

## **CHAPTER (4)**

### **EXPERIMENTAL WORK**

#### **4.1 Introduction**

With the increasing use of composite materials in structural applications, a corresponding increase in the need for experimental data has been found. Thus, the test methodology of composite materials has received considerable attention in recent years, which was mainly dependent on borrowing the test methods of metals. Because of the heterogeneity and anisotropy of composite materials, borrowing test methods from metals must be carefully scrutinized before directly applied to the characterization of composite materials [84].

The most common procedure to find out the fatigue behavior, and which is followed here, is to determine the number of cycles to failure of a number of specimens stressed at different stress levels. The test results are then plotted forming the S-N diagrams, which are then analyzed [84].

#### **4.2 Test Specimens**

##### **4.2.1 Materials**

The used specimens were made of woven-roving E-glass fiber, with equal intensity in both fill and wrap directions as the reinforcement with epoxy resin as matrix. Table A3.2 gives the properties of the used materials. The epoxy resin consists of two components, (A) is epoxy and (B) is a catalyst. The mixing ratio between the two components, A and B was (2:1) by weight. The cross-linking and curing took place at ambient conditions.

All specimens had a fiber volume fraction ( $V_f$ ) ranging from 55–69.5%. This range was used in previous works [83-88], [138-146] and has proved its suitability to ensure good adhesion between fibers and matrix, good strength and acceptable mechanical properties.

##### **4.2.2 Shape and dimensions**

The tubes were used to ensure having a plane uniform stress. All the test specimens had the following nominal dimensions, as shown in the Figure 4.1 and given in Table 4.1, which were measured after complete curing.

The thickness of the tube ends were built up by additional three layers with two different manufacturing methods  $M_1$  and  $M_2$  to study the effect of manufacturing method on the static and fatigue behaviour.

Two fiber orientations  $[0,90^\circ]_{3s}$  and  $[\pm 45^\circ]_{3s}$  were used to investigate the fatigue behavior of GFRE composites and under pure bending, pure torsion, pure internal hydrostatic pressure and combined bending & internal hydrostatic pressure.

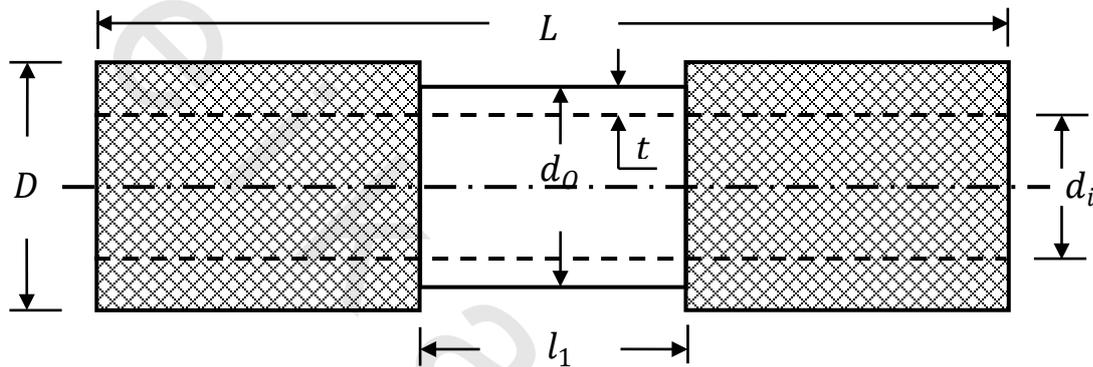


Figure 4.1 Dimensions of specimens.

