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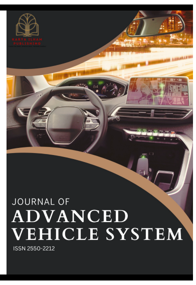

Structural Strain Analysis for Small Boat Using Fibre Bragg Grating

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ABSTRACT

Highly demanding in the fast-growing marine construction industry, increasing revenue and profitability requires advances in technology for cost-effective production in key areas of ship production and ship production management. The absence of information, particularly in the mechanical damage behaviour of marine structures, is addressed by structural health monitoring (SHM), which focuses on providing accurate and real-time information on the state and performance of structures. This research has been focused on Fibre Bragg Grating (FBG) strain gauge has been installed on aluminium boat, with a focus on the first order shear deformation theory. The results, showed the strain value slightly decreased when FBG located at midship area with maximum strain is 563.28 με compare to rear area with 300.60 με. This might be effected due to wave development at front area larger than wave at rear of the boat. Stress occurred in this area is very interesting need to be discovered especially for MRO (Maintenance, Repair and Overhaul) for marine structures activity.

1. Introduction

In the modern age, technological advancements are diverse, driven by the integration of state-of-the-art innovations. These advancements benefit both the public sector and the maritime industry. The shipbuilding and management industry, in particular, needs technical innovations to ensure cost-effective production due to increased demand. As a result, advancements in marine technology, especially in structural health monitoring, have become available. Structural health monitoring (SHM) is an engineering tool that monitors, verifies, and reports on the condition or changes in the condition of a structure, providing engineers with reliable information for management and decision-making [1].

In recent years, SHM has gained widespread recognition and adoption in structural engineering across various countries. The need for SHM has grown due to shorter construction timelines, increased traffic loads, the introduction of high-speed trains, and emerging dynamic and fatigue

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challenges. Additionally, the use of new materials, innovative construction techniques, slender designs, budget constraints, and time-saving imperatives highlight the necessity for enhanced control. In this context, SHM has become a crucial tool for effective management, ensuring quality and safety for users. According to Shashank J. Patil, SHM involves implementing strategies for identifying and characterizing damage in engineering structures [2]. The rapid advancements in sensor technology, data acquisition, communication, signal analysis, and data processing have greatly enhanced SHM. Although SHM often provides reliable data on a structure's current state, its application in actual civil engineering projects is still relatively new. Due to its multidisciplinary nature, there is room for improvement in various aspects of SHM technology. A standard SHM system consists of three fundamental subsystems: diagnostics, damage prognosis (DP), and predictive maintenance (PM) [3].

One of the three fundamental equivalent single layer (ESL) theories is the first-order shear deformation theory (FSDT), introduced by Reissner and Mindlin. FSDT accounts for shear deformation through the thickness by using a linear variation of in-plane displacement. However, because FSDT does not satisfy equilibrium conditions on the plate's top and bottom surfaces, a shear correction factor is required to reconcile the difference between the actual stress state and the assumed constant stress state. While FSDT is widely applicable, it can present significant issues in relatively thick laminates or in sandwich structures with low transverse shear modulus cores [4]. In FSDT, omitting the third part of Kirchhoff's hypothesis means the transverse normal is no longer perpendicular to the mid-surface after deformation [5]. This study primarily examines the stress distribution under various forces applied to the boat model, with the results being crucial for understanding stress patterns in the structure.

2. Methodology

First of all, the aluminum boat need to be prepared and ready to installed the FBG sensor stick on the boat body. Next, the aluminum boat need to test at water condition such as sea and lake to investigate the strain develop during sea trial. The aluminum boat has been purchased from the Boat yard Malaysia. The boat model is N330, specifically sample boats, each with specified dimensions as indicated in Table 1. Refer to Figure 1 for detail over view Kimple Aluminum Boat have been used in this study. The capacity of this boat can carry maximum 3 passengers with total weight less than 100kg. The aluminum plate thickness is bottom plate (1.4mm), side plate (1.4mm) and transom plate (2.0mm).

