Shrinkage Modeling of Thermoplastic Wing Rib

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Abstract: *During manufacture of parts made of thermoplastic composites in the process of thermoforming liquid of resin transfers to solid-state with occurrence of residual stresses in part which may lead to distortion of the shape of the product. Transition from liquid to solid is called the crystallization process, the reverse process – melting. In order to predict products distortion mathematical modeling techniques are developed. Methods are allowed to evaluate the degree of warpage of the selected design solutions and on the basis of these data to change the process parameters or product design.*

Behavior model of thermoplastic material has been developed by Skolkovo Institute of Science and Technology and then realized in Abaqus user subroutine UMAT.

The paper presents an example of the application of this material model for thermoforming process of the wing rib on the last states of the process – without draping process. The material of the wing rib is Tenax®-E TPCL PEEK-HTA40. Every ply was modeled by own solid element. The feature of modeling of plies is that one ply may differs in thickness in 2,3 times in construction that why they were modeled in CATIA.

Geometry distortion in modeling has good agreement with the experimental data.

Keywords: *Composite Materials, thermoplastics, thermoforming*

1. Introduction

Thermoplastic composite materials in modern aircraft manufacturing gradually become more and more common. One of the design solutions of thermoplastics at the moment are such the elements if wing as ribs, produced by hot pressing.

In hot pressing heated plate of composite material is laid in the desired shape, and then stamping. During the process the composite material subjected to high temperature and pressure from tool.

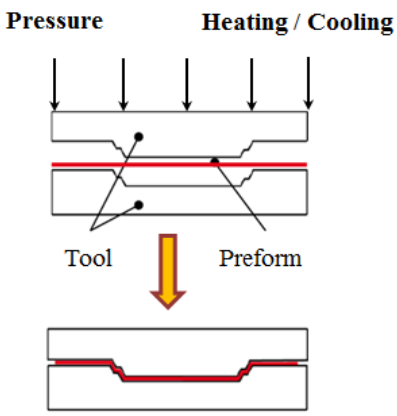

Figure 1. Typical process of thermoforming

In the pressing process the press plates are heated and melted composite material. Individual layers of material compacted to form good contact and durable bond between the adjacent layers. Then composite material is cooled at a rate to obtain a desired degree of crystallinity of the matrix. During all these processes is critical to maintain the proper temperature of the composite structure and the pressure exerted press plates. Otherwise, there will be significant residual stresses, unsatisfactory degree of crystallinity of the matrix, insufficient adhesion between layers and other defects.
In this paper, to solve the problem of estimating the distortion of the spoiler rib, the following analytical models of behavior of thermoplastic material:

- The model of thermal analysis
- The model of crystallization.

These models were implemented in Abaqus by user subroutine UMAT.

2. The initial data for the calculation of distortion

The material of the spoiler rib is Tenax®-E TPCL PEEK-HTA40 [1] - is a ThermoPlastic Consolidated Laminate (TPCL) made of several layers of thermoplastic powdered woven fabric. The powdered woven fabric is composed of the high tenacity carbon fibre product Tenax®-E HTA40 E13 3K 200tex and a PEEK matrix. The consolidated laminate can be simply heated above its melting temperature and then stamped in a metallic mould within a press in a few minutes. Properties of material are in Table 1.

Figure 2. Typical process of thermoforming

Table 1. Physical and mechanical properties Tenax®-E TPCL PEEK-HTA40

Properties (test direction)		Conditioning / Test temperature	Typical value	
Melting point	Peak	DSC	343°C	649°F
Glass transition temperature	Onset	23°C, 50% r.h./ 23°C, 50% r.h	143°C	289°F
Tensile* (warp, 0°) ISO 527-4	Modulus	23°C, 50% r.h./ 23°C, 50% r.h	60 GPa	8.7 Msi
	Strength		963 MPa	139.7 ksi
Compression* (warp, 0°) EN 2850 Type B	Modulus	23°C, 50% r.h./ 23°C, 50% r.h	59 GPa	8.6 Msi
	Strength		725 MPa	105.2 ksi
Flexural (warp, 0°) EN 2562 Type A	Modulus	23°C, 50% r.h./ 23°C, 50% r.h	64 GPa	9.3 Msi
	Strength		1166 MPa	169.1 ksi

*normalized to nominal thickness (0,31mm) (0,31mm)

Stacking sequence: (0,90)3/(0,90)r3

2.1 Technological process parameters

Simulated process defined by the following parameters:
• billet heating temperature in the module for IR heating: 390 ± 5 ° C.
• Duration of exposure shaped body in the closed mold: 90 seconds.
• Length of the work piece conveying unit for pressing after heating: <5 seconds.
• Cooling rate: <120 K / min (393 ° C).

