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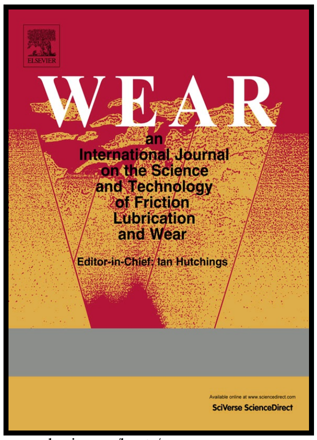

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Contact mechanics of high-density polyethylene: Effect of pre-stretch on the frictional response and the onset of wear

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Abstract

Nowadays, in many applications metal parts are replaced by light-weight polymer products. As a result of the processing history, these polymer fabricates are, more often than not, anisotropic, leading to a direction dependent mechanical performance. Recently we showed the frictional response of isotactic polypropylene is improved by pre-stretching the crystalline network. In the present work, the scratch response of isotropic high-density polyethylene (HDPE) is compared with that of several pre-stretched samples of the same material, subjected to a single-asperity contact with a rigid diamond indenter. The surface penetration and lateral force are measured in-situ for a range of applied loads and sliding velocities. In the direction perpendicular to the orientation, the observed response is comparable to that of isotactic polypropylene (iPP). Contrary, in the direction parallel to the oriented crystals abrasive wear is observed in HDPE already for relatively low applied loads. As the amount of anisotropy increases, the wear-rate also increases, leading to a decrease in global scratch resistance of these materials. The discrepancies between iPP and HDPE are explained by the intrinsic material behaviour; the lack of strain softening in HDPE prevents strain localization, hence the ever increasing local stress reaches its maximum value and brittle machining is observed.

Keywords: Contact mechanics, Scratch testing, Polymers, Sliding friction, Sliding wear, Micro-scale abrasion

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1. Introduction

Over the last decades, polymers are increasingly used in many types of applications due to their wide variety of physical properties combined with a low density. Numerous studies on the mechanical performance of these materials have lead to the application of polymers for demanding purposes, e.g. medical implants [1–6]. A challenging subject in dynamic loading where two or more relative moving parts are in contact, is the understanding of friction and wear between these parts, in a controlled manner [7–10]. The dissipation of energy due to friction facilitates brittle machining, therewith reducing the lifetime of a product. To circumvent the problem of having a complex loading condition or contact geometry, a so-called single-asperity sliding friction experiment or “scratch test” is considered [11, 12].

Even though this test method is well-defined in terms of geometry, applied load and sliding velocity, the contact area between indenter and test specimen is often poorly determined; conventionally it is modelled as ideally elastic, ideally plastic or a combination of both [7, 12–14]. However, for viscoelastic materials, this approximation is not valid, resulting in lifetime predictions that are often wrong. Therefore, in the recent past, dedicated experimental and numerical methods have been employed to study local contact phenomena qualitatively [15–22], and quantitatively [23–25]. Because of their transparency [26, 27] and well-determined deformation kinetics [28–32], often an isotropic, glassy material is used.

In practice however, from a processing perspective the use of semi-crystalline polymers is desired. Upon cooling from the melt, these materials partially crystallize, and their final mechanical performance is determined by the pressure, cooling-rate and flow-rate [33–35]. As a result, the polymer product is, more often than not, anisotropic, i.e. its microstructure is spatially dependent. In our previous work [25] we demonstrated the improved scratch resistance of isotactic polypropylene (iPP) by pre-stretching the crystalline network. The oriented crystals reduce the surface penetration by increasing the lateral stiffness, while the friction force is reduced by a factor of two when sliding in orientation direction.

In this work we extend the study of anisotropy to another widely used polyolefin: high-density polyethylene (HDPE). Following the same rationale as for iPP, an improved scratch resistance by pre-stretching HDPE is expected. Remarkably, the lack of strain softening in HDPE leads to the opposite effect; when sliding in orientation direction, strains are not able to localize, hence the accumulation of stress in the bow wave leads to local fracture

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