Table 1
The Aluminium Model Boat Dimension

Dimension	Size (m)
Length	3.30
Beam	1.16
Max. Depth	0.42
Transom Height	0.38
Weight	47kg

Fig. 1. Kimple Aluminium Boat Over View

The aluminum boat material used in the study is aluminum alloy marine grade H5052. Fabricated in China and imported by Boatyard Malaysia. The type of heavy duty FBG strain gauge purchased from China showed in Figure 2 for details.

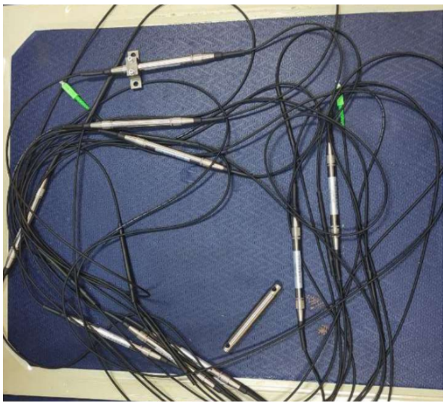

Fig. 2. The FBG Strain gauge over view

This FBG strain gauge has encapsulated with the SUS material for each unit and covered with heavy duty rubber sheet and cable. The specification and product information of FBG unit shows in Table 2 representative for all 9 units. Each unit have the series number printed at top of the body.

The calculation for strain is based on the standard value from the manufacturing FBG unit provided by the company. The formula has been defined by manufacturer shown in Eq. (1) for details.

$$Y = mX + C \tag{1}$$

where Y is current measurement wavelength of the strain grating, is strain value (need to determine from each FBG unit) and is central wave length (CW) from manufacturer.

Table 2
The Aluminium Model Boat Dimension

Strain Gauge	Series Number	Specification
1	230205-01	1540
2	230205-02	1542
3	230205-03	1544
4	230205-04	1546
5	230205-05	1540
6	230205-06	1542
7	230205-07	1552
8	230205-08	1554
9	230205-09	1556

The implementation of the FBG sensor is based on the length of the aluminium boat and the sensor itself. The location each of the FBG point has been allocated, and the arrangement is made to ensure the FBG sensor can be mounted on the boat's surface. Refer to the Figure 3 below for the detailed arrangement of the FBG sensor. Most of the FBG unit installed at front area are closed to the higher wave area if compared with the middle area and rear area. The FBG unit has been pasted with the heavy duty cellophane tape insulated with aluminium thin layer and water proof sheet.

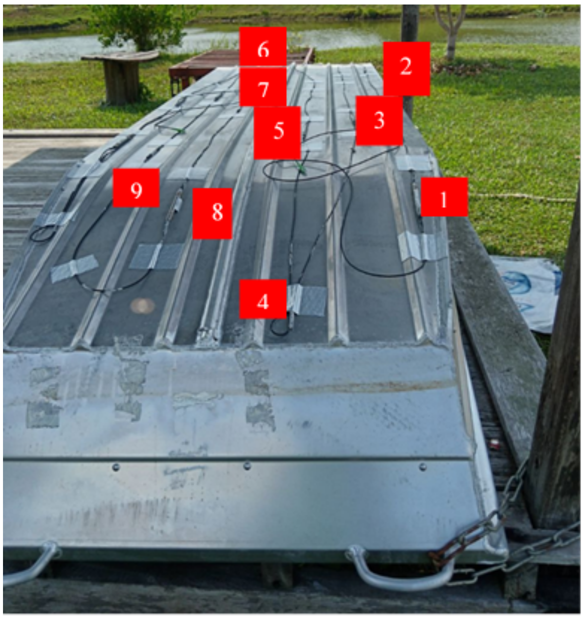

Fig. 3. FBG Sensor Arrangement

3. Results and Discussion

The results showed that it has significant impact for location of installation FBG strain gauge determined the area with higher stress will be increased if more loading impact. The details refer to Table 3. The minimum value for strain can be detected at FBG unit no. 8 where only 300.60 με with initial wavelength is 1553.87 nm. While the highest strain occurred at FBG unit no. 7 with 369.28 με. This effect also considered the longitudinal moment acting at mid-ship of hull increased the strain value. Another cause of this higher strain value due to the passenger load sat in this area. These loads are due to two main causes: the combination of on-board weights and buoyancy forces on one hand and wave effects on the other hand [6]. The FBG unit were positioned considering where the maximum strains due to every considered load are expected from beam theory. When considering beam theory, the best strain response from bending moment is located as far from the neutral axis as possible and parallel to the beam between FBG unit no. 2,3, 5 & 7 might be impactful in this case.

