Mechanical performance of i-PP: the effect of cooling rate

Citation for published version (APA):
Cavallo, D., Erp, van, T. B., Peters, G. W. M., & Govaert, L. E. (2011). *Mechanical performance of i-PP: the effect of cooling rate*. Poster session presented at Mate Poster Award 2011 : 16th Annual Poster Contest.

Document status and date:
Published: 01/01/2011

Document Version:
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Mechanical performance of i-PP: the effect of cooling rate

D. Cavallo, T.B. van Erp, G.W.M. Peters, L.E. Govaert

Introduction

The production of any type of polymer goods involves a cooling step to consolidate the desired shape. In order to increase productivity, high cooling rates – typically spanning from a few to several hundreds of ℃/s – are imposed. The industrially relevant example of isotactic polypropylene is considered in the Continuous-Cooling-Transformation diagram of Figure 1.

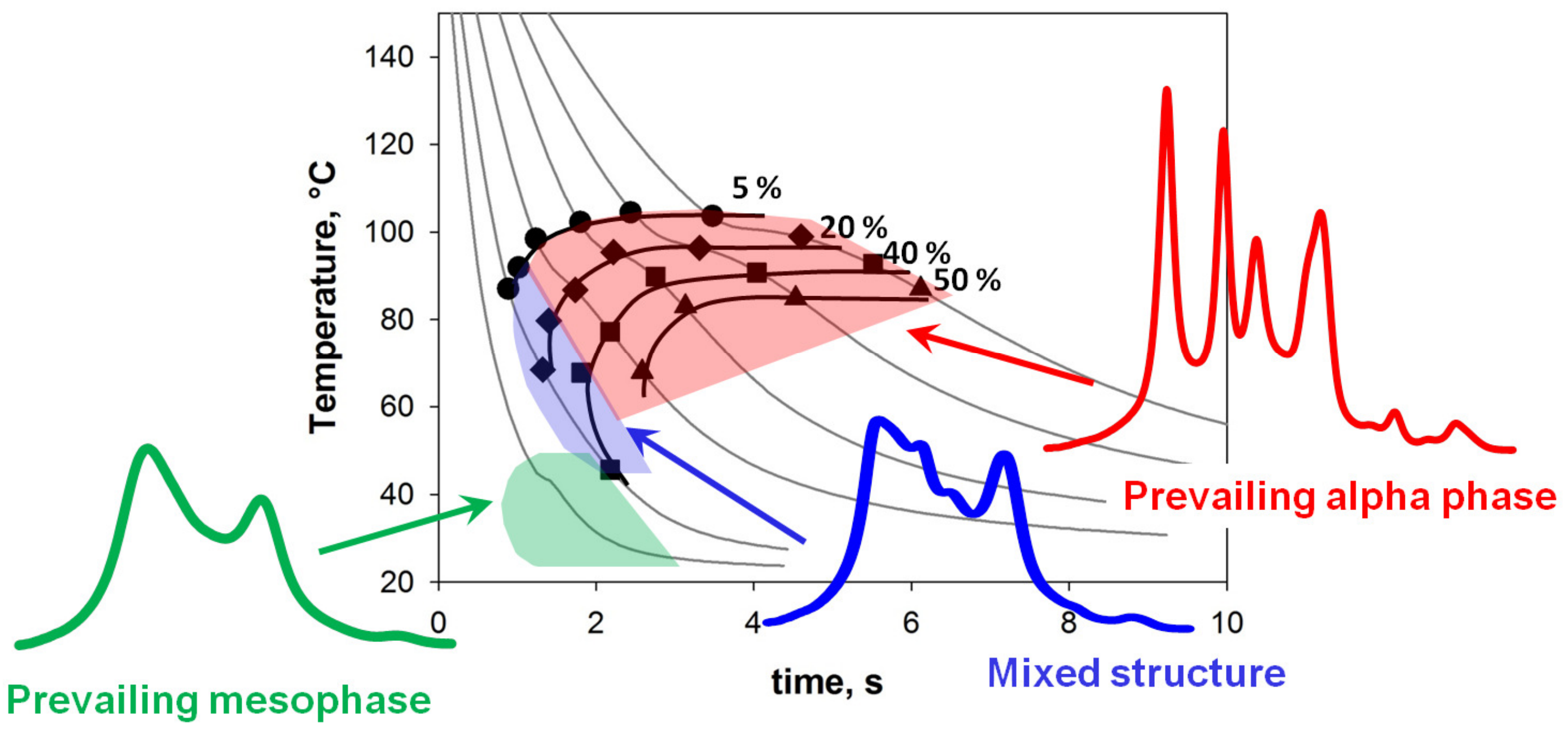

Figure 1. *Continuous-Cooling-Transformation diagram of i-PP.*

With increasing cooling rate from the melt, structure development takes place at progressively lower temperatures, and the thermodynamically stable monoclinic α-phase is progressively replaced by the metastable mesophase. The variation in mechanical properties associated with this structural transition is addressed in the present work.

