Review of Manufacturing Process for Good Quality of Composite Assessment

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Abstract. This review paper focuses on the detailed technique and process of fiber fabrication until it becomes composite which is useful for the manufacturing industry. The most famous fabrication methods are the open and closed mould. In general, open mould is a method which exposes the specimen to the atmosphere and the surface condition is not controlled. Close mould, however, is the opposite to open mould, that is in closed conditions without direct contact of the atmosphere and the surface condition is controllable. The manufacturing process techniques are presented comparatively. Discussion on fiber type that is more suitable for specific techniques are also presented in this paper.

1. Introduction
Treating such as heat treating or coating, machining, reshaping, are some of the techniques in manufacturing process. Furthermore methods on the testing, checking and planning are necessary to inspect the quality assurance during or after manufacturing [1]. Many developments appear to fabricate the fiber however it must meet the specific designs or manufacturing challenges [2]. Fiber reinforcement in composite has to go through composite fabrication process. The process normally involved metals or plastics by moulding or shaping mould into polymer group. Polymers commonly also known as plastics and most widely used in matrix materials especially in fiber composites. Polymer is the ‘glue’ used to hold together the high stiffness, high-strength fiber to become as matrix. It is popular due to its low cost, easy processibility, good chemical resistance, excellent corrosion resistance, low specific gravity and simple fabrication methods [3]. There are two classification of polymer that dominating matrices offered highest potential of composite structure which is thermoplastics and thermosets. Thermoplastics can be easily melted or softened when applied to heat and it will solidify while cooling [4]. However the thermoset composite comes with variety of forms, not easily become softly on heating, never melt once set, reformed after cured and the process is irreversible [5]. In thermoset polymer, the composite fabrication process involved form of moulding, to shape the resin and reinforcement fiber.
2. The composite manufacturing process

Manufacturing process to fabricate the composite can be divided by two processes which are open and closed moulding. Matrix exposed atmosphere and surface condition cannot be control is called open mould, it consisted of hand layup, spray up and filament winding. Close mould is more practical to be called as liquid composite moulding (LCM) with this method fiber would be fill in both sides of mould and resin will add into the mould cavity within laminates, consist of vacuum infusion process, pultrusion, resin transfer moulding (RTM) and light resin transfer moulding (LRTM).

2.1 Open mould

2.1.1 Hand layup

Hand layup process using application as manual to lay down the single layers or the manually laying 'plies' into a form of reinforcement known as 'prepreg' [6]. Thousands of fibers pre-impregnated with resin by pouring, brushing, spraying, paint roller and bundled into tows with arrangement of fibers either single unidirectional ply or woven together. Ply manipulated into shape by using hand. Then it has to be firmly stuck to the mould surface or previous layer and leaving no air pocket between plies. Fiber which is woven, knitted, stitched or bonded fabrices which has been saturated with resin using hand [7]. This process include the roller to force the resin deep into the fiber and left the fiber till cure under standard atmospheric conditions. Material used for composite in this paper is glass fiber and epoxy resin. This process has been conducted in three times in different volume fraction 40:60, 50:50 and 60:40 with laminate size 300×300×3mm [8]. Then specimens that have been made were tested with four tests which are tensile testing, impact testing, shear testing and hardness testing, this test using glass fiber as the material and natural fiber (banana fiber) with s-glass fiber for composite [9,10]. This hand layup process is using epoxy and hardener 1:10 as it resin then cured around 6-8 hours [11]. The results have been found when fiber content was increased that will influence the increases of brittleness and delaminating in mechanical properties. Investigation shows that 50:50 is a better composition with less brittleness. This process is for low tooling cost, versatile range of products, easy to handle, however it required labour intensive, low volume process and time consuming. The product for large commercial parts

