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New Nanoindentation and Nanoscratching Parameters of Thermoplastics

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Summary: The determination of hardness and modulus values from unloading curves in nanoindentations is particularly troublesome with thermoplastic polymers and the values can strongly depend on the maximal normal force. Quantitative analysis of the loading curves provides reliable nanoindentation coefficients k (μN nm$^{-3/2}$) as the slopes of linear plots that reliably characterize the pristine polymers and are potent interpolation tools. Kinks in the linear plots (here not observed with isotactic polypropylene (PP-it)) indicate plastic-viscoelastic transformations and separate the characterization of the degraded polymer with the smaller nanoindentation coefficients from the pristine polymer. The quantitative analysis of the correct relation between lateral and normal force in nanoscratching reveals the coefficient K (μN$^{-1/2}$) as a basic extrapolation tool with direct and quantitative access to scratch resistance as a measure for wear that replaces the unfounded and never constant so-called "friction coefficient F_L/F_N". The linear plots of the correct relation between lateral and normal force reveal the occurrence of plastic-viscoelastic transformations most distinctly by a kink and two linear ranges.

Keywords: atomic force microscopy (AFM); chain breakage; mechanical properties; nanoindentation; nanoscratching; thermoplastics

Introduction

Nanomechanical parameters such as hardness H and reduced elasticity modulus E_r of thermoplastic polymers are difficult to obtain according to the ISO 14577 norm[1] and they contain large undefined systematic errors.[2] The analysis of unloading curves is only possible after several unload/reload cycles that change the polymer until an apparently stable state is reached and the initial "noses" with negative initial slope have disappeared. The area function of the diamond indenter, which is needed for the calculation of H and E_r, is determined on fused quartz and applied to the indentation of the polymer with totally different indentation geometry and despite totally different properties of the unrelated materials. The values of H and E_r must be calculated with both a three- and an eight-parameter iteration step. They are not constant at some thermoplastics but depend on the maximal normal force F_N and the scatter of the values is large. Furthermore, the ISO norm does not care for the size of the exponent in the iterated power function for the corrected unloading curve. This exponent assumes values between 1 and 3 and even changes in that range when the final end-point of such iteration is changed. This lack of physical meaning of the unloading curves has also been shown in the absence of viscosity effects with the ceramic SrTiO3 in Reference [2]. Much better procedures are the quantitative analysis of the loading curves or the correct analytical treatment of nanoscratching results. It is important that new quantitative

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