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TITLE: Extensional viscosity of Polyaryletherketone (PAEK) composites in material extrusion (MEX) additive manufacturing

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ABSTRACT:

Material extrusion (MEX) is an additive manufacturing (AM) technique in which molten polymeric feedstock is extruded through a heated nozzle and deposited in successive layers onto a platform in order to build a three-dimensional part. During the extrusion and deposition stages in MEX, the feedstock material is subjected to complex mixed flows containing both shear and extensional components. This can be within the nozzle itself, as well as outside of the nozzle, post deposition [1]. Figure 1 demonstrates the shear and extensional flow components during different stages of the MEX process. Each flow component influences the feedstock's behaviour in fundamentally different ways: with polymers typically exhibiting strain hardening under extensional (stretching) deformations, in contrast to the shear-thinning response commonly observed during shear flow [2], [3], [4]. Figure 2 shows the changes in extensional and shear viscosity with increasing deformation rates for a standard polymer. At low deformation rates, in the linear region, the extensional viscosity (η_E) can be assumed to be three times that of the shear viscosity (η), this is referred to as Trouton's Law [5].

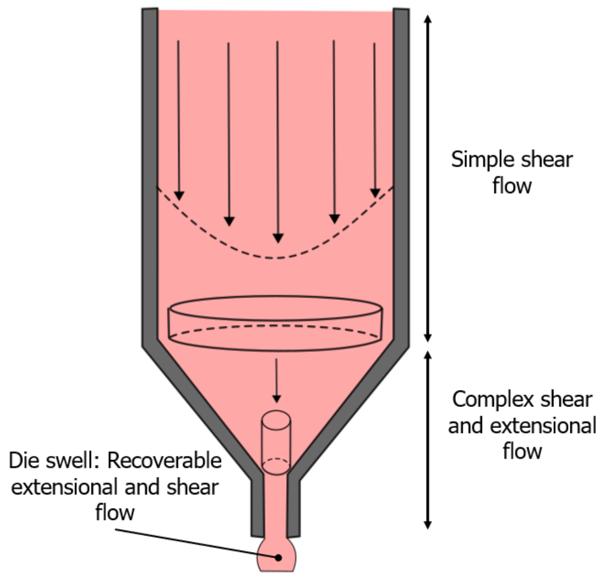

Figure 2. Extensional and shear flow components at different stages of the MEX printing process

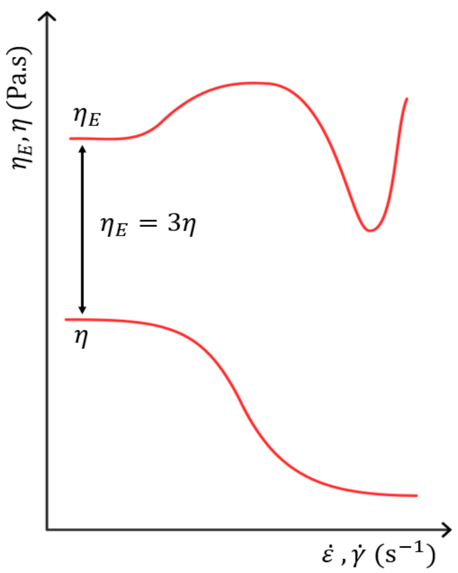

Figure 2. Changes in extensional and shear viscosity with increasing deformation rate

When a polymer's shear and extensional rheology are not matched to the flow conditions in MEX, processing problems can appear from nozzle clogging, unsteady flow, inconsistent extrusion rates or melt fracture which subsequently impact the layer-to-layer contact, and thus the overall mechanical performance of the printed part. Despite this, the extensional component is often neglected, with shear flow assumed to dominate at all parts of the extrusion process. It is crucial to understand both components in order to gain a greater understanding on their impact in MEX. Composite filaments are increasingly used in MEX processes to serve various functions, such as reduce shrinkage, improve stability, increase mechanical performance, and achieve higher thermal or electrical conductivity. However, the addition of fillers and fibre reinforcements in feedstock filament complicates the flow even further by altering a polymer's shear and extensional rheological profiles.

The addition of fillers generally increases a polymer's shear viscosity for all shear rates and can generate an increase in shear thinning [6]. Similarly, composite fillers also increase the extensional viscosity in the linear region [7]. However, at higher deformation rates, composite fillers can have a softening effect on the strain hardening region. The degree of impact is dependent on filler concentration and morphology [8]. The effects of composite filler on the extensional viscosity and its impact on extrudability within the MEX printing process is rarely discussed in detail, with research on high temperature semicrystalline polymer composites further neglected due to thermal limits of extensional rheometry apparatus.

In this paper, an extensional viscosity fixture (EVF) mounted on a rotational rheometer, is used to experimentally compare the extensional viscosity of semicrystalline Polyaryletherketone (PAEK) as well as its glass fibre (GF) and hollow glass sphere (HGS) composites at melt temperatures at a concentration of 10 wt. %. Such that the impact of filler and morphology on the extensional viscosity can be determined, and its influence on the MEX printing process.

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