





EXPERIMENTAL ANALYSIS ON THE COUPLED EFFECT BETWEEN THERMO-OPTICAL PROPERTIES AND MICROSTRUCTURE OF SEMI-CRYSTALLINE THERMOPLASTICS

Sinan Boztepe, Olivier De Almeida, Yannick Le Maoult, Fabrice Schmidt

Institut Clément Ader - École des Mines Albi

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Introduction

- Thermoforming processes for semi-crystalline polymers
- Adiation heat transfer in semi-crystalline polymers
- Optical scattering and temperature-dependent optical properties
- Experimental tests
- Conclusions and Future work





THERMOFORMING OF SEMI-CRYSTALLINE POLYMERS



 Final temperature state at the end of IR-heating step is crucial for an accurate thermoforming simulation





THERMOFORMING OF SEMI-CRYSTALLINE POLYMERS



- Transient heat transfer equilibrium coupled with IR radiation for various thermoforming processes
- Radiative source term (W/m³) and thermo-optical parameters are the key for IR-heating simulations



El Bakali et al., Key Engineering Materials, 554–57 (2013)

Narrow thermoforming window for semi-crystalline thermoplastics \rightarrow Semi - molten state



RADIATION HEAT TRANSFER IN SEMI-CRYSTALLINE POLYMERS



Accurate modeling of radiation propagation and absorbed radiation energy in the volume of

amorphous or low-crystalline polymers using Beer-Lambert Law

Scattering of radiation propagated through a medium of highly crystalline or filled thermoplastics





OPTICAL SCATTERING IN SEMI-CRYSTALLINE POLYMERS

Hemispherical and directional tranmission measurements of the identical samples <u>at T_{room} = 25 °C</u>



The clear offset between the two measurements was assumed to be part of the scattered light

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OPTICAL SCATTERING IN SEMI-CRYSTALLINE POLYMERS



- Adoption of the well-known relations for thermo-optical properties.
- Using two T_{λ} of the identical samples obtained via two different transmission measurements:





PRELIMINARY RADIATION HEAT TRANSFER MODEL



Preliminary model with single IR-lamp (1 kW) developed and absorbed energy computed using an

in-house developed software (RAY-HEAT).

• The computed ∇q_r (W/m³) used as input in a commercial FEM for transient heat transf. computation.





RADIATION IN SEMI-CRYSTALLINE THERMOPLASTICS



- Well-known optical scattering theories may address the scatterer-radiation transfer relation
- Evolution in microcrystalline morphology of the polymer under varying temperature









- Introduction
- Experimental tests

Test setup for temperature-dependent optical characterization

Error corrections for the test setup

Optical characteristics under varying temperature

Conclusions and Future work



TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS – (TEST SETUP)



- The analyses between the optical properties and temperature adopting a two-step testing procedure
- Optical characterization of the PO using FT-IR spectrometer (Bruker) and heating stage (Bruker-





TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS – (TEST SETUP)



- Non-invasive surface measurements using infrared thermal camera (FLIR SC325)
- The surface measurements performed using 0.75 mm thick PET mounted in the heating stage





TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS – (CORRECTIONS)



- Temperature measurements on both pre-defined vertical and horizontal axes.
- Temperature profiles on both vertical and horizontal axes for T_{set}= [25:10:105] (°C)





TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS – (CORRECTIONS)



- Temperature variation alongside the profiles are critical for an accurate optical analysis
- Temperature difference (ΔT_{max}) between set temperature of hot stage (T_{set}) and sample's middle zone





TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS – (CORRECTIONS)



Maximum temperature of the PO-based polymer is around 120 °C (\approx 400 K)

Wavelength (µm)

 $\lambda_{\max} = \frac{2.898 \, x 103 \, (K.\mu m)}{T \, (K)}$ Based on the Wien's displacement law ≈ 7.2 µ*m* for 400K \rightarrow T_{sample} 25 °C ----- 34 °C ----- 41 °C ----- 48 °C ----- 55 °C 62 °C ----- 71 °C ----- 83 °C Self-emission of the PO can not be ignored in MIR 80 range Self-emission = ε_{PO} . σ_{sb} . $(T_{set}^4 - T_{ambient}^4)$ 60 - $T_{\lambda - \text{directional}}(\%)$ $\Delta T_{\lambda} \approx 11 \%$ 40 -Reference measurement taken at each T_{set} = [25:10:105] (°C) 20 -Analysis on the decrease in T_{λ} (%) is on-going 5 10 15 20



TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS



- T_{λ} of the PO-polymer analyzed in NIR range between T_{room} and $T_{set} = 170 \text{ °C}$
- Assumed that the thermal properties and temperature profile of the PO polymer are similar to PET



- Transmission increases by the increase in temperature after 77 °C.
- $\Delta T_{\lambda} < 2$ % until 83 °C in the measured area on the sample



TEMPERATURE-DEPENDENT OPTICAL CHARACTERISTICS



- ♦ A dramatic increase in transmission after 110 °C
- Tranmission level reaches to the $T_{\lambda-\text{hemispherical}}$ after 121 °C and surpasses it











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CONCLUSIONS



- Microstructure and thermo-optical properties of highly crystalline thermoplastics need to be coupled for an accurate IR radiation heat transfer modeling.
- An experimental test set-up proposed for analyzing the temperature dependent thermo-optical properties of the semi-crystalline PO.
- Corrections has to be made for establishing an accurate relation between temperature and thermo-optical properties
- Optical measurements in NIR range showed the evolution in optical characteristics of semi-crystalline PO under varying temperature.



FUTURE WORK



- A quantitative relationship will be established between temperature and themo-optical properties of the semi-crystalline polymers
- The relation will be extended considering the changes in microcrystalline morphology under varying temperature
- Identification for the scatterrer-Wavelength (λ) relation and under heating conditions
- The established correlation will be used as thermo-optical model for building an advanced radiation heat transfer model.