Results and discussion

Polypropylene films around 200 um thick quenched at different rates were tested in constant strain rate or constant load experiments. Stress-strain curves of i-PP films (Figure 2 left) show a remarkable *decrease of the yield stress* with increasing cooling rate during solidification.

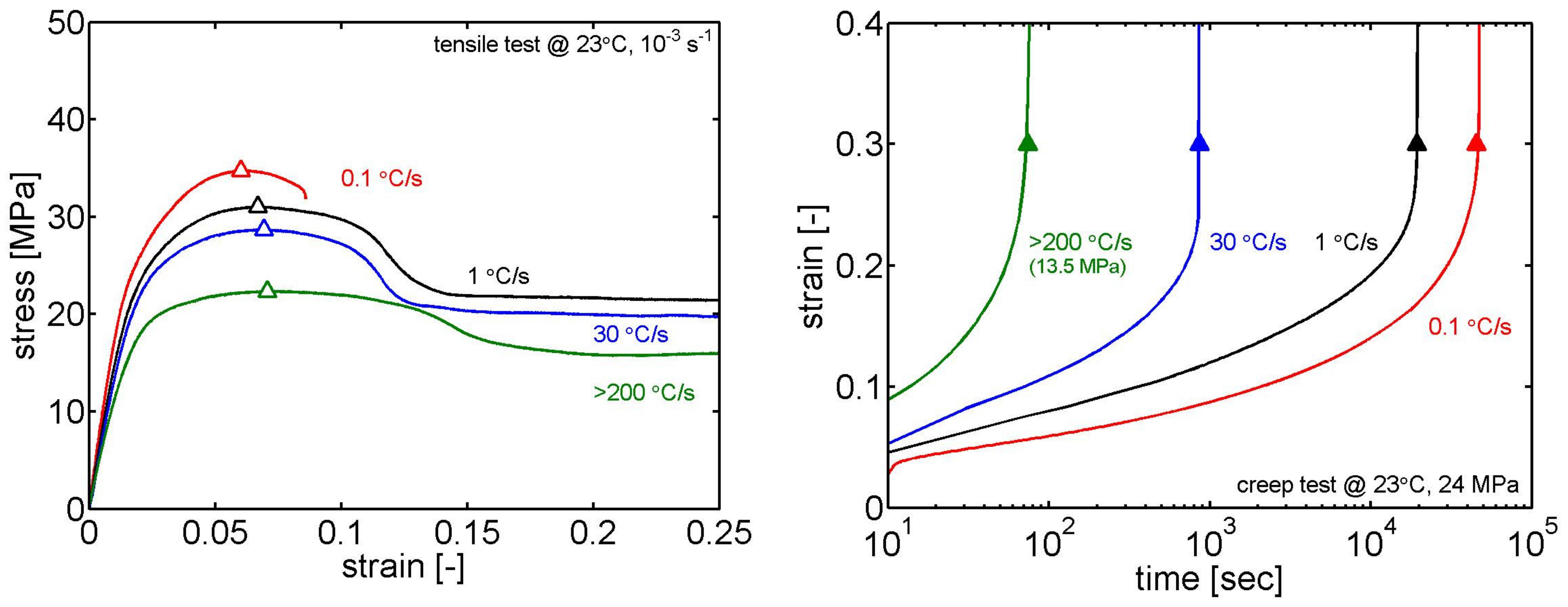

Figure 2. *Stress-strain curves (left) and creep curves (right) of i-PP specimens cooled at different rates.*

Moreover, when the same constant load is applied, samples crystallized under more drastic conditions are characterized by considerably *shorter failure time* (Figure 2 right).

The temperature and strain rate dependence of yielding is accurately described by a two-processes Ree-Eyring equation:

$$\sigma_y(T,\dot{\varepsilon}) = \sum_{x=1,2} \frac{kT}{V_x} \sinh^{-1}\left[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{0,x}} \exp\left(\frac{\Delta U_x}{RT}\right)\right]$$

where V and ΔU are the activation volume and energy respectively, and $\dot{\varepsilon}_0$ is a rate constant. Remarkably, the same values of V and ΔU are adequate to describe the deformation mechanism of samples crystallized in largely different conditions, leading to either to monoclinic or mesomorphic structure (Figure 3, left column). The differences among the samples simply lay in the value of $\dot{\varepsilon}_0$, which is therefore related to structural or morphological features.

