Vacuum infusion equipment design and the influence of reinforcement layers addition to the resin infusion time

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Abstract. The characteristic of composite material is greatly influenced by the manufacture method of composite. The conventional method that has been used such as hand lay-up and spray up are simple and easy to apply but the composite tend to have a void in it because of the air trapped during the manufacture process. Vacuum infusion is one of the modern composite manufacture process which can replace the conventional method. The problem of this method happens when the resin infusion time become longer due to the addition of reinforcement layers. When the resin infusion time is longer than the resin’s gel time, the resin will become gel and not able to flow into the mold. In order to overcome this problem, a study that observe the influence of reinforcement layers addition to the resin infusion time is needed. In this study, vacuum infusion equipment for composite materials manufacturing process that are designed consists of: 1x1m glass as the mold, 1L PVC tube for the resin container, 1L glass tube for the resin trap, and ½ HP vacuum pump with 7 CFM vacuum speed. The resin that is used in this study is unsaturated polyester resin (UPR) and the fiber used as reinforcement is fiber glass. It is observed that the more number of reinforcement layers the longer resin infusion time will be. The resin infusion time (in seconds) from two until six layers respectively for the area of 15x20cm are: 88, 115, 145, 174, 196; for the area of 15x25cm are: 119, 142, 168, 198, 235; and for the area of 15x35cm are: 181, 203, 235, 263, 303. The maximum reinforcement layers that can be accommodated for each 15x20cm, 15x25cm, and 15x35cm area are respectively 31 layers, 29 layers, and 25 layers.

1. Introduction
Composite material is a material that consist of two or more material that has a different shape and chemical composition from its origin material [1]. Composite material is a material consists of two or more materials that has a different characteristics physically and chemically which form a material with new characteristic [2]. Generally, composite material consist of two main components which are matrix and reinforcement. The manufacture process of the composite plays an important role to the characteristic of the composite. Hand lay-up and spray-up method are the examples of composite manufacture method that has been widely used. These two methods are simple, cheap, and doesn’t need many equipment to be applied. On the other hand, this method has some limitation in which it really depends on the ability of the operator. Some of the time, the quality of the repetition products don’t have the same quality. Furthermore, this method also have a big possibility for the composite to have a trapped air in it. This condition will lead to the decrease of quality to the composite.

Vacuum infusion is one of the modern composite manufacture method that can be the solution of the problems that exist in hand lay-up and spray-up method. By using the vacuum infusion method, it minimize the possibility of the air trapped in the composite. This method also allows the composite to be made in repetition with the same quality because it depends on the equipment design, in spite of depend on the operator’s ability. Vacuum infusion is performed by put in the reinforcement material into the mold before the resin is infused to the mold with the help of vacuum pump. Vacuum infusion method can distribute resin resulting well which resulting in the composite with low void content and increase the mechanical properties of composite [3].

Beside the manufacture method, the manufacture duration is also important to be noticed because resin has gel time that needs to be considered. The manufacture duration should not pass the gel time.
because when the gel time passed, the resin will change form into gel. This condition can be a problem because the resin gel cannot be infused into the mold and will interrupt the manufacture process. Based on this condition, a study that relates the influence of reinforcement layers on the resin infusion time in vacuum infusion equipment is needed. The vacuum infusion equipment that is used in this study is designed and used to observe the resin infusion time. The variations that used are the mold area and the number of reinforcement layers. The resin used in this study is unsaturated polyester resin and fiberglass is used as the reinforcement. In addition, the maximum number of reinforcement that can be accommodate by the mold in the designed vacuum infusion equipment is also observed in this study.

2. Experimental

2.1 Materials

The resin used in this study is unsaturated polyester resin with EVERPOL 324 AR-2 brand as specified in Table 1. The fiber used as reinforcement in this study is fiberglass that is cut into layers with area of 15x20cm, 15x25cm, and 15x35cm.

| Specification sheet EVERPOL 324 AR-2 |
|--------------------------------------|
| **Product Name** | EVERPOL 324 AR-2 |
| **Type** | Unsaturated Polyester Resin (Ortho Type) |
| **SPECIFICATION** | |
| **ITEMS** | **ACTUAL** | **STANDARD** |
| N.V. (%) | 56.5 | Check |
| Viscosity | 540 cps | 400-600 |
| Acid Value (Solution) | 24.9 | 15-25 |
| Color | Pink | Pink |
| Transparency | Turbid | Turbid |
| Gel Time | 21’04” | 20’-25’ |
| TI | 2.5 | 1.5-2.0 |

2.2 Vacuum infusion process

The principle of vacuum infusion is using the negative pressure to suck the air inside the mold and at the same time the resin is also sucked into the mold so that the reinforcement is impregnated in the resin. After the layer of resin and matrix are formed, the remaining resin will be sucked out of the mold. As a result, the layer with same thickness can be obtained by using this process. The material manufactured by using vacuum infusion process has a higher fiber to resin ratio than the hand lay-up and spray-up method resulting in the composite material that is stronger and lighter. The flow of resin going through the reinforcement can be determined by using Darcy Law that explain the flow of fluid going through porous medium. Darcy Law can be seen in Eq. 1.

\[ Q = \frac{KA\Delta \rho}{\mu L} \]  

Where \( Q \) = resin flow (m³/s), \( K \) = material permeability (m²), \( A \) = area where resin flows into (m²), \( \Delta \rho \) = pressure difference in lamination (kg/m.s²), \( \mu \) = dynamic viscosity of resin (kg/m.s), and \( L \) = distance that needed to be traveled by resin (m). Eq. 1 will be used further in this study to analyze the effect of the reinforcement layer addition to the resin infusion time.

