5.1 INTRODUCTION

This chapter describes the manufacturing process of a composite leaf spring as per the design presented in Chapter-3. The composite components can be manufactured by different processes like compression molding process, pultrusion process, filament winding process etc., which are explained below.

5.2 SELECTION OF FABRICATION PROCESS

Apart from the selection of material and selection of design procedure, the selection of manufacturing process also determines the quality and cost of the product. Hence, the composite leaf spring manufacturing process should fulfill the following requirements.

♦ The process should be amenable to mass production.
♦ The process should be capable of producing continuous reinforcement of fibers without any breakage.

5.2.1 Compression Moulding

Compression moulding is an established process for the manufacture of FRP products. In this process the material charge is filled in the die, which has the cavity resembling the product. By the application of pressure and heat the component is shaped and cured. These types of moulding process are not recommended for continuous mass production.
5.2.2 Pultrusion

In this process strand rovings and mats are pulled from one end of the line into a resin bath that contains liquid resins and curing agent. The fiber resin-stream is first passed through a series of preformers and through a long preheated die. The preformers are used to distribute the fiber bundles evenly and to squeeze out the excess resin. The final shaping, compaction and curing takes place in the die. Pultrusion process is normally used for producing long, straight structural members of constant cross sectional area.

5.2.3 Filament Winding

In filament winding process continuous fibers, under controlled tension are drawn from spools mounted on creel stands wetted with the resin by passing the fibers through a resin bath and wound onto the rotating mould. After achieving the desired thickness the process is stopped and the mould is removed from the machine and kept for curing. This process does not involve huge investment and also it can be used for continuous mass production. Since compression molding technique cannot be used for mass production of FRP products and pultrusion technique can be used only for producing straight products, Filament-winding technique is selected, which can be used for mass production of composite leaf spring.

5.3 FABRICATION OF COMPOSITE LEAF SPRING

5.3.1 Mould Fabrication

The mould used for the manufacture of FRP leaf spring should satisfy the following requirements.
The cavity of the mould should resemble actual shape and dimension of the leaf spring.

It should have a continuous positive surface of revolution.

It should be designed such that it can be rotated about an axis of revolution.

The mould is designed based on the dimensions of composite leaf spring. The design details of constant cross sectional composite leaf spring are presented in Chapter-3. After deciding the dimensions of the mould, it is manufactured using wood as the pattern material. Adding small wooden pieces along its boundaries creates the shape of the composite leaf spring. The mould is provided with two flanges on either side of it for connecting shafts as required. An attachment is fabricated for mounting of the mould on the spindle head of the winding machine, which is shown in Fig. 5.1.

![Fig. 5.1 Mounting attachment](image)
5.3.2 Filament Winding Machine

The mould that is used for the manufacture of composite leaf spring has an outer diameter of one meter. The mould after mounting on the machine has to be rotated as the fiber is wound on it. Hence a machine, which has the swing over diameter of 1m has to be used. This leads to the selection of the horizontal-boring machine, which has an adjustable swing over diameter.

5.3.3 Winding Set-up

The actual winding of the leaf spring involves the operation of the winding machine, after attaching the resin bath and mould. Before the process is started the epoxy resin and hardener combination has to be placed in the resin bath. The resin bath is an important unit of the winding set up. It provides the necessary matrix impregnation to the fibers before they are wound over the mould surface. The resin bath should accomplish the following requirements.

➢ It should wet the fiber roving uniformly with a controlled amount of resin.
➢ The capacity of the resin bath should be such that all the resin poured should be utilized completely.
➢ The resin must be maintained at constant temperature to maintain constant viscosity.
➢ It should avoid fiber breakage during impregnation.

The resin bath consists of a number of rollers, which are placed to guide the fibers. The fibers from the creel stand are allowed to pass through the rollers
that are placed well inside the resin bath. This enables the fibers to get completely soaked in the resin. The soaked fiber is then allowed to pass through two rollers, which are rotating in opposite direction. By this method the amount of resin in the fiber can be controlled. The mould is first mounted on the filament-winding machine using the fabricated attachment and it is rotated slowly at a speed of 15 RPM. The photograph of filament-winding set-up with resin bath is shown in Fig. 5.2.

5.3.4 Resin Preparation

The selected epoxy resin is 520F with hardener 758. For every 100 parts by weight of Dobeckot 520F, 10-12 parts by weight of hardener 758 is mixed well at a temperature of 20 to 40 degrees and used within 30 to 40 minutes. Since the gel time of the epoxy resin is 30 to 40 minutes. Therefore only the quantity that would get consumed in 30 minutes of winding had to be mixed with hardener at a time.

5.3.5 Filament Winding Process

After the preparation of the resin, the resin is poured into the resin bath and then the fiber placed in the creel stand is allowed to pass through the rollers in the resin bath. The soaked fiber is then allowed to pass over the mould. The process is continued till the desired thickness is achieved. The filament winding of fiber over the mould is shown as photograph in Fig. 5.3. The diagrammatic representation of filament-winding process is also shown in Fig. 5.4.
Fig. 5.4 Filament winding process of composite leaf spring
Then the process is stopped and the mould is removed from the machine and
the mould along with the material is kept for 12 to 15 hours for the resin to
cure. Then the material is cut at the two ends and the two leaf springs are
removed from the mould.