Table 4.1. The specimen specifications

Dimensions [mm]	GFRE Specimen	
	$M_1$	$M_2$
Thickness, $t$	2.2	3.2
Flexible rubber tube diameter, $D$	26	28
Outer diameter, $d_o$	24.5	26.5
Inner diameter, $d_i$	20.1	
Effective length, $l_1$	35	
Total length, $L$	120	

Where: All dimensions with tolerance  $\pm 0.1$  mm

$M_1$ : The first method of manufacturing

$M_2$ : The second method of manufacturing

### 4.2.3 Thin/ Thick walled tube

When the wall thickness of a tube is about one-tenth, or less, of its diameter, the radial stress that results from pressurizing the tube is quite small compared with the tangential stress. Under these conditions the tube is called thin walled tube. The wall thickness-to-

diameter ratio, shown in equation (4.1), we can be accepted in the presented work to check the specimens are thin or thick.

$$\text{The wall thickness – to – diameter ratio} = \begin{cases} \frac{t}{d_i} \leq 0.1 & \text{(For thin tube)} \\ \frac{t}{d_i} > 0.1 & \text{(For thick tube)} \end{cases} \quad (4.1)$$

Where:

$t$ : Thickness of tube.

$d_i$ : Inner diameter of tube.

The wall thickness-to-diameter ratios were achieved for all specimens with both manufacturing methods  $M_1$  and  $M_2$ , see Table A5.2.1 and Table A5.2.2 in appendix (5), then we calculated the average value and the standard deviation of this ratios for each manufacturing method as shown in Table 4.2.

Table 4.2. The average and standard deviation value of specimen wall thickness-to-diameter ratios

$t/d_i$	GFRE Specimen	
	$M_1$	$M_2$
<b>The average</b>	0.1070363	0.15312
<b>The standard deviation</b>	0.0015876	0.00284

*Where:  $M_1$ : The first method of manufacturing*

*$M_2$ : The second method of manufacturing*

Where, the average value of wall thickness-to-diameter ratios is greater than the theoretical value of 0.1, for all specimens with both manufacturing methods  $M_1$  and  $M_2$ , with acceptable values of the standard deviation, although, the average value of specimens with manufacturing methods  $M_1$  is very closed to the theoretical value of 0.1, we can be considered all specimens with both manufacturing methods  $M_1$  and  $M_2$  are thick walled tube. Because, the stresses magnitude when checked for the specimens with manufacturing methods  $M_1$  under the two types of tube (i.e. thin and thick) is very closed.

#### 4.2.4 Specimens Manufacturing

All Specimens with both manufacturing method  $M_1$  and  $M_2$  were manufactured using open mould technique, by wrapping the woven-roving fiber around a wooden mandrel and then pouring the resin manually on it while being rolled. The specimen preparation was conducted under ambient conditions to avoid residual thermal stresses; the manufacturing steps of both manufacturing method  $M_1$  and  $M_2$  may be summarized as follows:

#### **4.2.4.1 First Manufacturing Method, M<sub>1</sub>**

1. The woven roving fiber was cut down into typical parts of dimensions 195 x 145 mm, in order to have specimens with three layers and having 5mm circumferential overlap. The fibers were cut into two different fiber orientations, [ $\pm 45^\circ$ ] and [ $0,90^\circ$ ], and the ends were surrounded and fixed with a scotch tape to avoid any probable distortion.
2. The fiber sections were wrapped around the wooden mandrels, which were previously covered with cellophane layer, and then fixed around the mandrel with a scotch tape. This cellophane layer was used to ensure the ease releasing of the manufactured specimen with glazed inner surface, and it was slightly wetted before being wrapped around the wooden mandrel and then left to dry up. This was a way to make it easily wrapped, and to ensure having a tight smooth surface after drying up.
3. The mandrel, with the fiber wrapped around it, was then fixed to the molding machine, and being ready to start the molding process.
4. The Epoxy (component A) was added to the catalyst (component B) with percentage 2:1 by Weight just before molding, and mixed well. The final mixture was then manually poured at a low rate on the wrapped fiber fabrics, while rotating the mandrel. A Teflon mandrel was used to squeeze the specimen while being manufactured, in order to get rid of any extra resin, air bubbles and to ensure having a good cylindrical outer surface.
5. With time, the rate of pouring the prepared resin was increased. Then, at the end, another cellophane layer was inserted in between the Teflon and fiber mandrels to be wrapped around the specimen to have a glazed, void free, and clean outer surface.
6. Specimens were left three or four days before being slipped off the mandrels, and then the outer cellophane layer was removed. Then their lengths were adjusted to be 120 mm to suit the gripping system in the testing machine, and get rid of the uneven ends. Finally, the specimens were left for about three week before being tested; in order to have their mechanical properties well settled.

