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The effect of woven roving fiberglass total layers on resin infusion time in vacuum infusion

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Abstract. Composite material consists of reinforcement materials and resin as a matrix. Vacuum infusion isone of composite material manufacturing process. This process is to minimize the air cavity on composite material. The composite material will have good mechanical properties. There is a problem in vacuum infusion related to resin gelling time that must be considered. In this study, the area as well as the reinforcement layers are variated. Unsaturated polyester was used as resin and woven roving fiberglass was used as reinforcement. This study was obtained that resin infusion time data for woven roving, 15x20 cm of size, in two until six layers are 55 seconds to 78 seconds**;** whereas, the infusion times for 15x25 cm of size,in two until six layers are 119 seconds to 235 seconds**;** whereas the infusion time for 15x35 cm of size, in two until six layers are 181 seconds to 303 seconds. By data processing, the maximum fiber area that resin still can flow, for 6 layers, is 0,4391 m^2 (or 15 cm x 2.92m). Maximum fiber total layers for the specimen with 15x20cm^2, 15x25cm^2 and 15x35 cm^2 of areaare 147, 145 and 125 layers respectively.

1. Introduction
Composite materials are combination of two or more different components on macro scale, with these components having interfaces between them [1]. The material properties of the composite material will differ in the shape and chemical composition of the original substance [2]. There are several methods for manufacturing of compisite material, one of them is vacuum infusion. Vacuum infusion process is a process that use closed mold. This process is done by coating the reinforcement in the mold. Then the resin is fed into the mold. The resin infusion process is carried out using a vacuum pump, to allow the resin to be evenly distributed and to prevent the excess resin in the reinforcement. The vacuum infusion process can minimize the air cavities formation, so that the resulting composite material will have little free space and eventually be able to produce composite material products with good mechanical properties [3]. The reinforcement type manifested in this research is fiberglass with woven roving (WR), which is the most widely used fiberglass type in industrial composite materials. Resin that used in this research is unsaturated polyester, which is wide used resin in the manufacture industry.

However, there is a problem that often occur in vacuum infusion process namely a white spot. White spot is an area where the fiberglass was not filled by resin. White spot occurs because during the infusion, the resin begins to hardened. If the resin undergoes gelation when the infusion persists, some fiberglass will not be wetted by the resin. White spots should be avoided because it can reduce the mechanical strength. The fiberglass total layer must be considered as it may affect the resin infusion time. Therefore, to prevent white spots, this study is to obtain the effect of woven roving fiberglass total layers on resin infusion time, so that the resin can be flown among fiberglass.

2. Materials and methods

There are four stages that performed in this study. The first stage is to prepared all of the equipment and material that will used in this study, to make a vacuum infusion system. This research is focused on polymer matrix composite (PMC). PMC is one type of composite material in which composed of short fibers or continuous fibers combined into one by an organic polymer matrix [5]. The resin used in this study is Unsaturated Polyester Resin (UPR). UPR is an unsaturated condensation product or anhydrous acids and diols with or without diacids [6]. Fiber glass that used in this study is Woven Roving (WR) fiber glass.

After the tools and material are prepared, the vacuum infusion equipment system rearrangement can be done. All of the equipment and material must be rearranged because the vacuum infusion system is each separate device that must be combined to form a unified equipment system. The arrangement stage is done as well as to test the vacuum infusion equipment system in order to avoid air leakage. Vacuum infusion equipment schematic and arrangement can be seen in Figure 1.

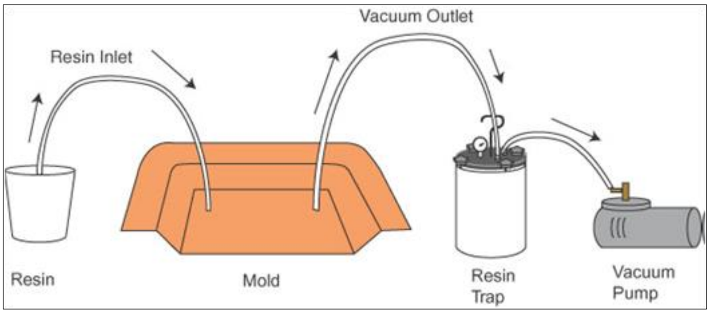

Figure 1. The vacuum infusion equipment arrangement

Second stage is, if the equipment system successfully arranged and can run without leakage, resin infusion process to fiberglass and research variations in the fiberglass total layers to the resin infusion time can be done immediately, and we get resin infusion time data in every total layers from 2 until 6 in three different fiberglass layer area. Finally, the data processing in order to get fiberglass dimension length and fiberglass total layer maximum.

3. Result and discussion

The results obtained the resin infusion time data on each woven roving fiberglass total layers from 2 to 6 layers, in the fiberglass area 15x20 cm, 15x25 cm, and 15x35 cm. The resin infusion data were 15 data from all composite material that successfully made. Test results can be seen in Table 1.

Table 1. Resin infusion time data in the fiber total layers' variation.

