Chapter 4

Experimental Setup and Sample Preparation

4.1. Introduction

This chapter provides details of the experimentation carried for SHM testing. SHM framework related to fiber optic sensor-based and the diffuse wave-based test is explained in detail. The experimental verification of the proposed methodology use signal details extracted from experimentation as input to neural network intelligence. Experiments are performed in repetition mode to get the reproducibility of output. Moreover, repeated experimentation using different samples having variation in notch location is carried out for verification of damage detection capabilities. Following a systematic testing procedure, the performance of the developed model is tested.

4.2. Sample Preparation

The initial step for experimentation is the preparation of the sample as per the test requirement. An aluminum beam of dimension 180x24x6 mm^3 is taken as a host material. Notch as per standard is made at different locations on the beam at 75 mm, 90 mm, and 105 mm from the fixed end. The reason for the selection of aluminum as the host structure material is its versatile nature and wide range of applications. The advantages of using aluminum in different applications is summarized in fig. 4.1.

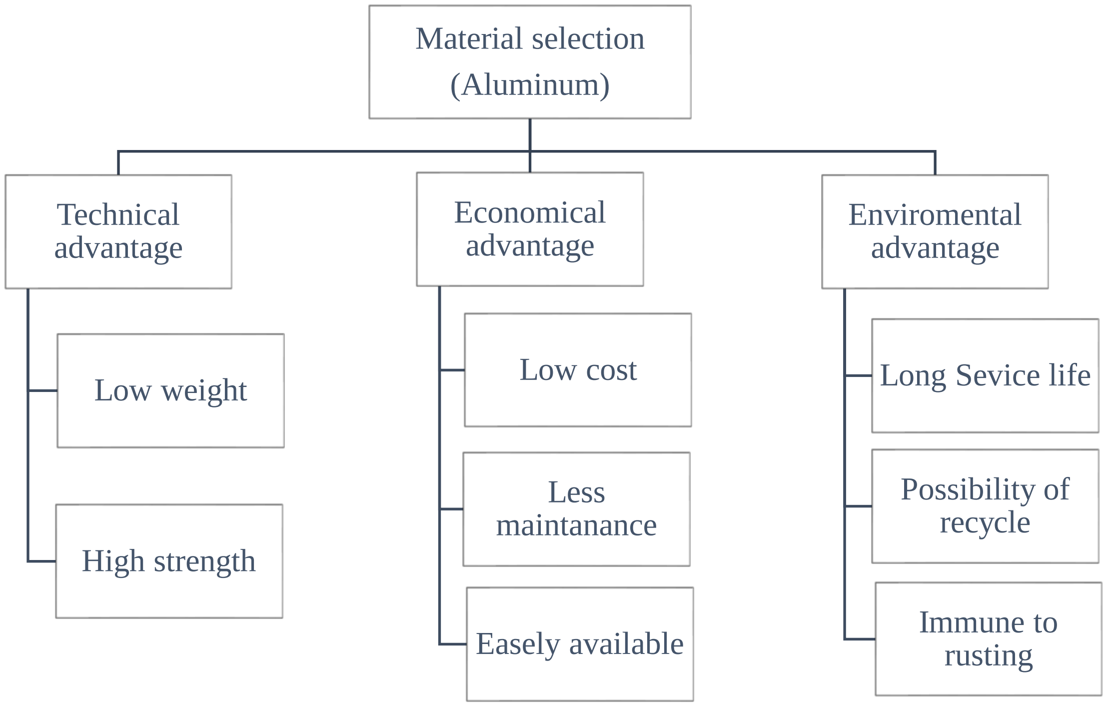

Fig. 4.1. Advantages of aluminum as a structural material

4.2.1. Notch geometry

ASTM standard for bending notch specimen used is E 399-12[3]. Following are the values of material and geometrical parameters:

Modulus of elasticity = 70 GPa

Yield stress = 215 MPa.

