A Study on Influence of Inlet Pressure and Fiber Architecture on the Quality of Sample Made From VARTM

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Abstract: In recent years, research is underway worldwide by scientists to successfully replace the majority of structural components that are denser, high weight and are costly with fiber reinforced polymer (FRP) composites materials that are lightweight and low cost without sacrificing strength requirements in various applications. Among the available composite fabrications techniques, Resin infusion process is a competent and most effective technique which has been successfully used by the industries for production of complex FRP composite components and structures with intricate geometric details. However in any fabrication process, understanding the effect of critical process parameters is highly important to ensure high quality of final composite materials with superior mechanical properties. Therefore, the present study is focused on studying the effect of critical process parameters such as fiber architectures, number of layers and inlet vacuum in the mould on the quality and mechanical properties of the e-glass/polyester composite laminates fabricated by means of resin infusion technique. Three different fiber architectures: (i) Chop strand (ii) Woven mat and (ii) unidirectional mat are selected. Moreover, three different fiber reinforcements layers (as 4 layers, 5 layers and 6 layers) with varied vacuum pressures: (i) 200 mm of Hg, (ii) 300 mm of Hg, and (iii) 400 mm of Hg are selected in the present study for preparation of samples. The results indicated a considerable effect of inlet pressure and the fiber architecture on the materials performance.
Keywords: GFRP, VARTM, Resin Flow, permeability.

1. Introduction:

In the group of the resin infusion composite fabrication techniques, Vacuum Assisted Resin Transfer Moulding (VARTM) is an advanced and highly efficient manufacturing technique that facilitates fabrication of large structures with superior mechanical properties [1, 2]. Vacuum assistant resin transfer moulding is a closed mould technique where, the resin is infused into the mold assembly purely due to the pressure difference created due to vacuum. VARTM processes are successfully used by the industries for production of FRP composite components due to their potential advantages such as low cost manufacturing, possibility for room temperature processing, less capital investment, less environmental and health hazards, shorter mould filling time, possibility to achieve fiber volume fraction upto 50-60% and more importantly it offers possibility for fabricating complex aircraft components with complex shapes with ease [3-4].

However, the success of VARTM process is heavily sensitive to flow front velocity, resin injection strategy (layout of the resin distribution network), location of resin injection and vacuum ports, fiber architecture, inlet vacuum pressure, permeability, mold filling time. The flow of resin in the infusion process or resin penetration rate in VARTM process is another crucial parameter that strongly influences the fiber volume fraction and the void content of the VARTM manufactured product. During mold filling stage, the resin needs to wet out all the reinforcement perform within mold cavity in the shortest possible time so as to avoid defects and to reduce material processing time. Particularly in case of thick composite fabrication, defects such as dry spots or voids can consequence of poor injection strategy and escape of volatile matter from the resin. Several authors [5-6] have reported that dry spots and voids in composites could lead to negative impact over the overall composite performance as well as on surface quality. Location of resin and vacuum ports also play a crucial role in fabricating defect free laminates by controlling resin flow front by manipulating such ports. Sozer et al [7] suggested that designing multiple gates at various locations of the mold cavity is helpful in achieving reasonable control over the flow front behavior. On the other hand, as VARTM technique is used mostly for manufacturing large structure that is expected to have long processing times [8]. In that scenario, it is compulsory to have resin polymerization or the gel formation longer than mold filling time. Otherwise, it can lead to defective and low quality composite laminate due to incomplete preform infiltration or wetting [9]. Therefore, in VARTM processes, in order to ensure adequate impregnation of the fiber - resin with lower viscosity values are more preferred along with the injection velocity should not be short otherwise chances of premature gelation of the resin are more [10]. Moreover, In VARTM process, the preform permeability is also one of the most crucial parameter which has great influence over resin flow and part thickness. Generally, Preform permeability is a function of porosity, applied pressure gradient, flow front distance, resin viscosity and its velocity, and flow time. Many authors pointed out that the existence of permeability variation along the liquid flow front might leads to various micro and macro defects including voids and dry-spots [11-13]. Therefore, there a need to better understanding of the relationships among process parameters of VARTM process for enlarging its applications in fabrication of complex products with zero defects.

The present study is focused on studying the effect of preform permeability, fiber architecture and different vacuum pressure on the flow behaviour and mechanical properties for a VARTM with two vacuum port and a single resin port.