2.1.2 Spray layup

Spray layup process is spray simultaneously on the chopped fiber and resins into the mould by a pneumatic gun [12]. Bath tub fabrication using glass reinforced unsaturated polyster layer (GFRP) layers with separated resin (acrylic resin) by spray lay up method. The specimens must be moulded to obtain smooth surface before laminated by spray layup to get several colours and thermal stability. This thermal stability temperature must be consistent with resin during spray lay up process. Base and activator resin heated first with 80°C approximate 24 hours using band heater wrapper around barrels before operate spray layup process to find suitable viscosity during spraying work [13]. GFRP was chopped with unsaturated polyster resin through nozzles at the back side of the tube, to avoid it suffered from heat and water, then the tub surface is polished. Besides that, the utilization of GFRP with epoxy resin also can be use in spray system to improve the well-known spray technique and deliver good wettability [14]. Three point bending test ASTM D3039 from both directions was conducted to measure the acoustic emission (AE) on the specimens. Replacement on jute woven fabric reinforced unsaturated polyester layer (JFRP) from GFRP has achieved similar modulus and bending stiffness by thickness calculation. High bending modulus achieved with GFRP or JFRP. JFRP laminated reached 75% bending modulus with same thickness as GFRP. This showed that JFRP be able to replace the GFRP to fabricate bath tub. Jute fiber can be very high and deliver good elastic modulus [15]. This process able to be corrected if any errors happen and any material will replaced, however it has inconsistent process, unfriendly environment and longer curing time. The product is light structure such as bathtubs and small boats.
2.1.3 Filament winding
Filament winding mainly used for manufacturing open (cylinders) and closed end structures (pressure vessel or tanks) or open (cylinders) consists of winding filaments under tension over a rotating mandrel [18]. The mandrel will remove the hollow final product when the resin cured. Derivation on mandrel outline and spatial relation between the feed eyes [19]. Feed eyes on kinematic equations for coupling mandrel motion is actually based on analytic geometry. Design proposal on small-angle composite square tubes winding has develop winding trajectories non-slippage condition whether it accurate and realible. The presentation on winding theory regarding winding error has to be done to choose suitable design for composite square tubes. Winding angle for square tube produce accoding to the fiber pattern. The results shows to obtain uniform equation small angle the center angle must be 90° [20]. This angle needed to measure the mechanical strength [21]. Performance crashworthiness using filament winding gives effect on speed of crushing, material, treatment and structure of temperature including hybrid ratio, orientation of fiber and tube wall thickness capable to give energy absorption [22,23]. This process easy to be handle, can use the existing textile process and huge part size however it has mandrel which expensive to consult, facing part configuration with mandrel extraction. The product is to produce pipe, gas tank and aerospace parts.

2.2 Closed mould
2.2.1 Vacuum Infusion Process
Vacuum infusion process used vacuum pressure as to lead resin become a laminate. The application is before resin been introduced to dry material in mould [24]. After vacuum process complete, resin be sucked into laminate using appropriate placed tubing. The process aided by an assortment of materials and supplies. Technique of vacuum infusion is well known and established since 1950 [25]. The development of vacuum infusion in Delft university of technologies using a reactive thermoplastic polymer is called anionic polyamide-6 (APA-6) [26]. This development capable to manufacture textile fiber reinforced thermoplastic composites parts to become thicker, larger and more integrated. This fiber has been compacted to become fiber bed during vacuum application and mold filling stages [27,28]. Bagged fiber has to be rotated approximately 90° after applying vacuum and inserted it in a vertically placed heated platen press [29]. The infusion pressure to be compacted using pressure at 0.8 bar and not exceed 1.0 bar in 10 min [30]. Easier to fabricate fiber when it is compacted and it showed fill-times higher than resin transfer moulding [31]. This process used less wasted resin, low tooling cost and easy to be handled. However, the process is complicated more on fabricate large component.

2.2.2 Pultrusion
Process to shape polymeric composite materials into a part using constant cross section. This process used reinforcement fibers mat and placed on creel racks. The reinforcement fibers has pulled over guide plate, then soak it into resin bath. Then it goes to enter curing die with correctly shaped. This shape characterized to ensure the material easier to be inlet and capable to remove resin excess. For prevention on premature material solidification, water cooling channel is installed at first part of the die, heating platens placed at the bottom and top surfaces for heat material polymerization. Cured composite material is pulled with caterpillar outside of the die and travelling cut-off saw to cut the material to desired length [32]. This process used to fabricate fiber reinforced thermoplastic pre-impregnated materials as composites [33,34]. Taguchi or Design of Experiments methods used in this process to find full factor design which all levels combination of variables tested [35]. Comparison was made on expected theoretical prediction from rule of mixtures (ROM) with engineering conventional available materials. This ROM evaluate elastic modulus with accepting assumptions regarding material behaviour and series model [36]. Results on pultrusion process achieved in experimental modulus and theoretical found very good agreement. This process has economic way in terms of curing and impregnated which minimized fiber cost, however high cost in to constant the cross-section and has heat die. The products are pipe, gas tank and aerospace parts.
2.2.3 \textit{Vacuum Bagging}

