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Design and Manufacturing of Natural Composite Chemical Container Tank Using Resin Flow Simulation

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Abstract

In this study, an investigation on mechanical properties of flax natural fiber composite is performed as a precedent study on the design of eco-friendly structure using flax natural fiber composite. The Vacuum Assisted Resin Transfer Molding-Light (VARTML) manufacturing method is adopted for manufacturing the flax fiber composite panel. The VARTML is a manufacturing process that the resin is injected into the dry layered–up fibers enclosed by a rigid mold tool under vacuum. In this work, the resin flow analysis of VARTM manufacturing method is performed. A series of flax composite panels are manufactured, and several kinds of specimens cut out from the panels are tested to obtain mechanical performance data. Based on this, structural design of chemical storage tank for agricultural vehicle was performed using flax/vinyl ester. After structural design and analysis, the resin flow analysis of VARTM manufacturing method was performed.

Key Words : Mechanical properties, Natural composite, Resin flow analysis, Structural design

1. Introduction

Recently due to increasing interest in eco-friendly materials, studies on eco-friendly fiber obtained from nature have been actively conducted to the area of composite. Although the natural fiber has less strength than the high strength fiber such as the carbon fiber, it has similar strength to glass fiber. Accordingly, it can be applied as very advantageous composite when an appropriate resin has been selected.

For the purpose of applying eco-friendly material of aircraft doors or interiors, this study evaluates mechanical properties of natural fiber composites. The mechanical properties of several natural fibers are reviewed and compared to select a proper nature fiber for the target study structure. After reviewing several kinds of natural fibers, several resins to be applied to the selected natural fiber are reviewed through comparison of mechanical properties including strength, interaction with fiber, cost, etc. Finally the flax is selected as a natural fiber due to higher strength and better mechanical behaviors than other natural fibers, and the vinyl ester is selected as a resin due to lower cost, easier procurement and better treatment for the resin injection. For easy and fast production of the complicated configuration structure, the vacuum assisted resin transfer molding(VARTM) manufacturing method is selected. The flax/vinyl ester composite specimens are manufactured and tested to find the mechanical properties. Based on this, structural design of chemical storage tank for agricultural vehicle was

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performed using flax/vinyl ester. After structural design and analysis, the resin flow analysis of VARTM manufacturing method was performed.

2. Investigation on Natural Fiber and Resin

Natural fibers applied as composite are mainly divided into the organic matter and the inorganic matter. The plant fiber is the representative organic matter among natural fibers, and inorganic matter is classified into mineral fiber, etc. Natural fibers being dealt with in this study are plant fibers such as flax, hemp, jute, sisal, agave, henequen, coir, etc[1,2].

For the eco-friendly structure design, properties of various natural fibers are compared. Firstly, the fiber contents shows that 71% in flax, 65% in jute, 72% in hemp and 69% in sisal. Through comparison of mechanical strength and stiffness, it is found that the flax fiber has the best properties. Fig. 1 shows the weaving configuration of the flax 2D fabric. Therefore the flax is selected as a natural fiber to be applied to the eco-friendly structure. Moreover, the flax fiber has better vibration absorption behavior, cheaper and easier procurement than other natural fibers. The flax fiber is widely produced in Europe currently, for instance, France occupies 80% of its supply. Recently the use of flax fiber increases for aircraft door, automobile interior, tennis racket, bicycle frame, table, building structure and mobile phone case, etc.[3].

The resin for natural fiber composite is mainly divided into thermoplastic resin, thermosetting resin and bio resin. Representative thermoplastic resins are polyethylene, polypropylene and polyamide, and the representative thermosetting resins are epoxy, vinyl ester, phenolic, etc. Recently, natural resins have been developed, for instance cashew nut shell oil resin (CNSL) collected from fruit peel of tropical tree as a representative bio resin.

In order to select a proper resin for this study, mechanical properties of polyester, vinyl ester, epoxy and phenolic resin are investigated. Although the phenolic resin has excellent flame resistance, it has a flaw of manufacturing process difficulty. The epoxy resin is widely used for carbon or glass fiber composite as well as for natural fiber composite, but a disadvantage is relatively high price. In this study, the vinyl ester is firstly selected due to cheap price even though somewhat low mechanical properties compared to epoxy. However the epoxy is used for comparison with the vinyl ester.

Recently, the resin transfer molding(RTM) process method is emphasized for curing the large complicated shape composite structures. The RTM is a method of injecting the resin into the preform enclosed by the moulds. The preform is made of dry fibers, fabrics or mats prior to injecting the resin. If the resin injection pressure is low of 0.7MPa while low viscosity and high molecule resin is used. The injection device and the mold are simple as well as low cost compared to high pressure injection device or the mould. This study adopts the VARTML(Vacuum Assisted RTM-Light) manufacturing process that the RTM uses vacuum circumstance to remove gas or air from the perform and the light mold due to low press injection. The VARTML method is slightly different from the RTM that consists of solid stiff moulds. It uses a solid stiff mould for one side while a flexible mould with vacuum for the other side. By using both the positive pressure and vacuum pressure, the resin filling time can be shorten less than the gelling time as well the fiber volume fraction is improved by reducing voids in the preform. Therefore the VARTML process is an advanced composite manufacturing method that allows much higher quality product than the hand lay-up process, and less manufacturing cost compared to the RTM and the autoclave method

3. Manufacturing of Specimen

In this study, the flax/vinyl ester composite specimens are manufactured using the VARTML method, and their mechanical properties are evaluated. The flax unidirectional fibers and 2D fabrics (600g/m2) are purchased from Composite Evolution company in Europe. The KRF-1031 vinyl ester resin is purchased from CCP Composite Company. The panels are firstly manufactured using the VARTML method. The specimen size cut out from the panel follows ASTM standards.