Density = 2710 kg/m^3

Length of the specimen (l) = 180 mm

Width of the specimen (w) = 25 mm

Thickness the specimen (d) = 5 mm

As per section 7.2.1 of the ASTM standard, Notch size is defined by the following equation

$$a = (0.45 - 0.55) * d \tag{4.1}$$

Therefore the notch size of the specimen is of range 2.5 - 2.75 mm. Section 7.2.1.1 recommends the standard ratio of notch depth to width of the specimen as

$$a/_{d} = \frac{1}{2} \tag{4.2}$$

From the above equation, we can calculate the notch depth a$= 2.5\ mm$.The standard root angle (γ) of the triangular notch as per section 7.2.2.1 must satisfy the following $\gamma \leq 90^0$. Taking $\gamma = 90^0$ we can define the complete geometry of the notch with a base length of 5 mm.

4.2.2. Sample preparation for FOS based SHM

For static strain testing, an aluminum beam of dimension 180x24x6 mm^3 having young’s modulus as 69 GPa and poison’s ratio as 0.33 is taken as a host material. Notch as per standard is made at 75 mm, 90 mm, and 105 mm from the fixed end of the beam. Four different sets of samples (samples *A*, *B*, *C*, *D*) with different numbers of notches and their locations are prepared. Three samples of each kind are prepared for the repetition of the experiment for standardizing the results. Annealing of all samples was done at 279 Kelvin temperature for 3 hours to remove the residual stresses produced by machining. The aluminium beam was then strapped to a plate onto which a plastic sheet was laid. A layer of silicone oil, which essentially acts as a parting agent, was laid on the plastic sheet in the vicinity of the Aluminium beam. The fiber optic cable was laid on the beam and held at the place where bonding is to be done. The bonding length chosen was 60 mm, and it was done exactly at equal distances from the central line along the width of the beam. A strain gauge was placed by the side of the fiber cable at the center of the beam. The mixture of resin and hardener was poured onto the fiber optic cable slowly to avoid the formation of air bubbles, which would create internal voids upon hardening. After curing for 24 hours in atmospheric temperature, samples for testing were obtained. Different types of cantilever beam samples considered under static strain testing are represented by symbols, as shown in table 4.1. The same sample with fix geometry and material properties is used for analyzing the dynamic strain under dynamic loading.

Table 4.1 Samples and symbols

Types of samples used in the analysis	**Symbols**
Sample without notch	*A*
Sample with a single notch at the center (notch at 90 mm.)	*B*
Sample with the double notch (notch at 75 mm and 105 mm)	*C*
Sample with three-notch (notch at 75 mm, 90 mm, and 105 mm)	*D*

For damage location testing, dimensions of the aluminum beam used in the experiment have the same cross-sectional geometry and length as in case of strain testing. Fiber optic cable is mounted on the surface of the beam samples at the middle centerline. The static load of 30N, 60N and 90N is applied at the free end of the beam. Different samples with notch positions varying from the fixed end with an interval of 15 mm has been selected for testing. To represent the notch location, a non-dimensional parameter (η) has been chosen and defined as follows:

$$\eta = \frac{x}{L} \tag{4.3}$$

Where x is the central location of the V-notch tip, and L is the total length of the beam. The schematic representation of the notch location ratio is shown in fig.4.2. Actual photograph of the notch and sample is shown fig. 4.3 and 4.4.

