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Modulus of Elasticity and Tensile Strength for Laminated Zinc Composite Plate

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Abstract

The concept behind preparing the laminated zinc composite plate is based on the principles of Metal Matrix Composites (MMC) and utilizes recycled zinc sourced from construction sites. The objective of this study is to fabricate a composite plate with a target modulus of 10 GPa, ensuring superior stiffness and load-bearing capabilities. The composite plate is constrained to a maximum thickness of 2 mm. The composite plate design involves a single type of material zinc sheets arranged in multiple layers and bonded using epoxy adhesive glue. A total of seven (7) zinc sheet layers were combined. The epoxy adhesive consists of two components, resin and hardener, mixed in a 1:1 ratio. This combination forms a strong bond between the zinc sheets, enabling the composite plate to withstand high pressure without delamination. Previous studies have reported that zinc plates exhibit excellent mechanical properties, including ultimate strength (120 MPa), compressive strength (110 MPa), tensile strength (120 MPa), and flexural strength (100–150 MPa). Tensile tests conducted in the laboratory yielded maximum stress values of 348 MPa, 320 MPa, and 250 MPa for three different zinc composite plates. In conclusion, after thorough analysis and calculations, the average modulus of elasticity for the zinc sheet composite was determined to be 14.3 GPa, exceeding the initial design target of 10 GPa.

1. Introduction

Definition of composite material is combination of two or more materials to produce high mechanical properties (1-2) such as strength, young modulus, toughness and thermal stability (1-3). Commonly, it can be formed in laminated composites which are originally from typical sheet of layers from difference materials or matrix. Their collection of laminate was stacked together with certain thickness and sometimes arranged in the same or different directions either in flat or curved surfaces [3]. The layer was separated by matrix components such as epoxy resin which is the type used in this present study. The selection of epoxy resin is based on their ability to bond with materials such as glass, wood and ceramics [2, 4].

Generally, composite material is broadly found in automative and aerospace application due to their weight and cost reduction [5-6]. Meanwhile, the application of composite materials in civil engineering is in reinforced material which are classified as matrix part; namely, polymer, metal, ceramic and carbon as well as other application such as fibrous composite [7-10]. The potential of using composite allows the design of lightweight structures. Previously, the materials used as composite is natural fibers, engineered bamboo, fiberglass, wood and mud bricks.

Limited study found in using metal as composite material in civil engineering specifically zinc laminated plate [11]. There are several types of metals suitable to be used in the field of biodegradable metal materials. The selection of zinc plate is recommended due to their mechanical properties of zinc are relatively high. The modulus of elasticity for zinc is generally not stated in an exact or fixed value, as there is no region of strict proportionality in the compressive stress-strain curve. Typical values for the modulus compressive of elasticity for zinc are between 70-140 GPa, which is considered high [12]. Furthermore, the tensile strength of wrought zinc gives a value of about 120-150MPa, according to the rolling direction. However, the tensile strength shown on a cast pure zinc is quite low, with the value of around 25 MPa [13]. While, [14] found that hot extrusion of pure zinc material (300 °C, extrusion ratio 10:1, 2 mm/min) could result in the ultimate tensile strength of up to 100 MPa.

The purpose of using this material is due to its toughness, high strength-to-weight ratio, high stiffness, low thermal expansion compared to other metals and good corrosion resistance [15]. Subsequently, high tensile strength and less budget are also among the reasons of this material selection. The technique used in assembling the zinc plate, hardener and epoxy resin is hand lay-up. The advantage of using this technique is less expensive [16-17]. The combination of hardener and epoxy resin can produce strong bond to bind the zinc plate securely and allowed them to withstand high pressure without delamination. Hence, the appropriate lamination scheme and material properties of individual lamina can provide additional flexibility to the designer to tackle the stiffness and strength performed by the laminate so that it meets the requirement of structural stiffness and strength. Therefore, tensile strength was determined with the relationship of stress and strain for laminated zinc plate.

2. Materials and Methods

This section describes the process performed in determining the Young's Modulus and tensile strength of laminated zinc plate. The preparation of zinc plate and epoxy adhesive is discussed followed by mechanical testing conducted as shown in **Fig. 1**.

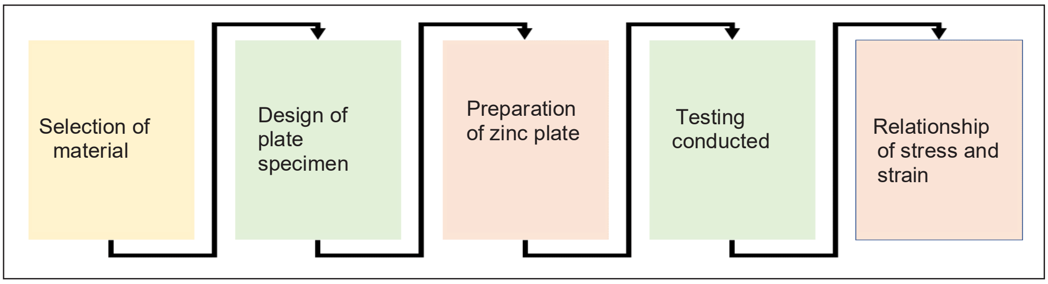


Fig. 1 *Process conducted in preparing the zinc plate*

2.1 Design of Plate Specimens

The number of layers made of zinc sheet prepared are seven, which are stacked horizontally with each sheet's thickness fixed at 0.23mm. Increases in thickness after using the binding material was also considered. Plate was designed with 15 mm long and 2 cm width as illustrated in **Fig. 2**.

