle \sigma_{33}^{(1)} \rangle}{\langle \sigma_{11}^{(1)} \rangle};
\]

\[
v_{12}^* = \frac{\langle \sigma_{11}^{(2)} \rangle - \sigma_{13}^* \langle \sigma_{33}^{(2)} \rangle}{\langle \sigma_{33}^{(2)} \rangle};
\]

\[
v_{21}^* = \frac{\langle \sigma_{22}^{(1)} \rangle - \sigma_{23}^* \langle \sigma_{33}^{(1)} \rangle}{\langle \sigma_{11}^{(1)} \rangle},
\]

where \(\langle \sigma_{ij}^{(n)} \rangle\) - the volume-average stresses in direction \(ij\) in the problem \(n\), and \(\langle \varepsilon_{ij}^{(n)} \rangle\) - the volume-average strains in direction \(ij\) in the problem \(n\).
From tasks 4-6 (Fig. 3), effective shear modules of the CM are obtained. From the volume-average stresses and the defining equations (1) we obtain the following relations for the shear modules (4):

\[
G_{12}^* = \frac{\langle \sigma_{12} \rangle}{\langle y_{12} \rangle}, \quad \langle y_{12} \rangle = \frac{u_i^*}{h_2} \left( \frac{h_2}{2} \right)
\]

\[
G_{23}^* = \frac{\langle \sigma_{23} \rangle}{\langle y_{23} \rangle}, \quad \langle y_{23} \rangle = \frac{u_i^*}{h_2} \left( \frac{h_2}{2} \right)
\]

\[
G_{31}^* = \frac{\langle \sigma_{31} \rangle}{\langle y_{31} \rangle}, \quad \langle y_{31} \rangle = \frac{u_i^*}{h_2} \left( \frac{h_2}{2} \right)
\]

where \( \langle \sigma_{ij} \rangle \) - the volume-average stresses to direction \( ij \); \( u_i^* \) - displacement to direction \( i \); \( h \) – the initial length of the UC in the direction of shear.

To determine the effective properties of the UC of the 3D woven, nine simulations are carried out, similar to those performed for the UC of the filament, but with the three additional shear calculations due to the completely anisotropic behavior of the 3D woven CM.

Two different yarn materials are considered – with a rubbery and glassy matrix states. The yarn material is defined as an orthotropic material with the properties calculated above. The orientation of the filaments in the yarn for 3D woven composite is shown in Figure 4.

![Figure 4. Orientation of the filaments in the yarn for 3D woven composite.](image)

For a matrix between yarns, properties in rubbery and glassy states are specified. The finite element model of a UC for 3D woven with a matrix is shown in Fig. 5.

![Figure 5. The finite element model of the periodicity cell of the 3D-woven matrix composite material.](image)

Tension in three directions was specified by displacement 0.1 mm to the face, while a restriction on six degrees of freedom was specified on the opposite side. Displacements were applied gradually, increasing according to a linear law.

The application of the boundary conditions to the UC of 3D woven CM and the deformed UC for tension along the x axis is shown in Fig. 6.
Figure 6. The application of the boundary conditions to the UC of 3D woven CM (along the x axis).

The effective Young's module in the X direction is defined as
\[ E_x = \frac{\sigma_x}{\varepsilon_x} = \frac{P/F}{\Delta x/l} \] (5)

where \( P \) is the resulting force in the embedment (the resulting loads from all nodes are summed), \( F \) is the cross-sectional area, \( \Delta x \) is the maximum displacement of the UC, \( l \) is the initial length of the UC in the direction of load application. Similar calculations were performed for tension in the Y and Z directions. To determine the Poisson's ratios in tensile calculations in three directions, deformations in the longitudinal and transverse directions are calculated. Since the material is anisotropic, it will have six different Poisson's ratios in different directions, which are calculated as
\[ \nu_{ij} = \frac{\varepsilon_{jj}}{\varepsilon_{ii}} \] (6)

where \( \varepsilon_{ij} \) – transverse strains, \( \varepsilon_{ii} \) – longitudinal strains.

