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INTEGRATIVE SIMULATION FOR ASSESSING THE MECHANICAL PERFORMANCE OF A WELD LINE ON INJECTION MOULDED THERMOPLASTIC PARTS

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Injection moulding is one of the most widespread techniques for forming thermoplastic parts at industrial scale. Weld lines constitute one of the main concerns of such forming process in terms of mechanical performance of the final part. In brief, weld lines are entities formed when two melt flow fronts collide inside a mould cavity. Given the rapid cooling rates usually employed in injection moulding, complete healing between the encountered melt fronts cannot be guaranteed. In addition, weld line formation is normally accompanied by a flow-induced molecular orientation of the polymer chains parallel to the weld line interface that makes more difficult the chain interpenetration [1]. On the other hand, when injecting fibre-reinforced thermoplastics, flow phenomena during the weld line formation usually induces a microstructure where fibres appear preferentially oriented parallel to the weld line interface. In consequence, mechanical properties in the region of a weld line are mainly dependent of the healing quality of the polymer interfaces, independently if the injected thermoplastic is reinforced or not.

Currently, most of the software simulating the injection moulding offer the possibility of predict the formation, the displacement and the final location of weld lines, but the quality of the healing is frequently given only in terms of qualitative scales. On the other hand, several attempts for modelling quantitatively the polymer chain interpenetration between two polymer interfaces can be found on the literature. Free-energy-driven chain inter-diffusion [1] and polymer reptation theory [2] can be mentioned among the approaches employed for describing the healing of polymer interfaces. Polymer diffusion at the weld line is basically a temperature-driven phenomenon; hence modelling approaches are strongly dependent on the thermal history at the weld line interface.

The aim of this work is on one hand to implement a physical model describing the local healing between polymer interfaces, using as input parameters the thermal history of a weld line interface given by commercial software of injection moulding. On the other hand, the objective is to establish an integrative simulation chain -from process to structural simulation- in order to predict, for example, the macroscopic tensile properties of injected thermoplastic parts containing a weld line.

An amorphous polymer and a glass-fibre reinforced semi-crystalline polymer were employed in the study. Tensile bar specimens with different thicknesses (3.0mm and 1.5mm) were injection moulded using one or two in-gates at the extremes of the specimens. In the first case, a specimen without weld line was obtained. In the last case, a specimen with a frontal weld line in the middle of the bar was produced. Different processing parameters (mould and melt temperature) were employed to induce different healing qualities at the weld line interface. Tensile tests at 1mm/min (with 10mm extensometer) were performed on the tensile bars in order to characterize the mechanical properties in traction of the materials with and without frontal weld lines. Injection moulding campaign and tensile testing were performed at PIMM laboratory (Arts et Métiers ParisTech, Paris, France).

In order to model the inter-diffusion of polymer chains at the interface of a weld line we resort to the reptation theory (De Gennes, Doi and Edwards), which describes the dynamics of a linear polymer chain (entangled regime) in the melt state. According to the theory, the characteristic time required by a polymer chain for reaching a new topological configuration at constant temperature can be estimated from the terminal relaxation time identified by standard rheological characterization of the polymer melt. In particular, such characteristic time can be associated to the shear rate at which the melt starts exhibiting rheo-thinning behaviour. In practice, the aforementioned characteristic time could be predicted then using the classical models describing the shear viscosity of polymer melts (e.g. Cross-WLF, Arrhenius) in function of the temperature, pressure and shear rate. Finally, the local healing degree at the weld line interface was quantified as the integral of the ratio between the physical and reptation time, where the start-point of integration is the end of filling and the end-point occurs when the local temperature reaches the glass transition or the crystallization temperature.

Injection moulding (filling, packing and cooling) of the tensile bars was simulated using commercial software for injection moulding. On one hand, geometry and position of the weld line was mapped from the process to the structural simulation mesh. On the other hand, evolution of the temperature field at the weld line during the forming process was exported from the process simulation software to the external-routine calculating the healing quality of the weld line as described in the previous paragraph. Afterwards, local healing quality factor was used to penalize the material model of the elements with a healing quality factor inferior to a defined criterion. Finally, elasto-plastic simulations of the tensile tests were performed with the aim of compare with the measured tensile properties. In this workflow, three main issues affecting the final simulation results are clearly identified: geometry of the weld line predicted by the process simulation, criterion for the healing quality of the matrix and material model of the penalized elements in the structural simulation.

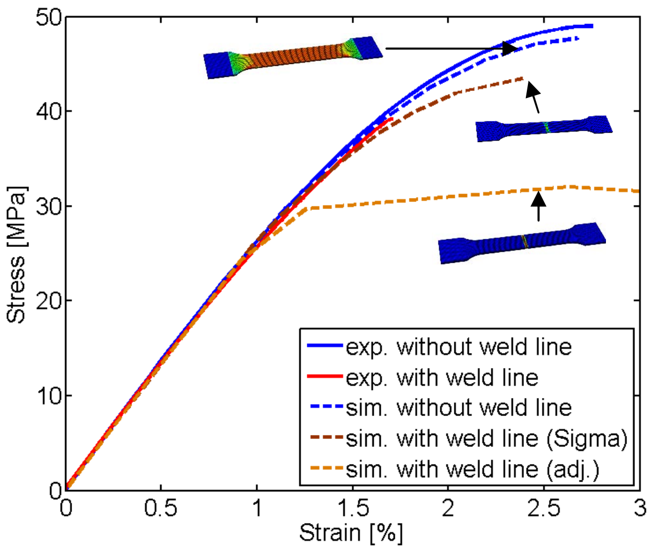

Figure 1. Experimental and preliminary simulation results of a tensile test for an amorphous polymer (with and without frontal weld line)

Experimental tensile tests on an amorphous polymer with and without frontal weld line are presented in Figure 1. As theoretically expected, Young modulus is not compromised by the existence of a weld line, but properties at rupture (stress and strain) are strongly affected by the presence of the weld line. In addition, some preliminary simulation results can also be observed in Figure 1. In that case, the influence of the weld line geometry (Sigma: default simulation result and adj.: transversal area of the bar) on the structural simulation results has been evaluated. The criterion for healing quality and the penalized material model (elasto-ideal-plastic) have been kept constant.

Additional simulation results and an extensive discussion in front of the experimental measurements will be included for the final version of the paper.

REFERENCES

[1] S. Kim and N. Suh “Performance prediction of weldline structure in amorphous polymers”. *Polymer Engineering and Science*, Vol. 26, No. 17, pp 1200-1207, 1986.

[2] C. Nicodeau “Modélisation du soudage en continu des composites à matrice thermoplastique”. PhD thesis, ENSAM, Paris, 2005