2.2 Geometrical parameters

Geometry of spoiler rib and the tool are illustrated in Fig.3-4.

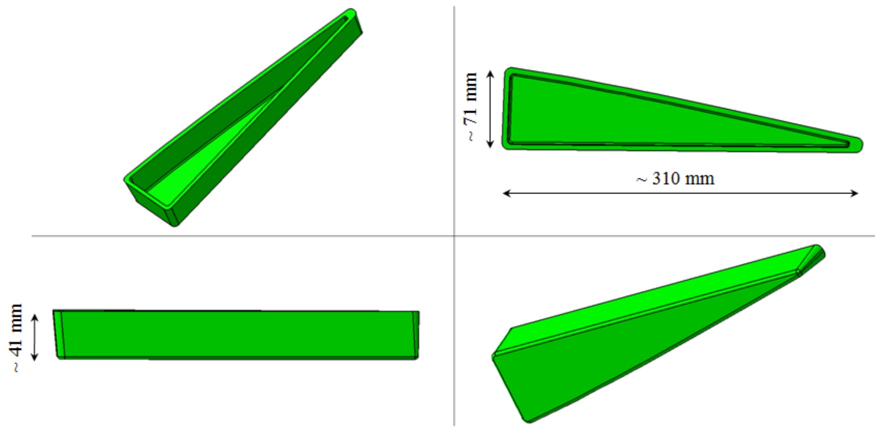

Figure 3. Spoiler rib geometry

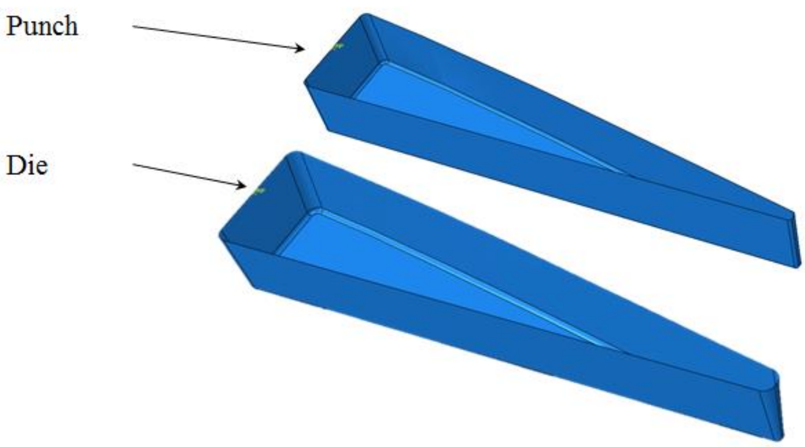

Figure 4. Tool geometry (modeled as rigid body)

Parameters to calculate the stresses in the user procedure UMAT, defined in the User Material in Abaqus are shown in Table 2.

Table 2. User material properties

1	E_{1f}	Elastic fiber modulus
2	E_{2f}	Elastic fiber modulus
3	ν_{12f}	Poisson's ratio of fiber
4	ν_{23f}	Poisson's ratio of fiber
5	G_{12f}	Fiber shear modulus
6	V_f	Fiber volume content
7	Arm_dir	Warp direction
8	Initial cristallization	Cristallization parameter

Parameters of the other equations of the model material (taking into account the loss of weight, melting point, glass and others) were given in the relevant procedures and functions FORTRAN-module.

3. FEA-modeling

Every ply was modeled by own solid element. The feature of modeling of plies is that one ply may differs in thickness in 2,3 times in construction that why they were modeled in CATIA, see Fig. 5.