Shear module are defined as
\[ G_{xy} = \frac{\tau_{xy}}{\gamma_{xy}} = \frac{P/A}{\Delta x/l} \] (7)

The obtained effective properties of the 3D-woven CM for the rubbery and glassy states of the matrix are presented in table 1.

| Property | Unit | Rubbery state | Glassy state |
|----------|------|---------------|--------------|
| \( E_1^* \) | MPa | 7155,9 | 6112,8 |
| \( E_2^* \) | MPa | 320,5 | 298,1 |
| \( E_3^* \) | MPa | 70599,6 | 67120,6 |
| \( \nu_{23}^* \) | | 0,006 | 0,004 |
| \( \nu_{13}^* \) | | 0,098 | 0,040 |
| \( \nu_{12}^* \) | | 0,384 | 0,255 |
| \( \nu_{21}^* \) | | 0,015 | 0,008 |
| \( \nu_{31}^* \) | | 0,015 | 0,008 |
| \( G_{12}^* \) | MPa | 356,2 | 297,0 |
| \( G_{23}^* \) | MPa | 1788,3 | 1679,6 |
| \( G_{31}^* \) | MPa | 966,5 | 904,1 |
| \( G_{21}^* \) | MPa | 1115,7 | 928,9 |
| \( G_{32}^* \) | MPa | 213,2 | 208,3 |
| \( G_{13}^* \) | MPa | 4100,8 | 3927,1 |
4. Cure kinetics simulation and shape distortion prediction

To verify the curing model, a 2D woven reinforced composite was considered. The choice of such a CM is explained by the fact that there are no known results in the literature on shape distortion for 3D reinforced composites. Such a statement of the problem made it possible to qualitatively assess the adequacy of the model and compare the simulation results with literature data. For 2D composites in the transverse direction, the coefficients of linear thermal expansion and chemical shrinkage are much larger than in the plane of the laminate. It is important to note that the developed technique allows predicting shape distortion for 3D reinforced composites with a thermosetting matrix. The difference between 2D and 3D reinforced composites is in the properties of the material after homogenization.

4.1. Main relationships for thermal behavior

The temperature distribution is defined by the heat equation and Fourier’s heat law:

\[ \rho \frac{\partial (C_p T)}{\partial t} = k \vec{\nabla}^2 T + q \]  

(8)

where \( \rho \) is density, \( C_p \) is specific heat capacity, \( T \) is temperature, \( k_{ij} (i,j = 1, 2, 3) \) is the heat conductivity tensor components, \( \vec{\nabla} \) denotes the Laplace operator, \( q \) is internal heat generation rate in a material as a result of an exothermic reaction.

Internal heat generation is defined as:

\[ q = \rho_m H_T (1 - V_f) \frac{dX}{dt} \]  

(9)

where \( \rho_m \), \( H_T \), \( V_f \) and \( dX/dt \) is density of the matrix, total heat released by the matrix during the curing reaction (energy per unit mass), fiber volume fraction, respectively, the chemical reaction rate.

In our algorithm depending on the thermoset polymer type, the following cure reaction formulations are implemented: \( n^{th} \) order, Prout-Tompkins autocatalytic and Kamal-Sourour (Eq. 10-12, respectively) [14]. Which model to use can be determined using DSC (Differential scanning calorimetry).

\[ \frac{d\alpha}{dt} = K(T)(1 - \alpha)^n \]  

(10)

\[ \frac{d\alpha}{dt} = K(T)\alpha^m(1 - \alpha)^n \]  

(11)

\[ \frac{d\alpha}{dt} = (K_1 + K_2\alpha^m)(1 - \alpha)^n \]  

(12)

\[ K(T) = A \cdot \exp \left( \frac{-E_a}{RT} \right) \]  

(13)

where \( K(T) \) – an Arrhenius-type relation for the reaction temperature dependency; \( A \) is the pre-exponential factor; \( m, n \) – model constants; \( E_a \) is the apparent activation energy; \( R \) is the universal gas constant; \( T \) is the temperature.

