

DEVELOPMENT OF VACUUM ASSISTED RESIN INFUSION (VARI) MOLDING TECHNOLOGY FOR THERMOSET BASED POLYMER MATRIX COMPOSITE WITH LOCALLY AVAILABLE RESOURCES

Sheikh Jamil Ahmed, Qumrul Ahsan and Mahbub Hasan

Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

ABSTRACT

Composites manufacturing techniques in Bangladesh are mostly primitive and carried out in open air. This is particularly dangerous especially in the case of thermoset resin based polymer matrix composite because the resin absorbs significant amount of air that remains in the final composite which produces blowhole type defects in the final composite. These types of defects are responsible for considerably lower properties and premature failure of the composite. Vacuum assisted resin infusion (VARI) molding is used widely in many countries of the world for fabrication of very good quality polymer matrix composite. However in Bangladesh, the process has not yet been used due to unavailability of the equipment and resources required for this process. The purpose of the present work is to develop a vacuum assisted resin infusion molding process for thermoset based composite fabrication using locally available resources and to manufacture the above mentioned composites using the developed process.

Keywords: Development, VARI Technology, Thermoset Matrix Composite, Locally Available Resources.

1. INTRODUCTION

This vacuum assisted resin infusion molding is a manufacturing process for fabricating composite structures. In the process, the reinforcement, which is usually composed of several layers of woven fiber mats, is placed in an open mold and a vacuum bag is placed on the top of the mold. The mold is connected with a resin source and a vacuum pump. As the vacuum is drawn through the mold, the liquid resin infuses into the reinforcing fiber mats. Curing and de-molding steps to finish the product follow this. Lazarus developed the resin infusion technique with a 70:30 fiber to resin ratio in an economic way for preparing marine composite having mechanical properties comparable with those prepared by wet layup and autoclave methods [1]. Lewit and Jakubowski developed a low cost VARTM process, which was the basis of vacuum assisted resin infusion molding process development [2]. Yingdan et al. analyzed the mold filling during vacuum infusion molding process and described a proper way of mold filling during vacuum infusion molding process [3]. Ahmed developed a vacuum assisted resin infusion molding (VARIM) process for manufacturing high temperature polymer matrix composites for high speed civil transport. His work on mold filling analysis and proper equipment choice was a great success in the

development of the vacuum assisted resin infusion molding process [4]. Goren and Atas further developed a manufacturing of polymer matrix composites using vacuum assisted resin infusion molding. They made the process much easier to understand and very economical by using proper equipments [5]. Hossain, Biswas and Ahsan studied jute epoxy composite properties made by vacuum assisted resin infiltration (VARI) technique. Their research found that the use of vacuum assisted molding technology in polymer matrix composite manufacturing can significantly improve the quality of the composite compared to the composite formed by traditional hand layup process [6].

Present research focuses on the development of vacuum assisted resin infusion molding process for manufacturing thermoset polymer matrix composites with the resources available in Bangladesh. It also addresses material characterization and process verification. Thus the work aims at developing a science-based technology vacuum assisted resin infusion molding process for manufacturing thermoset polymer matrix composites for the understanding of the process behavior. Process induced damage in the form of voids and macro-voids (dry spots) developed during processing are reported as this is the most significant problems in liquid composite molding

particularly for materials that cure at room temperature. These process-induced defects can cause significant changes in the geometry and serious degradation of the mechanical properties of the molded structure. The work includes design of mold, development of technique, determination of mechanical properties and qualities of the composite by destructive techniques and scanning electron microscopy.

2. MATERIALS AND METHODS

2.1 Materials

This process is aided by an assortment of materials. Those are;

2.1.1 Vacuum Bagging Films

Vacuum bagging films are sealed to the edge of the mould with vacuum bag sealant tape to create a closed system. Teflon paper is used as a vacuum bagging film. Since teflon paper is expensive and very difficult to manage, it had to be replaced by an alternative. As only thermoset based polymer matrix composite fabrication was involved, good quality polyethylene was used as alternative in the present study.

2.1.2 Sealant Tapes

Double side bag sealant tapes are used to provide a vacuum tight seal between the bag and the tool surface. It has to be so that it provides a strong bond between the vacuum bagging film and the mold surface under the pressure of vacuum. Ordinary two side tape cannot be used since they always create some leak and do not offer much tighter bond under higher vacuum pressure. Usually tacky tapes is used in this purpose, however those are not available in Bangladesh. Putty, used in doors and other household bonding purposes has all the characteristics of a sealant tape. This is why putty was used in the present study to create vacuum tight seal.

2.1.3 Release Films or Stopper Fabrics

Release films or stopper fabrics are typically placed directly in contact with the laminate. They separate the laminate from the distribution medium. Highly sophisticated fabrics are usually used for this purpose, which is very expensive. The fabrics that are used in umbrella, holds the same characteristics of stopper fabrics. Therefore umbrella fabric was used in the present study.

2.1.4 Mold Release Agent

Mold release agent is used to release the product from tools easily and obtain a smooth surface finish. For this purpose, either self adhesive teflon films or liquid release agents are utilized. In certain situations teflon films can also temporarily solve tool porosity problems. But general lubricant like oil can also be used in this purpose.

