A Brief Theory on Latest Trend of Filament Winding Machine

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Abstract— *Composite is stated as constituent of two or more materials which retain their own physical and chemical property during the time of application, but produce a component which inherent the properties of its constituent materials and makes it better for the real time usage. There are varieties of processing techniques for fabricating composite parts or structures such as: (1) Resin Transfer Moulding, (2) Pultrusion, (3) Filament Winding, (4) Autoclave Moulding. Among all these technique of exercising composite materials, the filament winding technique is the most appropriate because it avails the user with the ease of usage, as well as gives wide range of degree of freedom for fabricating or manufacturing objects. In the paper we basically reveal the maximum approach made to study basic theory related to the filament winding technique or method, which provides initial platform for the new learner.*
Keywords— composite, Resin Transfer Moulding, Pultrusion, Filament Winding, Autoclave Moulding.

I. INTRODUCTION THEORY

The up gradation in the field of material science has caused the present trend engineering science and technology for processing of composite materials. A Composite material is a material system consisting mixture of two or more **macro constituents** that differ in shape and chemical composition and which are insoluble in each other. The three main driving forces that has laid to the rapid development and use of composite materials are -

1. Military vehicles, such as airplanes, helicopters, and rockets, placed a premium on high-strength, light-weight materials. While the metallic components that had been used up to that point certainly did the job in terms of mechanical properties, the heavy weight of such components was prohibitive. The higher the weight of the plane or helicopter itself, the less cargo its engines could carry.

2. Polymer industries were quickly growing and tried to expland the market of plastics to a variety of applications. The emergence of new, light-weight polymers from development laboratories offered a possible solution for a variety of uses, provided something could be done to increase the mechanical properties of plastics.

3. The extremely high theoretical strength of certain materials, such as glass fibers, was being discovered. The question was how to use these potentially high-strength materials to solve the problems posed by the military's demands.

One can classify the study of composite into four different generation:

1st generation (1940s): Glass Fiber Reinforced Composites

2nd generation (1960s): High Performance Composites in the post-Sputnik era

3rd generation (1970s & 1980s): The Search for New Markets and the Synergy of Properties.

4th generation (1990s): Hybrid Materials, Nanocomposites and Biomimetic Strategies. [1]

According to TIFAC [2] - A 'composite' is a heterogeneous combination of two or more materials (reinforcing agents & matrix), differing in form or composition on a macroscale. Composites are commonly classified based on the type of matrix used: polymer, metallic and ceramic. In fibre - reinforced composites, fibres are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibres, and protects them from environmental damages due to elevated temperatures, humidity and corrosion. The principal fibres in commercial use are various types of glass, carbon and Kevlar. All these fibres can be incorporated into a matrix either in continuous or discontinuous form.

There are varieties of processing techniques for fabricating composite parts or structures .The various technique included are:(1) Resin Transfer Moulding, (2) Pultrusion, (3) Filament Winding, (4) Autoclave Moulding. Among all these technique of nurturing composite materials, the filament winding technique is the most appropriate because it avails the user with the ease of usage, as well as gives wide range of degree of freedom for fabricating or manufacturing of cylindrical objects. In a filament winding process, a single or band of continuous resin impregnated or pre-preg filaments is wrapped around a rotating mandrel and then is cured at room temperature or in an oven to produce the final product. The mandrel can be cylindrical, round or any shape that does not have re-entrant curvature.

II. COMPONENTS OF FILAMENT WINDING MACHINE

The essential components of filament winding machine are defined as under:

1. Mandrel
2. Job holder
3. Delivering eye
4. Control system

Mandrel: Mandrel[3] types that is used includes water-soluble mandrels and spider/plaster mandrells. The former type of mandrel is consider for pressure vessels where mandrel removal through small opening is desired. The sand is cast into a mold and cured, and the two mandrel ends are assembled and bonded. Two binders commonly used are polyvinyl alcohol and sodium silicate. It has advantage of low cost for small production quantities and excellent dimensional reproducibility. The disadvantage is high initial tooling cost. The latter form of mandrel is used for high tolerance mandrel surface in which a plaster sweep is used over removable or collapsible tooling. The plaster is cured, then overwrapped with Teflon tape or some other separator film. Following cure, tooling is removed, the plaster is chipped or washed out, and the release tape is removed, leaving inside the deires contour. Metal supported plaster is generally used for relatively large parts (3-6 m or 10-20 ft). The advantage of reusability and continuous winding process render expensive tooling worthwhile for high production applications. It is notable to say that mandrel size may be limited by torque or bearing strength of the wind axis attachments.

