VIRTUAL ADDITIVE MANUFACTURING BASED ON SEMICRYTSALLINE POLYMER POLYETHERETHERCETONE (PEEK)

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1. **Introduction**

Additive Manufacturing process is the most appropriate technique for fast creating mechanical components and it allows for building complex parts which could not be created in traditional technology like injection molding process. Many available tools allow to perform simulations of the Additive Manufacturing process but based on these tools user can perform analysis regarding with process for metals, thermosets or polymers. The analyses usually give information about the paths of created parts, temperature distribution and residual stress for simple material models. Empirical investigations indicate that for semi-crystalline polymers the crystallization kinetic has a strong influence on viscoelastic behaviour and consequently residual stresses and warpage of the obtained built components.
The present investigation describes the dual crystallization kinetics model for considered thermoplastic material PEEK and implementation whole process in Abaqus/SIMULIA software. The innovation of the proposed approach is to interpreting G-Code, which is an input for real machines dedicated to AM. The path and time of particular steps for process are extracted from the G-Code and they are included as one of inputs for simulation. Extended programming using user subroutines will help for perform simulation of real process of the additive manufacturing in order to optimize model before real production [1].

2. Dual crystallization kinetics model

The crystallization in polymers consists basically from nucleation and growth. Overall crystallization for non-isothermal conditions is described by the Velisaris & Seferis in 1986 who expanded Avrami Model for isothermal crystallization of polymers. Dual crystallization kinetics model quite good fits to experiments. Volume crystallinity is presented in equation (1) which represents two connected crystallization processes with respectively factors. The summation of the factors should be equal to 1 (2). Parameters from one curve of the process corresponds to homogeneous crystallization, the second one corresponds to heterogeneous crystallization. Each of the expressed process is described as (3). The proposed model describes non-isothermal conditions for high temperature polymers like PEEK [2], [3].

(1) $$X_{\upsilon c} = X_{\upsilon c\infty}(w_1 * F_{\upsilon c1} + w_2 * F_{\upsilon c2})$$

(2) $$w_1 + w_1 = 1$$

(3) $$\mathrm{F}_{\upsilon \mathrm{c,i}} = 1 - \exp\left[- \mathrm{C} \int_0^{\mathrm{t}} \mathrm{T} \times \exp\left\{ \frac{-\mathrm{C}_{\mathrm{i2}}}{\mathrm{T} - \mathrm{T}_{\mathrm{g}} + T_{add,i}} - \frac{-\mathrm{C}_{\mathrm{i3}}}{\mathrm{T}(\mathrm{T}_{\mathrm{m,i}} - T)^2} \right\} n_i t^{n_i - 1} dt, i = 1,2 \right]$$

3. Implementation of the printing process in Abaqus/SIMULIA

The implementation presented material model dedicated for PEEK was presented using Abaqus/SIMULIA software. Dual crystallization model was presented in incremental version to better description in FEM. Additionally, melting material model was implemented to simulate real behavior of the structure during the adding new layer of the material on partially crystallized material. Basic information about printing process is included in “G-Code” format file. Information from the G-Code file is translated to binary file where input is source for written subroutine UMATHT and subroutine UEPActivationVol in Abaqus. The simulation is performed according to real process (see Figure 1).