4.2. Main relationships for mechanical behavior

During cure three states of the matrix are successively replaced – liquid, rubbery and glassy. The process of curing the resin is associated with the appearance of a non-mechanical strains [9]. Non-mechanical strains represent the sum of strains from thermal expansion \( \varepsilon^T_{i,j} \) and from chemical shrinkage \( \varepsilon^C_{i,j} \):

\[ \varepsilon^P_{i,j} = \varepsilon^T_{i,j} + \varepsilon^C_{i,j} \]  

(14)

Thermal strains are defined as:

\[ \varepsilon^T_{i,j} = \int_0^t \alpha_{i,j}(T,X) \frac{\partial T}{\partial t'} dt' \]  

(15)

where the instantaneous coefficients of thermal expansion \( \alpha_{i,j} \) depend on temperature and degree of cure as
\[ \alpha_{i,j} = \begin{cases} \alpha_{i,j}^L & X < X_{gel} \text{ and } T \geq T_g(X) \\ \alpha_{i,j}^T & X \geq X_{gel} \text{ and } T \geq T_g(X) \\ \alpha_{i,j}^G & T < T_g(X). \end{cases} \] 

(16)

where \( \alpha_{i,j}^L, \alpha_{i,j}^T, \alpha_{i,j}^G \) – are linear coefficient of thermal expansion in the liquid, rubbery and glassy states, respectively; \( X \) – degree of cure; \( X_{gel} \) – degree of cure at gelation.

Chemical shrinkage is defined as

\[ \varepsilon_{i,j}^C = \int_0^t \beta_{i,j}(T,X) \frac{\partial X}{\partial t'} \, dt', \] 

(17)

where the instantaneous coefficients of chemical shrinkage \( \beta_{i,j} \) depend on temperature and degree of cure as,

\[ \beta_{i,j} = \begin{cases} \beta_{i,j}^L & X < X_{gel} \text{ and } T \geq T_g(X) \\ \beta_{i,j}^T & X \geq X_{gel} \text{ and } T \geq T_g(X) \\ \beta_{i,j}^G & T < T_g(X). \end{cases} \] 

(18)

where \( \beta_{i,j}^L, \beta_{i,j}^T, \beta_{i,j}^G \) – the linear coefficient of chemical shrinkage in the liquid, rubbery and glassy states, respectively.

The dependence of the glass transition temperature \( T_g \) on the degree of cure \( \alpha \) was defined using the Di Benedetto equation:

\[ \frac{T_g - T_{g0}}{T_{g\infty} - T_{g0}} = \frac{\lambda X}{1 - (1 - \lambda)X}, \] 

(19)

where \( T_{g0} \) and \( T_{g\infty} \) are the glass transition temperature of the uncured (\( X=0 \)), respectively, fully cured system (\( X=1 \)); \( \lambda \) is a material constant.

In [9], [12] the main constitutive relations are given, which serve to describe the curing process of a composite material with a thermosetting matrix. These models describe the material in rubbery and glassy states.

In this paper, we use the defining relations of the elasticity model, in which the modules are piecewise constant and are written as:

\[ \sigma_{i,j} = \begin{cases} C_{i,j}^{R\ell} \varepsilon_{k,l}^{M\ell} & T \geq T_g(X), \\ C_{i,j}^{G\ell} \varepsilon_{k,l}^{M\ell} & T < T_g(X). \end{cases} \] 

(20)

where \( C_{i,j}^{R\ell} \) and \( C_{i,j}^{G\ell} \) components of the elastic modules tensor in the rubbery and glassy states, respectively.

To be able to simulation using the finite element method, we use the direct Euler scheme

\[ \varepsilon_{k,l}^E(t + \Delta t) = \varepsilon_{k,l}^E(t) + \Delta \varepsilon_{k,l}^E, \] 

(21)

where

\[ \Delta \varepsilon_{k,l}^E = \Delta \varepsilon_{k,l}^T + \Delta \varepsilon_{k,l}^C, \] 

(22)

\[ \Delta \varepsilon_{k,l}^T = \alpha_{k,l} \Delta T, \] 

(23)

\[ \Delta \varepsilon_{k,l}^C = \beta_{k,l} \Delta X, \] 

(24)

where \( \Delta T \) and \( \Delta X \) – are the temperature, respectively, degree of cure increment over the time step. According to the article [9] the coefficients for linear shrinkage in the liquid state \( \alpha_{k,l} \) and \( \beta_{k,l} \) are taken as zero.

