DEVELOPMENT OF

SPRAY ON BAG FOR

MANUFACTURING OF LARGE COMPOSITES PARTS:

DIFFUSIVITY ANALYSIS

by

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Maman, ca y est , tu peux respirer maintenant.

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ABSTRACT

Bagging materials are utilized in many composites manufacturing processes. The selection is mainly driven by cost, temperature requirements, chemical compatibility and tear properties of the bag. The air barrier properties of the bag are assumed to be adequate or in many cases are not considered at all. However, the gas barrier property of a bag is the most critical parameter, as it can negatively affect the quality of the final laminate.

The barrier property is a function of the bag material, uniformity, thickness and temperature. Improved barrier properties are needed for large parts, high pressure consolidated components and structures where air stays entrapped on the part surface. The air resistance property of the film is defined as permeability and is investigated in this thesis. A model was developed to evaluate the gas transport through the film and an experimental cell was implemented to characterize various commercial films. Understanding and characterizing the transport phenomena through the film allows optimization of the bagging material for various manufacturing processes.

Spray-on-Bag is a scalable alternative bagging method compared to standard films. The approach allows in-situ fabrication of the bag on large and complex geometry structures where optimization of the bag properties can be varied on a local level. An experimental setup was developed and implemented using a six axis robot and an automated spraying system. Experiments were performed on a flat surface and specimens were characterized and compared to conventional films. Air barrier

properties were within range of standard film approaches showing the potential to fabricate net shape bagging structures in an automated process

Chapter 1

INTRODUCTION

1.1 Composite Manufacturing Approaches using Film Bags

Many composite manufacturing approaches are utilizing a film bag as a flexible mold surface to provide a pressure cavity between the opposing mold sides (Figure 1.1). Examples include autoclave and out-of-autoclave (OOA) prepreg processing but also various infusion processes such as the Vacuum-Assisted Resin Transfer Molding (VARTM) process. In general, the bag conforms to the laminate when an internal vacuum or external positive pressure is applied. The pressure difference between the inside and outside of the bag provides the consolidation pressure but also could enables air/gas molecules to penetrate through the film into the composite potentially creating undesirable voids in the structure translating into poor final properties [2].

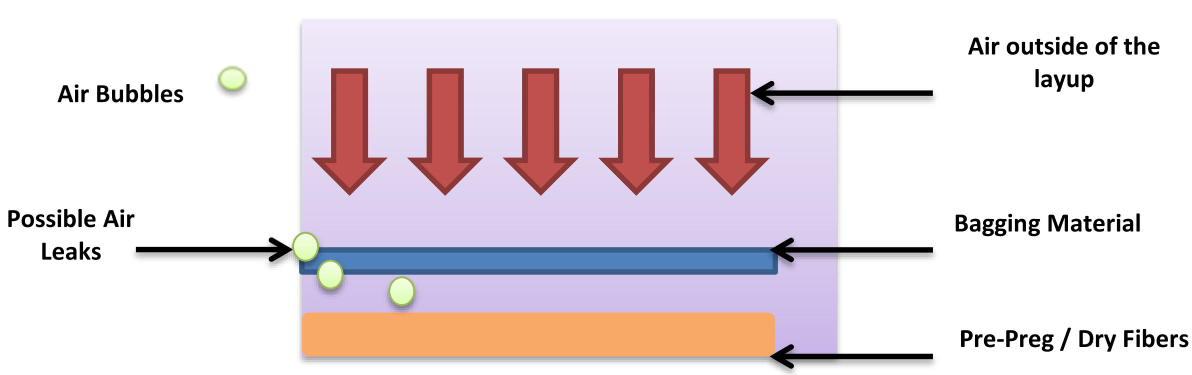


Figure 1.1: Role of the bagging material during consolidation

The properties of the bagging materials affect the gas transport into the mold cavity. The bag is often subjected to high temperature and pressure during the curing of the laminate significantly increasing gas flow rates through the film. In particular in components with large distances to the vent, a significant pressure drop under a permeable or very thin bag can be observed as seen in Figure 1.2. A detailed study of the influence of pressure drop with bag properties is provided in the thesis and allows optimum selection of the bag for a particular application.