Job holder: The job holder is defined to perform the operation of holding male mandrel on to which the reinforced matrix is to be laid during the process running. At the same time job holder resembles one of the axis. The job holder can also be the mirror as head and tailstocks similar to a lathe machine.

Delivering eye: Since the basic concept of the filament winding is defined considering two axis system, the delivering eye represent the same. It could be single end effector/delivery eye or the complete resin holding system. Based on the type winding methods and patterns the end effectors application fluctuates at the point of placing the reinforced matrix.

Control system: The control system basically comprises of, mechanically, electrical and software integration well controlled with computer interference.

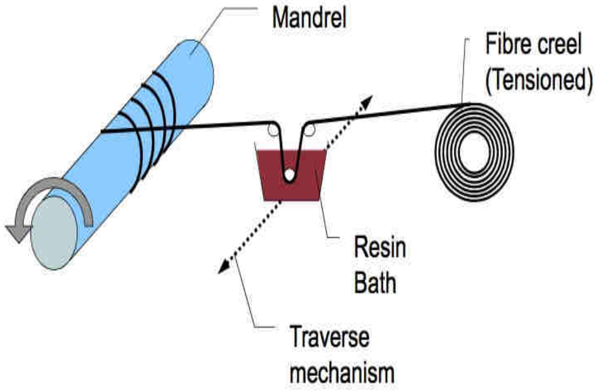
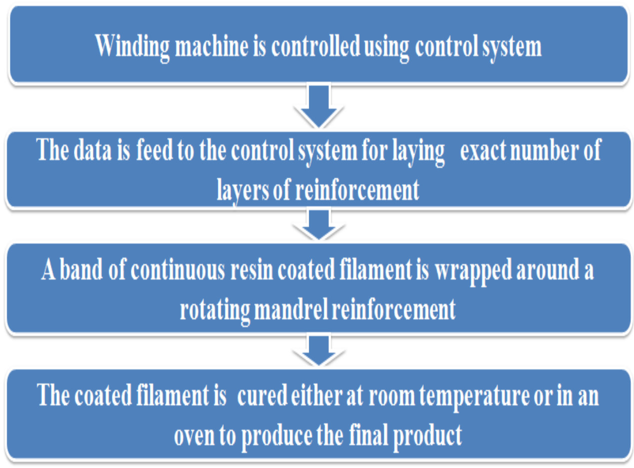
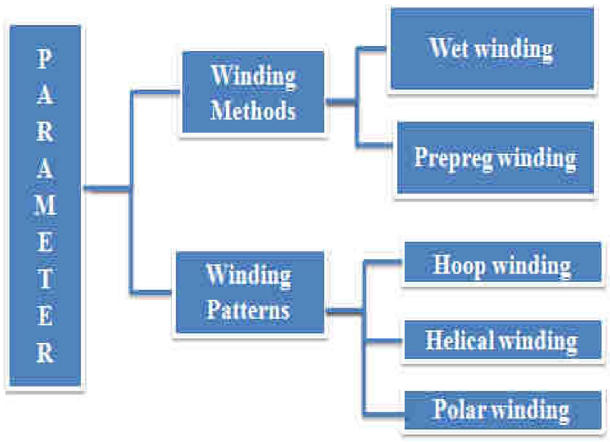


Fig. 2.1: filament winding process

III. FLOW CHART FOR THE PROCESS



IV. INFLUENCING PARAMETERS FOR WINDING



Winding methods: In this portion we discuss of two types of winding method[2], wet winding in which the fibre is passed through a resin bath and wound onto a rotating mandrel simultaneously and in prepreg winding preimpregnated fibre tows are placed on the rotating mandrel.

Winding patterns: This parameter is denoted by α [4]. The first type of winding pattern is hoop or circumferential where α is 90˚, the second type is helical winding the value of α lies in the range of 0˚ to less than 90˚. The third form is the polar winding where the value of α is no longer fixed and varies over the length of mandrel.