5.3.6 Metallic Eye

It is very difficult to fabricate a composite leaf spring with the eye
portion by filament winding process. Hence, a separate metallic eye is
fabricated and then fixed to the leaf spring. The two metallic eyes required for
one leaf composite spring is taken from an already available conventional leaf
spring and is welded to a rectangular plate having a sufficient area to fix with
composite leaf spring.

5.3.6.1 Selection of Joint

The purpose of joint is to transfer loads from one member to another in
a structure. The selection of joints has a special significance in fiber reinforced
composite structures for two reasons,

(1) The joints are often the weakest areas in a composite structure.

(2) The composite materials do not posses the forgiving characteristics of
ductile metals, namely, their capacity to redistribute local high stress by
yielding.

For composite structures, the basic joints are either mechanical or bonded.
The bonded joints are difficult to disassemble without either destroying or
damaging substrates and may be affected by service temperature, humidity and other environmental conditions. These are also difficult to inspect for joint quality. Hence, mechanical joints are selected for joining of metallic eye with composite leaf spring. This permits quick disassembly for repairs/replacements without destroying the substrates and easy inspection for joint quality. It also has some disadvantages like add weight to the structure, machining of holes that interrupt the fiber continuity etc. The number of holes and diameter of each hole are considered in the design stage itself to avoid failure due to drilling of holes in the composite structure. Holes are drilled both on the plate and the composite leaf spring. Then the plate is fixed to leaf spring using a bolt and nut. The diagrammatic representation of the metallic eye is shown in Fig. 5.5. The photograph of composite leaf spring with metallic eye and steel leaf spring are shown in Fig. 5.6.

![Fig. 5.5 Metallic eye connected to the composite leaf spring](image)

5.4 FABRICATION OF EXPERIMENTAL SET-UP

The main problem faced in using a standard material fatigue-testing machine for testing a leaf spring is the displacement. The standard machines are designed for a displacement in the order of microns. But the leaf spring
fatigue-testing machine must permit displacements in the order of centimeters. The machine must be capable of exerting heavy loads in the range of a few tones. The machine must be equipped with a suitable fixture, which will simulate the actual mounting of the leaf spring in the automobile. This leads to the need of a servo-hydraulic fatigue-testing machine for testing.

The Servo-hydraulic fatigue-testing machine for testing of leaf springs is providing only displacement in a form of millimeters to centimeters and loading-unloading in the simulated manner as in the automobiles. This is alone not sufficient for fatigue analysis. The correct numerical values of number of cycles that are completed, loading and unloading values for one cycle for calculating stiffness variation as cycles goes on increasing, stresses at any location as number of cycles goes on increasing and frequency of the test are also required for proper fatigue analysis. In this context, interfacing equipment is also having significant role in the fatigue test.

5.4.1 Requirements of Testing Machine

1. As leaf springs of various automobiles ranging from light motor vehicle to earth moving equipment are to be tested, the machine should require a wide range from 500 kg to 20 tones.

2. As the leaf springs deflect in the order of centimeters, the machine should have sufficient stroke length.

3. The machine should be provided with a flexible fixture arrangement, which facilitates easy mounting of different types of leaf springs with little modification.
4. The machine should be provided with a user-friendly automatic control.

5. As it is quite difficult to record the results of the test manually, the machine should be equipped with an online computer and other accessories to interface.

5.4.2 Fatigue Testing Machines

There are many fatigue-testing machines available today. These are classified into different types based on fatigue testing methods under which the simulation required. The different types of fatigue testing machines are given below:

- Programming fatigue testing machine
- Service duplication fatigue testing machine
- Random load fatigue testing machine
- Constant amplitude fatigue testing machine

The characteristics of above machines are analyzed and the requirements of leaf spring fatigue testing machine are matches with constant amplitude fatigue testing machine. Hence, the constant amplitude fatigue-testing machine is fabricated, which is shown as photograph in Fig. 5.7.

5.4.3 Servo-Hydraulic Constant Amplitude Fatigue Testing Machine

The main parts of the fatigue-testing machine are Hydraulic power pack, Direction control value and Hydraulic double acting cylinder. The circuit diagram of servo-hydraulic constant amplitude fatigue testing machine is shown in Fig. 5.8.
Fig. 5.6 Photograph of steel and composite leaf springs

Fig. 5.7 Photograph of experimental set-up
Fig. 5.8 Hydraulic circuit of experimental set-up
5.4.3.1 Hydraulic Power Pack

Specifications of the hydraulic power pack

Load = 200 kN
Stroke = 60 mm
Velocity = 2500 mm / min
Oil = Servo Hydraulic oil
Maximum pressure = 160 bar
Discharge = 9.08 gallons / min
Pump power = 11.2 kW
Speed = 600-2000 rpm
η_mech. = 85 %
Accumulator = AC – 125 – 1 – 10 (Bore = 125 mm)

