Optimization of technological modes for moulding composites using vacuum infusion technology

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Abstract. The aim of this study is to optimize the resin infusion time of carbon fiber reinforced plastic laminates depend on temperature gradient using vacuum infusion technology. At room temperature the resin infusion time of moulding large composites part cause production slowly. So the infusion time must be considered in the production of large composite part. We can decrease the resin infusion time by heating the mould with greater temperature logically. But there will be thermal damage in finished composites product. In this paper we studied the resin infusion time and proper temperature gradient without losing its composites properties. This study leads to the development of rapid production in vacuum infusion technology.

1. Introduction
Composite Materials are becoming more popular gradually replacing traditional materials with extra strength, lighter weight and thermal properties. Many composites industries are exploring use of fiber reinforced composites in all application which includes aerospace, automotive and water transport, construction industry, toys, instrumentation, medicine, etc. Based on application and reinforcement used, there are many ways to manufactures parts with fiber reinforced composites [1]. Various techniques are available depending on type of reinforcement used and application of the product. If we compare different manufacturing process, most of the polymer composite products are made with vacuum infusion technology because of huge potential to manufacture critical parts with required properties at economical rate. Vacuum infusion process is being developed in many laboratories in an attempt to find this suitable process. Various types of resin infusion processing have emerged as popular manufacturing options due to their relatively low cost-per-properties ratio [2, 3].

Present work studies the resin infusion times through a carbon fiber reinforced plastic set up by multiple layers depend on different temperature gradient during the resin injection filling stage of a vacuum infusion process by using simulation software PAM-RTM. The aim of our work is to optimize the resin infusion time of two different carbon fabric (Plain weave and Twill weave) based on two different viscosity of epoxy resin with four different temperature gradient. In our work we defined the maximum testing temperature gradient as 60°C. And then we define the optimal resin infusion time based on simulation results and experimental results. This study from simulation and experimental results can effectively avoid slow production caused by the longer infusion time at room temperature.
2. Methodology
The first part of our work is analysing of physical and mechanical properties of carbon fiber and epoxy resin for the simulation of sample composite part. Secondly we created 3D geometry of carbon fabric in “MSC Digimat” software and export to the “Visual-Enviroment” program for meshing geometry. And calculate the resin infusion time with different temperature gradient by using simulation software PAM-RTM. Thirdly for the experimental results two carbon fabric (plain weave and 2/2 twill weave) and two type of epoxy resin which have different viscosity were used. After the moulding of carbon fabric is set up, the resin injection stage of a vacuum infusion process is started under loaded temperature gradient (30˚C, 40˚C, 50˚C, 60˚C) respectively. Simultaneously start record the resin infusion time by stopwatch until the end of the injection process. Finally we compare the difference between simulation and experimental results and optimize the proper temperature gradient for rapid production of large composite parts. Physical-mechanical characteristics of (3K, 2x2 twill weave carbon fiber fabric) and(3K, plain weave carbon fiber fabric) are shown in following table 1 [4].

Table 1. Physical-mechanical properties of carbon fabric

| Material properties          | Unit | 3K, Plain Weave | 3K, 2x2 Twill Weave |
|-----------------------------|------|-----------------|---------------------|
| Fiber diameter              | mkm  | 7               | 7                   |
| Fiber density               | g/cm³ | 1.76            | 1.76                |
| Yarn linear density         | Tex  | 3000            | 3000                |
| Fabric dimension            | mm   | 400×200×0.15    | 400×200×0.15        |
| Fabric orientation          | Four layer | (90˚,0˚,90˚,0˚) | (90˚,0˚,90˚,0˚)     |
| Tensile strength            | Mpa  | 401±31,00       | 253±24,48           |
| Strain                      | mm   | 0.083±0.0036    | 0.061±0.0021        |
| Specific heat capacity      | J/(kg/K)| 1050           | 1100                |
| Thermal conductivity        | W/(m.K)| 0.15           | 0.2                 |
| Permeability, K₁            | m²   | 5.93×10⁻¹⁰     | 3.99×10⁻¹⁰          |
| Permeability, K₂            | m²   | 1.66×10⁻¹⁰     | 2.83×10⁻¹⁰          |
| Permeability, K₃            | m²   | 0.75×10⁻¹⁰     | 0.95×10⁻¹⁰          |

For the production of composite sample, the composition of epoxy resin Epoxy-20 and Epoxy-20 (high viscosity) (Table 2) were used as binding materials. The choice of this resin was associated with its good strength to weight ratio, high modulus for superior rigidity, fire resistance and fatigue resistance for durable strength [5].