V. APPLICATION OF FILAMENT WINDED PRODUCT

Industry	Typical Application
Oilfield	Piping Systems Drive Shafts
Paper and Pulp	Paper Rollers Piping Systems
Infrastructure and Civil Engineering	Column Wrapping Support Structures Power Poles
Commercial Pressure Vessels	Water Heaters Solar Heaters Reverse Osmosis Tanks Filter Tanks Compressed Natural Gas Tanks
Aerospace	Rocket Motor Cases Drive Shafts Fuel Tanks

VI. WORK DONE OR BEING DONE IN THE SIMILAR ALLIED AREA

The field of material science, especially composite has become an extensive area of research due to the variation in consumer specification in terms of design, price, and performance. Usage of single PIC 18F452 micro controller [5] for controlling the actuation various components as well as the utilisation of software such adEasyWinder, FiberGrafiX, and CADWIND which are capable to generate different pattern for winding purposesis favoured for controlling of modern filament winding machines. Designing and implementation of tension control system [6] which consisting of magnetic break, servo motor, a PID control unit, a load cell and a data converter, the system is used for simulating the effect of tension force in the filament winding machines. Usage of ALGOR, [7] commercial finite element package to carry out the stress analysis of the machine structure to find whether the structure is capable of withstanding the static and dynamic loading or not. The system designed [8] is centrally controlled by cost effective PLC to control fiber winding control and tension control through PID control and also for the tension control a actuator is designed and implemented. Based on the direct exposure of Technology Information, Forecasting & Assessment Council (TIFAC) to composite applications, the responsibility of implementing the programme was assigned to TIFAC [2] the following projects have been launched under the Advanced composite Programme in collaboration with industry partners:

(1) Project on "Development of composite pressure vessels": The project was launched in March 2002 under the Advanced Composites Programme of TIFAC in partnership with M/s. Kineco Pvt. Ltd., Panaji and with technology support from IIT-Bombay.

(2) Project on "Development of Filament wound Glass Reinforced Epoxy (GRE) Pipes":due the wide application potential of GRE pipes, a project on the development of glass reinforced epoxy (GRE) pipes by filament winding technique is being considered by TIFAC.The GRE pipes would be developed as per ASTM standards, using indigenously developed 4- axes CNC filament winding system for catering to high pressure applications with operating pressure of 32 atm and surge pressure of 40 atm with temperature ranging from sub zero to 110 0C.

(3) Project on "Development of Filament Wound Composite Pipe Fittings": In view of application potential of filament wound pipefittings, a project on development of filament wound composite pipefittings is being considered by TIFAC. Under the project, it is proposed to fabricate composite pipefittings as per ASTM standards using indigenously developed 6-Axis CNC Filament winding system along with high-end software. Research to improve the efficiency of a filament winding machine process by combining the WITNESS modeling program with the search capabilities of a genetic algorithm to minimize the cost of producing a composite mandrel.

In [9] improve production efficiency using the motion control card, VC++ 6.0 language of FRP sand-filling pipes. Likewise we have control winding motion for elbow pipe[10] using Industrial computer, control cabinet NXI00 and robot, VC++6.0, OPENGL for achieving flexibility, multiple degree of freedom . Automation approach through mechanical component [11], to minimize human interference. Using PLC, PID, control 14 circuits to controol dwelling angle . Establishing of closed-loop tension control system [12] PLC, angle sensor, industrial control computer, numeric servo-electromotor, air cylinder, actuators are used for desirable system response aided with real time feedback filament tension . DSP and CPLD, PID controller and feed forward

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control [13] motion synchronization system developed for attaining stability and reliability in the process.