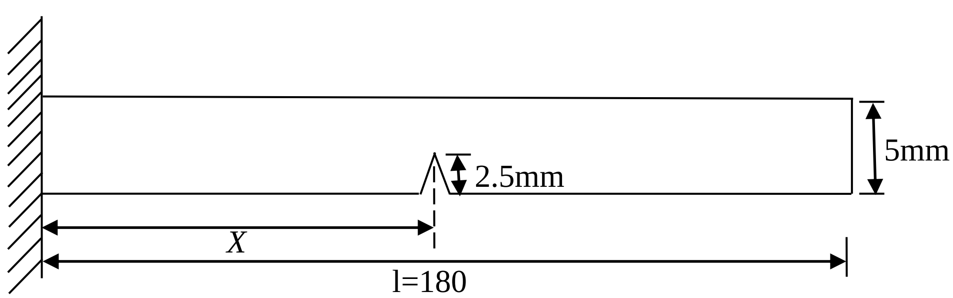

Fig. 4.2. Schematic of sample notch location ratio

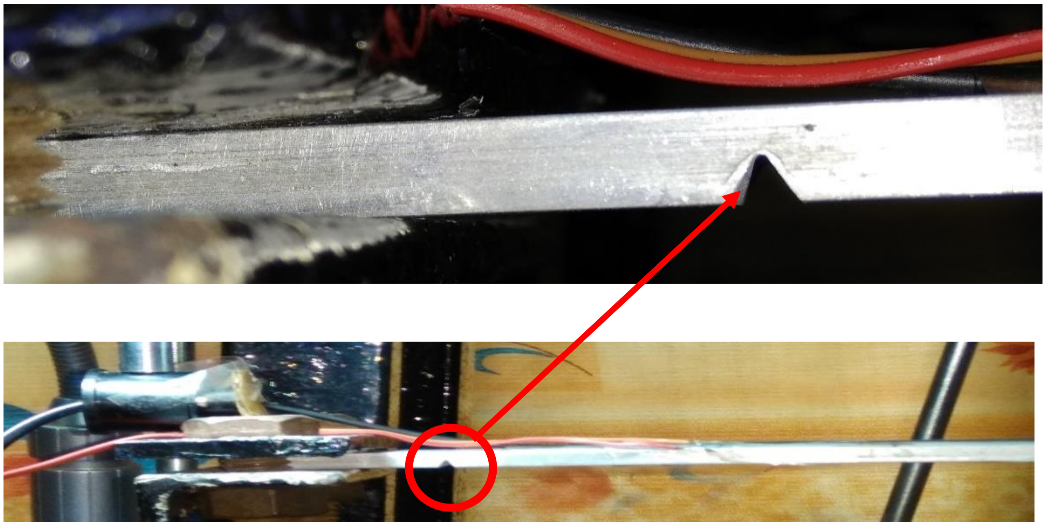

Fig. 4.3. Actual photograph of the sample with a notch

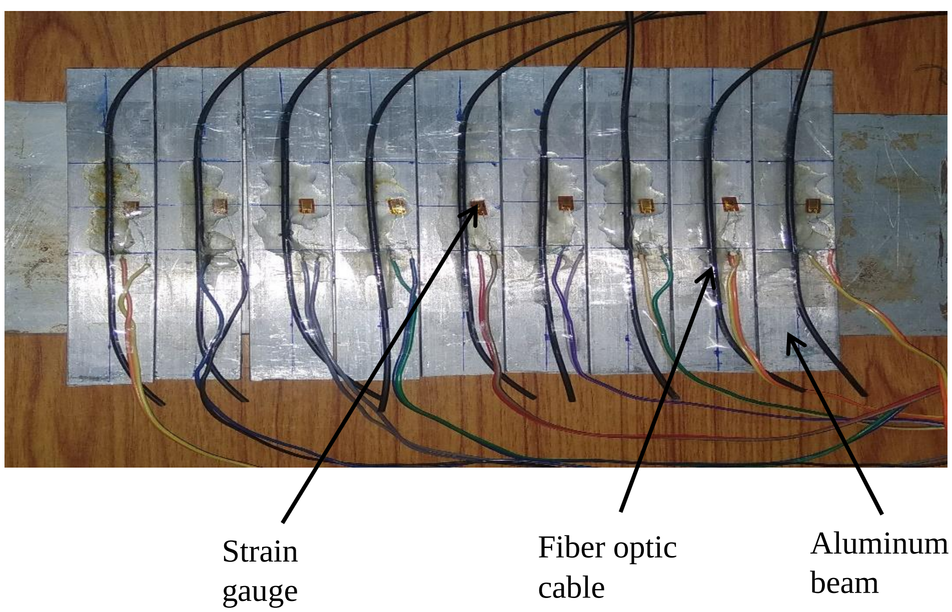

Fig. 4.4. Actual photograph of samples for FOS testing

4.2.3. Diffuse wave-based sample for SHM

The test sample used in this study is a 6063 aluminum alloy plate with dimensions 200x x50x5 mm^3. Four different types of samples are used in experimentation, which includes:

1. A healthy sample.

2. The sample with 20 mm double notches at 90 mm from the fixed end.

3. The sample with 20 mm double notches at 75 mm and 90 mm from the fixed end.

4. The sample with 20 mm double notches at 75 mm, 90 mm, and 105 mm from the fixed end.

Each of the Notches has a depth of 20 mm and a base width of 1 mm. Notches are symmetrically cut at the opposite edges throughout the thickness of the beam. Schematic of the sample used in the experiment is shown in fig. 4.5. Actual photographs of various samples used in the testing are shown in fig. 4.6.