Table 3
The Strain Results

Strain Gauge	Strain (με)	Central Wavelength (nm)
1	539.76	1539.431
2	563.86	1541.491
3	539.16	1543.534
4	530.12	1545.613
5	553.61	1547.459
6	331.33	1549.886
7	369.28	1551.870
8	300.60	1553.835
9	309.64	1556.336

The strain gauge for all FBG unit has been analysed and shows in Figure 4 for the detail value. The FBG unit no. 1, 2, 3, 4 & 5 showed the strain value has higher impact compare to the strain FBG unit no. 6, 7, 8 & 9. Horizontal loading or vertical loading also impact at these areas between 1 – 5. Similar results also have been detected when FBG strain gauge unit installed at vertical specimen when perform the tensile testing at UTM (Universal Testing Machine). The variable loading input command is reflected in the load cell readings [7].

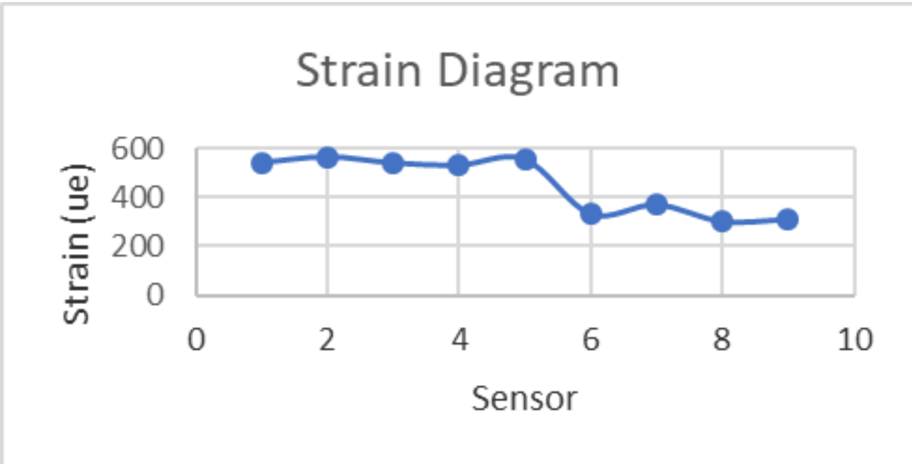

Fig. 4. FBG Strain Gauge value

In particular, the changes in the acquired sensor data. This is said to be so because, at the beginning the value for the sensor without any movement or applied force is low while when the sensor is applied with force or movement there is an increase in the strain value. This observation indicates that, as the strength rating for a boat model increases, its ability to withstand stress before breaking decreases. Furthermore, it can be concluded that increasing the force rate improves the mechanical quality of the model in terms of displacement. However, subjecting the model to high forces weakens its mechanical properties in terms of stress and strain. Consequently, stress and displacement play an important role in determining mechanical properties. Material selection also affects stress and displacement, as derived from this data. In this investigation, aluminum was used.

When the maximum force is applied, the highest strain value is on sensor 2 which produces a value of 563.86 µε and for the lowest value is on the 8th sensor which is 300.60 µε.

4. Conclusions

In conclusion, this paper aims at demonstrating the suitability of FBG strain gauge unit to measure the stress performance for marine applications on aluminium boat. It has significant effected that those FBG unit at specific location might be effected to increased loading strain value. The strain at front area of the boat has impact from accumulated wave and rear area with heavy loading can also be increased with the strain value drastically affected.

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