2. Materials and Methods

2.1. Sample Preparation: In the present study, the laminates are prepared for three E-glass fiber architectures and same density (450 Grams for Square Meter, GSM). The three fiber architectures considered were: (i) Uni-Directional Mat (UDM), (ii) Chopped Strand Fiberglass Mat (CSM) and (iii) Woven fabric. Whereas, the the polyester resin is chosen as the matrix material. For fabrication of flat laminates, VARTM technique was adopted. The schematic setup of the VARTM process was shown in figure 1.

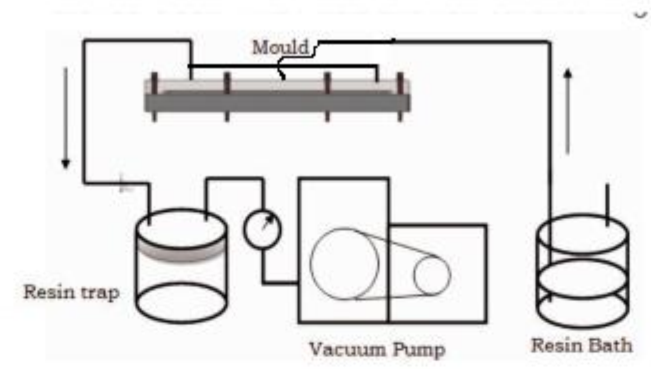

Fig 1: Schematic of VARTM setup with double vacuum ports.

The main components of schematic setup include: a vacuum pump, a square mould with two halves, and ports (both vacuum and resin ports). A square mould was made of a low carbon steel block of 25mm thickness. Moreover, the lower part of the mould is machined with a cavity of 8mm diameter and also there is a provision for the rubber gasket between the two half's to ensure perfect vacuum. On the other hand, the upper half is made with a transparent acrylic plate with sufficient thickness to with stand the force due to clamping and pressure due to vacuum pump. The upper mould design consists of three ports in diagonal position. Out of which, the two outer ports are connected to vacuum pump so as to create a vacuum inside the mould assembly. Whereas, the remaining central ports is the resin ports used to supply resin into the mould cavity from resin source through use of pipes and driven by created vacuum in the mould. To prevent resin leakage, both halves of the mold are held tight by means of nut and bolts. Preparation of composite laminates begins with cutting the selected 3 types of fiber reinforcements to required dimensions. Followed by preparation of resin mixture, such that required amount of polyester resin was then mixed with Methyl ethyl ketone peroxide which is used as catalyst in a jar and stirred well. Catalyst was added in the required ratio of 1:100 to the polyester resin. Later, cobalt napthanate which acts as an accelerator was added to the resin mix in the same ratio and made ready. Once both the required reinforcement layers (4 layers, 5 layers and 6 layers) and resin mixture is made ready, the vacuum pump is switched on to evacuate entrapped air in the mould. The pump is made on until the sufficient negative pressure is created in the mold assembly such that the resin flows into the mold assembly due to created pressure difference. The mould filling time and the resin flow pattern were recorded using a digital camera focused on the mould. The laminates were then allowed to cure in the mould until they are completely cured. After curing, the laminates were cut to prepare test sample specimens as per the standards selected in the study.

2.2. Testing

Three different mechanical tests were performed (i) tensile, (ii) flexure and (iii) impact test loading, in accordance with ASTM D638 (ASTM, 2000a), and ASTM D256 (ASTM, 2000b), respectively. The crosshead speed of the testing machine was maintained 10 mm/min constant for both the tensile and bending tests, and the results obtained are reported in the following section. However, the Porosity, Permeability and Reynolds number were analytically determined based on the recorded data with reference to the analytical models developed, presented in the literature [14-16].

3. Results and Discussion:

The experiments were conducted as per the standards mentioned in section 2.2, and the corresponding variations in the mechanical properties for the samples prepared by varying the process parameters are presented below. The variation of the flow pattern is also studied by considering the Reynolds number.