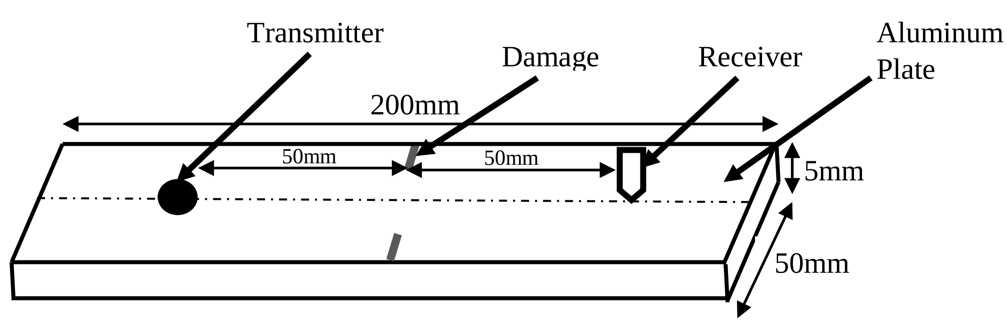

Fig. 4.5 Schematic diagram of the sample used in diffuse wave analysis

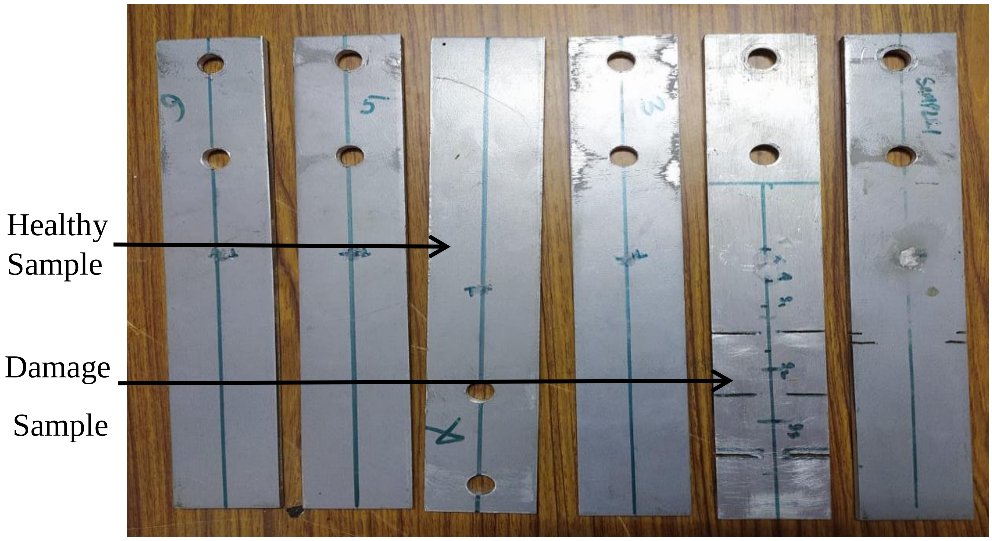

Fig. 4.6. Samples used in diffuse wave based SHM

For the assessment of damage, a ratio of the notch volume and the total volume of the beam has been considered and is defined in equation as follows:

$$V_r = \frac{Volume\ of\ damage\ zone}{Total\ volume\ of\ the\ beam} \tag{4.4}$$

This ratio is used as the target values for analyzing the designed neural network.

4.3. Experimental Equipment’s

Good quality and precise equipment have been procured and used for conducting the experiments. The following are the details of the various equipment.

