Design and Fabrication of Weighing Machine Made Up of Epoxy Matrix Composite Material Embedded with Load Cell

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Abstract

In recent days it is found many of the electronic weighing machines which are made up of conventional materials. By using the composite material over the conventional materials it helps to meet diverse design requirements with significantly less weight. As well as increase in strength-to-weight ratio and also improves stiffness and impact properties. It also exhibits excellent corrosion resistance. Hence considering all these properties of composite materials, weighing machine can be made from composite materials, instead of conventional materials like steel, aluminum etc. This paper discusses the fabrication of composite plate by hand layup process. The fabrication involves reinforcing glass wool and copper sheet in epoxy polymer matrix. The load cell is embedded in between the two composite plates. The main emphasis of this work is fabrication of weighing machine made up of composite material. And these weighing machines are easily portable and less expensive. It can be used in laboratories and provisional shops for weighing purposes.

Keywords: Composite materials, load cell. Circuit board hand layup technique

I. INTRODUCTION

Smart material is one of the upcoming fields in science and technology. The integration of sensors and actuation capabilities in the material has made the task challenging. This paper is intended to develop active smart material by the integration of weighing sensors in the fiber reinforced polymer (FRP). Components weighing sensors are used has inserts and are inserted in glass fiber and epoxy (toughened) matrix specimens.

Specimens are prepared as per ASTM standards ASTM D368 and D790 for mechanical testing. In FRP fabrication procedure are developed to integrate weighing sensors. The weighing sensors are carefully inserted in FRP layer using hand layup technique, the specimens are embedded with weighing sensors are also prepared for verifying sensing capability.

Mechanical strengths of materials are tested by means of tensile, flexural, hardness, impact tests. These sensing capabilities of the material are studied by experimentation technique. The proposed material can be used for replacement of the existing physical electronic weighing system. The outcome of this work may be encouraging from the weight reduction and cost reduction point of view.

The rest of the paper is organized as follows:

principles, applications & developments of weighing machines are discussed in section 2, methods of composite fabrication are discussed in section 3, advantages of composite materials are discussed in section 4, materials used in the composite plate are discussed in section 5, Electric inserts used in the weighing machine are discussed in section 6, steps involved in hand layup process are discussed in sections 7, design and calculation of weighing machine are discussed in section 8. Result and discussion is discussed in section 9, and finally section 10 gives the conclusion.

This paper gives clear idea about the test properties of the composite material and application of composite material.

II. PRINCIPLES, APPLICATIONS & DEVELOPMENT OF WEIGHING MACHINE

The weighing machine which is made up of composite material works on the following principles:
The sensors are used to detect and measure a relative change in a force or applied load, so it detects and measures the rate of change in force.

2) Identify force thresholds and trigger appropriate actions and detect contact and/or touch.

3) A dead-weight test stand is normally used in order to reach accurate and repeatable sensor loading.

4) Load cells or weight sensors are mechanical devices used to convert force or weight into electrical signals.

5) A strain gauge is located within load cells and changes resistance when pulled or pushed.

6) An electronic control unit that measures resistance changes processes the electrical signals.

7) Finally, these electrical signals are converted into readings on the display.

III. METHODS OF COMPOSITE FABRICATION

There are various methods for fabrication of composite material; mainly the two methods are used in the most fabrication of composite materials, and these two are:

a) Hand layup process
b) Pultrusion process

Because these methods are very less expensive compared with other fabrication methods of composite materials. Among these two methods, hand layup method is discussed below, because this method is followed in this work:

**A. Hand Layup Process:**

Hand lay-up process involves cutting the reinforcement material to size using a variety of hand and power-operated devices. These cut pieces are then impregnated with wet matrix material, and laid over a mold surface that has been coated with a release agent typically a resin gel-coat. The impregnated reinforcement material is then hand-rolled to ensure uniform distribution and to remove trapped air. More reinforcement material is added until the required part thickness has been built-up.

