To Study effect of VARTM process parameters for composite strength: Taguchi approach

A T Bhatt\(^*\) and P P Gohil\(^1\)

\(^1\)Faculty of Technology and Engineering, The M.S. University of Baroda, Vadodara, Gujarat, India.
\(^*\) E-mail: alpa1109@yahoo.com

Abstract: Vacuum assisted resin transfer moulding (VARTM) has become well known fibre reinforced composite (FRC) manufacturing technique for various applications like boat hull, automobile parts, wind blades, aircraft parts etc. As name suggests, vacuum is used to assist resin to flow inside fabric during impregnation. The flow of resin happens due to the pressure difference created due to vacuum supply pipe (at vacuum pressure) and resin supply pipe (at atmospheric pressure). The flow of resin bonds the fabric to make a solid part. Various parameters affect the quality of part produced by VARTM. In this paper effect of three process parameters were studied, which include number of layers, position of resin supply and vacuum supply location. Each parameter with three levels was studied to find the effect of these parameters on tensile strength and flow velocity. Jute and polyester resin were selected as material to prepare laminates. The experiments were performed as per Taguchi Orthogonal Array L(9). It has been observed that the mechanical properties were best achieved when position of resin supply was at middle, vacuum supply location was from edge to centre and numbers of layers were five.

1. Introduction

Vacuum Assisted Resin Transfer moulding a very old method, was known as vacuum infusion method. It was used to manufacture boat hull in 1950s [1] but over the period, due to limitations of this method, this method was called trial and error method to manufacture fibre reinforced composite parts. Details of VARTM process, its application and its variants were discussed by Suumerscale and Searle [2] in his review. VARTM history, development and future trends have been discussed by Bhatt et al. [3]. As shown in figure 1, in VARTM resin was infused inside the layers of fabric due to pressure difference created between resin supply pipe (at atmosphere pressure) and vacuum pipe (at vacuum pressure set by vacuum pump). The fabric was laid on glass table, after applying three coats of release spray. The layers fabric were covered with peel ply, High Permeable Media (HPM) and vacuum bag and sealed by sealant tape. From one end vacuum was created and from other side resin was supplied.

![Figure 1: Schematic view of developed VARTM setup.](image_url)
Various factors affect the quality of part produced by VARTM. Kuentzer et al. [4] wrote about how to control void content by bleeding the resin flow which ensures flow between and within tows. Kadari et al. [5] found that higher vacuum, high mould temperature and low inlet resin pressure can increase fibre volume fraction and reduce void. Rodriguez et al. [6-7] talked about unsaturated and saturated permeability of jute fabric. The permeability decreases during unsaturated condition due to fibre absorption and permeability also decrease during saturated flow due to fibre swelling. It was observed that jute absorbs more resin then glass. Saturated permeability was higher than unsaturated permeability. Tripathi et al. [8] have discussed permeability analytically, numerically and experimentally to measure the flow rate. Flow compaction behaviour was studied by Grimsley et al. [9] They studied dry and wet compaction of fabric. The fabric dry compaction took place while applying vacuum. When resin was introduced to fabric wet compaction occurred. Due to fabric lubrication, laminate thickness reduced. After which, resin pressure increased and there was spring back effect in laminate thickness. Laminate final thickness varied till resin curing took place. To improve the dimension tolerance of laminate during VARTM Gama et al. [10] have performed debulking cycle to get better compaction. However to get uniform thickness it was suggested to refer Closed-Micro-Flow where in uniform thickness with high flexural strength may be achieved by keeping vacuum line and infusion line closed after infusion and giving additional compaction by secondary vacuum line. Yoon et al. [11] performed experiments to find effect of gravitation, permeability, and resin supply pressure and tube head loss on filling time. The maximum filling time was achieved when the flow was against gravity. It was studied that by using longer pipe, filling time increases and applying pressure more than atmospheric pressure, chances of vacuum leakage increases. Rigas et al. [12] performed numbers of experiments to understand the effect of resin supply location, distribution media and cyclic load with double vacuum bag on fibre volume fraction. Heider and Gillespie [13] have commented that due to pre-infusion, de-gasification, fabric debulking and fabric drying void content will minimise. The HPM, resin pressure, fabric porosity will help to get 3D flow during impregnation. They also talked about dual state flow and effect of capillary to increase microscopic flow. Ghabezi et al. [14] have worked on effect of resin inlet tube diameter and suggested to use tube diameter 1.5 to 2 times the thickness of laminate.