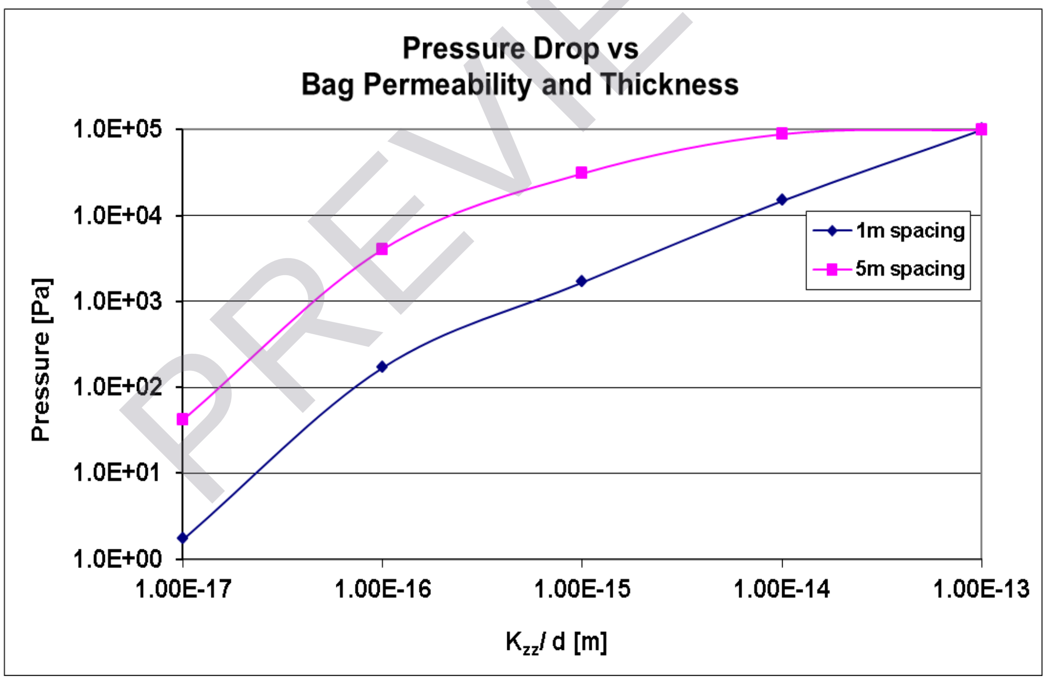


Figure 1.2: Relationship between bag properties and pressure drop in a part

The importance of the bag in composite processing combined with the limited knowledge of the air transport in these systems provides the motivation for the current research. Selection of the right bagging material will depend on the process cycle parameters (pressure, temperature), part geometry and quality requirements. A detailed study of existing bag properties is provided in this thesis and will allow selection of the correct bag for a given process setup.

1.2 Bagging Materials

There are multiple bagging materials used in the composites manufacturing industries with the three most common materials being nylon, silicone and apton film bags (Table 1.1 and Figure 1.3). They differ mainly in their use temperature, reusability, cost and barrier properties.

1.2.1 Thin Film bags

Thin films bags are the standard type of bagging materials used in industry and are made of either nylon, for standard application, and polytetrafluoroethylene or others engineered plastics for elevated temperature uses. [2] One of the benefits of the thin film bags is their transparency, in particular for infusion processes where the resin flow front can be visually observed. Those bags also provide excellent air barrier properties as well as chemical resistance however, manufacturing issues are encountered during the use of standards bagging materials. Those issues need to be addressed in the early stages of the manufacturing design because of the potential to increase significantly parts cost [1]. Conventional bagging structures have to be sealed to the mold surface creating possibilities for leaks at the bag/sealant interface, bridging, and bag breakages [2, 3]. In the manufacturing of large parts, seams created at the interface of multiple bags are leakages sources, where leaks will prevent the parts to achieve and maintain a good gas barrier during consolidation.

Consistency achieved during the manufacturing is also a major issue and the quality of the bagging process depends largely on the skill level of the operator. Leaks encountered while bagging a part affect the compaction pressure and create defects. Automation would be the key to improve repeatability and robustness.

