A comparison process between hand lay-up, vacuum infusion and vacuum bagging method toward e-glass EW 185/lycal composites

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Abstract. This study about reinforced e glass fibers with processed of lycal composites resin by using hand lay-up, vacuum infusion, and vacuum bagging method. Plain-weave type woven glass fabric, commercial code: EW185 cloth, has been used as the GFRP. Experiments carried out include tensile testing to obtain tensile stress, tensile strain, and elastic modulus performed using UTM (Universal Testing Machine) tools. In addition, density, composite thickness, mass fraction and fraction of composite material volume and SEM (Scanning Electron Microscope) photographs can be determined to see the bond density between fibers and resins. Specimen preparation refers to ASTM D3039 which is the standard tensile test for composites with a polymeric matrix. Compared with hand lay-up, vacuum infusion, and vacuum bagging method, Vacuum infusion has the best ultimate tensile strength that is 346.15 MPa and average modulus elasticity is 10673.4 MPa. Failure Mode is also DAT.

1. Introduction
Composite is a special class of materials, consisting of two or more materials on macroscale. The performance and properties depend upon the matrix and reinforcement materials. The major proportion of material is called as matrix and minor is known as the reinforcement [1]. Glass fiber-reinforced polymer composites (GFRP) have been tremendous growth in the aerospace industries construction, shipping, automotive industries, and manufacturing industries. The benefits of GFRP is good in long-term durability, enhancement of growth resistance, energy absorption capacity, impact resistance and fatigue endurance are well-recognized [2]. E-glass fiber has less alkali content and stronger. It has better tensile and good compressive strength, good stiffness and has poor impact resistance [3]. Thermosetting polymers are an excellent substitute for most of the conventional materials. Epoxy resins are one of the extensively used thermosetting resins. It is mostly used in the form of coatings and structural adhesives for many engineering applications in addition to its usage as matrices for fibre-reinforced composites due to its superior thermal and mechanical properties, excellent corrosion and chemical resistance [4]. Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. Mohan Kumar S et al. [5] described about hand lay-up process, the materials is E Glass Fibers, used polyester ester resins with maximum tensile strength is 306 MPa, Flexural Stress 209 MPa, Impact Strength is 151 MPa. Nayak et al. [6] studied tensile properties E-Glass fibre mat reinforced CNSL-Epoxy
Composites used hand lay-up technique, the maximum tensile strength is 178 MPa. The vacuum infusion process is a closed-mold process that is capable of manufacturing high performance and large-scale with low tooling cost. Correia N S et al. [7] describes vacuum infusion process. The ability to model infusion process has major potential reducing costs by increasing predictability and ultimately achieving consistent production. The flexibility of the vacuum bag introduces a novel aspect which is not present in RTM: the fluid pressure field that induces flow also modifies the local compaction state of the reinforcement and ultimately alters permeability. A model of flow in Vacuum Infusion must therefore include local deformations of the porous medium and effects of compaction on permeability. Vacuum bagging was originally developed for manufacturing high quality and large composite parts. It utilizes the pressure to achieve the unique requirements. The advantages vacuum bagging is flexible mold tooling design and selection of mold materials, able to manufacture large and complex composites parts with good quality.

2. Experimental method and material
Plain-weave type woven glass fabric, commercial code: EW185 cloth, has been used in this research as reinforcing material, while epoxy resin (lycal type) has been utilized as the matrix material [8]. Fiberglass is a composite material consisting of glassfibers in a matrix of polymer [9]. It used e-glass cloth 185 (EW 185 cloth) from justus. EW-185 cloth is woven e-glass fiber with 185 g/m² areal weight. Pustekbang-LAPAN use this type of fiber because this fiber is cheaper and easier to obtain.