2. Parameter involved in VARTM process

Various parameters affect the mechanical properties of laminate, thickness uniformity and fibre volume fraction. The most important were pressure, temperature, viscosity, permeability, volume fraction, filling time, angle of attack of the nozzle, orientation of fabric layers etc. Cause and effect diagram prepared to show various factors responsible for getting variation in part thickness, fibre volume fraction and tensile strength of FRP composite laminates is depicted in figure 2.

![Cause and Effect Diagram](image_url)

Figure 2: Cause and effect diagram for fiber volume fraction.
In this paper VARTM process has been studied using some of the parameters causing variations in output. This includes a) numbers of layers (4, 5, and 6), b) position of resin supply (Top, Bottom, and Middle) c) vacuum supply location (EC – edge to centre, CE- centre to edge, LR- left to right). Figure 3 shows the detail of all three arrangements.

Figure 3: Location of vacuum supply (EC, CE, LR).

3. Materials and Methods

From table 1, for 3 variable and each variable with 3 levels, Taguchi L(9), orthogonal array has been used to study the effect of variables on tensile strength, weight fraction and thickness variation. Taguchi Orthogonal Array L(9) method is used to study the effect of more than one variable for given output with less numbers of experiments then full factorial design. Taguchi method can be used to study which parameter causes more variation in output than the other and which level gives better result for a given parameter [15]. Table 2 shows numbers of experiments to be conducted for parameters shown in table 1, with Taguchi Orthogonal Array L(9) design. The experiments are performed not as per the standard order but as per run orders to remove biasness in the experiments.

Table 1: Parameter matrix.

| Level | Parameters         | Number of Layers | Position of Resin Supply | Vacuum supply location |
|-------|--------------------|------------------|--------------------------|------------------------|
| 1     | 4                  | T (Top)          | EC (Edge to centre)      |
| 2     | 5                  | M (Middle)       | CE (Centre to edge)      |
| 3     | 6                  | B (Bottom)       | LR (Left to right)       |

Table 2: Design matrix – Taguchi L(9).

| Run Order | Std. Order | No. of Layers | Parameters | Vacuum supply location |
|-----------|------------|--------------|------------|------------------------|
| 4         | 1          | 4            | Top        | Edge Centre            |
| 5         | 2          | 4            | Bottom     | Centre Edge            |
| 1         | 3          | 4            | Middle     | Left – Right           |
| 6         | 4          | 5            | Top        | Centre Edge            |
| 10        | 5          | 5            | Bottom     | Left – Right           |
| 7         | 6          | 5            | Middle     | Edge Centre            |
| 11        | 7          | 6            | Top        | Left – Right           |
| 8         | 8          | 6            | Bottom     | Edge Centre            |
| 9         | 9          | 6            | Middle     | Centre Edge            |
4. Developed experimental setup

The experimental setup was developed to perform experiments as shown in figure 4. Plunkeet [16] has developed similar type of setup. Special arrangements have been made to ensure supply of resin 500 mm above and 500 mm below the level of table. C-Frame has been arranged on table to locate the camera and lamp. As shown in figure 4, resin is supplied from top (500 mm above the table level), vacuum from periphery and resin from centre. Table 2 shows standard order 1, Run order 4 to correlate the below arrangement.

![Figure 4: Developed experimental setup.](image_url)

The resin is taken 2 times the weight of fabric. Jute is taken as reinforcement as it is ecofriendly and less number of experiments has been performed with VARTM process and polyester with MEKP (1%) and cobalt (0.5%) as matrix to make laminate. The resin, hardener and accelerate ratio is so chosen as to ensure enough time for impregnation before geletion. Similar fibre matrix combinations have been used by other experts as well. [17-20]. Size of laminate was kept 300 mm X 300 mm. Before starting the impregnation following preliminary activities have been done. (i) Application of three coats of release spray (ii) weighing of fabric layers (iii) weighing of resin two times more than fabric layers (iv) readiness of vacuum bagging and vacuum leak check. During impregnation flow velocity of resin has been observed by camera. After impregnation, (i) vacuum pump was kept on for 3 hours (ii) room temperature curing was done for 24 hours for each laminate (iii) thickness was checked at 25 locations, for each laminate (iv) all laminate were weigh after curing (v) tensile test as per ASTM 3039 [21-23] was done for all laminates (vi) fibre weight fraction was obtained by solvent method.