#### **4.2.4.2 Second Manufacturing Method, M<sub>2</sub>**

The difference in manufacturing steps between this method and first method may be summarized as follows:

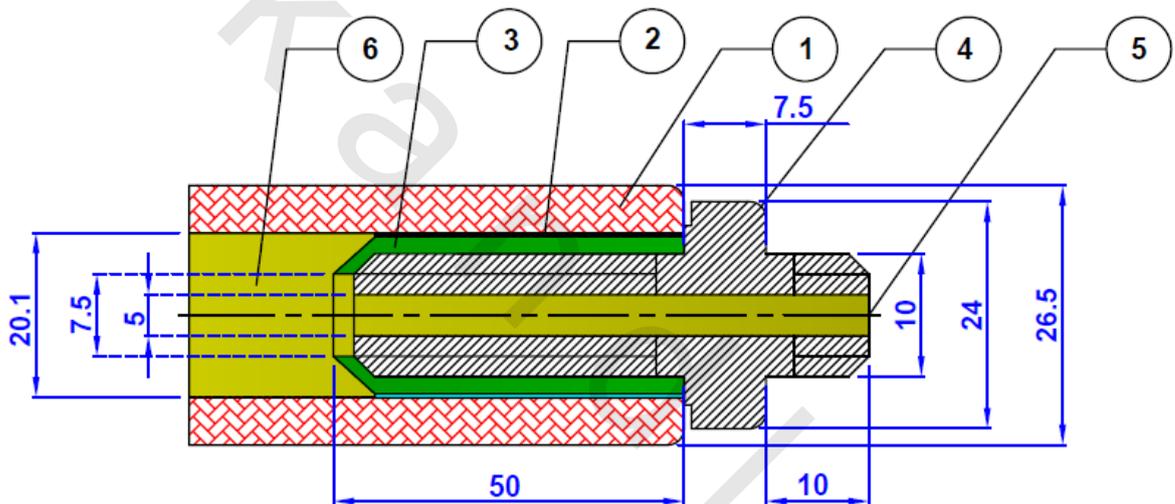
1. The woven roving fiber was cut down into three parts of dimensions 70 x 145 mm, 80 x 145 mm and 90 x 145 mm, for first, second and third layer respectively.

2. The steps from step 2 to step 5 in the first manufacturing method were done for first layer only.
3. Specimens were left three or four days before being wrapped the second layer around the wooden mandrels over the first layer, leaving the cellophane layer between them.
4. Repeat steps (2) and (3) with the second and third layers.

#### 4.2.5 Specimens Closure System

For the application of internal pressure efficiently, the specimen should be fixed properly to the testing machine. The fixation should be strong enough to avoid leakage of testing oil, fracture or slip of the specimen at the matching region.

Figure 4.2 shows the details of GFRE tube closure system for fixation to the testing machine.



- |  |                                      |
|--|--------------------------------------|
| (1) GFRE Specimen                                | (4) Hydraulic Joint with Square Head |
| (2) Epoxy Resin for fixation and sealing element | (5) Testing oil Hole                 |
| (3) PVC Nut                                      | (6) Testing oil                      |

Figure 4.2 Schematic of Specimen closure system details (Dim. in mm)

#### 4.3 Testing Machine

The used testing machine was designed by Mohamed [147]. The general layout is shown in Figure 4.3, Figure 4.4 and Figure 4.5 while Figure 4.6 shows a recent photo for the testing machine.