To improve the strength of the flax fiber composites, a special treatment to remove the remaining moisture must be needed. Therefore the fibers are laminated on the panel moulds after drying in oven for 15 minutes at 110℃ temperature. The curing temperature of 80℃ is maintained for 2 hours, then the post curing temperature of 120℃ is

maintained for an hour. Fig. 1 shows the manufactured panel for specimen.

Fig. 1 The manufactured panel for specimen

4. Mechanical properties of flax/vinyl ester specimen

In order to compare with the mechanical properties of flax fiber evaluated through previous studies, this study evaluates the mechanical properties of the UD flax /vinyl ester specimen and the flax fabric/vinyl ester specimen manufactured using the VARTML method. For the different type tests such as tension, compression, flexure and in-plane-shear, 5 specimens per a type test are manufactured to obtain the mean value. Specimen tests are performed by both JNTP (JeonnamTechnopark, Korea) and AMRC (Advanced Manufacturing Research Centre with Boeing, UK).The specimen tests follow the ASTM standards(D3039, D6641, D790, D5379).

The specimen test results conducted by JNTP shows that the fiber volume fraction of the UD flax fiber composite is 35% and the fiber volume fraction of the 2-D flax fabric composite is 34%. These volume fractions are higher than the volume fractions of 25% of Hughes et al. 's specimens. In case of comparison of tensile strength, the tensile strengths of the UD flax composite and the 2-D flax fabric composite manufactured by JNTP are 157.5MPa and 76.7MPa, respectively which are much higher strength than the reference strengths of 122.4MPa and 62.0MPa. Another specimen tests of the UD flax fiber//vinyl ester are performed by AMRC to compare with JNTP 's test results. The AMRC test results show much higher strength values than JNTP test results due to the moisture removing treatment and the post curing treatment. Test result such as tensile strength is 227.2MPa withfiber volume fraction of 51%.

5. Structural Design Considering of Resin Flow Simulation

After investigation on mechanical properties of flax/vinyl ester composite, the design of eco-friendly structure using flax/vinyl ester was performed. The selected target structure is chemical storage tank for agricultural vehicle. In order to evaluate the structural design results of chemical storage tank, the structural analysis was performed by the finite element method using MSC. Nastran. According to stress analysis results, the maximum compressive stress was 17.4MPa and tensile stress was 12.1MPa. Therefore, structural safety of design results was confirmed. The buckling analysis was done by the same FEM model. The minimum buckling load factor was 7.3 and was confirmed safe from buckling. Through the structural analyses, it is confirmed that the designed chemical storage tank using natural flax composite is acceptable for structural safety and stability. Fig. 2 shows stress contour of agricultural chemical tank by FEM analysis.

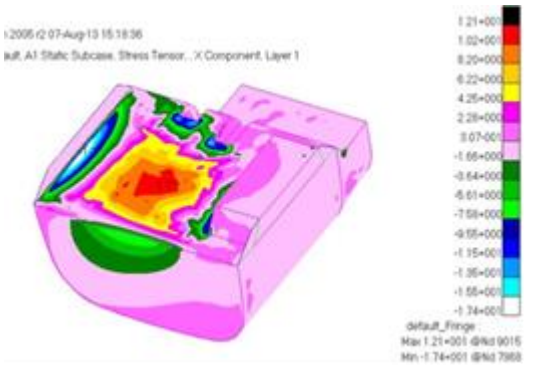

Fig. 2 Stress contour of agricultural chemical tank

After structural design and analysis, the resin flow analysis of VARTML manufacturing method was performed. The flow analysis of flax/vinyl ester composite tank was performed to confirm the manufacturing possibility using VARTML and to predict of resin flow filling time and confirm no dry-patch. The resin flow analysis was performed using the RTM-Worx FEM flow simulation solver. The permeability coefficient data is important for resin flow analysis. Therefore the design and manufacture of a permeability test rig and subsequent test were performed before resin flow simulation.

In this work, after investigation on structural analysis and resin flow simulation results of chemical

storage tank, the prototype tank was manufactured using flax/vinyl ester. In order to manufacture the prototype tank, the VARTM method is adopted. Finally, in order to evaluate the designed tank, the performance test was performed. According to the performance evaluation result, structural safety was confirmed.

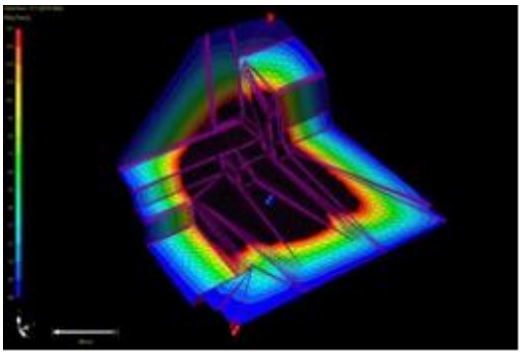

Fig. 3 Resin flow analysis result of lower part

6. Conclusions

In this study, an investigation on mechanical properties of flax/vinyl ester natural fiber composite is performed as a precedent study on the design of eco-friendly structure using flax/vinyl ester composite. The Vacuum Assisted Resin Transfer Molding-Light (VARTML) manufacturing method is adopted for manufacturing the flax fiber composite specimen. The mechanical properties of the manufactured flax composites specimens are compared with flax composite data cited from some references. The experimental data show that the flax/vinyl ester composites using the proposed VARTML manufacturing method have much better mechanical properties than the reference test results. Based on this, structural design of chemical storage tank for agricultural vehicle was performed using flax/vinyl ester. After structural design and analysis, the resin flow analysis of VARTML manufacturing method was performed. Through the structural analyses, it is confirmed that the designed chemical storage tank is acceptable for structural safety and stability.

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