Gwinstek digital storage oscilloscope GDS-1000B series with an output frequency range of 1 kHz-2000 kHz has been used as a data acquisition system. A Helium-Neon

(He-Ne) laser source has been utilized to provide the fiber optic cable with a necessary laser beam with a specific wavelength of 1556 nm. The iron stand has been used to have a slot for sample fixation. Aluminum samples having strain gauge and optical fiber fixed at center gauge length, as described in section 3.2.2 are used for testing the cantilever beam structure. An optic to electric converter has been used to perform the necessary conversion of the optical signal obtained from the fiber cable into an electrical signal. A fiber optic cable of diameter 2000 micron having a refractive index value 1.45 has been used for the sensing purpose. A strain gauge of 120 ohms has been used for the measurement of strain. Motor with an attached pulley and metallic string along with a speed controller and force sensor was used for force application and static loading. For the dynamic analysis, a small vibrator motor with an unbalanced mass of 2 g, rotating at 1400 rpm has been used. Wooden pan is used for static loading using different weights for obtaining variation in amplitude of vibration. Quarter bridge 1(Wheatstone bridge) with lead and normal resistance as 120 ohms and excitation voltage as 3volts (1.5+1.5 in series) has been used. The major components of the setup are shown in fig. 4.7.

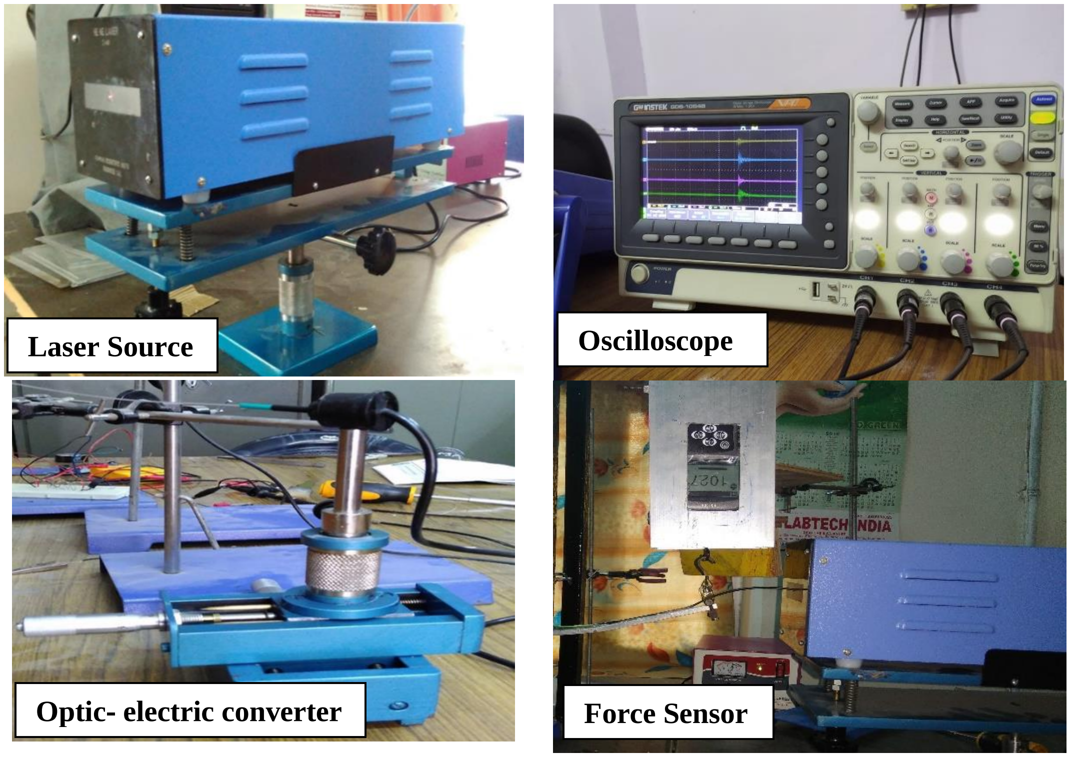

Fig. 4.7. Major equipment's used in FOS based testing

For analyzing the diffuse zone, a cantilever structure made with aluminum has been used as a base sample. The test sample used in this study is a 6063 aluminum alloy plate with dimensions 200x50x5mm^3. A DVMAXACT DX-4003 function generator is used to produce an impulse of 250 kHz central frequency. The signal from the function generator is transferred to a transducer to generate a diffuse field. PZT sensors are used for receiving signal signatures through a coned shape designed sensing tip. This conical tip design increases the sensitivity of the PZT. The basic types of equipment used in the diffuse wave experiment are shown in fig. 4.8.