![Figure 1. Plain-weave-woven fabric [10].](image1)

2.1. Vacuum infusion process
The Vacuum Infusion Process is a technique that uses vacuum pressure to drive resin into a laminate. Materials are laid dry into the mold and the vacuum is applied before resin is introduced. Once a complete vacuum is achieved, resin is literally sucked into the laminate via carefully placed tubing. This process is aided by an assortment of supplies and materials [11]. Figure 2 showed the procedure of composite manufacturing using vacuum infusion process. The experiment manufactured composite with this process. The glass fabric have been used in this research as reinforcing material, epoxy resin (lycal type) has been utilized as the matrix material.

![Figure 2. Vacuum infusion process [12].](image2)
The vacuum infusion composite consists of 60% fiber and 40% resin mass fraction, 45% fiber and 55% resin volume fraction, 1.59 gr/cm$^3$ density, and 2.9 mm thickness.

2.2. Vacuum bagging process
Vacuum Bagging Process is a closed-mold process that is capable of manufacturing high performance and large scale glass fiber reinforced polymer parts with low tooling cost. Vacuum bagging was originally developed for manufacturing high quality and large composite parts. It utilizes the pressure to achieve the unique requirements. The advantages vacuum bagging is flexible mold tooling design and selection of mold materials, able to manufacture large and complex composites parts with good quality. Vacuum bagging is similar to the open mold of hand lay-up process, can be easily modified for manufacturing different part geometries. The disadvantages vacuum bagging is vacuum bag, flow distribution medium, peel ply, sealing tape and resin tubing may not be reusable. Chance of air leakage is high and strongly depends on worker's skill, experience. The resin injection pressure is limited between the environmental pressure (e.g., the atmospheric pressure) and the vacuum [10].

![Figure 3. Vacuum bagging process.](image)

![Figure 4. Vacuum bagging process in Aerostructure Lab.](image)

The vacuum bagging composite consists of 73% fiber and 27% resin mass fraction, 48% fiber and 52% resin volume fraction, 1.4 gr/cm$^3$ density, and 2.96 mm thickness.

2.3. Hand lay-up process
Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal.
The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut and placed on the surface of mold after per sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardner (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked.

After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed.

The hand lay-up composite consist of 61% fiber and 39% resin mass fraction, 46% fiber and 54% resin volume fraction, 1.58 gr/cm³ density, and 2.96 mm thickness.

2.4. Measurement

The woven glass fiber-reinforced lycal was used in this test, the total thickness of the laminate is ±2.9 mm. Tensile specimens were cut out of the laminates according to ASTM D3039. The number of tensile specimen are 5 specimens per manufacturing process manually cut out.

The tests was conducted from the beginning to the failure using a 100kN universal testing machine, Tensilon RTF 2410, serial number R3300143, at room temperature [12] ±23°C with constant crosshead speed. Load and strain measurement were automatically recorded during each test using a tensilon software. The displacement rate was 2 mm/min.
2.5. Scanning Electron Microscope
Morphology characterization of glass composites methods hand lay-up, vacuum infusion and vacuum bagging process was done by using Scanning Electron Microscope (SEM) Inspect S50-AMETEX with Genesis APEX 2. Morphology can be seen in cross section specimen fracture with magnification 500x

3. Result and discussion
Figure 8, 9 and 10 shows the fracture samples of hand lay-up, vacuum infusion and vacuum bagging method for EW 185/lycal composite. It was observed that the resin of hand lay-up samples are mostly on the surface whereas in the fiber part there is no resin attached. This affects the mechanical strength of the sample because at the center has not formed a composite between fiber with resin. Figure 8 espouses this argument.

For vacuum bagging process, it appears that the resin is already binding to the fiber. Still, the visible voids exist between the fibers. Figure 9 espouses this argument.
Figure 9. Surface morphology of vacuum bagging composite: (a) 1000x magnification, and (b) 2500x magnification.

For the vacuum infusion process, it appears that the resin is perfectly bonded with fiber. No more gases and voids are present in the sample. Fractures look like wood fibers. Figure 10 espouses this argument.

