Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 44 (2016) 298 – 303

www.elsevier.com/locate/procedia

6th CIRP Conference on Assembly Technologies and Systems (CATS)

Process Simulation and Automatic Path Planning of Adhesive Joining

Martin Svensson[a,*], Andreas Mark[a], Fredrik Edelvik[a], Jonas Kressin[a], Robert Bolin[a], Daniel Segerdahl[a], Johan S. Carlson[a], Per-Johan Wahlborg[b], Mathias Sundbäck[c]

[a] *Fraunhofer-Chalmers Research Centre for Industrial Mathematics, Chalmers Science Park, SE-412 88, Göteborg, Sweden*
[b] *Swerea IVF, Box 104, SE-431 22, Mölndal, Sweden*
[c] *Volvo Car Corporation, Volvo Car Sverige AB, SE-405 31, Göteborg, Sweden*

[*] Corresponding author. Tel.: +46-31-772-4245; *E-mail address:* martin.svensson@fcc.chalmers.se

Abstract

Adhesive joining is frequently used in the automotive industry. In the pursuit of reducing weight, adhesive joining is important due to the possibility of joining different types of materials. The process is often automatised in order to reduce cycle time. In this paper we aim to present a novel framework that includes detailed process simulation and automatic generation of collision free robot paths and in this way improve the quality of the joint and reduce both cycle time and processing time. To verify the simulations, the properties of the adhesive bead have been compared to experiments with good agreement.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
Keywords: process simulation, rheology, VOF, volume of fluid, immersed boundary method, automatic path planning, computational fluid dynamics

1. Introduction

In 2015 the European Union has an emission target of 130 grams of CO_2 per kilometre for new cars that are registered in EU. On average, the cars produced in 2014 was well bellow this limit. However, in 2021 the target reduced to 95 $g\,CO_2\,/\,km$, which is a 23% reduction from the average emission levels from 2014. To meet this regulation, car manufacturers have to find different ways of reducing the fuel consumption. The use of light weight materials, separately or in combination with conventional steel structures, is an important step in this direction but by introducing new materials, new demands in the manufacturing process emerge.

Adhesive joining is a method which addresses the problems connected with multi-material combinations and weight reduction which is why many manufacturers are increasingly substituting welding methods in favour of adhesive joining. Since adhesive joining is a relatively new technique in mass production the process itself is not optimal. The processing time to design, plan and evaluate new adhesive features is long and there is a significant amount of material waste connected to it. To reduce processing time, off-line programming is used to plan the motion of the robotised adhesive dispenser but due to the complex characteristics of the adhesive the result is hard to predict and the station operator has to manually correct the motion to achieve satisfying results.

No previous attempts to simulate the adhesive dispensing process can be found in literature. There are however similarities with the sealing spray process where a few publication can be found [1,2]. In this paper we are proposing a method for combined process simulation and automatic path planning for adhesive joining applications. With this approach both the cycle time and processing time can be reduced and at the same time the quality of the joint, in a geometrical aspect, can be assured. In Section 2 we describe the process simulation, in Section 3 the automatic robot path planning and sequence optimization and in Section 4 how these are combined in the virtual product and production software Industrial Path Solutions (IPS).

2. Process simulation

The process simulation is based on numerically computing the flow of the adhesive as well as the surrounding air using IBOFlow, the in-house fluid flow solver at Fraunhofer-Chalmers Centre (FCC) [3]. Since the adhesive exhibits non-Newtonian properties, a Carreau-Yasuda rheology model is implemented. In order to validate the numerical framework, simulations where the adhesive is applied with different velocities, mass flows and at different heights are compared to experiments.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
doi:10.1016/j.procir.2016.02.113