Process involved differential of acting cross two sides pressure of a flexible membrane to generate a uniformly distribution load. Uniform clamping force gives strong bonding since sheets bonding needs high surface level contact between mating surfaces [37]. Compression specimen and removed air from vacuum bag under atmospheric pressure was done by pumping or vacuuming to harden and compact process. Fiber mixture resin can become laminate, it happen by atmospheric pressure however balance of excess resin flow into catch pot. The clamping methods in this process used atmospheric pressure to grip resin-coated components from lamination until adhesive cures in room temperature [38,39,40]. Fiber inserted in single-sided mould to become fiber mat using resin with hand rollers. Silicone such as nylon film and sealant tape has been used to compact the wet laminate fiber using atmospheric pressure. Silicone is easy remove from mould and environmental friendly. It gives lesser time to fill resin flow and produce flexible thickness [41]. It also prevent high temperature occurred and compression for long periods of time over multiple cycles [42]. Vacuum and pump used to suck air inside mould into bleeder cloth and resin catch pot. This process are lower void content, higher fiber contain laminates and less amount volatiles emission, however it has additional cost for bagging material and required high operator skill especially on resin usage. The products are vehicles body part and door panels.

2.2.4 \textit{Resin Transfer Moulding (RTM)}

RTM description process consisted of fiber that was closed in mould with mechanical clamp to avoid air moisture. Resin then injected into mould which has fiber with vacuum pressure until the fiber fully impregnated. Mould is open after the resin cured and composite removed from mould. Finishing operation on this process required to form a post-curing process. One inlet port used for resin injection and one outlet port is used to remove air inside the mould [43]. Evaluation on mechanical properties of fiber reinforced polyester has been investigated [44]. Injection pressure used in RTM about 200 kpa. Direction on fiber should be 0 and 90°. Preparation on resin (polyester) mixed with 1.5 % Methyl Ethyl Ketone Peroxide (MEKP) about 1.5% and cobalt (CoNAP) 0.2% cured the fiber in 30 minutes [45]. About four plies of fiber in different thickness have required, this thickness is not varying. However with small variation occurred give drastic impact on injection pressure [46]. Two injections constant with all parameters used to avoid repeatability, then water-jet cutting use to cut. Results gives 0 degrees is highest tensile strength compared others and increased volume fiber will increase tensile strength and flexural strength [47]. This process gives lower void content and high fiber volume good on safety environment, however it limited to smaller components and tooling cost so expensive. The products are vehicle seat and spar.

2.2.5 \textit{Light Resin Transfer Moulding (LRTM)}

LRTM used rigid lower mould and semi-flexible, composite upper mould supported by steel. It is a hybrid combination between the wet bagging and vacuum compression moulding. Concept of LRTM is resin injected into the mould by an injection channel [48]. Inlet of the resin placed on the top of the mould at the same area with vacuum connection to control the amount of resin inside the mould. Fiber reinforcement is then placed into lower mould and sealed by the clamp. Preparation on carbon nanofiber (CNF)-loaded polyester (thermoset) composite can be in two different ways, injection or mix with gel-coat through mould [49]. This process put dry fiber reinforcement in mould and impregnated with thermoset liquid to be composite [50]. 2wt % CNF gel-coat showed volume resistivity below 10^5Ω cm with 0.5 wt % CNF matrixes in electrical characterization. Polyester resin crystal used because low viscosity 250 Mpa.s and low exothermic with cobalt-naphthenate mixture methyl ethyl ketone peroxide (MEKP). The orientation of fiber could be random, 0°, 40° and 90° respectively in three separate cavities [51]. LRTM Spartan II gives low pressure injection machine with two levels vacuum pump to assist resin flow and vacuum for mould closure [48]. The matrix cured in 24 hours room temperature and post-cured 40° for another 15 hours. Flexural properties tested according to ASTM D-790 and result showed flexural and tensile strength improved at 0.5 wt. % of CNF with better adhesion matrix CNF and fiber glass. Increasing CNF load will reduce electrical volume resistivity. This process has less cycle time,
clean environment process and less wasted resin, however it tooling cost expensive and the process need to handle with care. The products are mold set, fittings and hoses.

3. Discussion
There are certain techniques to produce products using manufacturing process to fabricate composite. Concept to fabricate composite are open and closed mould. Open mould is suitable to produce low volumes part and cost cheaper than close mould. Other advantages of open mould are its effectiveness and used low density core material. Meanwhile for the closed mould concept more on to produce high volumes part with lower labour cost. Other benefit is to reduce waste and emission during the process and lead to clean environment as well as using less material and reduced disposal costs.

4. Conclusion
Development on fabrication composite depends on fiber and product selection for several applications. This open and closed mould concept provides an idea to produce high quality product. Combination and integration of each process has applied in order to obtain better results. Mechanical properties have been test at the end follow with ASTM standard to ensure the product and process capable to be used in manufacturing industry. Consideration on substitution of natural fiber to current synthetic materials should take into account for better opportunity in the future.

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