Figure 10. Surface morphology of vacuum infusion composite: (a) 1000x magnification, and (b) 2500x magnification.
Figure 11-15 below show the tensile properties of the composites.

**Stress-Strain Chart of Hand Lay Up Composite**

![Stress-Strain Chart of Hand Lay Up Composite](image)

**Figure 11.** Stress-strain chart of hand lay-up composite.

Figure 11 shows that hand lay-up composite has 260.98 MPa ultimate tensile strength (UTS) and 8660.52 MPa elastic modulus. The reference experiment of Mohan Kumar S *et al.* [5] described about hand lay-up process, the materials is E Glass Fibers/polyester composite with maximum tensile strength is 306 MPa.

**Stress-Strain Chart of Vacuum Bagging Composite**

![Stress-Strain Chart of Vacuum Bagging Composite](image)

**Figure 12.** Stress-strain chart of vacuum bagging composite.

Vacuum bagging composite has 271.3 MPa ultimate tensile strength (UTS) and 9221.9 MPa elastic modulus.
Vacuum infusion composite has 346.15 MPa ultimate tensile strength (UTS) and 10673.4 MPa elastic modulus.

Figure 14. Ultimate Tensile Strength (UTS) comparison between hand lay-up, vacuum infusion, vacuum bagging composite.

Figure 14 shows the comparison of ultimate tensile strength (UTS) between hand lay-up, vacuum bagging, and vacuum infusion composites. The average value of tensile strength is 260.982 MPa for hand lay-up, 346.15 MPa for vacuum infusion, and 271,298 MPa for vacuum bagging process. The reference experiment of Filippo Cucinotta et al. [12] said that average tensile test of hand lay-up and vacuum infusion, is 520 MPa and 446.5 MPa. Materials Nylon/Epoxy had modulus young 763 MPa using hand lay-up method, Prashant Meshram, et al. [14]. Nayak et al. [6] studied tensile properties of E-Glass fibre mat reinforced CNSL-Epoxy Composites using hand lay-up technique, the maximum tensile strength of the composite is 178 MPa.
Figure 15. Comparison of elastic modulus between hand lay-up, vacuum infusion, and vacuum bagging composite.

Figure 14 shows a comparison of tensile strength of EW185 cloth/lycal composite with different manufacturing method: hand lay-up, vacuum infusion and vacuum bagging. The samples fabricated by vacuum infusion have higher tensile strength than vacuum bagging and hand lay-up method. Figure 15 shows that vacuum infusion samples has higher Young’s Modulus compared to vacuum bagging and hand lay-up samples. The reason contributed to these phenomena is processing route.

Vacuum infusion shows the better mechanical properties because in the process it gets a compression force that can keep the time of resin spreading to cures completely. In addition, the process is also carried out in vacuum conditions so that the gases inside the mold have been removed. Indirectly, the atmospheric pressure will reduce the voids or space inside the sample. Minimized the voids or space inside the sample can improve the mechanical properties [15]. For vacuum bagging process there is a chance of air leakage is high and strongly depends on worker’s skill and their experience. The resin injection pressure is limited between the environmental pressure (e.g., the atmospheric pressure) and the vacuum [15].

However, this process is still not effective because the vacuum is not able to eliminate the gas and voids that already stuck in the laminate because of the curing process that has been started before the vacuum process. Nevertheless, some of the gas and voids on the surface can be removed with vacuum so it has better mechanical properties than hand lay-up.

The hand lay-up process is only performed using rubber are pressed manually using a hand to remove air from the layers of fiber and matrix. It also can eliminate voids in the layers but the process is less effective because force and pressure applied was not simultaneous to the laminate [16].

4. Conclusions
The experiment of EW185 cloth/lycal composite shows that vacuum infusion is the most effective manufacturing process. Vacuum infusion composite has the highest UTS and modulus young value of 346.15 MPa and 10673.4 MPa.

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