(i) Variation of Mould Fill Time:

The Figure 2 represents the variation of mould filling time with respect to the vacuum created in the mould. From Figure 2 (a), it is clearly apparent that the mould filling time for 4 layers and 5 layers is decreasing with increase in vacuum. Whereas, for the case of sample with 6 layers, the fill time is steadily increasing with the increase in vacuum. This is due to the mould cavity clearance being decreased from four layered to five layers. However, in the case of six layered preforms, the permeability is decreasing in perpendicular direction to the fiber direction. Similarly, for the fiber perform, the variation of mould filling time is represented in Figure 2 (b), where it is found that there is an influence of density of laminate within the 5 mm depth mould cavity, as it has a significant influence on the permeability of the preform. Hence it is evident that the mould filling time at lower vacuum is very low, and at higher vacuum the mould filling time is increasing continuously. This particular observation is due to of the fiber washout phenomena. This can be avoided by using a special fiber mat having bonding agent which cannot be dissolved by styrene present in the resin. Figure 2(c) represents the variation of mould fill time for woven mat preform. It is found that the mould filling time is steadily increasing with increase in pressure. This is due to the reduction in vacuum causing slow flow of the resin.

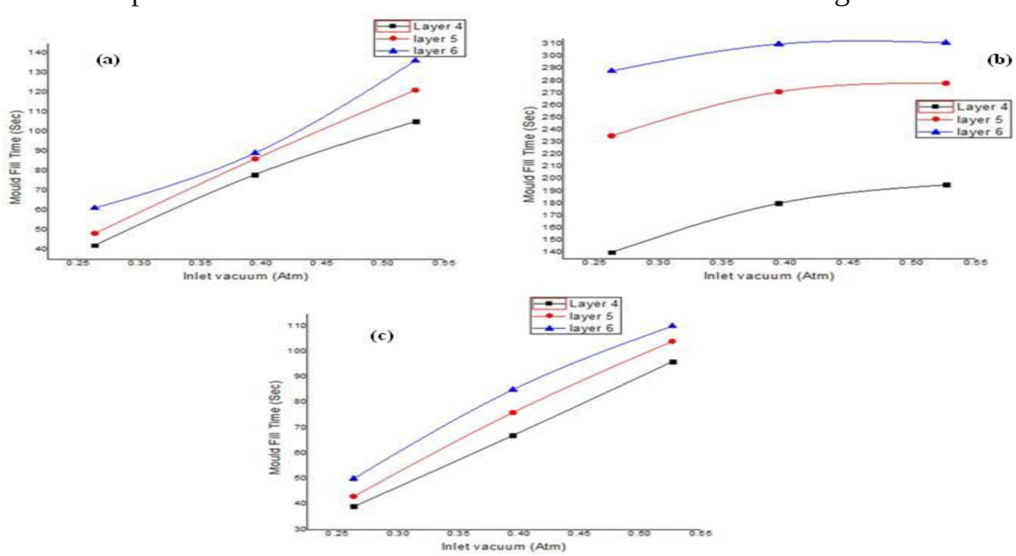

Figure 2: Variation of fill time with respect to Vacuum Pressure in (a) chop strand, (b) uni-direction (UD) and (c) woven mat preform

(ii) Variation of Permeability

The variation of permeability for chopstrand preform is shown in figure 3(a), and it is observed that the permeability decreases with increase in vacuum. But this aspect is specific with the type of mat, due to fiber washout phenomena. It can be avoided by designing appropriate inlet lines. Figure 3(b) represents variation of permeability for uni-direction preform and it is seen that the permeability decreases with increase in vacuum. Figure 3(c) represents the variation of permeability for woven mat preform. It is seen that for 4 and 5 layers, permeability is increasing with increase in vacuum due to fiber restricting the easy flow of resign, later it is decreasing. Where as for the case of 6 layers, the permeability is decreasing with increase in vacuum.