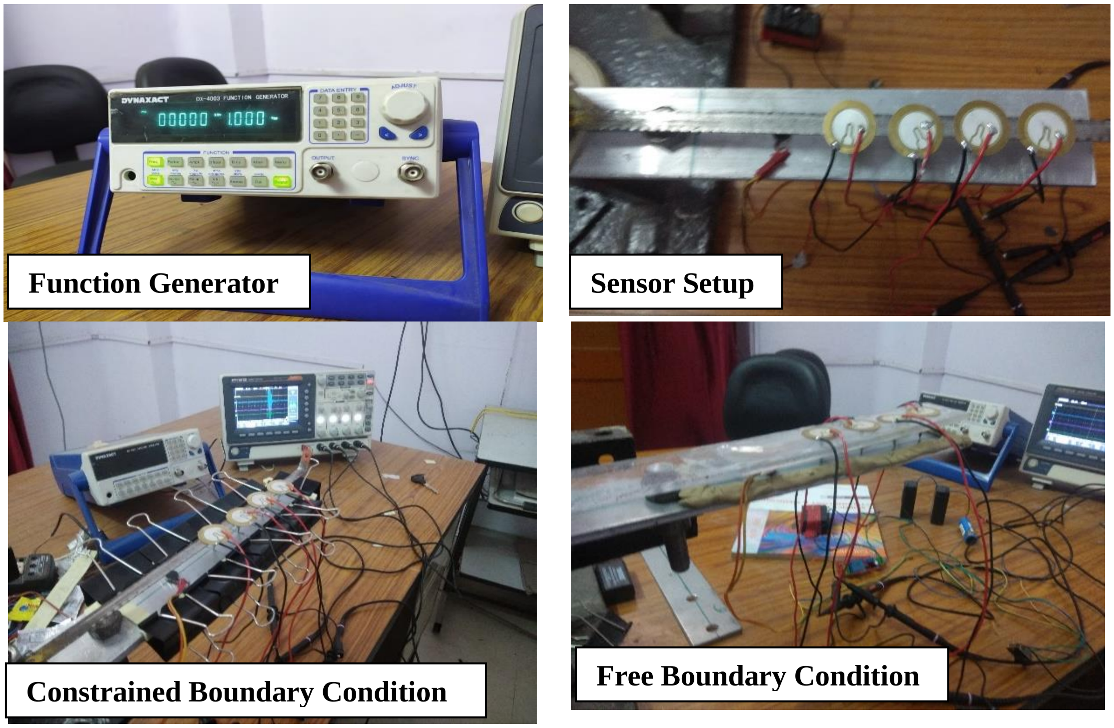

Fig. 4.8. Additional equipment’s used in Diffuse wave based testing

4.4. Setup development and data acquisition

The setup is developed for three testing’s. Initial experimental setup is designed for strain approximation under static and dynamic loading conditions. The same setup has been used for damage location analysis. The complete setup of the related experiments is shown in fig. 4.9.