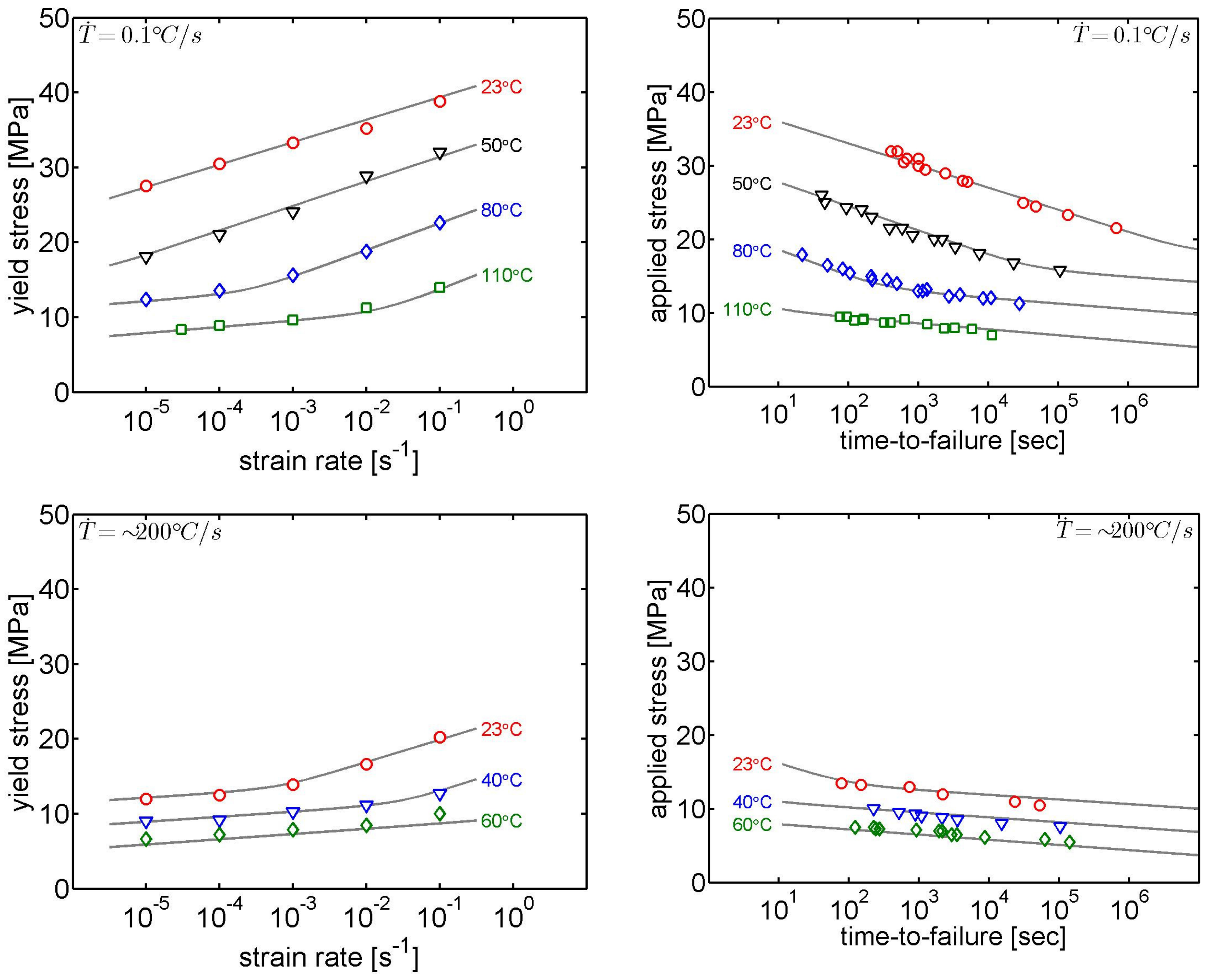

Figure 3. *Deformation kinetics (left) and time-to-failure (right) of i-PP specimens cooled at different rates. Gray lines are predictions.*

The deformation kinetics can be used to predict durability of the material when submitted to constant load (Figure 3, right column). Indeed, for temperatures and load conditions where ductile failure is observed, the time-to-failure is simply calculated from the experimentally determined creep rate, $\dot{\varepsilon}$, according to:

$$t_f = \frac{\varepsilon_{cr}}{\dot{\varepsilon}(\sigma,T)}$$

where ε_{cr} is a fitting parameter, constant for all the explored conditions, which represent the critical strain at failure.

Conclusions

The mesomorphic i-PP shows a drastic decrease of the mechanical performances respect to the α-phase, with a sensible reduction of material durability. This must be taken into account if a fast cooling step is involved in the production process.

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