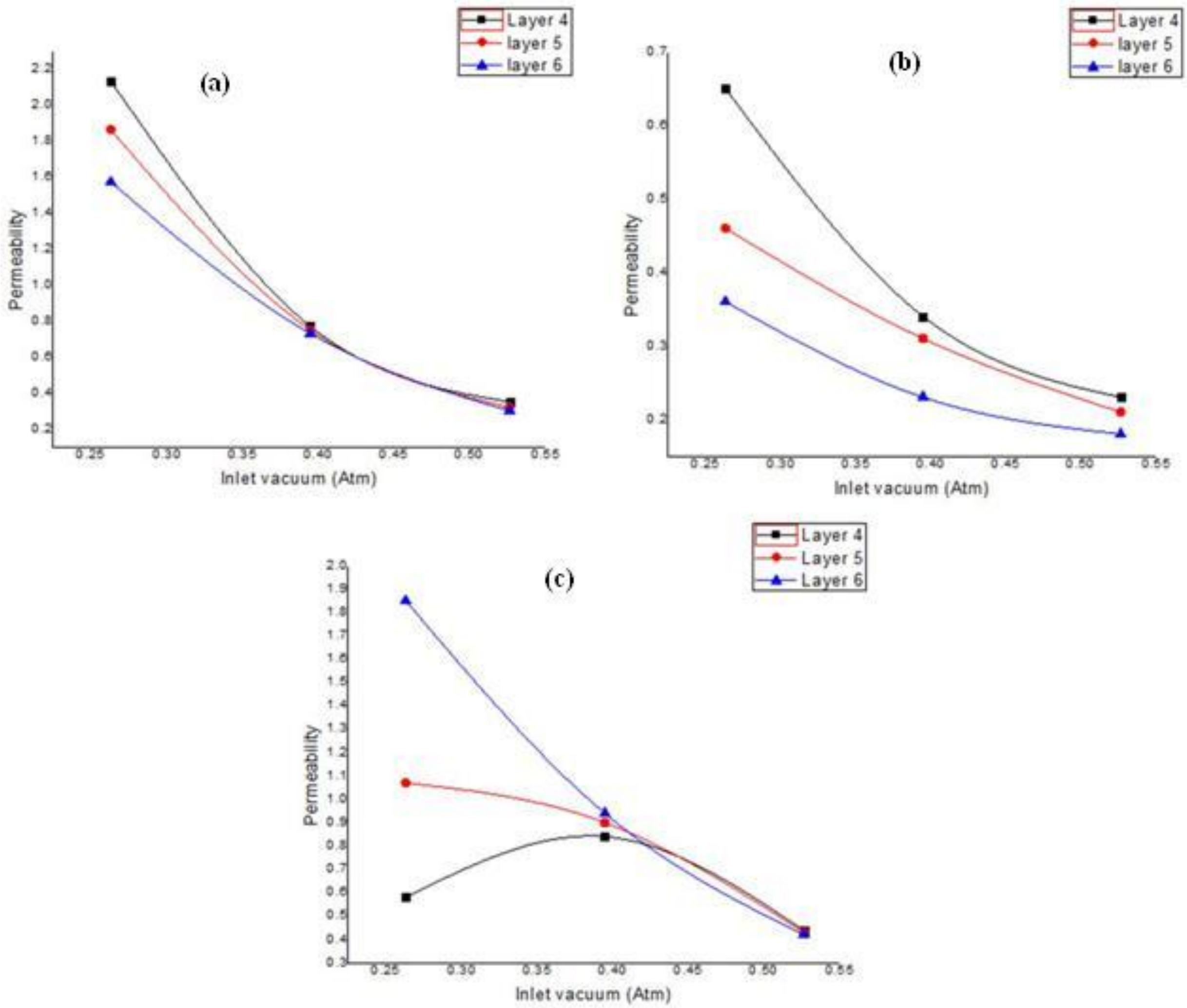

Fig 3: Variation of permeability with respect to Vacuum Pressure in a chopstrand, UD strand and Woven mar preform

(iii) Variation of Reynolds Number:

The variation of Reynolds number for chopped strand mat is represented in figure 4(a). It is observed that Reynolds number is decreasing with increase in vacuum for all 4,5 and 6 layered preforms. The variation of Reynolds number for UD mat is shown in figure 4(b). Here it is evident that the Reynolds number decreased initially and later increased consistently. Figure 4(c) represent variation of the Reynolds number for woven mat preform. It is seen that Reynolds number is decreasing with increase in vacuum.