1.2.2 Alternative and upcoming bagging process

1.2.2.1 Re-usable bags

Reusable bags are often made out of silicone material. Complex geometry reusable bags are fabricated with thick sheets cut and bonded together to replicate the outer dimensions of the laminate. The bag is typically framed within a support structure to be able to lift and place it onto the mold. Reusable bags are thick (above several millimeters) and thus can be too heavy to support its own weight. The handling of the bagging assembly often required in the manufacturing of wings aircraft adds cost and complexity to the process [1]. In addition, the bag wears down during each application due to mechanical and chemical stresses onto the material. This limits the number of cycle an individual bag can be used before repair or replacement. Fabrication of reusable silicone bags are difficult to be automated and this issue is affecting the parts turn around during manufacturing. [4] The chemical resistance of reusable bags is comparable to nylon's films; however the air barrier properties are significantly higher and governed by the thickness of the bag which can be adjusted to provide a robust structure reducing risk of tear, compatibility with the resin and to provide an improved gas barrier.

1.2.2.2 Spray on Bag

The spray-on-bag is a bag which is built to the shape of the parts by spraying a polymer that gels and form a net shape air-barrier for vacuum bagging.

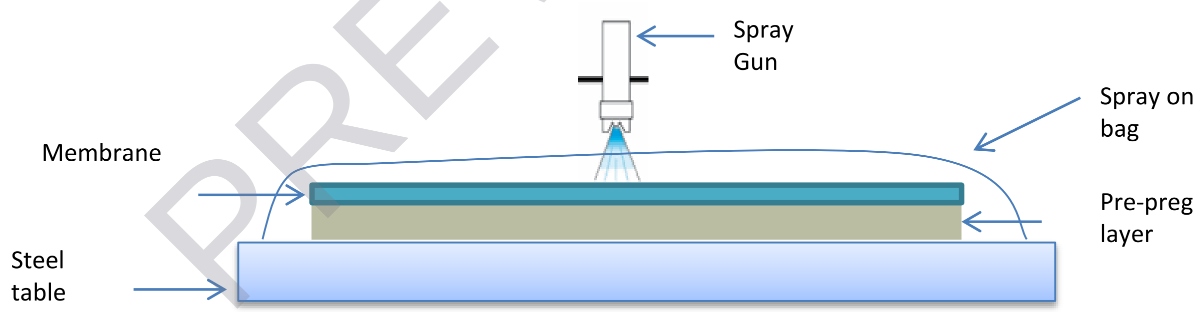


Figure 1.3: Schematic of Spray on Bag

New types of in-situ spray-on bagging materials have been developed by various companies such as Smooth-On and EZ-Spray [4]. The spray-on bag method will allow spraying of the bagging materials over large sections without creating seams as multiple sections are simultaneously sprayed and cured onto the part surface. Another benefit is the ability to automate the spray parameters which improves repeatability and robustness. An experimental spray cell has been developed and is attached to a robot or multi-axis actuator allowing a fully controlled and controllable spraying pattern. Figure 1.4 shows the setup installed at UD-CCM. The system is being used to fabricate small samples for material evaluation.

Figure 1.4: Spray bagging work cell at UD-CCM

1.2.3 Summary of bagging materials

Properties critical to vacuum bags such as the continuous temperature, and the air diffusivity of bags materials were collected and are presented in table 1.1.

Type of Material	Nylon[3]	Silicone[4]	Kapton [5]
Maximum Temperature use	215°C	240°C	426°C
Price	Low	Medium	High
Common Thickness	5 mil- 25 mil	Variable thickness*	5 mil-25mil
Air Diffusivity* [$m^3 m/m^2$ Pa s]	2.28 e-20 [25]	2.10 e-15 [25]	2.9e-21 [25]

Table 1.1 : Bagging Materials Summary

The air diffusivity of silicone is 5 orders of magnitude higher than nylon film and is still accepted as a good air barrier for the manufacturing or large parts. [3] A material having air diffusivity within this range will then be meeting current industrial's requirements.

Nylon Film

Silicone Bag

Kapton

Figure 1.5: Current bagging materials used in industry

1.3 Goals and Thesis Organization

Low-cost and scalable bagging concepts are being investigated to meet the next generation composite boat manufacturing process. The current state-of-the-art requires a manual bagging after the lay-up of the material into the mold. A variety of bagging materials exists with nylon film being the most commonly used in the composite industry. They are often selected minimizing cost of the bag. The manual layup is not only extremely labor-intensive but it also often results in leaks at seams or at the interface to the tooling surface. Lately new alternatives such as spray-on bagging have been developed to create complex geometry and leak-free bags.

Within this context four goals of the thesis are defined: 1) Understanding the fundamental gas transport mechanisms in a bagging structure, 2) Experimental characterization of permeability in thin films, 3) Define bag permeability requirements based on the process setup, and 3) Implementation of a new bagging process using spray-on polymers. Together the research will allow to identify requirements for bags in particular for large and complex geometry structures.

