Transformation of tribological modelling of squeeze flows to simulate the flow of highly viscous adhesives and sealants in manufacturing processes

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For the description of the flow processes of an adhesive during pressing, existing CFD models are very complex and should be replaced by more efficient methods. The Partially Filled Gap (PFG) model developed for tribological systems, which is firmly established in practice, is used for this purpose. This paper shows an academic example of a comparison between a CFD calculation, the PFG model and an analytical solution based on the Reynolds equation, showing that the PFG method is well suitable to the problem presented. In an outlook the future potential of this approach is discussed.

1 Introduction

Bonded joints continue to play a very important role in practical manufacturing processes. Adhesives are used in practically every industry to join 2 or more workpieces [1]. On the one hand it is important for the strength of the bond that the joint is completely filled with the adhesive and on the other hand that not too much excess adhesive escapes during the joining process and pollutes the components as well as the environment. In order to describe and predict the relevant processes, it is the aim of the authors to carry out fundamental systematic investigations. First and foremost, the aim is to find out how the initial application pattern correlates with arising air inclusions and excess adhesive quantities. Both experimental and numerical experiments are planned. With regard to modeling, the requirement is that a complex 3D CFD modeling with VoF (Volume of Fluid) approaches is currently required [2]. This approach is often not only numerically ineffective, but also demanding in terms of convergence. For this reason, a different strategy based on the experience of another scientific discipline, tribology, will be pursued here.

In tribological questions, gap flows are usually modelled 2-dimensionally, whereby the direction perpendicular to the gap plane is not discretized. The underlying assumption is primarily the absence of a flow in this direction. Furthermore, only the flows due to the pressure gradients in the direction of the gap plane as well as the viscous resistances due to the shear perpendicular to the gap plane are considered in the momentum balance. These approaches lead to the Reynolds equation, which has been applied for more than 100 years and is firmly established in practice [3]. In addition, Müller et al. developed the PFG (Partially Filled Gaps) model, which can also be used to describe the dynamics in gaps that are not completely filled with fluid, but also contain significant fractions of air [4]. The next section compares the results of the PFG model with those of a CFD simulation for an academic example.

2 Results and Outlook

Further details on the following explanations are published in [5], in particular the settings and assumptions behind the models are documented in more depth there.

Scenario and Conclusions

Fig. 1, left shows the scenario examined. This simulates how the adhesive flows over time from an initial triangular distribution when the upper plate is moved downwards at a constant speed. In addition to the fluid distribution, the velocity fields and especially the pressure distribution were documented in [5]. Since this example is quite simple, there is also an analytical solution using the Reynolds equation. However, this solution is based on the assumptions described above and only takes into account a rectangular distribution of the fluid, which is actually reached only after a certain time. This “analytical” solution should serve as a further reference and not as an exact solution due to the underlying assumptions.

Fig. 1 on the right shows the comparison of the maximum pressures over time for the three different methods. It can be seen that, as expected, the pressure increases over-proportionally. The flow mainly takes place from approx. 0.8s onwards. All three methods show the same non-linear trend and agree very well with regard to the values. The PFG model naturally (because it is based on the same assumptions) provides almost identical results as the solution using the Reynolds equation.
The slight discrepancy between the CFD calculation and the other two curves especially near t=1.0s is partly due to numerical effects in the CFD calculations. On the other hand, the CFD simulation shows not an ideal rectangular shape of the adhesive, which is curved at the left and right edges (which is physically plausible) [5]. The differences in the interval up to 0.6s are based on the fact that on the one hand during this phase vertical flows also occur in the CFD calculation and on the other hand that the Reynolds solution assumes a rectangular configuration (necessary for an analytical solution). However, this interval is far less relevant for the resulting system behaviour, which is shown by the fact that the determining flows and pressures occur at the end (e.g. the pressures are 3 orders of magnitude larger there than at the time t=0.6s).

From this study it has been concluded that scenarios of this kind can be described very well with the PFG model. Not only did the pressures show only minor differences to the CFD calculation, but also the velocities, the (almost non-existent) pressure gradients above the height and the position of the flow fronts largely corresponded to the assumptions. From this it could be concluded that the PFG model, originally developed for tribological problems, has a great potential to efficiently simulate adhesive flows during the compression process [5].

**Potential and Outlook**

The overall goal of the collaboration between the authors’ institutions is to find suitable application patterns for minimizing air bubbles and adhesive use. The simulations will be compared with Hele-Shaw experiments in the future. Not only rather conventional patterns (see Fig. 2, top left) will be tested, but also more “exotic” ones (see Fig. 2 top middle and right), which can be realized by automated adhesive application. A greater demand on this question arises, for example, when bonding windows in frame corners (see 2, bottom). The amount of adhesive that emerges is a very disturbing effect, since the excess adhesive must be removed from the pane after the pressing step. In addition to the conventional application pattern (left), the influence of improper application (middle) and unconventional patterns (e.g. right) will be investigated.

**Fig. 2: Initial adhesive application patterns, top:** rectangular surfaces, left- conventional application pattern, middle and right - "exotic" application patterns **bottom:** frame corner of a window, left- conventional, middle- improper application, right- "exotic" pattern

**References**

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