Table 2. The physical properties of the binding materials

| Material properties | Unit | Epoxy-20 | Epoxy-20 (HV) |
|---------------------|------|----------|---------------|
| Viscosity           | Pa.s | 0.5      | 1             |
| Density             | g/cm³| 1.1      | 1.4           |

3. Modeling and simulation calculations
MSC Digimat software is used to create geometric models. When creating a new analysis, the solver Type "Digimat-FE" was selected. The program Digimat was used to generate 3D geometrical model only. To fully define, you must specify its linear density, or select the number of fibers, the diameter of one fiber, and the thickness of the cross section. These parameters for the construction of models of fabrics of plain and twill weaving were the same because carbon fiber properties for different weaving were also the same in our study. The geometry sizes of both fabrics are (200mm×400mm) respectability and laminate layers are set to 4 layers with orientation angle (90˚, 0˚, 90˚, 0˚). In the case of plain and twill weaving, we must specify 2D. Then created 3D geometric models of plain and twill weave are as following figure 1.
Figure 1. The construction of the geometrical models of fabrics in MSC Digimat: a – View of the constructed geometric model of plain weaving; b – View of the constructed geometric model of 2/2 twill weaving

Visual-mesh module from finite element analysis package “Visual-Enviroment” was used to generate geometry mesh of carbon fabrics (figure 2). It provides automatic and guided surfaces clean up, application specific mesh generation and intuitive post mesh editing features. Visual-Mesh generates simulation specific meshes for Manufacturing and safety applications in order to achieve the best possible quality result in combination with the shortest possible simulation time. When creating a geometry mesh, the mesh Type "2D Topo mesh" was selected, set the element size to “10” and mesh method to “Tria” [6].

Figure 2. 3D mesh model of carbon fabric in Visual-Mesh program

The created mesh geometries were imported to PAM-RTM software to calculate the resin infusion time. For the fabric, standard parameters were set, and gravity acted on the z axis, which was directed along the thickness of the fabric, in a negative direction, i.e. this corresponded to the impregnation of the fabric, which is affected by gravity. And then parameters for the binder were selected. Figure (3a, 3b) shows the viscosity for the binder Epoxy-20 and Epoxy-20 (High viscosity). The reinforcing materials were(3K, plain weave carbon fabric) and (3K, 2x2 twill weave carbon fabric), which have different isotropic permeability coefficient (Figure 3c, 3d).

Figure 3. Parameter of fabric and binding materials in PAM-RTM software: a – Properties of Epoxy-20; b – Properties of Epoxy-20 (High viscosity); c – Fabric properties of plain weave; d – Fabric properties of twill weave
When modeling the impregnation process, not only the characteristics of the fabrics and binder used in the experimental study were taken into account, but also the type of fabric, the number of layers, the pressure inlet and outlet ports of the binder, as well as the pressure in the vacuum pump were duplicated [7]. In the experimental part, the binder was fed and withdrawn from the sample using a vacuum tube. Groups of points through which the sample was fed and withdrawn from the sample are shown in figure 4, where the feed port of the binder is located at group 1 and has a blue color, and the outlet at group 2 and has a green color.

![Figure 4. Boundary conditions of carbon fabric in PAM-RTM](image)

As a result of the simulation, the following results were obtained for the samples, which are shown in figure 5. In this paper we present the simulation results at 60˚C according to the limitation of pages and the numerical parameters are given in table 3.

![Figure 5. Simulation results of carbon fabric at 60˚C](image)

4. Modeling and experimental results

For the experimental results we used two different type of carbon fabric and two different viscosity of resin. After the moulding of carbon fabric is set up (figure 6a), the resin injection filling stage of a vacuum infusion process is started under loaded temperature (figure 6b). Simultaneously start record the resin infusion time by stop watch until the end of the injection stage.
5. Optimizing of resin infusion time depend on temperature gradient

The objective of our work is to optimize the resin infusion time influenced by changing temperature gradient. So, the reduction of resin infusion time at proper temperature gradient is the main result. From the table it can be seen that the rapid resin infusion time has twill weave in both viscosities of epoxy resin, plain weave has the slow infusion time. Such results are due to the facts that in twill weaving fibers are least curved, which allows resin to flow more efficiently through the material. To be precise the results, we used simulation program and experimental results. And at the end of the analyzing both results is almost identical (Table 3).
Table 3. Simulation and experimental results of resin infusion time

| No | Type of fabric | Binding materials | Temperature °C | 
|----|----------------|-------------------|----------------|---|
|    |                |                   | 30  | 40  | 50  | 60  | 30  | 40  | 50  | 60  |  |
|    |                |                   | Simulati on | Exp erimental | Simulati on | Exp erimental | Simulati on | Exp erimental | Simulati on | Exp erimental | Simulati on | Exp erimental | Simulati on | Exp erimental |
|    |                |                   | 9.1 | 9.7 | 8.3 | 8.8 | 7.4 | 7.8 | 6.5 | 7.1 |   |   |   |   |
|    |                |                   | 4.5 | 4.9 | 4.4 | 4.4 | 3.6 | 4.4 | 3.1 | 3.7 |   |   |   |   |
|    |                |                   | 13.2| 14  | 12.1| 13  | 11.1| 12  | 10  | 11  |   |   |   |   |
|    |                |                   | 7.1 | 7.6 | 6.5 | 6.8 | 5.9 | 6.5 | 5.4 | 5.9 |   |   |   |   |

6. Conclusion

The present work illustrates how resin infusion time optimization in PAM-RTM may be used in the design of large composites parts. The application of this optimization gives as possible and perspective design temperature and allows reducing the resin infusion time. There are other calculation conditions, which have different boundary conditions. As a result of the research, it was found that resin injection time of vacuum infusion process is depending on the temperature gradient and the viscosity of resin. Increasing of temperature gradient can reduce resin infusion time 50%, but at the same time it can cause thermal damage in finished composites product [8]. Therefore, we must consider the proper temperature gradient to reduce the infusion time. In this way we can improve the vacuum infusion process for the production of large-sized structures.

References

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