Fig. 1: Hand Layup Technique

IV. ADVANTAGES OF COMPOSITE MATERIALS

Advantages of composites over their conventional counterparts are the ability to meet diverse design requirements with significant weight savings as well as strength-to-weight ratio. Some advantages of composite materials over conventional ones are as follows:

- Tensile strength of composites is four to six times greater than that of steel or aluminum.
- Improved torsion stiffness and impact properties.
- Higher fatigue endurance limit (up to 60% of ultimate tensile strength).
- Lower embedded energy compared to other structural metallic materials like steel, aluminum etc.
- Composites are less noisy while in operation and provide lower vibration transmission than metals.
- Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements.
- Long life offers excellent fatigue, impact, environmental resistance and reduce maintenance.
- Composites enjoy reduced life cycle cost compared to metals.
- Composites exhibit excellent corrosion resistance.

V. MATERIALS USED IN THE FABRICATION OF COMPOSITE PLATE

FRP materials constitute of fibers and resin. The fibers are used as reinforcement materials, which will give mechanical strength to the materials, and epoxy resin is used as matrix material, which will make good bonding. In the present work, in order to make FRP composite as a smart material, in addition to the glass fibers the metal inserts are also used. This not only increases the mechanical strength, but also gives the sensing capability to the materials. The present work, materials used and method employed for fabrication are discussed in details as below:
A. Glass Wool Fiber:

Glass wool is non-combustible, non-toxic and resistant to corrosion. It has low weight by volume, low thermal conductivity, stable chemical property and low moisture absorption rate. It is having different thermal and mechanical properties. Glass wool is the best insulating material against noise, cold and heat and also excellent fire resistant properties. Barium carbonate, calcium carbonate, magnesium carbonate, arsenic oxide and sodium carbonate these are the raw materials for glass fibers.

In the present study the amount of fiber to be added in a concrete mix is measured as a percentage of the total weight of the concrete. The fibers with the modulus of elasticity of 55 GPa, specific gravity 2.68, aspect ratio of 125 are used.

![Fig. 2: Glass Wool Fiber](image)

Table – 1

<table>
<thead>
<tr>
<th>Mechanical parameter of Glass Wool Material</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>1595.84 MPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.22</td>
</tr>
<tr>
<td>Density</td>
<td>2600 kg/m³</td>
</tr>
</tbody>
</table>

B. Matrix Material:

In fabrication of composite materials the matrix material plays an important role. The different types of matrix materials, polymer matrices are the most commonly used because easy to fabricate the complex parts with less tooling cost and also have excellent room temperature properties. Epoxy, vinyl ester, polyester and phenolics are the most commonly used thermoplastic resins. Among them, epoxy resins have many advantages such as good performance at different temperatures, excellent bonding nature with variety of fibers and superior electrical and mechanical properties.

It is also have low shrinkage up on curing and good chemical resistance. Above mentioned thermoplastic polymers in that epoxy (LY 556) having several advantages and it is chosen as excellent matrix material for the present research work. Common name of epoxy is Bisphenol-A-Diglycidyl-Ether. Figure 3 shows the Epoxy LY556 and Hardener HY951. The material properties of Epoxy LY556 in FRP composite are listed in Table 2.

![Fig. 3: Epoxy LY556 and Hardener HY9](image)

Table – 2

<table>
<thead>
<tr>
<th>Mechanical parameter of Epoxy LY556 Material</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>1442 MPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.35</td>
</tr>
<tr>
<td>Density</td>
<td>1270 kg/m³</td>
</tr>
</tbody>
</table>
### Copper Sheet:

A systematic integration of thin copper sheet in a FRP material not only increases the mechanical properties, but also gives sensing capabilities to the structure. Thin copper sheets of thickness 0.02 mm are selected for the fabrication. The figure 4 shows thin copper sheet.

![Thin Copper Sheet](image)

**Table 3**

<table>
<thead>
<tr>
<th>Mechanical properties of copper</th>
</tr>
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<tbody>
<tr>
<td>Young’s modulus</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>

### VI. Electric Inserts Used in the Weighing Machine

#### A. Circuit Board:

![Circuit Board](image)

There are three main components of an ICSP system: Application Circuit, Programmer and Programming Environment. The application circuit must be designed to allow all the programming signals to be directly connected to the PIC micro MCU. Figure 1 shows a typical circuit that is a starting point for when designing with ICSP.

The application must compensate for the following issues:

- Isolation of the MCLR/VPP pin from the rest of the circuit.
- Isolation of pins RB6 and RB7 from the rest of the circuit.
- Capacitance on each of the VDD, MCLR/VPP, RB6, and RB7 pins.
- Minimum and maximum operating voltage for VDD.
- PIC micro Oscillator.
- Interface to the programmer.