5.4.3.2 Direction Control Valve (DCV)

The direction control valve consists of the following parts for function,

(1) 4/3 way valve  (3) Limits switches
(2) Solenoid control (4) Relay

5.4.3.3 Hydraulic Double Acting Cylinder

Specifications of the double acting cylinder

Piston diameter = 125 mm
Rod diameter = 50 mm
5.4.3.4 Heat Exchanger

The oil at the outside of the piston is forced out of the cylinder. This oil is passed to DCV. The port is now connected to the exhaust port of the valve. Hence the oil flows out through the exhaust port. The oil is passed through the heat exchanger before it is send back to the oil reservoir. Here heat exchanger used is water at room temperature.

5.4.4 Design and Fabrication of Fixture

A fixture for mounting different types of leaf springs is designed analyzed for deflection and stress. Then the fixture is fabricated. The features of the leaf spring mounting fixture are

- It facilitates easy mounting of different leaf springs ranging from car leaf springs to lorry leaf springs with little modifications.
- The fixture simulates actual loading of the vehicle.
- The fixture has the provision of pre-loading, as the stroke of the cylinder is limited.

The designed fixture for the testing of leaf springs is shown in Fig. 5.9. The pre-loading is realized by means of providing a screw-jack arrangement, which can be raised or lowered based on the amount of pre-loading required.

5.4.5 Computerized Control of Fatigue Testing Machine

After installing fatigue-testing machine it is required to interface the testing machine with computer because of following reasons.
(a) Testing of steel leaf spring

(b) Testing of composite leaf spring

Fig. 5.9 Fixture for testing of leaf springs
Counting the number of cycles is inhuman

A computerized control is a must for programmed tests, random load tests, and service duplication tests.

Recording various measurements like load applied, stress at different locations and displacement is not possible manually.

Detection of failure can be achieved.

Post processing of results is easier.

The leaf spring is to be examined for any defects like cracks, surface abnormalities etc. and the dimensional and material details of the composite leaf spring are recorded. The leaf spring is mounted on the leaf spring mounting fixture of the fatigue-testing machine. The strain gauges are mounted on the various places of the leaf spring. The signals from load cell are amplified and fed into an Analog to Digital (A/D) converter. The A/D converter converts the analog to digital signals, which are now ready to fed into the computer. The signals from various strain gauges can also fed into the computer using the bridge arrangement as shown in Fig. 5.10 and also signals from various strain gauges are connected to strain indicator for verification of strain values. The strain values are multiplied with the tensile modulus to get stresses at different locations. This entire process is facilitated by the use of 8-channel A/D converter. The particular channel can be read by using software. The software is developed for controlling the data acquisition system. The various values read and displayed on the screen and also recorded in a file for post-processing. The computer interfacing details are shown in Fig. 5.11. The required accessories for interfacing are as follows,
Fig. 5.10 Interfacing circuit for strain indicator

Fig. 5.11 Computer interface for experimental set-up

Hardware:

- Computer
- Strain gauges
- Strain indicator
- Amplifier
- Data acquisition card
- Load cell
Software:

The following computer programs are developed to control the testing machine automatically.

- Program to control entire circuit
- Program to count the number of cycles
- Program to give load calculations
- Program to give stress-strain calculations

5.4.6 Load Cell Calibration

The load cell for measurement of the load is calibrated using Amsler’s wood testing machine. The load cell is loaded in both directions using the machine and the output of the A/D converter with the corresponding load value is recorded using the computer. A calibration chart is drawn and the slope of the graph is calculated. The graph obtained is linear and with no hysterisis.

5.4.7 An Alternate Arrangement for Constant Amplitude Test

An alternative arrangement for constant amplitude testing without the help of the computer is also designed and fabricated. This arrangement uses limit switches for sensing the end positions of the ram movement. An electro-hydraulic circuit is designed and fabricated to control the setup, which is shown in Fig. 5.12. After mounting the leaf spring in the experimental set-up, it is rubbed properly at four locations for fixing the strain gauges with the help of adhesive bonded material. After pasting the strain gauges the strain indicator
Fig. 5.12 Electro hydraulic circuit for alternate arrangement

is interfaced with bridge circuit as shown in Fig. 5.13 for getting strain values. Limits switches are connected to DCV via relay and limit switches are fixed at the required locations in the experimental set-up such that the leaf spring will touch when it reaches to upper limit and lower limit as shown in Fig. 5.13.
5.5 CONCLUSIONS

- Filament winding set-up is fabricated and then the designed composite leaf spring is fabricated.

- A fatigue-testing machine capable of conducting fatigue test on any type of leaf springs is fabricated.

- A computer interface is developed for automatic controlling and recording of the fatigue test.

- An alternative arrangement for constant amplitude testing without the help of the computer is also designed and fabricated.