



Computational Fluid Dynamics Modeling of the Spray Process of Resin Over a Laid Up Fiber Stack for the Purpose of Fiber Impregnation and Composite Materials Manufacturing

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Abstract. Composite materials are group of engineering materials which are combinations of more than one material type with the intention of getting specific material properties. The components of the composite may be metals, ceramics, plastic or other materials. The manufacturing methods of composite materials especially fiber reinforced plastics requires combining two or more materials in defined orientation. Among the different fiber reinforced plastic composites manufacturing methods hand layup method comprises 22% and exclusively implemented in developing countries. Other advanced manufacturing methods such as resin transfer molding, compression molding and auto calve require high capital and technical expertise. It is possible to say all the manufacturing methods have their own limitations. Resin spray over a laid up fiber stack is first phase of a new manufacturing setup which will be followed by pressure compaction. In this paper the spray process is modeled using computational fluid dynamics in 3D spray region of size $30 \times 30 \times 60$. In the modeling spray characteristics of the fairly viscous unsaturated polyester resin using different nozzle types have been analyzed. The result shows only few types of nozzles are capable of spraying the 0.3 kg/m-s viscosity liquid with fairly good area and distance of coverage. In the case of pressure swirls atomizer about 30 cm distance from the atomizer results a fairly uniform distribution.

Keywords: Composite materials · Spray · CFD modelling · Manufacturing

1 Introduction

Composite materials are group of engineering materials which are combinations of more than one material type with the intention of getting specific material properties. Fiber reinforced plastics are groups of composite materials with a reinforcing element, fiber, and a compatible resin binder (matrix) to obtain specific and unique characteristics and properties [3–8]. Composites materials receive much attention not only

because they are on the cutting edge of active material research fields but also due to appearance of many new types of composites, e.g., nano-composites and bio-medical composites. Composite materials have great deals of promise for its potential applications in various industries ranging from aerospace to construction due to its various outstanding properties. While metals and plastics are currently the dominant materials in product development applications, composite materials with superior physical performance characteristics are increasingly used to replace traditional metal and plastic material in engineered products [2]. Most widely used composite material groups are fiber reinforced plastics (FRP) with components of glass fibers, carbon fibers, Kevlar fibers, etc. and thermoset matrixes such as polyester, epoxy and vinyl ester. The composite materials technology is emerging; many new classes of materials have been developed to satisfy various new applications, a ceramic matrix composite that incorporates a metal phase to increase the toughness of the brittle ceramic matrix is one of them [1]. It is possible to say pure metals and metallic alloys will be replaced by the most versatile material generations, composite materials. The main advantage behind these composite materials is attaining material properties that could not be attained by pure materials, for instance in carbon epoxy composite, the material gets the strength from the carbon fiber and the toughness from the epoxy.

The manufacturing technology with composite materials is one of top research areas. Combining materials with different properties to a single product is not as straight forward as single component metals or plastic manufacturing. The main manufacturing technique implemented are Hand layup/open mold processes, Resin transfer molding, Compression molding, Autoclave and other continuous processes with increasing in development of new and modified processes [9]. All types of processes have their own strength and weakness. Hand layup manufacturing method comprising 22% share is easy to implement and requires low investment with compromise of quality, productivity and exposure of toxic chemicals [9]. Resin transfer molding with different varieties being developed requires relatively higher investment than hand layup and it has pressure related issues. Autoclave is implemented for high performance products with low productivity and very high investment. Compression and injection moldings with high level of productivity applied only for low performance products. Other continuous processes mainly have limitation of shape complexity. This paper is part of a PhD research work of full composite manufacturing set up (Fig. 1). The system incorporates a spray and a compaction stage. The resin will be sprayed over the laid fiber stack. The sprayed mist of resin will infiltrate through thickness by capillary effect of fiber and compaction pressure applied by the pressure plate backed by a pushing balloon enlarged by compressor pressure. In this setup resin infusion is mainly towards the thickness which is unique, in most other processes the resin infusion is along the width and length or simply areal.

2 Material and Methods

The specific geometry of fiber stack selected is flat shape of dimension 30 cm \times 30 cm in a vertical position with intention of studying the most difficult position in composite materials manufacturing practice. The composite components modeled are unsaturated

polyester resin of viscosity 0.3 kg/m-s and E glass fiber chopped strand mat. The former being a liquid phase to be sprayed over the laid up stack of fiber.