The testing machine is a strain controlled, rotating at constant speed of 380 rpm (6.33 Hz), and capable of performing six different fatigue loading condition and hydrostatic pressure load:

- 1) Pure bending,
- 2) Pure torsion,
- 3) Combined bending and torsion, (in-phase or out-of-phase),
- 4) Combined bending and hydrostatic pressure, (open and closed cylinder),
- 5) Combined torsion and hydrostatic pressure, (open and closed cylinder),
- 6) Combined bending, torsion, (in-phase or out-of-phase) and hydrostatic pressure, (open and closed cylinder).

The load conditions (bending and torsion) are independent, and have the facility to apply different mean stresses. The specimen is subjected to a uniform load, along its whole length, through a gripping system consisting of two halves that enclose the specimen in between.

#### **4.3.1 Load measuring system**

The applied loads, (bending or torsion), were measured by two load cells, (each one is fixed on one of the two different grippers), consisting of four active strain gauges, forming a full bridge. The signal is amplified and displayed on oscilloscope. The whole system was calibrated, in order to read out the oscilloscope signal as moment or torque. The calibration curves are shown in Figures A3.2 and A3.4. And the change in internal pressure was records by pressure gauge and stopwatch to measure the pressure rate, then stress, strain and other mechanical properties were calculated using equations were presented in chapter (3).

#### **4.3.2 Testing procedure**

##### **4.3.2.1 For pure bending and pure torsion moments test**

The testing procedure was similar to that found in the work [83-88], [138], and may be described as follows:

1. The oscilloscope and the measuring devices were turned on and left for 5 minutes to warm up.

2. The PVC nuts were fitted inside the specimen ends in order to support them and connect the specimen with hydraulic joints, and flexible rubber tubes were used to cover the ends from outside, to avoid gripping problems.
3. The specimen was fixed to the testing machine via the grippers, while avoiding loading the specimen during grasping; this was checked via the oscilloscope.
4. The amplitude stress component was adjusted using the eccentric coupling Figure 4.7 for bending and twisting moments.
5. The machine motor was turned on, measuring the time using a stopwatch and following the oscilloscope reading.
6. The machine motor was turned off, and the specimen was considered to have failed when the oscilloscope reading falls down by 20% of its initial value and the duration was recorded, i.e. 20% reduction in stiffness.
7. The previous steps were repeated at different stress levels until we cover the required life span, from  $10^3$  to  $10^6$  cycles.
8. The resulting number of cycles and the corresponding loads were used to calculate the stresses and to plot the S-N curve.

#### **4.3.2.2 For pure hydrostatic internal pressure test**

The testing procedure for pure hydrostatic internal pressure may be described as follows:

1. The specimen was fixed to the testing machine via the hydraulic joints.
2. The gear pump Figure 4.5 was turned on and the pressure inside the specimen was increased gradually to the burst pressure using flow control valves Figure 4.5, measuring the pressure inside the specimen via pressure gauge.
3. The gear pump was turned off, and the specimen was considered to have failed, when the pressure gauge reading falls down of its highest value, or when see leakage from the specimen.
4. The resulting burst pressure was used to calculate the hoop and longitudinal strength of the specimen.

### **4.3.2.3 For combined bending and internal pressure test**

The testing procedure for combined bending and internal pressure may be described as follows:

1. Repeat the steps 1 and 2 in pure bending moments test.
2. The specimen was fixed to the testing machine via the hydraulic joints then the grippers.
3. The amplitude stress component was adjusted by the same method in pure bending moment test.
9. The gear pump was turned on, then the internal applied pressure was adjusted by the same method in pure internal pressure test, after that, turn on the machine motor, measuring the time using a stopwatch and following the oscilloscope reading.
4. The machine motor and the gear pump were turned off, and the specimen was considered to have failed as the pure bending moment test.
5. Achieve the steps 7 and 8 as the pure bending moment test.