Total Layers	Woven Roving Fiberglass Area		
	15x20 cm	15x25 cm	15x35 cm
	Resin Infusion Time (s)		
2	55	69	97
3	59	75	104
4	66	80	110
5	71	87	118
6	78	92	123

Table 1 shows that in fiberglass total layer addition or the fibers thickness, resin infusion time becomes even greater. Research data is appropriate to Darcy law. In Darcy law, if the fiberglass layers L is enlarged then the resin flow rate (Q) will decrease. Small resin flow rate (Q) indicates it takes a long time to wet the entire fiberglass made. The dimension of the resin flow rate (Q) is m^3/s. Because of this, the resin infusion time is directly proportional to the fiberglass total layers. From Table 1 data, it is possible to determine the fiberglass maximum dimensional length that can be flown by the resin at each layer amount. The calculations performed by extrapolating the line equations from the graph between the fiberglass area to the resin infusion time. The graphs between the fiberglass area to the resin infusion time on two to six total layers can be seen in Figures 2.

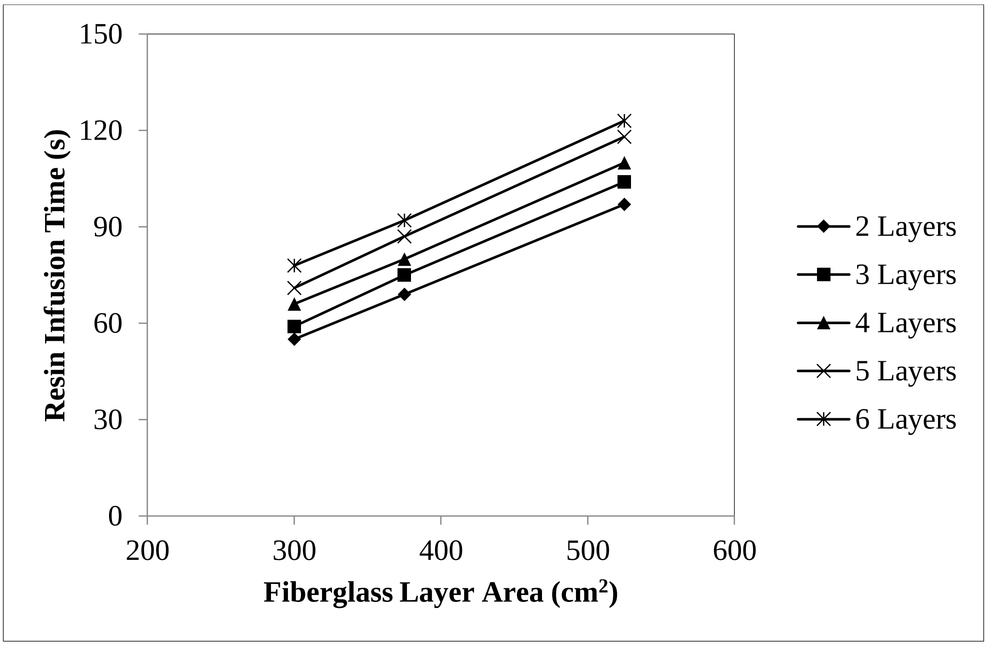

Figure 2. Relation of resin infusion time to fiber area at 2 to 6 layer.

Using linear regression, we obtain the line equation in the graphs in Figure 2, from 2 until 6 layers consecutively $y = 0.1867x – 1$, $y = 0.199x - 0.2857$, $y = 0.1982x + 6.8571$, $y = 0.2025x + 8.5714$ and $y = 0,201x + 17.286$. The x-axis shows the fiberglass area (cm^2), and the y-axis represents the resin infusion time (s). Line equation of each graph is then extrapolated by substituting the y value as the resin infusion time for 15 minutes or 900 seconds, obtained from UPR resin geltime for 20 minutes minus 5 minutes' preparation. From these extrapolations will be obtained the area dimensional maximum woven roving fiberglass that can be made on each layer. The woven roving fiberglass maximum length dimension can be calculated by dividing the maximum area by the fiberglass dimensional width. The fiberglass dimensional width in this case is the resin inlet and outlet in the fiberglass side. Since the fiberglass dimensional width that used into the composite material in this study is only 15 cm, the maximum area obtained is assumed to be applicable only to 15 cm. In the maximum fiberglass dimension length calculation, the maximum fiberglass area obtained is divided by the by 15 cm. Fromthe divided result obtained maximum woven roving fiberglass dimensional length which can be flown by resin in each layer. The maximum fiberglass dimension length can be seen in Table 2.

Table 2. Maximum fiberglass dimensional length (m)

Fiberglass Total Layer (Layer)	Fiberglass Maximum Dimension Length (m)
2	3,21
3	3,01
4	3,00
5	2,93
6	2,92

From Table 2 there is a woven roving fiberglass dimensional length which can be flown by resin in each layer from 2 to 6 layers, on 15 cm dimensional width. If the fiberglass dimensional length used does not pass through the maximum length data, the resin can still flow because it has not thickened or undergone gelation, in other words the resin has not passed its geltime. In contrast, the resin cannot flow if the fiberglass dimensional length used is greater than the data in Table 2. Because the resin has entered geltime. From the calculation it can be said that in order to avoid the gel-time resin problem in vacuum infusion which gives white spot on composite material, the fiberglass dimensional length made into composite material at 15 cm fiberglass width in every layer number from 2 to 6 layers should not pass the fiberglass dimensional length calculation data in Table 2.

