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Model reduction, data-based and advanced discretization in computational mechanics

Reduced-order model of optimal temperature control for the automated fibre placement process

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ABSTRACT

Industrialising manufacturing processes for aeronautic composite parts is a challenging issue. Among the existing techniques, the Automated Fibre Placement (AFP) is a promising one, since it allows the making of large and complex pieces with good productivity and repeatability. However, in order to ensure the regulatory requirements, the process must be controlled efficiently. In this paper, we propose the off-line computation of a parametric solution to a minimisation problem subject to heat equation. To solve this saddle-point problem with the so-called PGD method, we considered using Uzawa's technique or the Ideal Minimal Residual-based formulation, the aim being real-time control of the heat source within the AFP process.

1. Introduction

Automated Fibre Placement (AFP) is one of the main technologies employed today to manufacture advanced composite laminates from unidirectional prepregs [1]. This technique consists in laying and welding tapes of prepregs, building a laminate with more or less complex geometry, as depicted in Fig. 1.

In the 1990s, numerical models were proposed [2,3], with crude assumptions far from real process conditions. Improvements were made in [4,5].

In [6], even if the model itself was more relevant (3d domain, anisotropic material, inter-ply interfaces…), the numerical method was novel. To achieve a global thermo-mechanical process modelling, the numerical strategy proposed was based on the Proper Generalized Decomposition (PGD) [7,8]. This method uses a separated representation of the unknown field, reducing the computational complexity of the system. A key asset of this technique is its ability to introduce parameters (from process, from material, even from geometry…) as extra-coordinates into the model, without incurring the *curse of dimensionality*. Thus, in a single computation we have access to a multi-parametric virtual chart providing all possible solutions for each combination of the considered parameters [9–13].

Then, the computational vademecum can be exploited *on-line* for process control or process optimisation purposes. Indeed, within the AFP we want to efficiently control the heating power: tapes have to be heated enough to ensure the melting of the matrix coating the fibres and the cohesion with the previously laid tapes, while not exceeding a threshold

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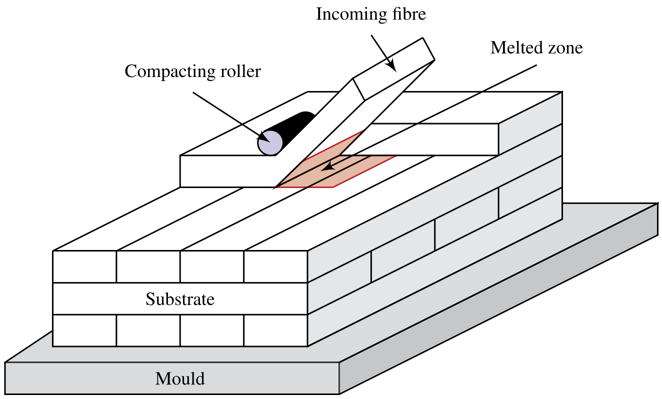

Fig. 1. Process sketch.

from which material burns, for a given process velocity. Indeed, both reticulation and thermal degradation depend on temperature and on the time spent at that temperature [14].

Therefore, we took advantage of the PGD to build *off-line* static and transient virtual charts in order to determine the best power associated with a draping velocity profile [15].

However, in those simulations, solutions were computed from equations provided by underlying physics of the studied phenomena, the optimisation being carried out as post-process. We propose here to compute directly the solution to an optimisation problem in order to get the separated representations of both the field and the control to obtain it. That is to say that the optimisation is made directly *off-line*, reducing the cost of the post-process and improving the real-time control of the AFP.

Within the next section, we present the equations governing the phenomenon under consideration. In order to have a reference solution, the system is solved by a standard finite element method (FEM). Thereafter, section 3 shortly presents the so-called PGD, and we take benefit of this technique in section 4 to build virtual charts to be used for control. Section 5 focuses on the writing and solving of the optimal system. We improve the obtained results by applying an iterative scheme in section 6. To circumvent the drawback of this additional loop, we also tried a modified PGD-based solver in section 7. Lastly section 8 addresses few conclusions and perspectives.

2. Process modelling

Let us consider a unidirectional stacking of layers constituting a homogeneous domain Ω, depicted in Fig. 2. This picture also makes explicit the meaning of some geometrical parameters.

We assume the heat source acts only on a part of the upper boundary, denoted by Γ_P in Fig. 2. With the assumption of a steady state, within a large piece, a Dirichlet condition is set on the boundary Γ_D, homogeneous for the sake of simplicity. On the remaining boundaries, gathered under the unique name Γ_N, we consider homogeneous Neumann conditions, once again for the sake of simplicity.

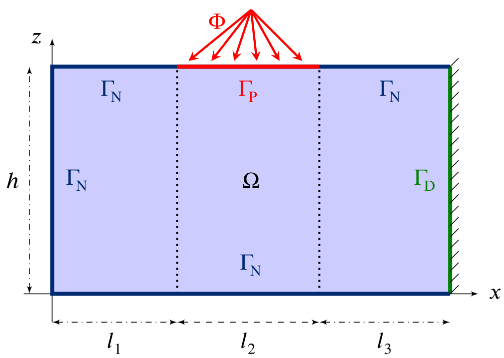

Fig. 2. Domain of study.