Characterization of Microscale Deformations due to Creep in Glass-Mat Thermoplastic (GMT) Composites at Elevated Temperature

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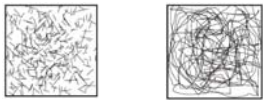
Introduction

Glass-Mat Thermoplastic (GMT) composite materials are increasingly being used in the automotive industry due to its high strength-to-weight ratio and ease of processing.

Application – 3D semi-structural parts such as seat frames, wheel wells and under body panels.

Materials – Commercial grade isotactic polypropylene (iPP) matrix reinforced with approximately 40% wt. short- or long/continuous- random glass-fibre mats*



* Source: Ericson M. and Berglund L., Composites Science and Technology, Vol. 43, 1992

Objectives

This work is part of a larger experimental program aimed at characterizing the creep response of GMT materials. As the polypropylene matrix is inherently viscoelastic, it is necessary to determine if the matrix material will be significantly affected by creep loading at elevated temperature.

Scope

1. To characterize the effects of thermal aging (long-term exposure) on the iPP matrix phase of a GMT:
   - crystallinity changes, secondary crystallization
   - degradation, formation of oxidation products
2. To measure microscopic level creep deformation of composite due to combined stresses and temperatures:
   - *in-situ* imaging of creep deformation
   - identify the deformation regions (matrix areas or interface/interphase)

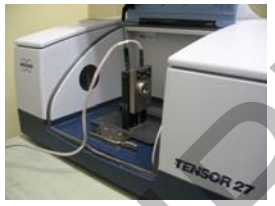
Methods

To characterize the effects of thermal aging on extracted iPP matrix:

- Aging at 90 and 140 ºC with different morphologies
- Wide-angle X-ray diffraction (WXRD) and Fourier Transform infrared spectroscopy (FTIR) were used to detect crystallinity and chemical changes

To measure creep deformations:

- Polished specimens, cut from as-received molded composite plaques according to ASTM-1708-02a
- Miniature tensile tester, optical microscope and scanning electron microscope (SEM) were used for observations



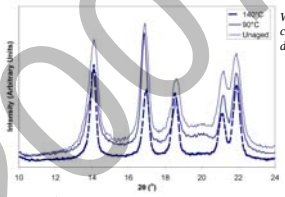
FTIR with thin film sample aged in heating stage allowed in-situ scanning of crystallinity changes and formation of oxidation products over the course of elevated temperature aging.

Machined (left) and polished (right) microtensile specimens for creep testing under optical microscope for in-situ imaging under creep loading.

Miniature tensile tester with environmental chamber was placed under an optical microscope (50X magnification) for in-situ measurement of creep deformation at different stress and elevated temperature levels.

Results

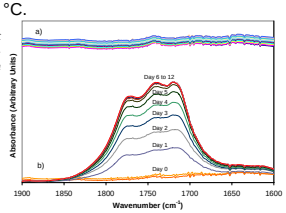
Crystallinity determined quantitatively from WXRD results showed increase in crystallinity after aging at both temperatures due to reduced area of amorphous-halo.



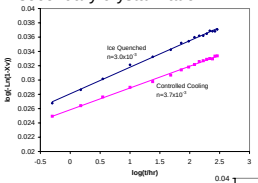
WXRD data of controlled cooling sample aged for 12 days in 90 and 140°C.

FTIR data also showed increase in crystallinity at both temperature levels but oxidation products detected for sampled aged at 140 °C.

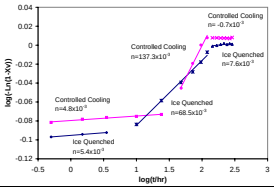
FTIR spectrum of development of carbonyl groups (1900-1600 cm^{-1}) aged for 12 days in a) 90 °C and b) 140 °C.



Avrami plots showed the kinetics of secondary crystallization for samples with different morphologies. Crystallization was accelerated when aging at 140 °C due to oxidation chain scission – the shorter chains facilitated secondary crystallization.

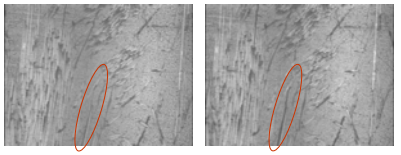


Avrami plots with Avrami exponents (reported in figure) aging for 12 days in 90 °C (left) and 140 °C (below).



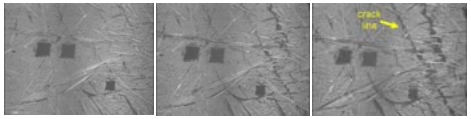
Creep deformation observed under optical microscope. Deformation mechanism (plastic and/or elastic):

Propagated through the matrix/fibre interface



Polished GMT PP/glass specimen under creep loading at 20 MPa and 80 °C for 0 hrs (left) and 24 hrs (right) at 50X magnification. Sample is loaded in-plane.

Matrix shear deformation; indentation shows that the shear deformation in matrix phase is transverse to the general fibre orientation; interfacial cracks are minimal



Indented and polished GMT PP/glass specimen under creep at 40 MPa and 80 °C for 0 hrs (left), 1 hr (centre) and 5 hrs (right) at 50X magnification, loaded in-plane.

Conclusions

Crystallinity increased during aging at elevated temperature through increased chain mobility.

Plastic deformations are concentrated within the matrix phase. The deformations are non-recoverable after the stresses are released.

Future Work: *In-situ* monitoring of progressive failure mechanisms for a range of thermo-mechanical loading conditions.

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Acknowledgements

This work was supported by General Motors Corp. and the ORDCF Center for Automotive Materials and Manufacturing (CAMM). Special thanks to J. Tang, P. Dasappa, J. Mui, P. Kruger, A. Shin and D. Jürgen-Lohmann for laboratory support.