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Filament breaking length — Experimental and numerical investigations

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Abstract

The tendency of liquid adhesives to draw threads or stretch filaments during manufacturing, a consequence of the visco-elastic properties of all polymer liquids, is a serious issue in industrial bond bonding processes. Description of that phenomenon and identification of influencing parameters have not yet matured enough to allow practitioners adjusting adhesives such to minimize filament breaking lengths. Existing approaches are either too general—by focusing on global rheological properties or too complex—thus impossible to implement in industrial processes. The present paper presents and validates an approach that mitigates between simplicity and complexity, and offers practitioners an estimate for filament breaking length. The methodology requires, besides geometrical (dimensions) and process parameters (displacement rates) only basic rheological parameters (density, viscosity, surface tension, flow-index, and phase shift) that can be determined using standard equipment. The approach was first validated on Newtonian resins, extended to non-Newtonian ones, and complemented by validated Computer Fluid Dynamics calculations to extend the range of rheological parameters considered. Finally, a relatively simple estimate for filament breaking length was proposed, which proved accurate if compared to experimental evidence, as differences between predicted and measured values ranged between 1 and 10 %.

Keywords: C: rheology; D: visco-elasticity.

1. Introduction

1.1. Filament stretching as an industrial problem

Due to their visco-elastic flow properties, commonly used adhesives have an intrinsic tendency to draw threads, colloquially called angel hair, as illustrated in Fig. 1. Resulting filaments often lead to fouling of substrates, system components and adhesive work surfaces, especially in automated applications. Contamination of the application system grows gradually with each manufacturing step until the production process has to be interrupted for cleaning, which can significantly reduce process efficiency, in turn leading to higher costs. If cleaning of the plant is not carried out in time, product quality cannot be guaranteed. A particular danger is to carry over contamination into adjacent areas, downstream production stations, or onto the visible or functional surfaces of the product. This issue, in some areas, is so severe that it even prevents the use of bonding technology in favour of joining processes that are otherwise disadvantageous from a technological point of view.

The key issue in industrial processes is that, despite the awareness for filament stretching occurring, it cannot be avoided, but only limited. Adhesive manufacturers try, mostly empirically, to reduce the magnitude of filament stretching, or at least to specify the tendency of the adhesive to draw threads in the technical data sheets. At present, however, there is still no satisfactory theory that would describe the cause of the threading of high-viscosity adhesives, and no universal standardised methods for quantifying this behaviour.

Figure 1: Filament stretching illustrated with honey between two fingers

The basis for the mathematical description of the deformation of matter are constitutive equations, which link the acting stresses to corresponding deformations. In rheology, there are two borderline cases. At one end, there

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