4.3. Material properties
Resin properties were used from [3]. Table 2 shows the parameters for the kinetic equation (12) of the Kamal-Soro model.

| Property | Unit | Epoxy resin |
|----------|------|-------------|
| m        |      | 0.51        |
| n        |      | 1.49        |
| A₁       | s⁻¹  | 1528        |
| A₂       | s⁻¹  | 1.6         |
| E₁       | kJ/mol | 59.4       |
| E₂       | kJ/mol | 26.3       |
| H₁       | J/kg  | 198.9       |

Elastic properties, coefficients of thermal expansion and chemical shrinkage for 2D reinforced CM were also set based on the data of work [3].

4.4. Finite element simulation
Cure model has been implemented in ABAQUS with using user subroutines HETVAL, UEXPAN, UMAT. User subroutines are implemented in the FORTRAN programming language.
To check the model and FORTRAN code a test simulation for the U-shaped (60×40×20 mm) part was performed. Temperature cure cycle and boundary conditions shown in the Fig. 7a and Fig. 7b, respectively.

![Figure 7](image)

**Figure 7.** (a) Temperature cure cycle; (b) Boundary conditions.

Boundary conditions include constraints, heat transfer coefficient α, heat flux from tool qᵣ. Constraints of the model simulates the location of the part on a tool (iso-static mounting). In virtual tests a cure cycle in the furnace/autoclave and typical heat transfer coefficients on the part and tool surface is specified. Heat transfer coefficients on the surface of the part were taken equal 8 W/(m²·K).
Curing process is modeled using subroutines HETVAL according to equations (9), (12), (13). For this the cure kinetics equation was integrated by the improved Euler's method. The cure degree, cure rate and temperature at each integration point during a cure cycle are defined at each time step. The thermal conductivity tensor components of the composite, specific heat and density of the resin were defined by the functions of the process temperature and degree of cure.
The increment of temperature and shrinkage strains at each time step with using subroutines UEXPAN is specified according to equations (16), (18), (19) and (22)-(24).
The elastic properties of the orthotropic homogenized laminate with using subroutines UMAT are specified. Simulation results presented in the Fig. 8-10 include thermal and mechanical effects. Residual strains are induced by chemical shrinkage during cure and thermal expansion during cooling. The qualitative picture of the deformation corresponds to the experimentally observed decrease in the angle of L-shaped and U-shaped parts [3], [4], [11], [15]. Angular deviation in this work is 1.8 degrees.

![Figure 8. Cure degree (a) and cure rate (b) at the laminate centre point.](image1)

![Figure 9. (a) Cure degree after 17000 s; (b) Displacement (m) after 17000 s (the main contribution to shape distortion is chemical shrinkage).](image2)
5. Conclusions
General approach proposed in this paper permits to modelling the manufacturing process of thermoset composite reinforced with 3D woven. This approach can be used for both 3D textile and 2D textile composites.
A technique for homogenization and determining the effective elastic properties of CM with 3D woven reinforcement for the rubbery and glassy states of the matrix is proposed.
The general methodology for cure simulation and prediction of shape distortion is described. The technique was verified for laminate composites based on literature data.
In further development, it is supposed to clarify the actual distribution and values of the heat transfer coefficients on the part and tool surface by airflow simulation using CFD (ANSYS CFX, ANSYS Fluent). This may be important for products requiring increased manufacturing accuracy, such as reflectors for antennas and radio telescopes.
The literature describes relations for obtaining effective coefficients of linear thermal expansion and chemical shrinkage for CM with 2D woven reinforcement. These relations will not be valid when changing the architecture of weaving, in particular for CM with 3D woven reinforcement. In further development, a methodology will be developed for determining the effective coefficients of linear thermal expansion and chemical shrinkage for CM with 3D fabric reinforcement for different fiber volume fraction. Using these coefficients, an accurate calculation of residual strains can be performed using the proposed methodology for prediction of shape distortion.
In the future work, a tool will be added to the finite element model to more accurately take into account the effect of temperature expansion of the tool on shape distortion, mechanical and thermal contacts between the part and tool.

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