2.1. Numerical framework

The flow field is modelled by the incompressible Navier-Stokes equations

$$\nabla \cdot \bar{u} = 0$$
$$\rho_f \frac{\partial \bar{u}}{\partial t} + \rho_f \bar{u} \cdot \nabla \bar{u} = -\nabla p + \mu \nabla^2 \bar{u},$$

where $\bar{u}$ is the fluid velocity, ρ_f is the fluid density, p is the pressure and μ is the apparent viscosity defined as the ratio between shear stress and shear rate, $\mu = \frac{\sigma}{\dot{\gamma}}$. The finite volume method is used to solve the Navier-Stokes equations. The equations are solved in a segregated way and the SIMPLEC method derived in [4] is used to couple the pressure and the velocity fields. All variables are stored in a co-located arrangement and the pressure weighted flux interpolation proposed in [5] is used to suppress pressure oscillations. The two-phase flow is modelled with the Volume of Fluid (VOF) method, where the local property of the fluid is dependent on the volume fraction. The volume fraction is transported with the local velocity field. To keep the interface between the adhesive and the surrounding air sharp, a hybrid CICSAM convective scheme is adopted [6]. The Continuum Surface Force derived in [7] is used to model the surface tension. A Cartesian octree grid is used for the spatial discretisation of the fluid domain and dynamic refinements around moving objects and interfaces between phases in the flow are used.

Further, the immersed boundary method [8] is used to model the presence of moving objects, without the need of a body-fitted mesh. In the method, the fluid velocity is set to the local velocity of the object with an immersed boundary condition. To set this boundary condition, a cell type is assigned to each cell in the fluid domain. The cells are marked as fluid cells, extrapolation cells, internal cells or mirroring cells depending on the position relative to the immersed boundary. The velocity in the internal cells is set to the velocity of the immersed object with a Dirichlet boundary condition. The extrapolation and mirroring cells are used to construct implicit boundary conditions that are added to the operator for the momentum equations. This results in a fictitious fluid velocity field inside the immersed object. Mass conservation is ensured by excluding the fictitious velocity field in the discretised continuity equation. A thorough description of the method and an extensive validation can be found in [8].

Adhesive is injected to the domain through source cells located at the position of the orifice of the dispenser. The fluid velocity in these cells corresponds to the mass flow obtained by

$$\dot{m} = \rho v_{robot} \left(\frac{\Phi_{nom}}{2} \right)^2,$$

where ρ is the density of the adhesive, v_{robot} is the velocity of the dispenser and Φ_{nom} is the nominal diameter of the bead.

2.2. Rheology

The apparent viscosity of the adhesive is modelled according to the Carreau-Yasuda model [9],

$$\mu = (\mu_0 - \mu_\infty) \left(1.0 + (\lambda \dot{\gamma})^2 \right)^{0.5(N-1)} + \mu_\infty,$$

where the apparent viscosity, μ, is dependent on the local shear rate, $\dot{\gamma}$, λ and N are material constants derived from experiments, see Table 1 and μ_0 and μ_∞ are the zero-shear-rate viscosity and the infinite-shear-rate viscosity which represents the upper and lower Newtonian plateaus defined as

$$\lim_{\dot{\gamma} \to 0} \frac{\sigma_{xy}}{\dot{\gamma}_{xy}} = \mu_0$$

and

$$\lim_{\dot{\gamma} \to \infty} \frac{\sigma_{xy}}{\dot{\gamma}_{xy}} = \mu_\infty.$$

Table 1. Carreau-Yasuda parameters for M91 rubber adhesive

Parameter	Value (t)	Unit (t)
Zero-shear-rate viscosity, μ_0	130000	$Pa \cdot s$
Infinite-shear-rate, μ_∞	60	$Pa \cdot s$
Carreau time constant, λ	1000	s
Power law index, N	0.3	-

The rheology model is shown in Figure 1 together with experimental data of the M91 structural rubber adhesive used extensively at Volvo Car Corporation from cone-plate rheometer measurements performed at Swerea IVF and parallel plates and capillary rheometer measurements from [10].

2.3. Validation

The numerical framework and rheology model are validated by simulating three different bead set-ups with different properties, see Table 2.

Table 2. Set-up variations for different beads.

Bead set-up	Nominal diameter (mm)	Application speed (mm/s)	Application height (mm)
Bead 1	2.5	150	2.5
Bead 2	3.5	300	3.5
Bead 3	5	300	5

Simulations are then compared to experimental data where the three different set-ups are used to apply adhesive to a sheet metal plate with length 200 mm using a SCA dispenser, model