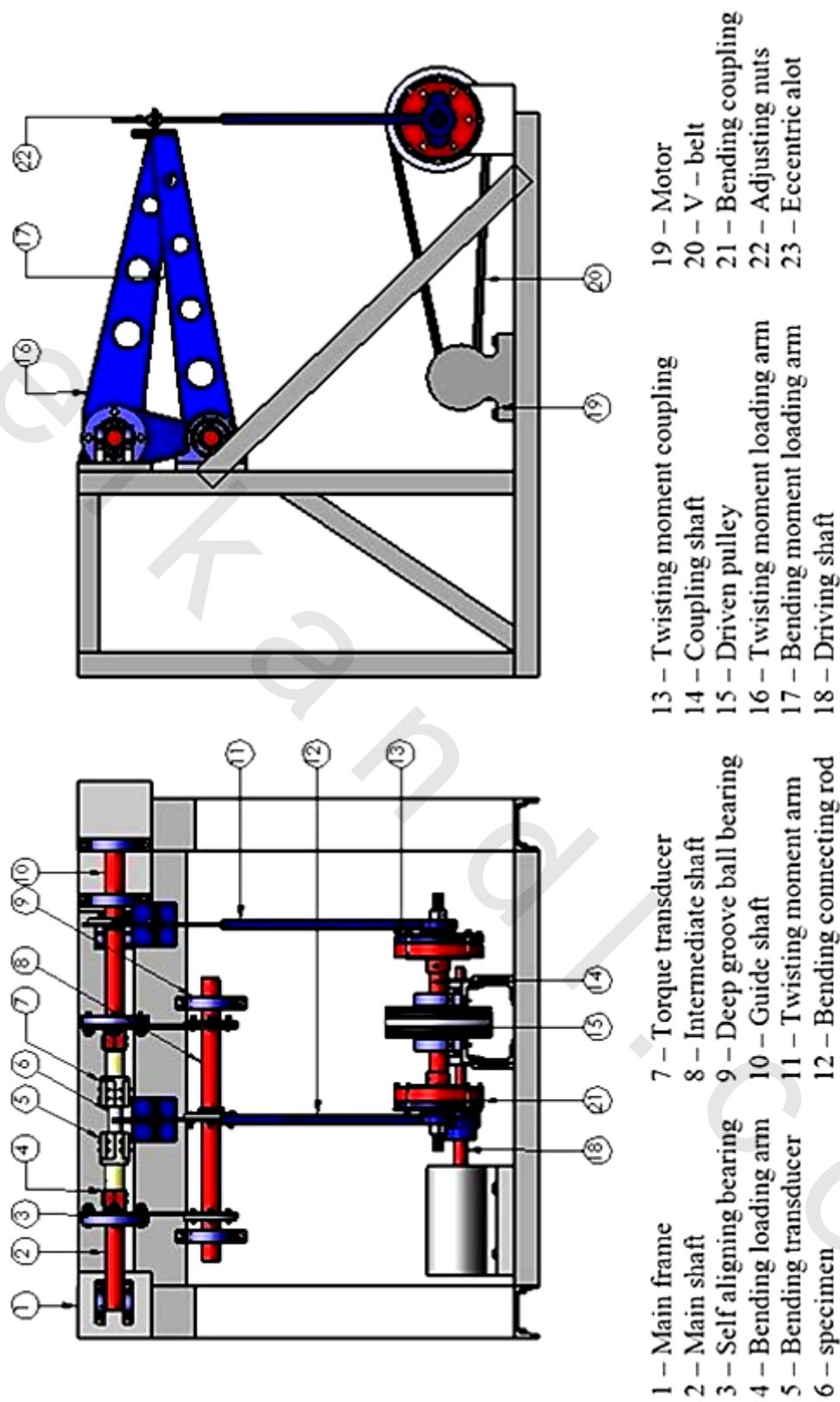


Figure 4.3 General layout of mechanical testing machine

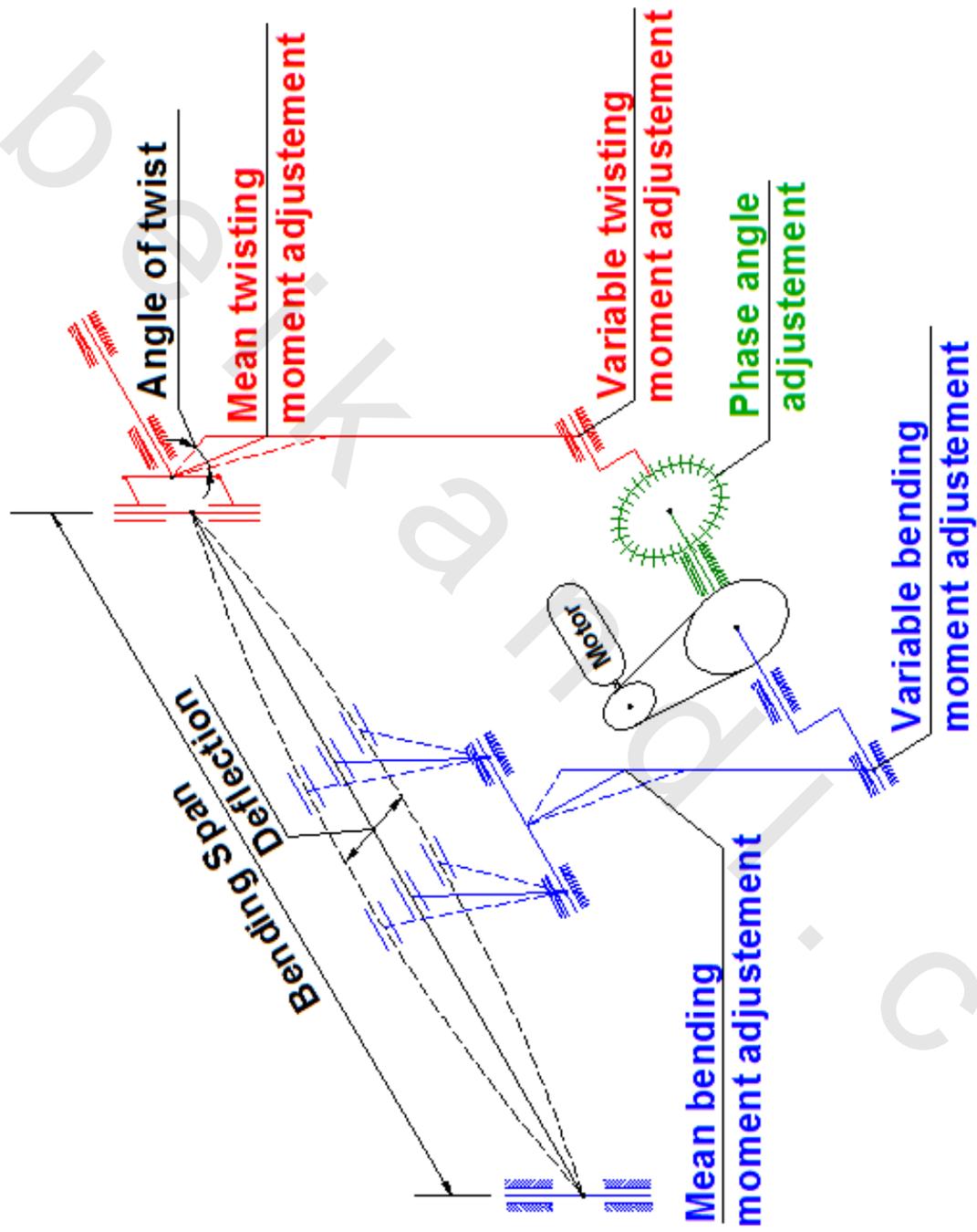


