In situ study of double yielding in PA11: Role of the amorphous and crystalline fractions

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Abstract

It is shown that polyamide 11 (PA11), a semicrystalline polymer (SCP), exhibits two well-distinct successive yield points on its characteristic stress-strain curve during tensile deformation below Tg (cf. figure 1). This phenomenon, denoted as double yielding (DY), has been observed in other SCPs like PA6(1)(2). Previous work has demonstrated an intimate relationship between the first yield point σy1 and molecular dynamics in the amorphous phase. The second yield point σy2 is more sensitive to morphological changes in the crystalline phase(3). Studying the origin of DY is pivotal to provide more insights into the complex and hierarchical deformation mechanisms in SCPs.
The purpose of this work is to investigate more thoroughly the origin of such phenomenon and to relate it to the deformation mechanisms occurring in the amorphous and crystalline phases of PA11. Particularly, we wish to highlight the specific deformation scenario and the chronology of the deformation events happening between the two yield points. In that regard, we aim at understanding the specific roles both phases play in the onset of plastic (and thus permanent and heterogeneous) deformation and the initiation of damage mechanisms such as cavitation and/or lamellar fragmentation. A macroscopic mechanical analysis by the means of tensile, creep and recovery tests is carried out and supported by a microstructural examination using in situ USAXS/SAXS/WAXS techniques performed at ESRF. Such fine methods are necessary to monitor real-time microstructural evolution and damage mechanisms during tensile deformation at the scale of lamellar stacks and uncover the co-dependent involvement of crystalline lamellae and inter-lamellar amorphous regions in the appearance of DY.

On one hand, the main results demonstrate the connection between σy1 and the onset of plastic flow in the amorphous phase as modelled by a thermally activated process. On the other hand, σy2 marks the onset of crystalline lamellae de-structuration. Between the two yield points, deformation seems to be governed by both amorphous and crystalline mechanisms operating interdependently. In addition, we investigate the influence of the test temperature on DY and the underlining deformation and damage mechanisms. Finally, these findings address crucial comprehension elements regarding the onset of heterogenous and irreversible deformation in SCPs.

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