2.3 Vacuum infusion equipment design

The first step of the equipment design is deciding the size of desired composite material. In this laboratory scale study, the composite is made in form of rectangle layers with the size of 15x20cm, 15x25cm, and 15x35cm. Vacuum infusion equipment designed for this study consist of: 1x1m glass as the mold, 1L PVC tube for the resin container, 1L glass tube for the resin trap, and ½ HP vacuum pump with 7 CFM vacuum speed. These equipment are then assembled like as seen in Figure 1.
This vacuum infusion equipment is then used to discover the effect of reinforcement layer addition to the resin infusion time. Beside the different area of mold, which are 15x20cm, 15x25cm, and 15x35cm, the number of reinforcement layer are also varied. The number of reinforcement used in this study are 2 until 6 layers. The data obtained from this study is the resin infusion time that is measured by using the stopwatch which is turned on when the vacuum pump starts to operate and resin inlet is opened and is turned off when the resin wet the reinforcement completely.

3. Results and Discussion

3.1. The effect of reinforcement layer addition to the resin infusion time

The infusion time data obtained from this study can be seen in Table 2. Table 2 shows that the more number of reinforcement resulting in the longer infusion time. The more number of reinforcement provide a longer distance for the resin to wet the reinforcement. According to Darcy Law from Eq. 1, when the distance needed to be traveled (L) by the resin is further, the flow rate (Q) of resin becomes lower. As a result, the time needed for resin to wet the reinforcement become longer.

From the view of fluid mechanic, as seen in Figure 2a, resin flows from resin inlet through the gap in spiral tubing to the flow media and the lamination beneath. Resin flows horizontally to the other lamination and resin outlet while flows vertically to the lamination under the flow media. Resin that has reached the spiral tubing on the other side is then flows through the gaps in the spiral tubing and flows out to the resin outlet. As seen in Figure 2b, there are a position difference between the resin in the top side and the bottom side. Fluid or in this case resin, tend to flow through the media that has a high permeability. As a result, on the top side which is closest to the flow media, the resin wet the reinforcement faster than the one in the bottom side. After flowing through flow media, resin is then flows down through the pores in reinforcement layer like fluid that flows into capillary tube. This condition resulting in the longer infusion time with the addition of the reinforcement layer because the distance that is needed to be traveled by the resin to wet the reinforcement become longer.

| Number of Reinforcement Layer | Resin Infusion Time (s) |
|------------------------------|-------------------------|
|                              | Reinforcement Area      | Reinforcement Area      | Reinforcement Area      |
|                              | 15 x 20 cm              | 15 x 25 cm              | 15 x 35 cm              |
| 2                            | 88                      | 119                     | 181                     |
| 3                            | 115                     | 142                     | 203                     |
| 4                            | 145                     | 168                     | 235                     |
| 5                            | 174                     | 198                     | 263                     |
| 6                            | 196                     | 235                     | 303                     |
3.2 The calculation of maximum reinforcement layer

Beside the effect of reinforcement layer addition to the resin infusion time, the number of reinforcement layer that can be accommodate by the mold is also needed to be observed for further use of the vacuum infusion equipment. By using the vacuum infusion equipment that has been designed, the infusion time data for different number of reinforcement layer and area are obtained and can be seen in Table 2. The specification of the resin used in this study, including the gel time, can be seen in Table 1. The calculation of maximum reinforcement layer is performed by using the linear equation of the extrapolated data from Table 2. The extrapolated graph for the different reinforcement area can be seen in Figure 2. By using the linear regression, the linear equation of infusion time for the reinforcement area of 15x20cm, 15x25cm, and 15x35cm respectively are $y = 27.5x + 33.6$; $y = 28.8x + 57.2$; and $y = 30.4x + 115.4$ with $y$ as the infusion time and $x$ as the number of reinforcement layers.
From Table 1, it can be seen that the gel time of EVERPOL 324 AR-2 resin is 21 minutes 4 seconds so the maximum time for extrapolation is set to 15 minutes with the assumptions that the rest 6 minutes is used for mixing and degassing process of the resin before infused into the mold. The number of maximum reinforcement layer can be obtained by substituting 15 minutes or 900 seconds as y parameter for each linear equation that has been obtained before. It is then observed that the maximum number of reinforcement layers that can be accommodated by the designed equipment are 31 layers for the reinforcement area of 15x20cm, 29 layers for the reinforcement area of 15x25cm, and 25 layers for the reinforcement area of 15x35cm. This condition is because for the wider reinforcement area, the resin infusion time as seen in Table 2 is longer due to the longer distance needed to be traveled by resin.

4. Conclusion
Vacuum infusion equipment was designed and used to discover the influence of reinforcement layers addition to the resin infusion time. Unsaturated polyester resin was used as the reinforcement. The designed equipment consists of: 1x1m glass as the mold, 1L PVC tube for the resin container, 1L glass tube for the resin trap, and ½ HP vacuum pump with 7 CFM vacuum speed. The wider area and the more number of reinforcement layers resulting in the longer infusion time. Overall, vacuum infusion equipment that has been designed in this study can be used to make composite material with unsaturated polyester resin as the reinforcement with the maximum reinforcement layers that can be accommodated for each 15x20cm, 15x25cm, and 15x35cm area are respectively 31 layers, 29 layers, and 25 layers.

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