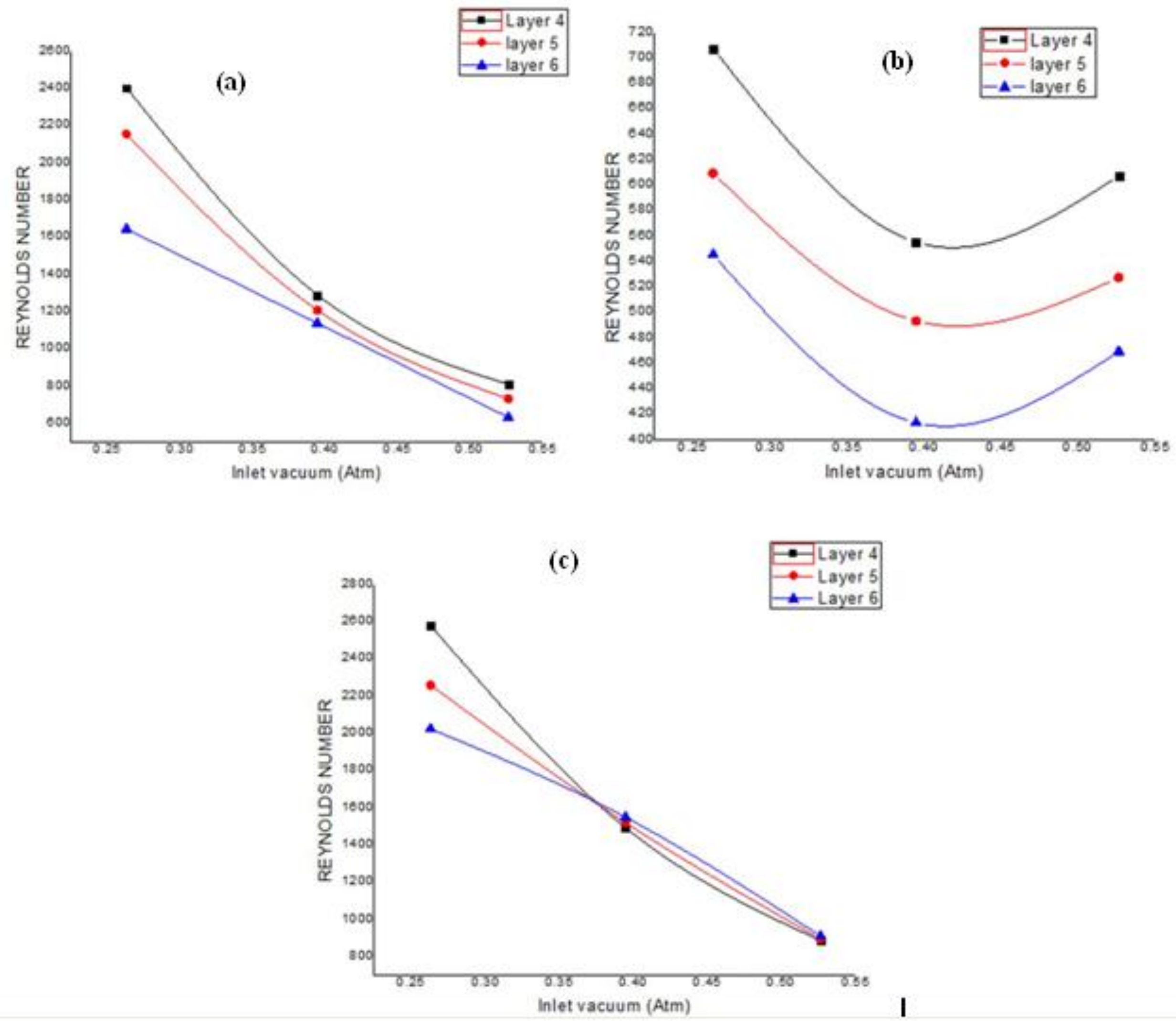

Fig4: Variation of Reynolds number with respect inlet Vacuum Pressure in chopstrand, UD strand and Woven mat Preform.

(iv) Variation of Tensile Strength

Variation of tensile strength with respect to vacuum pressure for chopstrand mat is represented in figure 5(a). For 4 layered preform the tensile strength is increasing with increase in vacuum pressure. For 5 layered preform the tensile strength is initially decreasing with increasing the vacuum, then later it is increasing. For 6 layered preform, the tensile strength is gradually decreasing with increase in vacuum. Figure 5(b) represents the variation of tensile strength for UD strand mat. It is observed that the tensile strength is increasing with increase in vacuum, later it is decreasing. The variation of tensile strength with respect to vacuum pressure for woven mat preform is shown in figure 5(c). For 4 layered mat, the tensile strength initially increased, then it is deacreased with increase in vacuum. For 5 and 6 layered preforms it is initially decreased, later increased.