The MCLR/VPP pin is normally connected to an RC circuit. The pull-up resistor is tied to VDD and a capacitor is tied to ground. This circuit can affect the operation of ICSP depending on the size of the capacitor. It is, therefore, recommended that the circuit in Figure 1 be used when an RC is connected to MCLR/VPP. The diode should be a Schottky-type device. Another issue with MCLR/VPP is that when the PIC micro MCU device is programmed, this pin is driven to approximately 13V and also to ground. Therefore, the application circuit must be isolated from this voltage provided by the programmer.
B. Load Cell:

Fig. 7: single point load cell

Force applied onto the weighing pan is converted into electrical signals by the load cell and output to the indicator. Suppose the specifications of the load cell are as follows:
- Rated capacity: 6 kg
- Rated output: 1 mV/V
- Recommended excitation voltage: 10 V

When the rated output is 1 mV/V and the excitation voltage is 10 V, the load cell will output 10 mV to the indicator. This is the output voltage when the rated capacity of 6 kg is loaded.

\[(\text{Load}) \ 6 \text{ kg} \rightarrow 10 \text{ mV} \quad (\text{Output Voltage})\]

If we want to weigh an object of 6,000 g using this load cell and display the result from 1 g (1 g is called the minimum weighing value), how many mV will be output for a load of 1 g? Since the load cell will output 10 mV for a load of 6 kg, 
\[
\frac{1,6000 \text{V} \times X}{10 \text{ mV}} = \frac{X \times 10 \text{ mV}}{6000}
\]

\[X = \frac{10 \text{ mV}}{6000} = 1.6 \mu \text{V}.
\]

Therefore, the input sensitivity of the indicator must be lower than 1.6 μV. For example, if the input sensitivity of the indicator were 1.8 μV, 1 g display would not be possible.

VII. W EIGHT CALCULATION AND FABRICATION PROCESS OF COMPOSITE MATERIAL

- Step 1: Calculated amount of epoxy (LY 556) is measured using weighing machine of 387gms and hardener (HY 951) of 3.87gms
- Step 2: Teflon sheet is coated on the mould prepared of 310x310mm for easy removal of the materials
- Step 3: Epoxy and hardener are mixed in a container and stirred continuously for 10min so that no bubbles are formed
- Step 4: The mixed epoxy is poured into the mould and final finishing is done using brush.
- Step 5: A glass fiber is cut of 310x310x0.48mm and is placed on the poured epoxy matrix in the mould.
- Step 6: Again the second layer of epoxy is coated on the glass fiber.
- Step 7: A copper sheet is cut of 310x310x0.0533mm and is placed on the mould.
- Step 8: A third layer of epoxy is poured on the copper sheet and is hand laid up.
- Step 9: Again a Teflon sheet is coated on the plate and placed on the mould.
- Step 10: Finally load is applied on the upper plate so as to take up the proper binding.
- Step 11: The plates left for drying continuously for 18hrs.
- Step 12: Finally the plates are obtained 310x310x4 mm dimensions.

A. Calculation of Amount of Epoxy and Hardener Required:

Thicknes (T) = 4.5mm

\[
\begin{align*}
V_{\text{total}} &= 0.310 \times 0.310 \times 0.310 \times 0.0045 \\
&= 4.324 \times 10^{-4} \text{ m}^3 \\
\rho_{\text{epoxy}} &= 1156.6 \text{ kg/m}^3 \\
T_{\text{copper}} &= 0.0533 \text{ mm} = 5.33 \times 10^{-5} \text{ m} \\
T_{\text{glass wool}} &= 0.48 \text{ mm} = 4.8 \times 10^{-4} \text{ m} \\
V_{\text{copper}} &= 0.310 \times 0.310 \times 0.310 \times 5.33 \times 10^{-5} \\
&= 5.122 \times 10^{-6} \text{ m}^3 \\
V_{\text{glass}} &= 0.310 \times 0.310 \times 0.310 \times 4.8 \times 10^{-4} \\
&= 4.6128 \times 10^{-5} \text{ m}^3 \\
V_{\text{epoxy}} &= V_{\text{total}} - V_{\text{copper}} - V_{\text{glass}} \\
&= 3.35 \times 10^{-4} \text{ m}^3
\end{align*}
\]
M= V epoxy x ρ
M= 3.35x10^-4x1156.5
M= 0.387 kg
Mass of epoxy for 1 layer= 0.096kg= 97gms
Mass of hardener in the ratio 1:10 = 9.7gms
The prepared mould after fabrication is shown in below figure 8