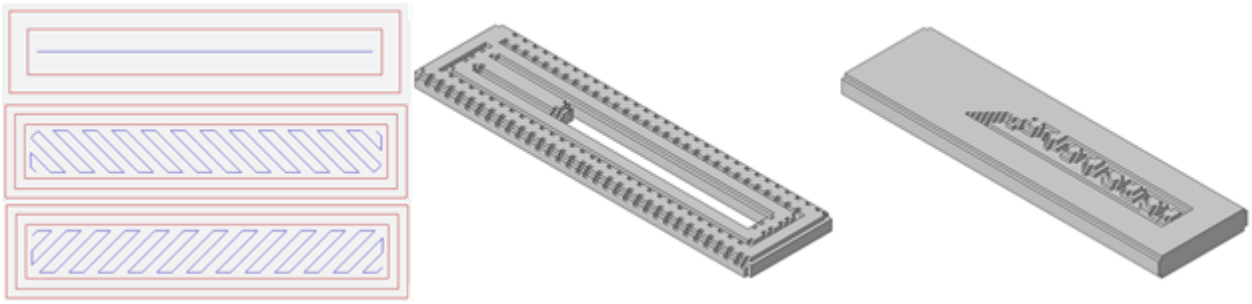

Figure 1: Additive Manufacturing simulation based on paths generated from G-Code

The results are extracted from analyses in different cooling rate (see Figure 2).

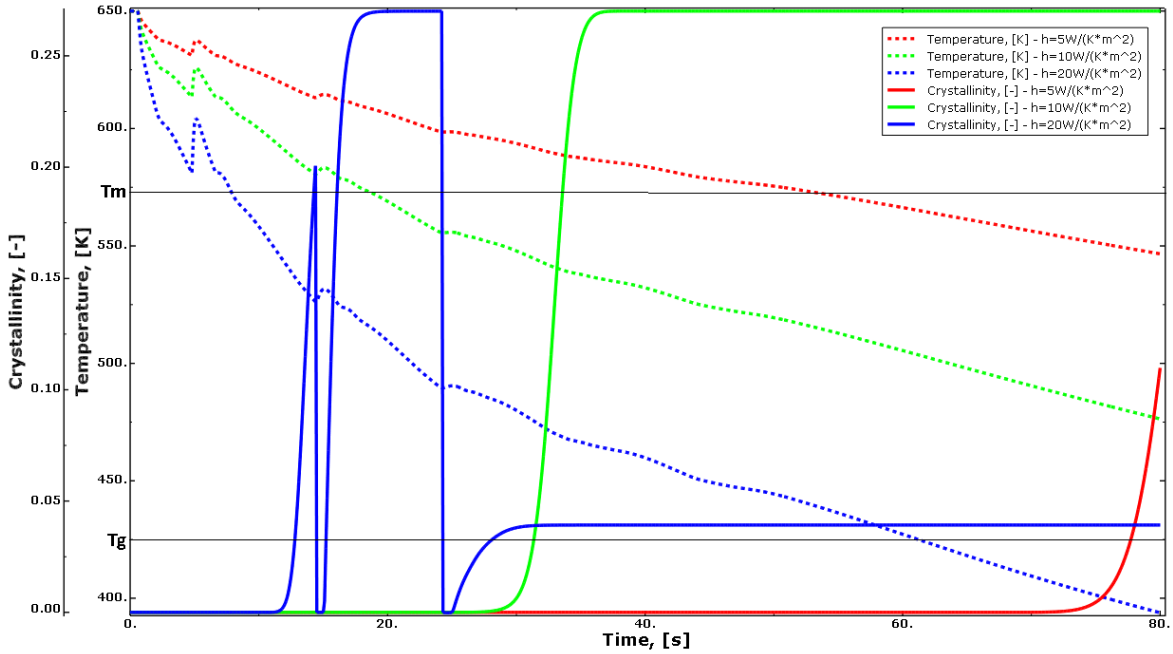

Figure 2: Temperature distribution (K) and crystallinity (-) with different heat of transfer measured at the specific node.

4. Conclusions and further investigations

The investigations presents fundamental information about the crystallization of the polymers in non-isothermal conditions and implementation in CAE softwares. The approach to the interpreting G-Code file which is the same in real Additive manufacturing process is described. Based on the conduction of the same process in simulation as in real indicates to optimize process parameters and orientation part in the chamber in order to obtain part with required conditions. The presented simulations are the first step to calculate warpage and residual stresses analysed structures and compare with real tests. Prepared approach will allow performing mechanical simulations and improve quality manufactured structures made from polymers.

6. References

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