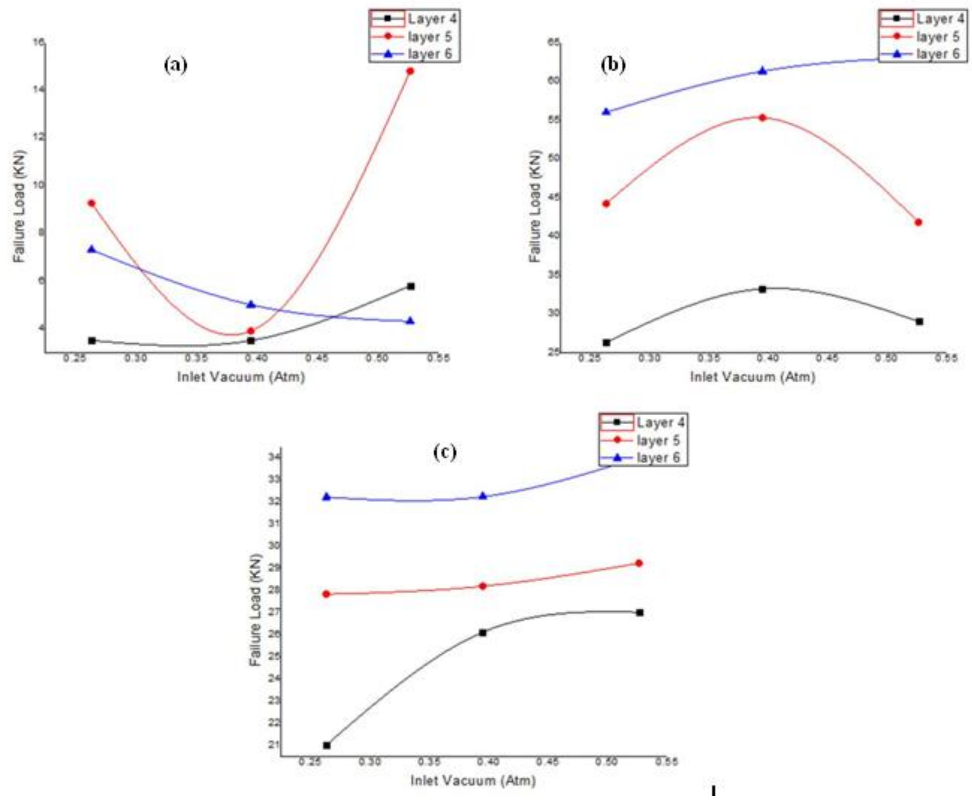

Figure 5: Variation of Tensile Strength with respect to Vacuum Pressure in chopstrand, UD strand and Woven mat Preform

(v) Variation of Impact Strength

Variation of impact strength with respect to inlet vacuum for chopstrand mat samples is given in figure 6(a), where the impact samples made with laminates produced at lower vacuums had better impact strength properties when compared to the samples produced at higher vacuum. However for samples made from UD mat, the variation is given in figure 6(b), it is clear that the impact strength has increased consistently. Figure 6(c) shows the variation of impact strength with respect to inlet vacuum for woven mat preform. The impact strength for 4 layered preform increased rapidly with increase in vacuum. Whereas for the 5 and 6 layered preforms, the impact strength increased consistently with increase in vacuum.