The actual design consist of two plates made of composite materials of 7mm thickness (epoxy, glass wool fires) which as shown in fig 9. A separate circuit board is mounted, so as to convert a mechanical deformation into electrical signal and in turn into a digital form. Two load cells are connected to the board as shown in fig. 9 which takes up the load.

As the load is applied on the upper plate which is in contact with the ball bearing sensors, the plate under goes deflection, this deflection is sensed by the sensors (ball bearing) which is in analog form. This analog signal has to be converted into digital signals using analog to digital converter which is provided in the circuit board. These signals are displayed on the digital display which is provided on the upper plate.

VIII. CONSTRUCTION AND WORKING OF WEIGHING MACHINE

Fig. 8: Final Composite Plate

Fig. 9: Model of weighing machine

Fig. 10: Actual Model of Weighing Machine
IX. CONSTRUCTION

A complete weighing machine is made of composite material (epoxy, glass wool, copper sheet) with load cells. The composite material plates are made by hand layup process. Sensors (load cell) are placed between two plates and legs fixed below the plate 2 at the corners, and a separate programmed circuit board (PIC16FXX) is set up and is connected along with battery is provided below the plate 2 and the display is provided at top plate, the composite material should possess the properties of stainless steel.

A. Working:

As the load is applied on the upper plate which is in contact with the ball bearing sensors, the plate under goes deflection, this deflection is sensed by the sensors (ball bearing) which is in analog form. This analog signal has to be converted into digital signals using analog to digital converter which is provided in the circuit board. These signals are displayed on the digital display which is provided on the upper plate.

X. RESULT AND DISCUSSION

The proposed smart FRP specimens are prepared with 1.5 percent of thin copper insert. The fabricated specimens are tested to validate their mechanical strength, the mechanicals strengths are verified experimentally

Mechanical Strength Test Results

Mechanical strengths of prepared specimens are experimental verified by using, flexural, impact, tensile and hardness tests. The tests are carried out in national institute engineering college, Mysore, Karnataka. The specimens are tested with fibers and electrical inserts parallel and perpendicular to the loading directions as per ASTM standards D368 and D790.

1) The FRP specimen with copper inserts shows the flexural stress at maximum flexure load. This suggests that the metal inserts increases the flexural stress at maximum flexure load strength of the specimen and also flexural modulus.

2) The tensile strength of FRP specimen with metal inserts is almost same. This suggests that the metal inserts in FRP specimens will not make much difference in tensile strength.

3) The below table shows impact test result

<table>
<thead>
<tr>
<th>Test type</th>
<th>Impact strength</th>
<th>Max value</th>
<th>Min value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shore-D55</td>
<td>78kJ/m²</td>
<td>83.5kJ/m²</td>
<td>75.5kJ/m²</td>
</tr>
</tbody>
</table>

Table 4 shows that Izod test results of the specimens. The breaking energy of FRP specimen with maximum value and minimum values are shown.

4) The below table shows the hardness test

<table>
<thead>
<tr>
<th>Test type</th>
<th>Hardness number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockwell hardness test</td>
<td>60rhn</td>
</tr>
</tbody>
</table>

The table 5 shows the hardness report in which the material has the hardness of 60rhn.

XI. CONCLUSION

- The weighing machine made of FRP composites with metal inserts, has led to following specific conclusions
- Successful fabrication of FRP based composites integrated with electrical inserts by hand-lay-up technique is possible.
- Mechanical Tests are carried out and the proposed specimens are having good mechanical properties.
- The composite material plates have the mechanical properties similar to stainless steel according to the tested report.
- The metallic weighing machines are heavy; hence the weighing machines fabricated out of composite materials are light in weight (2.5kgs).
- The machine can weigh up to 25kgs, which can be used in market for weighing vegetables.

REFERENCES