2.1.5 Resin Distribution Medium

A highly permeable layer called “resin distribution medium” placed on the top of the preform spreads the

resin quickly over the lateral extent of the part. This is very important since the phenomenon holds the key for successful flow of the resin through the mold. A well designed resin distribution medium was needed for this purpose. But this is also not available in Bangladesh. A net, usually used as fences, was utilized in the present study.

2.1.6 Breather Fabrics

Breather fabrics are non-woven fabrics, which allow air and volatiles to be removed from within the vacuum bag throughout the cure cycle. They also absorb excess resin present in some composite lay ups. A particular breather cloth is usually used for this purpose. However it is not available in Bangladesh. A fabric, used in shirt collar, was used in the present study.

2.2 Manufacturing Process

The reinforcement and accompanying materials (such as release films, peel plies) were laid on the mold surface as per the sequence shown in Fig 1. Before starting the process, vacuum pump was connected to the desiccators and resin was degassed for about 5 minutes to remove a significant amount of the trapped gasses. After this initial degassing, vacuum pump was connected to the mold and the preform was sealed with a polyethylene sheet and air was evacuated by a vacuum pump. Liquid resin with hardener from an external reservoir was drawn into the component by vacuum. The liquid resin with hardener was infused into the preform until complete impregnation. When the resin completed full wetting of the preform, the vacuum pump was turned off because further infusion would cause resin go inside the vacuum pump. However, high pressure from above was still necessary because the resin was not cured yet. In order to apply this pressure a positive impression of the mold was used during this process. This pressure was applied by a hot press machine with a load of about 30KN. A temperature of about 100°C was maintained to accelerate curing. Curing was done for at least 1 hour.

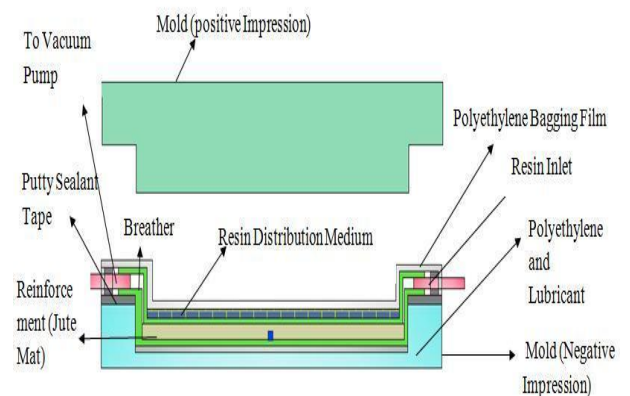


Fig 1. A typical stacking sequence of vacuum assisted molding process.

2.3 Mechanical Tests of Composites

Specimens for mechanical test were carefully cut from the composite and finished to the accurate size. Tensile tests were conducted on dumbbell shape specimens according to ASTM-D638-03 using universal testing machine at a cross head speed 3mm/min. Three point bending tests were carried out according to ASTM-D790-03 using the same testing machine mentioned above. Impact tests were conducted according to ASTM-D6110-04. Water absorption tests were carried out according to ASTM -D570 for 2 and 24 hours. For each test and type of composite, three specimens were tested and the average values are reported.

3. RESULTS AND DISCUSSION

During the initial degassing, significant amount of air and trapped gasses were removed from the resin. This trapped gasses and air if not removed would have remained as blowholes and voids inside the final composite. After initial degassing, the process of vacuum assisted molding was started. Sometimes it was found that the resin did not completely wet the preform inside the mold (negative impression). One of the reasons for this is improper distribution medium. At first a mosquito net was selected as distribution medium, which did not have enough space to facilitate the resin flow. As a result, there was incomplete flow of resin through the mold and the resin flow stopped in the midway. This problem was solved by using fences as distribution medium. Again when too many layers of very small mesh sized fiber was selected, then incomplete flow was found in the middle of the mold. In order to solve the problem, medium and large mesh sized fiber was used. But if small mesh sized fiber are prerequisite, then a large mesh sized fiber mat or distribution medium can be placed between layers. Other reasons of incomplete flow was found to be leak during processing, clogging by some putty gets inside the tube. Sometime it was found that the flow was complete; however the composite prepared was porous. The main reason for this problem was trapped gasses. Although the resin was degassed, complete removal of the trapped gasses was not possible. This might remain during processing and give rise to pore or blowhole type defects. This problem was solved by perforating the stopper clothes so that these gasses were removed by the squeezed pressure applied by the vacuum. If this problem is taken care of, then the resin completely wets the preform and after hot pressing a good quality composite manufacture is possible. A typical picture during resin flow through the preform is shown in figure 2.