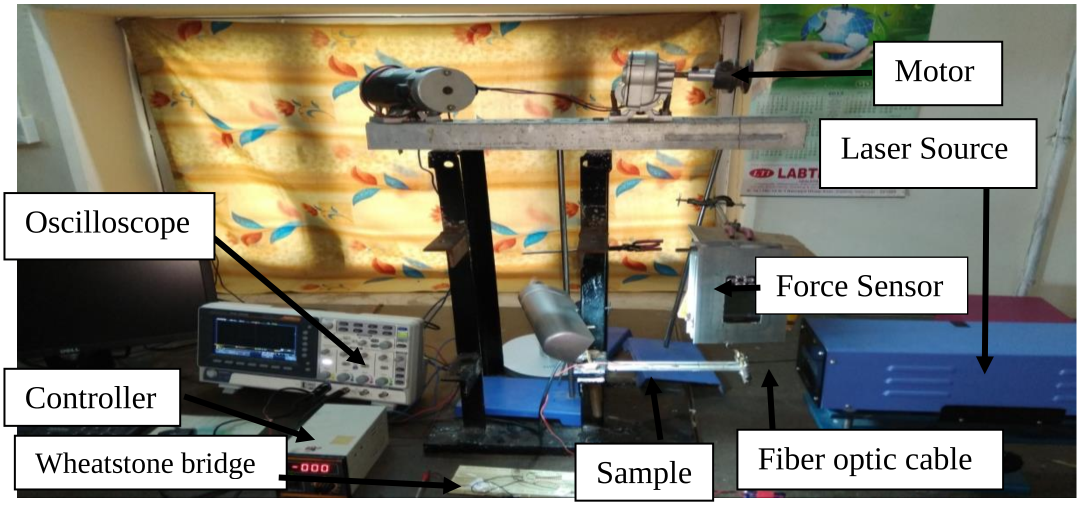

Fig. 4.9. Complete experimental setup for FOS testing

A laser produces an optical signal which travels through the optical fiber to the sensing area where the external impulse can be captured as a small change in the light property. FOS used here for signal generation is of transmission type surface-mounted optical sensor. The change in the signal property is detected by the photoelectric detector, which is further processed into the optic electric converter. The optic-electric converter changes the optical signal into an electrical signal, and the signal gets stored in a digital storage oscilloscope. The signal is saved as voltage versus time curve in the time domain. Fast Fourier transform is applied to the signals to convert time-domain signals into the frequency domain. Different optical parameters like the real part, imaginary part, magnitude, amplitude, and phase, are analyzed using ANOVA (analysis of variance) test. Data points are obtained for each sample under specific static and dynamic loading. Initially, for strain approximation under static loading, two parameters, namely phase change, and intensity change, are used as input for further analysis. Amplitude and the real part of the intensity, are investigated along with phase change under dynamic condition. Further improvement is observed in damage location problem by using phase change, real part, and amplitude as the useful parameter for analyzing damage.

The diffuse wave setup is developed, as shown in fig.4.10. A conventional function generator has been used to produce an impulse. The signal from the function generator is transferred to a transducer to generate a diffuse field. The diffuse wave field is received by a transducer at the receiver end. Initially, the distance of the exciter and receiver is kept 100 mm. The signal from the receiver is passed to a digital storage oscilloscope for analysis. The approximate and detailed coefficients of wavelet transform are obtained, which are used as input parameters for detecting the damage.

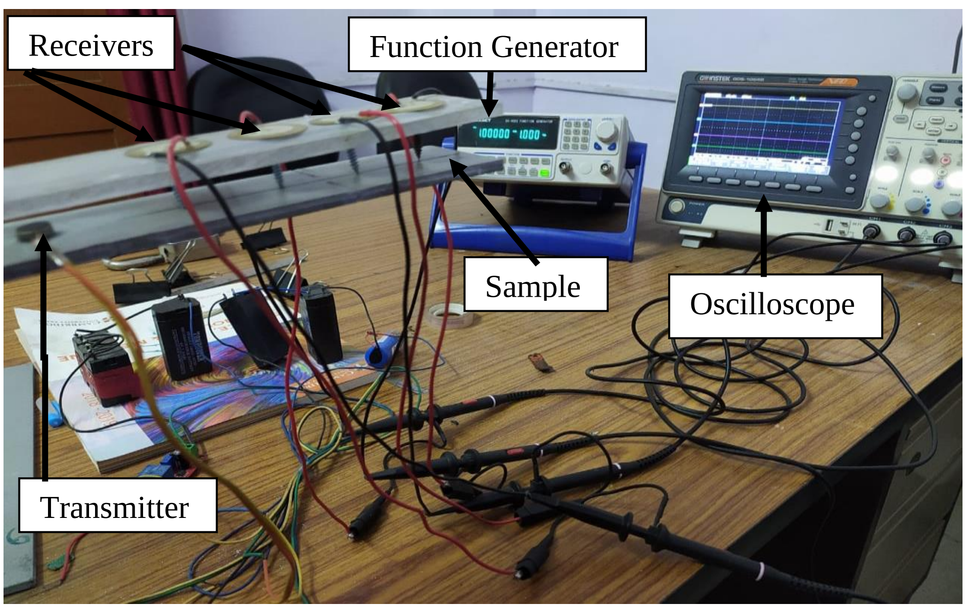

Fig. 4.10. Experimental setup used in diffuse wave analysis