VII. FILAMENT WINDING VS. FIBER PLACEMENT TECHNOLOGIES

Filament winding process is in existance over 50 years. Its application is well defined in table 5.1. Fiber placement, on the other hand, is a relatively new kid on the block. Tape laying and tape placement technology grew rapidly in the 1970's and 1980's as a better means of laying up prepreg materials in widths that were both precise and faster. Later the particular field people found that combination of tape laying machines and filament winding machine technologies could be brought together for better accuracy. The number of fiber placement machines have grown from a few half dozen in the 1980's to numbers in the 40-50 range today. Some are very small while others are large enough to make commercial aircraft structures and wind energy blades that have significant dimensions on the order of 40-60 meters (~120- 180 feet). Fiber placement is often used for high performance structures where the fiber path within a given layer is designed to more precisely be laid down to be in conformance to the major local load conditions. Consequently it often is desired to "steer" the fiber tow or band into various angles that better optimize the load-carrying capability of the structure. Fiber placement also allows one to cut material and add material as necessary for tapering, expanding, crossing open areas (windows, doors, complex spaces, etc.) more efficiently. Consequently fiber placement scrap rates are much lower than filament winding or tape laying processes because materials are used much more efficiently. Table 7.1 from the reference [14] gives a basic platform of difference between the two methods.

Table7.1: comparison table between filament winding and filament placement technology

Parameter	Filament Winding	Fiber Placement
General Terminology	Most commonly called Filament Winding (FW)	Sometimes called differently within the industry: Fiber Placement (FP), Automated Tow Placement (ATP), Automated Fiber Placement (AFP)
Mandrel	Requires forming mandrel of some sort (usually does not go into an autoclave for final cure processing later)	Requires forming mandrel of some sort (often built for subsequent entry into an autoclave; typically for aerospace applications)
Resin Application State	Resin form may be: • Wet resin bath or wet resin bath with drum • Prepreg resin/fiber form • Dry fiber only – no resin	Resin must be a prepreg resin/fiber form (thermosets) or in a thermoplastic form
Fiber Forms	Fiber in various possible dry or prepreg forms: • Individual rovings (glass fiber designation) • Individual tows (carbon fiber designation) • May be any number of rovings or tows (typically anywhere from 1 to >60, depending on the width desired for winding) • "Tape" may also be selected form	Fiber comes only in prepreg form: • Width developed by number of rovings, or tows, must be manageable • Width typically on order of 0.10-inch to 0.50-inch in band (may be slightly wider) • Aerospace uses narrower widths than commercial applications
Fiber Tension	Fiber rovings or tows are continuously under tension (pulling) during winding process and are not "cut"	Fiber rovings or tows are not under tension, but are "placed" onto the surface and compacted in place using

	until winding typically completed	"normal" pressure applied via a roller following the prepreg fiber width. Relies on "tack" to stick.
Cutting, Adding Fibers	Fibers are not cut during the process and are not added during the winding process – cut fibers lose tension and slip out of designated position (angle,location, pre-tension) on mandrel	Fiber roving and tow bands may often be cut, or added, during the placement process at any point in time using software to designate "when" and "which"tows
Fiber or Tow Cutting Mechanism	Not applicable – fibers are not cut	Mechanical knives (aerospace) or laser (commercial) mechanisms
Fiber or Tow "Steering"	Fibers are tensioned and take up a path of least resistance unless they are trapped in position mechanically (end fittings, mandrel rotation, pin rings, etc.)	Fiber tows and bands may be "steered" along different paths and angles on the surface since they are not tensioned like those used in filament winding
Resin/Fiber Temperature	Prepreg fiber is warmed up (to room temperature) prior to winding; resin baths for "wet" winding approach usually are at room temperature but often may be heated to obtain certain desired viscosity level; some applications may even cool the resin material	Fiber is in prepreg form – and is usually in "chilled" state. Fiber is preheated just before mandrel lay-down so it flows and compacts onto the mandrel.
Applicable Resin Systems	Large variety of resin systems available: • Polyesters, vinyl esters • Polyurethanes • Phenolics • Epoxies • Cyanate esters • Bismaleimides (BMI) • Polyimides • Various exotic systems • Various thermoplastic matrices	

VIII. SIGNIFICANCE OF THE STUDY

The significance or importance of filament winding comes into existence where weight is an issue, or decrease of weight to increase performance. Since this fabrication technique allows production of strong, lightweight parts, especially for components of aerospace, hydrospace and military applications and structures of commercial and industrial usefulness. Continuous fiber reinforcement provides the structural performance required of the final part. The fiber is the primary contributor to the stiffness and strength of the composite and the the resin matrix that holds everything together, provides the load transfer mechanism between the fibers that are wound onto the structure, the resin matrix also serves to provide the corrosion resistance, protects the fibers from external damage, and contribute to the overall composite toughness from surface impacts, cuts, abrasion, and rough handling. Besides, the strength-to-weight advantages and low cost of manufacturing, the parts obtained from the process have better corrosion and electrical resistance properties. As mentioned earlier that mechanical strength of the filament wound parts depends on process parameters like winding pattern and winding method.