Chapter 2 of the thesis describes the importance of bags as a gas barrier in existing composites manufacturing methods and outlines alternative bagging methods. A review of existing transport mechanisms is presented and assumptions were made in the ones relevant to bagging materials. Diffusion laws are defined as well as the modeling process used to predict diffusivity values. It also describes the transport mechanisms occurring through a bag based on diffusion and establish the permeability requirement. Chapter 4 presents the spray on bagging concepts and films obtained using the developed spray on cell. A benchmarking on the materials considered is presented followed by the hardware requirements and steps to develop the automated spraying bag cell. The film formation quality is then analyzed and methods to increase the quality of the films suggested. Chapter 5 is a summary of the experimental permeability data collected using our developed permeability cell. The final chapter summarizes the thesis findings and outlines potential future work.

Chapter 2

FLOW MECHANISM THROUGH BAG

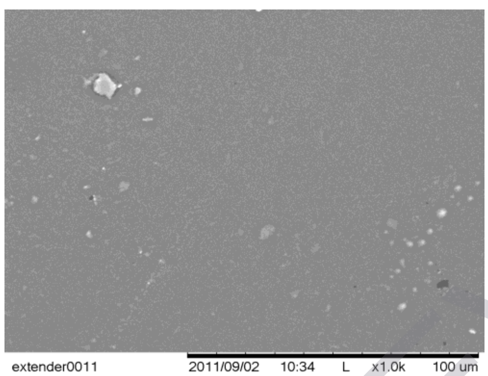
2.1 Review of Transport Mechanisms

Various transports models have been developed to explain transport phenomena through non-porous, partially or fully porous films. Bags used for composites manufacturing are not perfect gas barriers and are subject to gas diffusion through them. Those flows can be characterized under two governing mechanisms: Diffusion and Darcy flow [5]. Diffusion is a transport phenomenon that occurs without requiring a bulk motion. [6] It is a mass transport concept, which refers to a transit of species due to a concentration gradient. Darcy flows is a pressure driven flow through open channels or pores.

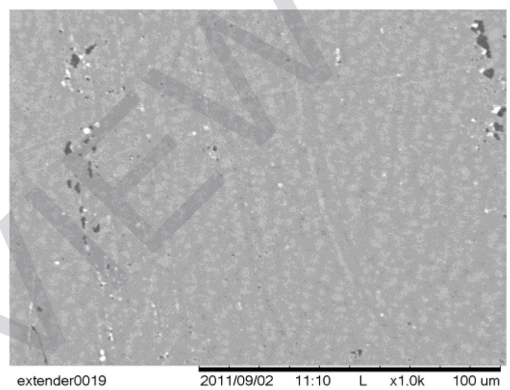
2.1.1 Film Microstructure

The microstructure of a film is an indicator of the transport mechanisms occurring through the film. Films with an open structure, [2.1-Multi-Membrane] will be governed by Darcy's flow mechanism [7] while a film with a homogenous closed structure follows the diffusion's law. Scanning electron microscopy was performed on standard bagging films (Nylon, ETFE) and an alternative material (polyurea) considered in this thesis. A membrane was also analyzed for comparisons in Figure 2.1.

The structure of the nylon, ETFE and polyurea were all very similar as all of them demonstrate a homogenous closed structure without connecting pores between the film surfaces. In contrast, the membrane showed a complex network of fibers making it porous. Based on the surface microscopy, porous media mechanisms are not likely to occur with the bagging films and diffusion is being considered as the driving mechanism for the bagging materials.

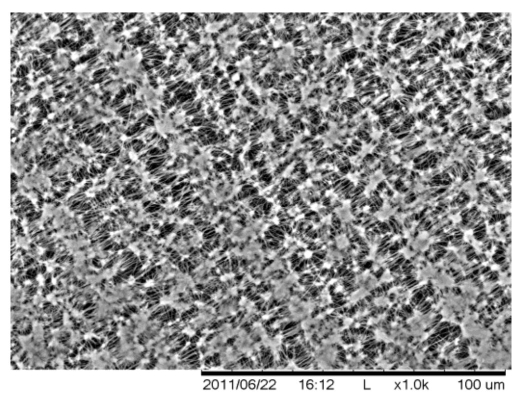


Polyurea



Nvlon

Kapton



Multi-Membrane