Plasticity of crystalline plastics

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Most of commodity polymers are crystalline with lamellae arranged in stacks with amorphous layers, both in [nm] range. Initial stage of deformation takes place in the interlamellar regions because of their low modulus [1]. Tensile deformation includes straining of fragments of molecular chains in the amorphous phase which is accompanied by lamellae separation, rotation and interlamellar shear. At the yield an intensive chains slip in crystals is observed for many polymers. In others crystalline polymers some cavities are formed near or around mechanical yielding. The formation of nanopores is triggered from free volume pores [2]. There is a competition between cavitation and activation of crystal plasticity [3]. Cavitation is observed in polymers with negative pressure at yield higher than required for holding the cavity open. Closing pressure caused by surface tension is related to the cavity size through $p= 2\cdot\gamma_s/r$. Cavitation is then controlled by crystal plastic resistance, yield strength, surface tension, amorphous layers thickness-L and free volume pores. It appeared that filling the free volume pores with low M_w substances suppressed cavitation [4]. SAXS under strain showed that no cavities are smaller than L. Cavitation pore is formed suddenly in a single step and not by the growth [5]. Cavitation causes the redistribution of stress resulting in irregular lamellae shear, fracture and micronecking. Crystallinity is then a decisive in tensile drawing rather than crystal resistance. Three important implications follow: (1) no cavitation is observed in low strength polymers, cavitation is a rule for higher strength, (2) applying positive hydrostatic pressure suppresses cavitation, (3) polymers with less entangled macromolecules cavitate very easily [6]. Channel die compression was used to identify acting deformation mechanisms. Crystallographic slips sets in, transverse and chain slips are observed [7]. The slips are activated by dislocations emission from crystal edges. The morphology at high compression ratio resembles monocrystal texture. Two new modes of nucleation of edge and screw dislocation half loops from lamella faces that are independent of lamella thickness were discovered [8].
Few of observations may serve as indication for new industrial processes, for example for foaming [9].

[1] *M.Polinska, A.Rozanski, A.Galeski, J.Bojda, Macromolecules, 2021, 54, 9113−9123*
[2] *A.Pawlak, A.Galeski, Macromolecules, 2021, 54, 9113−9123*
[3] *A.Rozanski, A. Galeski, Macromolecules, 2011, 44, 7273-7287*
[4] *A.Rozanski, A. Galeski, Int.J.Plasticity, 2013, 41, 14-29*
[5] *V.Rahmanian, A.Galeski, A.Rozanski, Macromolecules, 2024, 57, 1337 – 1353*
[6] *J. Krajenta, A. Pawlak, A. Galeski, J. Polym. Sci., B. Polym. Phys. 2016, 54, 1983-1994*
[7] *A.Galeski, Z.Bartczak, A.S.Argon, R.E.Cohen, Macromolecules, 1992, 25, 5705-5718*
[8] *A.S.Argon, A.Galeski, T.Kazmierczak, Polymer, 2005, 46, 11798-11805*
[9] *D.Elumalai, et al. Industrial Eng.Chem.Research, 2025, accepted*