These two parameters enables the winding process to take place from linear two axes to upto six axes process, which gives us winded part of conical or one side enclosed geometry also. The former parameter can vary winding tension, winding angle and resin content in each layer of reinforcement upto desired thickness and strength of the composite geometry are achieved. The properties of the finished composite can be varied with the different type of winding pattern selected. Firstly, the hoop winding pattern which is a circumferential winding that approaches an angle of 90 degrees, secondly is the helical winding in which the fibers are winded at helical angles, thirdly is the polar winding, fibres are wrapped from pole to pole, as the mandrel arm rotates about the longitudinal axis. The latter parameter, winding method which first account for wet winding in which the fibres are passed through a resin bath and wound onto a rotating mandrel and the second is the prepreg winding which the preimpregnated fibre tows are placed on the rotating mandrel. Among the two winding methods, wet winding is more commonly used for manufacturing fibre reinforced matrix composite cylinders because of the following advantages: low material cost; short winding time; and the resin can be easily varied to meet specific requirements.

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REFERENCES

[1] Tim Palucka and Bernadette Bensaude Vincent, “History of composites overview”, April 2015.
[2] Information Forecasting & Assessment Council (TIFAC) to composite applications, Department of Science and Technology. GOVT. of India.
[3] S.T. Peters , Yu. M. Tarnopol ‘skll, “Hand book on filament winding machine”.
[4] Micheal L. SKkinner, Ronald R. Roser, and Kirk J. Samowitz,” Computer Control of Fiber Glass Filament Winding Machines”, IEEE Transactions on Industry Applications, VOL. IA-21, NO. 4, July/August 1985
[5] Saad Mutasher, Nazim Mir Nasari, Lee Chai Lin, “Small-Scale Filament Winding Machine for Producing Fiber Composite Products”, Journal of Engineering Science and Technology Vol. 7, No. 2 (2012) 156 – 168.
[6] Nikat Akkus, Garip Genc, Cemal Girgin, “Control ofthe Pretensionin Filament Winding Process actamechanica et automatica, vol.2 no.3 (2008) .
[7] M.R.M.Rejab, K.Kadirgama, M.M.Noor, M.S.M.Sani and R.Daud, “Paper on Modification and Testing of Four – Axes Filament Winding Machine”, International Conference on Science & Technology: Applications in Industry & Education (2008) .
[8] A paper on Low Cost 2-Axis PLC Controlled Filament Winding Machine with simplified Fiber Winding Angle and Tension Control System by Trinankur Hazra, March 2011.
[9] Jiazhong Xu, Rongguo Wang, Tao Sun, Qingmin Huang and Honghong Yang, “Design of Four-Axis Winding Machine for Tapered Composite Pole Using Heated-Mandrel Curing”, International Journal of u- and e- Service, Science and Technology Vol.7, No.1 (2014) pp.253-260.
[10] Zhong Weifeng, Yang Honghong, Li Huazhong, Xu liazhong, “Control System Design of Robotized Filament Winding for Elbow Pipe”, 2nd International Conference on Measurement, Information and Control, 2013.
[11] Benjamin Amborn Wollner, thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of master of science, “ Development of a fabric winding system for the automated manufacture of prefabricated wind turbine blade roots”, 2011.
[12] Ren Sheng-le and Lai Yi-nan, Wang Yong-zhang and Lu Hua, “A New Fiber Winding Precisiong Tension Control System”, Proceedings of the IEEE International Conference on Automation and Logistics Shenyang, China August 2009.
[13] Jiazhong Xu, Bo You, Deli Jia and Dongjie Li, “Motion Synchronization System of Filament Winding Machine”, Proceedings of the First International Conference on Innovative Computing, Information and Control, 0-7695-2616-0/06 2006 IEEE.
[14] Dr. Scott W. Beckwith, “Filament Winding vs. Fiber Placement Manufacturing Technologies”.