Next, The Table 1 data is processed into graphs to see the relationship between the fiber total layer to the resin infusion time in a more easily visible form. The graphs are made up in three graphs for the three fiberglass areas made, which are 15x20 cm, 15x25 cm, and 15x35 cm. Below is a graph of testing the relationship between the woven roving fiber total layers against the resin infusion time on the fiberglass area of 15x20 cm, can be seen in Figure 3.

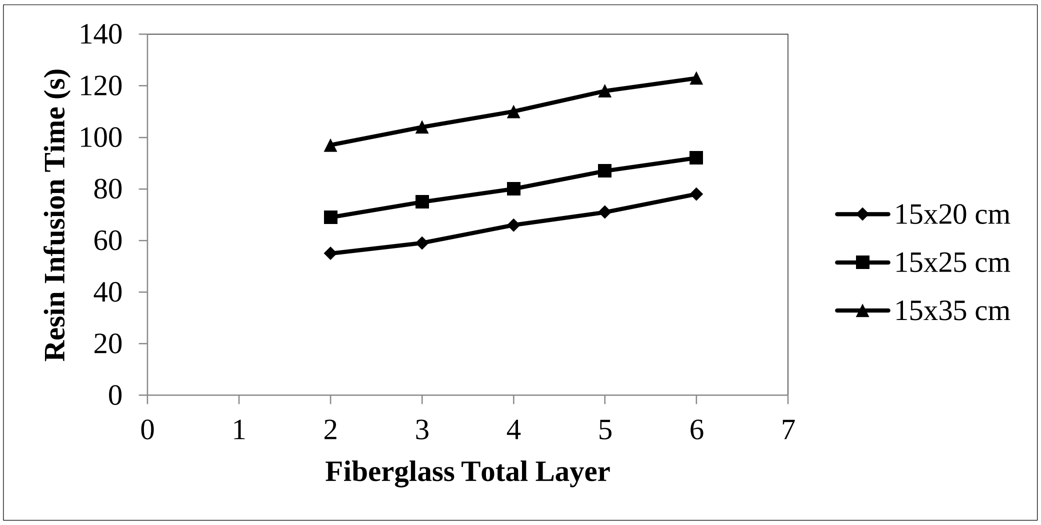

Figure 3. The relation of resin infusion time to the fiberglass total layers.

Using linear regression, we obtain the line equation in the graphs in Figure 3, from 15x20 cm until 15x35 cm consecutively $y = 5.8x + 42.6$, $y = 5.8x + 57.4$, and $y = 6.6x + 84$. In Figure 8 to 10, the x-axis shows the fiberglass total layers, and the y-axis shows the resin infusion time. Using linear regression, we will find the graph equation. The line equation is extrapolated by substituting the y value as the resin infusion time for 15 minutes or 900 seconds. From the y value of 900 seconds substitution will be obtained the maximum woven roving fiberglass total layer that can be made using the vacuum infusion equipment system in this study. From substitution result value y = 900 seconds then got result shown in Table 3.

Table 3. The fiber total layer maximum in every fiber area that used

Fiberglass Area (cm x cm)	Total Layer Maximum (Layer)
15x20	147
15x25	145
15x35	123

From Table 3 we obtained the woven roving fiberglass total layers that can be flown by resin in each fiberglass area 15x20 cm, 15x25 cm, and 15x35 cm. In each data the fiberglass maximum total layers for each fiberglass area, the resin can still flow because it has not thickened or undergone gelation, in other words the resin has not passed its gel time. Conversely, the resin cannot flow if the fiberglass layer is used more than the data in Table 3. because the resin has entered gel time. From the calculation it can be said that in order to avoid the gel time resin problem in vacuum infusion that cause white spot on the composite material, the woven roving fiberglass total layers made into composite material on 15x20 cm, 15x25 cm, and 15x35 cm fiberglass should not pass the calculation data in Table 3.

4. Conclusion

Based on test results, the longer resin infusion time, woven fiberglass roving total layer is increase. In other words, the relationship between time infusion resin with a number of woven roving fiberglass layers is directly proportional. The maximum woven roving area and length dimensional at 2 to 6 fiberglass total layers in 15 cm width dimensional is obtained as follows: 2 layers, Area: 0.4825 m^2, Length: 3.21 m. 3 layers, Area: 0.4524 m^2, Length: 3.01 m. 4 layers, Area: 0.4506 m^2, Length: 3.00 m, 5 layers, Area: 0.4402 m^2, Length: 2.93 m. 6 layers, Area: 0.4391 m^2, Length: 2.92 m. Then the maximum woven roving fiberglass total layers to be resin in each fiberglass area is as follows, fiberglass area of 15x20 cm is 147 layers, fiberglass area of 15x25 cm is 145 layers, fiberglass area of 15x35 cm is 123 layers.

Acknowledgement

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