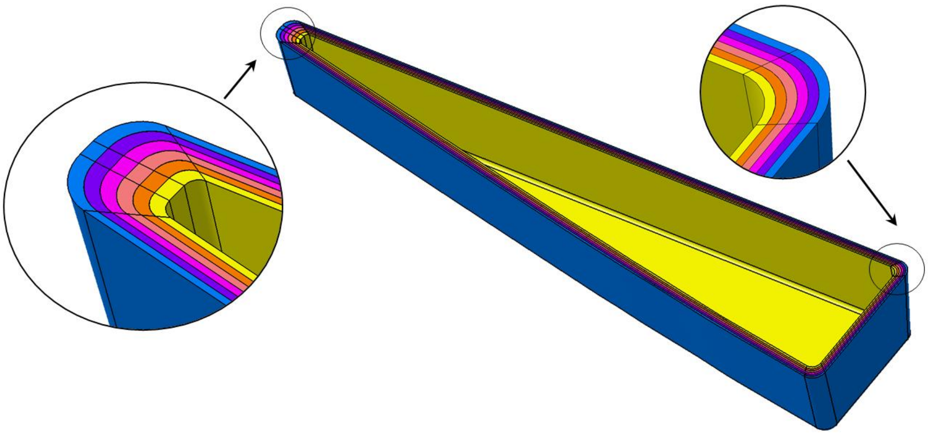

Figure 5. Spoiler rib stacking in CATIA

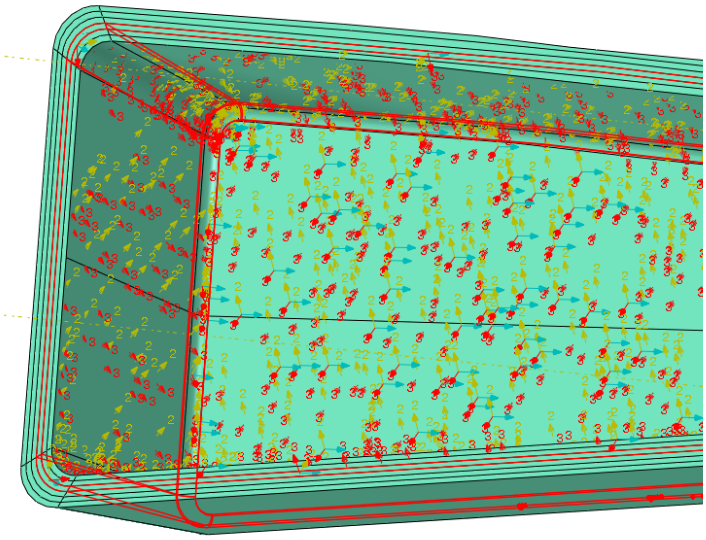

Figure 6. Plies orientation in Abaqus

3.1 Contact interactions

To implement interaction between rib and tooling in the crystallization process of the binder in the computational model were set conditions of mechanical contact between the surface of the rib and tooling at the first step of the calculation. In the second step of the calculation (warpage) mechanical contact was turned off. At this point, the rib is located in the matrix and the calculation of warpage is performed.

3.2 Temperature boundary conditions

To ensure the technological conditions of melting and crystallization of the preform given time variable temperature. In step between dwell punch and die temperature of the billet is 390 ° C and held for 90 seconds. Then, the contact with the matrix is removed and the preform is cooled at a speed of 393 ° C / min. up to room temperature.
Temperature was set for all nodes ribs.

4. Warpage FEA-modeling results

Scalar fields of stresses and displacements were obtained for spoiler rib on the step of dwell and release from the mold until equilibrium state of preform, see Fig. 7.

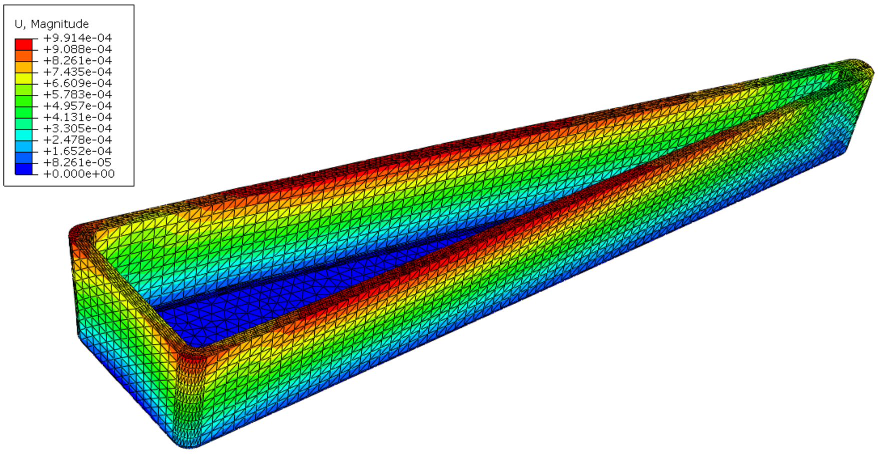

Figure 7. Displacement field of spoiler rib at the last step of calculating

Deviations rib belts was about 1 °, in which the original slope angles snap 91 °, see. Distortion values in the production of belts also was about 1 °.

The calculation estimates the distortion of geometry based on thermoforming implemented in Abaqus user model of thermoplastic material behavior with the layers of solid modeling elements and the corresponding orientation, showed the possibility of using this material model for such complex parts like spoiler rib.
Verification of the model requires the specification of parameters of the experimental user material model. In the next phase of work is scheduled to enter into account the degree of interlayer coupling through the calculation of the density of contact and autohesion (interdiffusion of thermoplastic polymers).

5. References

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