5. Results and Discussion

5.1 Tensile strength and flow velocity

Table 3 and figure 5 show effect of various parameter and their levels on tensile test. As per this the tensile test was maximum when number of layers are 5, position of resin supply is at middle and vacuum supply location is from edge. ASTM D3039 was used to measure the tensile strength of laminate. 250 mm X 25 mm laminate were cut from each laminate to find the value of tensile strength. It is also important to notice that vacuum supply and number of layers are more important parameters than resin supply location to get the maximum tensile strength.

| Std. Order | No. of Layers | Resin Position | Vacuum supply location | Tensile stress, N/mm² | Flow velocity mm/s |
|------------|---------------|----------------|------------------------|-----------------------|--------------------|
| 1          | 4             | Top            | Edge Centre            | 63.12                 | 6.25               |
| 2          | 4             | Bottom         | Centre Edge            | 48.63                 | 5.55               |
| 3          | 4             | Middle         | Left – Right           | 47.61                 | 8.33               |
| 4          | 5             | Top            | Centre Edge            | 52.56                 | 4.32               |
| 5          | 5             | Bottom         | Left – Right           | 59.23                 | 7.16               |
| 6          | 5             | Middle         | Edge Centre            | 63.41                 | 3.33               |
| 7          | 6             | Top            | Left – Right           | 29.53                 | 8.13               |
Table 3 and figure 6 show effect of various parameter and their levels on flow velocity. As per this figure flow velocity is maximum when number of layers is four, resin supply is from top and vacuum supply is from centre. The resin supply location is an important parameter to increase the flow velocity. This shows that flow velocity maximum does not ensure high strength in laminate. The quality of laminates depends on how well the resin is equality distributed between and within tows.

5.2 Variation in part thickness

Mechanical comparator with dial gauge was used to measure laminate thickness at 25 different locations. The readings were taken randomly at different location for each laminate. It was observed that the thickness at vacuum supply and resin supply location was different than at other locations. Refer figure 7 (a) and (b) to study the variation in thickness at resin supply location and vacuum supply location.

Except covering the areas shown above, other readings were taken at 25 locations, randomly on full laminate. Figure 8 shows maximum variation in thickness and mean thickness of each laminate. The minimum variation of 0.17 mm in four layers and maximum variation of 1.3 mm in six layers has been observed over the entire thickness of laminate. This shows that as we increase number of layers the variation in thickness also increases.
Figure 8: Thickness variations in laminates.

5.3 Fibre weight fraction
To find fibre weight fraction solvent method is been used by authors. Tetra Hydro Furan (THF) is been used as solvent. The laminates were cut in size of 10 mm X 10 mm and initial weights were noted after which the laminates were kept in solvent for 48 hours and again the weight was measured after removal of resin. As per this, 70% fibre weight fraction was observed. To find out fibre volume fraction rule of mixture can be applied.

6. Conclusion
The work was performed to investigate the importance of position of resin supply, vacuum supply location and number of layers in making laminate of jute- polyester FRP composite with VARTM process. The maximum tensile strength observed when numbers of layers were 5; resin supply was from middle and vacuum supply was from edge to centre. As number of layers increased variation in laminate thickness increased. It has been found that by increasing flow velocity tensile strength did not increase. Solvent method was used to find fibre weight fraction of jute in laminate and 70% fibre weight fraction was achieved average in all laminates.

