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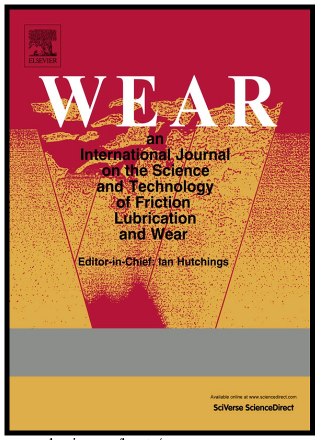

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Contact mechanics of isotactic polypropylene: Effect of pre-stretch on the frictional response

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Abstract

Polymers are increasingly used in applications where relative moving parts are in contact. The dissipation of energy due to friction, i.e. heat production, reduces a product's lifetime significantly. Since in processing often an extrusion or injection moulding step is used in product formation, the induced anisotropic microstructure leads to a spatial variation of mechanical properties, for example frictional resistance. In this work we compare the scratch response of isotropic isotactic polypropylene (iPP) to the response of various oriented iPP systems. Subjected to single-asperity contact with a rigid diamond, the surface penetration and lateral force are measured. For various combinations of applied normal load and sliding velocity, the surface penetration and lateral force are measured. Optical profilometry measurements are used to explain the (large) differences in residual scratch profile between tests performed in the direction parallel and transverse to the orientation direction, respectively. As the anisotropy increases with the amount of orientation, both the maximum tensile stress and the strain hardening increase substantially. The penetration depth, for oriented systems governed by the transverse viscoelasticity and yield stress, is comparable for all loading angles and decreases with increasing amount of orientation. The direction of lowest frictional resistance is shown to be the direction parallel to the oriented crystals. The combination of decreasing global deformation and friction reduction as a result of pre-stretch decelerates strain localization, therewith delaying crack initiation which eventually leads to abrasive wear. Along with that, the substantial amount of elastic recovery after scratching in the transverse direction is related to the pre-tension of the perpendicular crystal network.

Keywords: Sliding friction, Contact mechanics, Scratch testing, Polymers

1. Introduction

The advanced physical properties that polymers can display, e.g. light-weight, self-lubricating or corrosion resistant, make them an interesting alternative for metal parts in many structural and dynamic applications. Particularly semi-crystalline materials, i.e. materials that partially crystallize upon solidification, are widely used in automotive industry and in medical implants [1–6]. In these products, surface contact is a challenging subject because of complex loading conditions involving many variables [7–10]. Simplification to a well-defined contact situation is required for proper analysis; in this work we consider a single-asperity sliding friction experiment, often referred to as "scratch-test". This test allows to study a wide range of loading conditions in a controlled manner [11, 12].

Friction is generally understood as being the resistance encountered by one body sliding over another. Since little is known about local contact phenomena causing frictional resistance, extensive long-term testing is often required and life-time predictions mostly turn out wrong. Reason for this, is the determination of the true, in-situ, contact area in a sliding friction experiment, which is usually approximated being either ideal elastic, ideal plastic, or combinations thereof [7, 12–14]. However, due to the non-linear viscoelastic nature of polymers this is a strong assumption; the complex interplay between compressive and tensile stresses leads to development of a so called "bow-wave", significantly changing the real area of contact. More accurate is the estimate of this area from the residual deformation [15] or in the case of transparent materials, the in-situ observation, using a microscope mounted at the back-surface of the sample [16, 17].

To circumvent these challenges, over the last two decades Finite Element Methods (FEM) computations are increasingly employed to study non-linear contact problems in a qualitative [18–25], and quantitave way [26, 27]. Numerical scratch simulations, validated by experiments, are a powerful tool in the visualization of the complex deformation field, i.e. stress and strain distribution. In the recent past, hybrid experimental/numerical studies have been performed on the contact mechanics of glassy polymers. Starting with polycarbonate (PC) as a well-characterized

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