2.1 General Model Setup

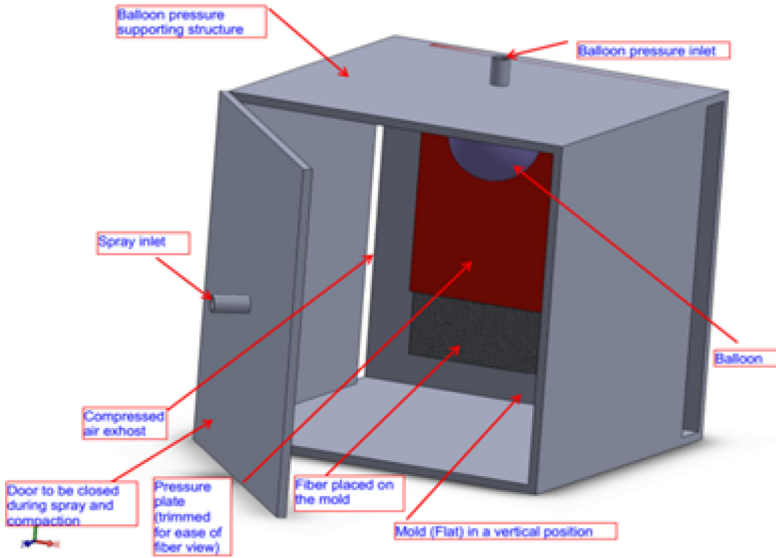


Fig. 1. General process setup

The model setup (Fig. 1), shows the whole set up of spray and compaction phases of the flat geometry of product selected 30 cm × 30 cm size in vertical position. The fiber stack of dimension 30 cm × 30 cm, density 450 g per meter square (gsm) and 3 number of layer stack is placed in the mold (flat) in vertically position. The frame door will be closed and resin to be sprayed through the spray inlet to the fiber stack. After the spray phase completed, the process will get in to the next stage of the process i.e. the compaction phase which is not addressed in this paper.

2.2 CFD Modeling Setup up for the Spray

The spray phase modeling is performed with a 3D geometry of size 30 cm × 30 cm × 60 cm flow region (Fig. 2), where the 30 cm × 30 cm is the sample size and the 60 cm length is the variable distance between the nozzle tip and the laid fiber. (0, 0, 0) is the coordinate for atomizer position. Flow rate of 0.02 kg/s or 20 g/s is expected for 10 s to spray about 0.2 kg resin which results a composite product of 35% to 65% fiber to resin ratio.

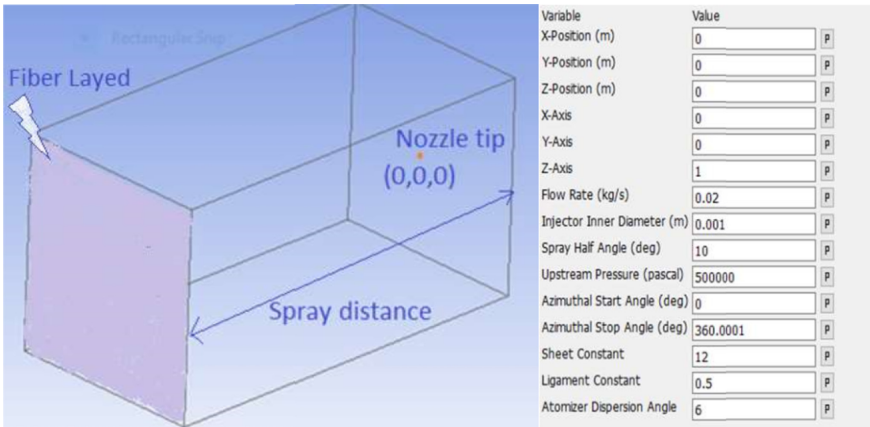


Fig. 2. CFD spray setup

2.3 Mesh Generation and Analysis Mesh Generation and Analysis

3D mesh is generated with hex dominant method of element size 0.0375 m. The mesh/grid of the model is shown in Fig. 3. The mesh was generated based on medium relevance center and has 1377 nods and 1024 elements. The grid was refined to confirm mesh independence. When the percentage different between the two successive meshes is negligible, it is possible to say there is mesh independency. To identify mesh independency, the simulation was proceeded from coarse to medium mesh and the variation of the desired simulation out was checked. It is also possible to have mesh independent solution by using a very fine uniform mesh. However, analysis time will be too much.