References
[1] Williams C, Summerscales J and Grove S 1996 Resin infusion under flexible tooling (RIFT): a review Compos. Part A Appl. Sci., 27(7), 517-24
[2] Summerscales J and Searle T J 2005 Low-pressure (vacuum infusion) techniques for moulding large composite structures P I MECH ENG L-J MAT, 219(1), 45-58
[3] Bhatt A T, Gohil P P and Chaudhary V 2018 Primary manufacturing processes for fiber reinforced composites: History, development & future research trends Mater. Sci. Eng., 330, 012107
[4] Kuentzer N, Simacek P, Advani S G and Shawn W 2007 Correlation of void distribution to VARTM manufacturing technique Compos. Part A Appl. Sci., 38(3), 802-13
[5] Kedari V R, Farah B I and Hsiao K 2011 Effects of vacuum pressure, inlet pressure, and mold temperature on the void content, volume fraction of polyester/ e-glass fiber composites manufactured with VARTM process. J. Compos. Mater., 0(0), 1-16
[6] Rodriguez E S, Francucci G and V Analia 2008 Study of saturated and unsaturated permeability in natural fiber fabric The 9th International conference on flow process in composite materials.
[7] Francucci G, Rodriguez E S and Analia V 2010 Study of saturated and unsaturated permeability in natural fiber fabrics Compos. Part A: Appl. Sci. and Manuf., 41(1) 16-21
[8] Tripathi A and Shukla M 2015 Determination of permeability of polymer matrix composites produced by VARTM JAPME, 1(6), 6202-10
[9] Grimsley B W, Hubert P, Song X L, Cano R J, Loos A C and Pipes R B 2001 Flow and compaction during the vacuum assisted resin transfer molding process.
[10] Gama B A, Li H, Li W, Paesano A, Heider D and Gillespie J W 2001 Improvement of dimensional tolerance during VARTM processing. Proceedings of 33rd international SAMPE technical conference. 33, 1415–27

[11] Yoon M K, Baidoo J, Gillespie J W and Heider D 2005 Vacuum assisted resin transfer moulding (VARTM) process incorporating gravitational effects: A closed-form solution. J. Compos. Mater., 39(24), 2227-42

[12] Rigas E J, Mulckern J T, Walsh S M and Nguyen S P 2001 Effects of processing conditions on vacuum assisted resin transfer moulding process VARTM.” ARL-TR-2480.

[13] Heider D and Gillespie W 2010 VARTM variability and substantiation. Proc. Jt. Adv. Mater. Struct. Cent. Excell.

[14] Ghabezzi P, Golzar M and Jalall S R 2010 Effect of inlet tube dimensions on VARTM mould filling time. The 2nd International Conference on Composites: Characterization, Fabrication and Application.

[15] Chang C and Chen W 2016 Experimental study of progressive compression method of resin deliver in liquid compression moulding. Proc. eng. technol. innov., 2, 23-25

[16] Plunkett B 2010 Vacuum Assisted Resin Transfer Molding (VARTM) System. Advanced Materials and Technologies Laboratory Mechanical Engineering. Department, Virginia Tech Summer.

[17] Ho M, Wang H, Lee J H, Ho C, Lau K, Leng J and Hui D 2012 Critical factors on manufacturing processes of natural fiber composites. Compos. B. Eng., 43(8), 3549-62

[18] Sanjay M R, Arpitha G R, Naik L, Gopalakrishna K and Yogesha B 2016 Applications of natural fibers and its composites: An overview. Compos. B. Eng., 7(3), 108

[19] Deb A, Das S, Mache A and Laishram R 2017 A study on the mechanical behaviors of jute-polyester composites. Procedia Engineering 173 631-38

[20] Das S and Bhowmick M 2015 Mechanical properties of unidirectional Jute- Polyester composite. J Textile, 5(4), 1

[21] Zikre H and Bhatt A T 2016 Comparison of mechanical properties of fiber reinforced plastic laminates composite with different thickness, manufacturing techniques and structure. Int Conf Multidiscip Res Pract., 4(1), 62e7

[22] Babu B Z and Pillai K M 2004 Experimental investigation of the effect of fiber-mat architecture on the unsaturated flow in liquid composite moulding. J. Compos. Mater., 38(1), 57-79

[23] Anil, K C, Girisha K G and Sreenivas Rao K V 2015 Effect of fiber orientation on specific gravity, hardness and flexural strength and tensile property of jute/hemp hybrid laminate composite. Appl. Mech. Mater., 766, 75-78