Figure 4.4 Schematic arrangement of mechanical testing machine

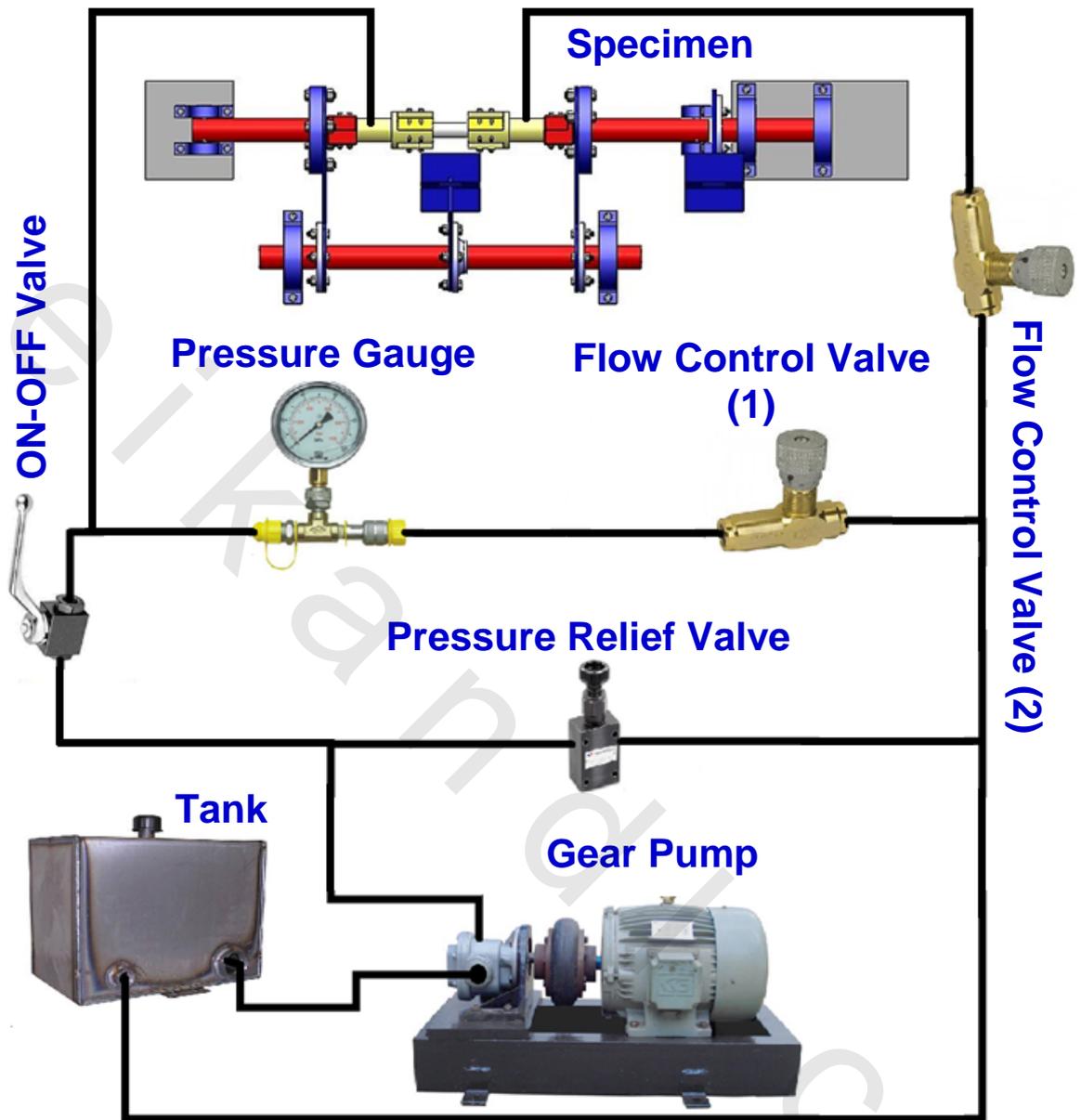
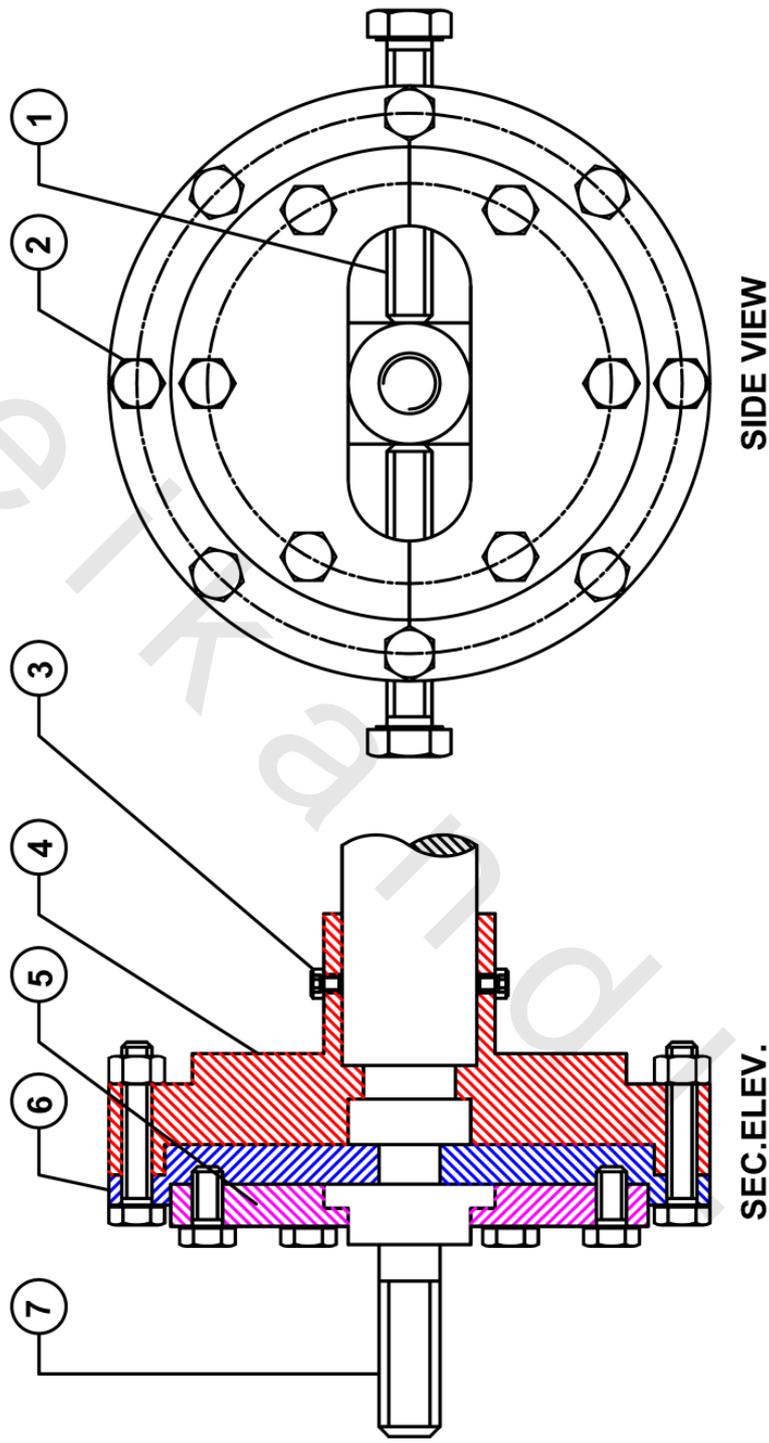


Figure 4.5 General layout of hydraulic testing machine.



Figure 4.6 Mechanical Testing machine



**SIDE VIEW**

- (5) Crank Holder
- (6) Main Flange
- (7) Crank

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- (1) Adjusting Screw
- (2) Tightening Bolts
- (3) Shaft Fixation Bolts
- (4) Input Flange

Figure 4.7 Bending and twisting Coupling