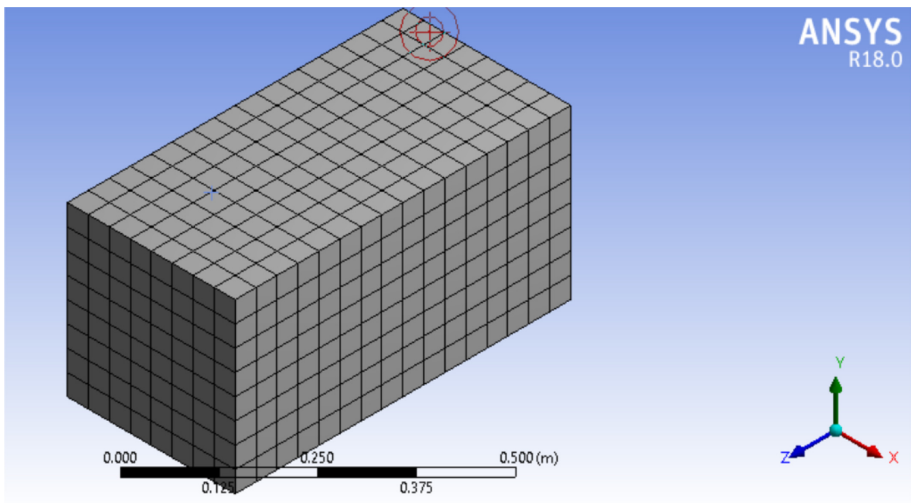


Fig. 3. Mesh generated

2.4 Governing Equations

Multi-phase Eulerian-Lagrangian approach is implemented for solving the flow problem and for tracking the path of droplets. The phases are air, continuous phase and resin droplets. The dispersed phase/droplet is solved by tracking large number droplets through the calculated flow field. The dispersed phase can exchange momentum, mass, and energy with the fluid phase. The CFD package ANSYS Fluent predicts the trajectory of a discrete phase particle or droplet by integrating the force balance on the particle, which is written in a Lagrangian reference frame. This force balance equates the particle inertia with the forces acting on the particle, and can be written as:

$$\frac{d\vec{u}_p}{dt} = \frac{\vec{u} - \vec{u}_p}{\tau r} + \frac{\vec{g}(\rho_p - \rho)}{\rho_p} + \vec{F} \tag{1}$$

Where \vec{F} is an additional acceleration (force/unit particle mass) term, $\frac{\vec{u} - \vec{u}_p}{\tau r}$ is the drag force per unit particle mass and τr is the particle relaxation factor, \vec{u} is the air velocity \vec{u}_p is the particle velocity, μ is the molecular viscosity of the fluid, ρ is the fluid density, ρ_p is the density of the particle.

3 Results and Discussion

Air atomizing spray nozzles are preferable for viscous liquids rather than hydraulic nozzles for a better dispersion and angle of coverage. Among the various types of atomizers modeled in this study: simple cone atomizer, Flat fan atomizer, plane orifice atomizer pressure swirl atomizer, Air blast atomizer, effervescent atomizer only few of them are capable of atomizing and spraying the viscous liquid unsaturated polyester resin of viscosity 0.3 kg/m-s. As it can be seen in the particle mass concentration contour pressure swirl atomizer and Effervescent atomizer result a better distance and angel of coverage (Figs. 4, 5, 6 and 7) .

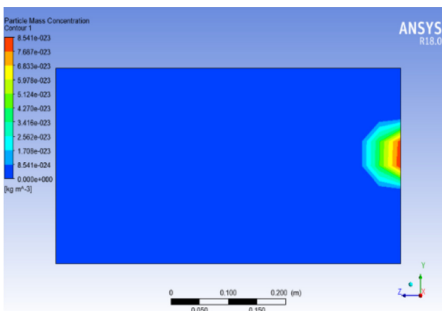


Fig. 4. Pressure swirl atomizer (particle mass concentration contour)