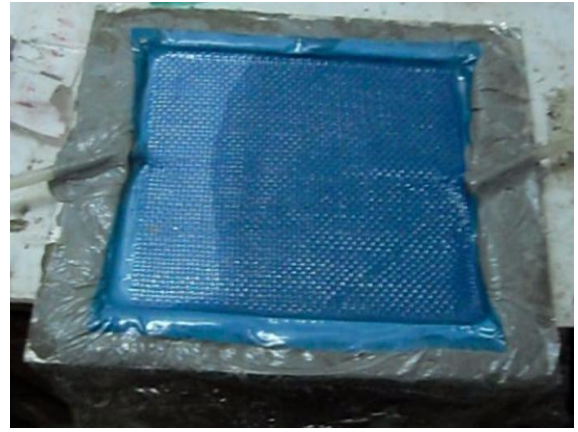


Fig 2. A typical picture of resin flow through the preform.

3.1 Characterization of Composites

For each of the prepared composite, three samples were cut from three different positions and their properties was tested by means various testing methods.

3.1.1 Mechanical Test Results

Table 1 shows the average mechanical properties of the manufactured composite. The tensile properties of the specimens were higher compared to those usually found in case of composites produced by hand lay up process. The flexure properties of the composites were higher than those of composite prepared using hand lay up process due to better mechanical interlocking in case of VARI process. The impact properties of the composites were due to better mechanical entanglement between the fiber and polymer matrix. Those were reasonable in term of cost of the composites since the process is relatively cheaper. Water absorption of the composites was quite low. In the present study, 2 and 24 hour immersion in water was tried and it was found that most of the water was absorbed during initial 2 hours of immersion.

Table 1: Mechanical properties of manufactured composites

Tensile Strength (MPa)	41.78
Young's Modulus (GPa)	2.01
Flexural Strength (MPa)	38.22
Flexural Modulus (GPa)	1.56
Impact Resistance (J/m)	27.78
Water Absorption after 2 Hours (%)	4.52
Water Absorption after 24 Hours (%)	4.92

3.1.2 Scanning Electron Microscopy

Scanning electron micrograph of a composite surface is shown in figure 3. The presence of negligible amount of resin in the scanning electron micrograph indicated that there was good adhesion between the resin and the fiber (jute mat). The load used during curing was higher (~30KN). That is why some damage in the mat was found.

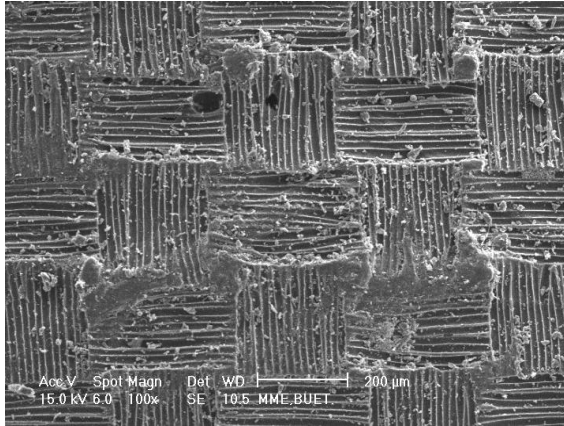


Fig 3. Scanning electron micrograph of a composite surface.

A typical fracture surface of composite is shown in figure 4. It shows fiber twist and fiber pull out indicating a very good interfacial bonding between the matrix and the fiber.

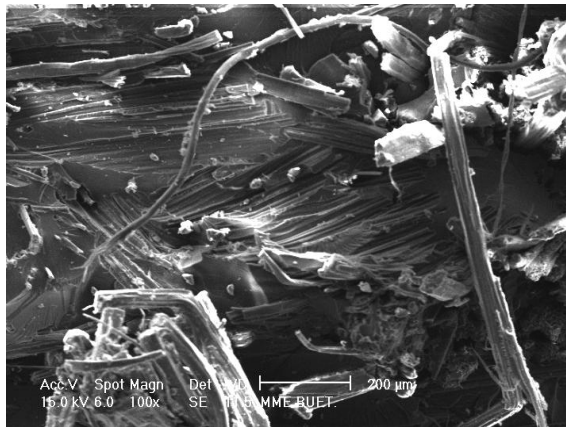


Fig 4. A typical fracture surface of the composite.

4. CONCLUSION

From the present research, the followings can be concluded;

(1) With appropriate mold design based on the developed model, sound sheets with high fiber volume fraction were successfully molded. Thus, vacuum assisted resin infusion molding process was found to be feasible for fabrication of thermoset polymer composites.

(2) The developed process is a closed one, offering an environmentally benign manufacturing through the reduction of VOC emission.

(3) A model for the polymer flow behavior was verified experimentally, with capabilities for prediction of flow pattern, inside the mold and evolved defects in vacuum assisted resin infusion molding operation. This model is a useful tool for process and mold design.

(4) Several case studies using the developed process has found reasons of formation of macro-voids and the importance of inlet ports location and the proper ventilation for elimination of these defects.

(5) The process model should help advance the manufacturing technology for the production of affordable high temperature thermoplastic based polymer composites in future.

(6) The mechanical properties of sheets produced by vacuum assisted resin infusion molding were reasonable and good in term of cost.

5. REFERENCES

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6. MAILING ADDRESS

Mahbub Hasan

Department of Materials and Metallurgical Engineering,
Bangladesh University of Engineering and Technology,
Dhaka-1000, Bangladesh