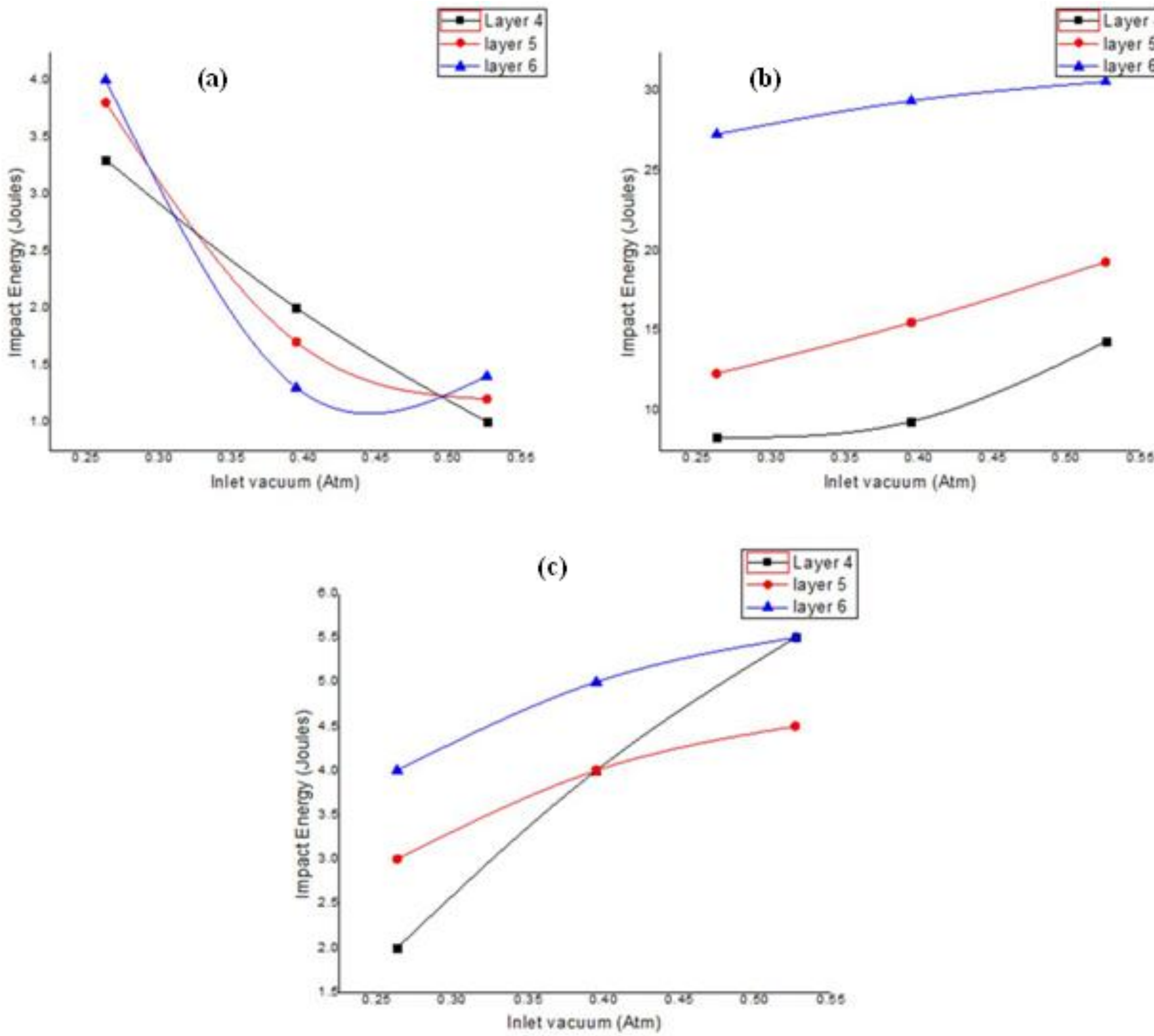

Figure 6.: Variation of Impact Strength with respect to Vacuum Pressure in Chopstrand, UD Strand and Woven mat Preform

Conclusions:

The contemporary study has remained focused on understanding the mechanical performance of VARTM samples made from three different fiber architecture and three different performs. A performs of 4 layers. 5 layers and 6 layers were subjected to study with three different vacuum pressures in the mould (200, 300 and 400 mm of Hg). A considerable effect of the parameters mentioned above has been witnessed with respect to the mechanical properties and the quality of the laminate.

a) It is witnessed that the mechanical properties for the samples with 6 layers are higher when compared to the other laminates and could be improved with an increase in initial vacuum in the mould.

b) The mould filling time depends on the number of layers and the Vacuum being applied on the preforms, higher the vacuum lower the mould filling time. Whereas as the number of layers in the mould increases the time required to fill the mould also increases this is due to the increase in the permeability of the mat stacked.

c) Moreover, the permeability for all the preform are governed by on the initial vacuum supplied to the mould. At 200 mm of Hg pressure for chopstrand and UD the preform has higher permeability. However, for the woven mat the permeability for four layers is high at 300 mm of Hg pressure. In general, the permeability is inversely preoperational to the number of layers in the mould.

d) The Reynolds number which is the measure of type of flow is greater than 300 for all the three initial vacuum pressure indicating a turbulent flow in all the three pressures. However, the UD preform indicated a low turbulence in the flow when compared to the other two preforms.

e) The material properties for the samples with 6 layers and high vacuum pressure were high when compared to the other caucuses discussed.

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