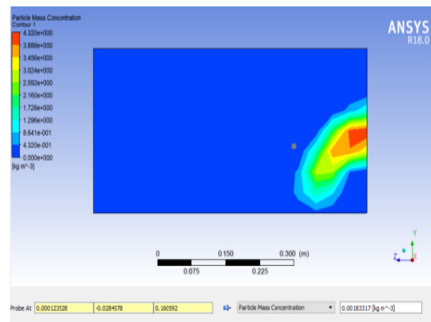


Fig. 5. Pressure swirl atomizer (particle mass concentration contour)

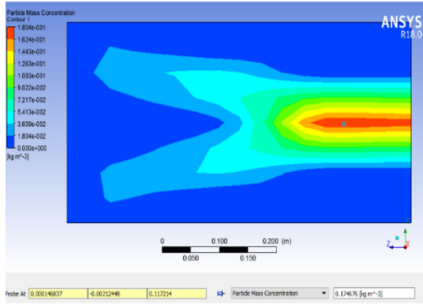


Fig. 6. Pressure swirl atomizer (particle mass concentration contour)

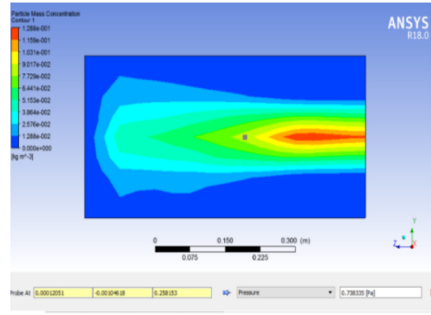


Fig. 7. Effervescent atomizer (particle mass concentration contour)

In the cross sectional view of the spray distribution, it can be possible to see the concentration coverage at different distances from the nozzle in the case of pressure swirl atomizer. It is possible to see that at distances 10 to 20 cm far from the nozzle tip have low concentration and with short distances less than 10 cm the angle of coverage is small. So, it requires balancing between the two (Fig. 8).

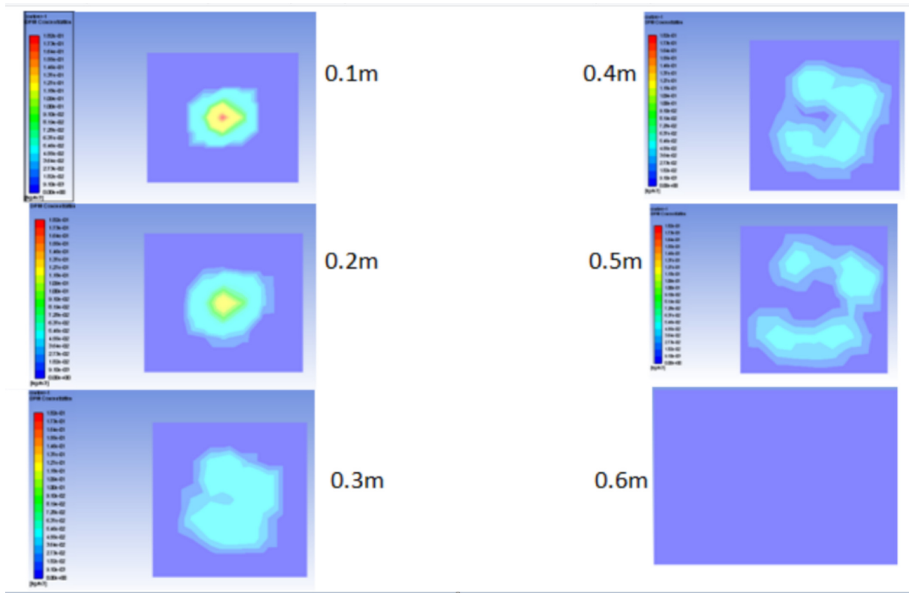


Fig. 8. Cross-sectional view: resin distribution at different distances for pressure swirl atomizer

4 Conclusion and Recommendation

Spraying and uniformly distributing a resin over a laid up fiber stack is a critical work in order to easing the next compaction process. Challenges that may happen during the spray of the fairly viscous polyester resin are uneven distribution, accumulation and drop down, high level of resin mist, wastage and others. These problems can be solved by properly selecting nozzle type, setting appropriate parameters such as pressure. In this paper mainly type of nozzles which can be applied are modeled using computational fluid dynamics modeling. It has been observed Pressure swirl and Effervescent types of atomizers result a better angle of coverage/area and distance in the simulation. In the case of pressure swirls atomizer about 30 cm distances from the atomizer tip results a wider and relatively uniform distribution.

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