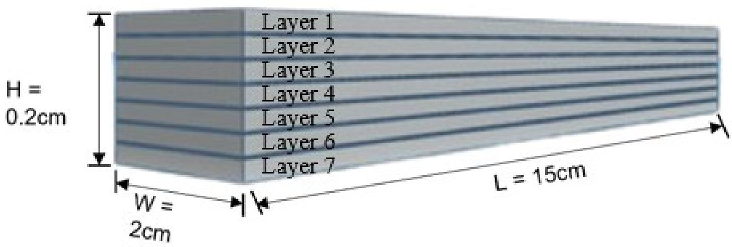


Fig. 2 *Diagram of zinc plate*

2.2 Preparation of Zinc Plate

All the required materials and tools, the epoxy glue and zinc sheets for the project were purchased from the online shopping platform known as Shopee. The scissors and plastic adhesive brushes were prepared in assembling the zinc plate. The selected epoxy glue with brand X-Traseal (**Fig. 3(a)**) helps chemically bond materials and able to withstand high temperature and pressure.

Meanwhile, the surface of the zinc sheet was cleaned of dirt and grease with a soft cloth to ensure optimal adhesion of the epoxy adhesive. To ensure the precision and consistency of the dimensions of each zinc piece, the zinc sheet was measured and labelled with a ruler and marker as shown in **Fig. 3(b)**. Each piece was to be of uniform size and exactly 15 cm long and 2 cm wide. The zinc sheet was then cut into seven pieces using scissor.

(a) **(b)**

Fig. 3 *Materials used in preparing the zinc sheet (a) Epoxy glue; (b) Labelled zinc sheet*

To prepare the epoxy adhesive, the hardener and epoxy were thoroughly mixed, maintaining a 1:1 ratio. This ensured proper curing and adhesive properties of the adhesive. The mixing process between hardener and resin was performed on the plate using plastic adhesive brushes, with the plate serving as a surface to create a controlled environment. In the layering technique as shown in **Fig. 4(a)**, a thin and uniform layer of epoxy resin was applied to the prepared zinc sheet surface. Each subsequent piece of zinc was strategically placed, resulting in the formation of a sandwich-like structure as can be seen in **Fig. 4(b)**. This sequential process was repeated to achieve the desired thickness of 2mm, with 7 layers of zinc pieces firmly bonded together to form a zinc plate. To ensure the integrity of the bonding process, each layer was manually pressurized (**Fig. 4(c)**) after the bonding process was completed to remove trapped air bubbles and improve the overall adhesion between the zinc pieces. The edges were aligned carefully to ensure a neat and uniform appearance. These same procedures are repeated to design three specimens of zinc plate.

(a) **(b)** **(c)**

Fig. 4 *The process of preparing the zinc plates began with (a) applying the epoxy resin to the zinc surface; (b) gluing more pieces of zinc to the epoxy resin surface; and (c) final plate*

2.3 Testing of Mechanical Property

The zinc specimen plates were tested subjected to tensile testing in the Light Structure laboratory to evaluate their tensile strength. This test allows accurate measurements of the tensile strength, yield strength and elongation of the zinc sample plates, providing valuable insight into their mechanical properties. To perform the test, each zinc specimen plate was clamped securely between the upper and lower grips of the Universal Testing Machine (UTM Instron). The clamps were tightened by turning the steering wheels to ensure a firm and stable grip on the specimens as displayed in **Fig. 5**.

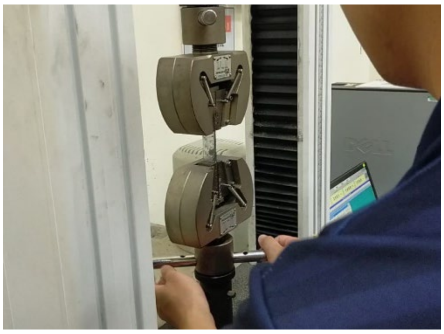


Fig. 5 *The clamps were tightened by turning the steering wheels to ensure a firm and stable grip on the specimens*

During the test, the real-time analysis of the behaviour and mechanical properties of the specimen was continuously recorded and updated on the computer. This allowed immediate observation and recording of all relevant data until the point of failure or breakage was reached. The entire procedure, including clamping and testing, were repeated for a total of three zinc specimens to ensure consistency and reliability of results. Detailed visual documentation of the failed zinc samples was created by capturing high-resolution images to accurately identify and determine the specific type and location of failure in each sample. These visual records serve as a valuable reference for the next in-depth analysis in this report.

3. Results and Discussions

This section analyse the tensile strength obtained and modulus of elasticity of laminated zinc plate.

3.1 Pattern of Plate Failure

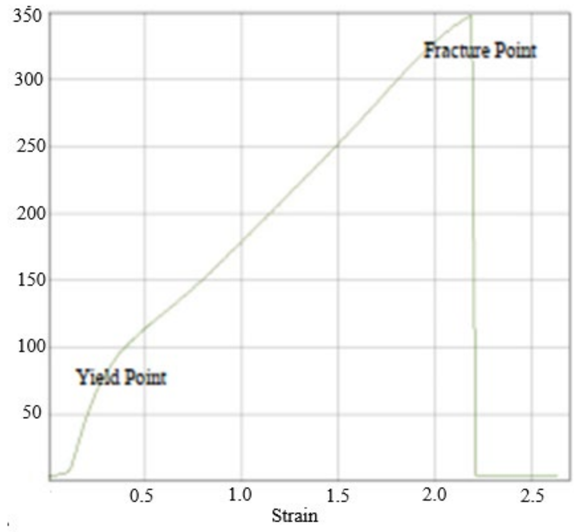
Fig. 6 shows similar pattern of the tensile test failure occurrence which was fractured in the middle regions of the specimens without affecting the positions of grip.

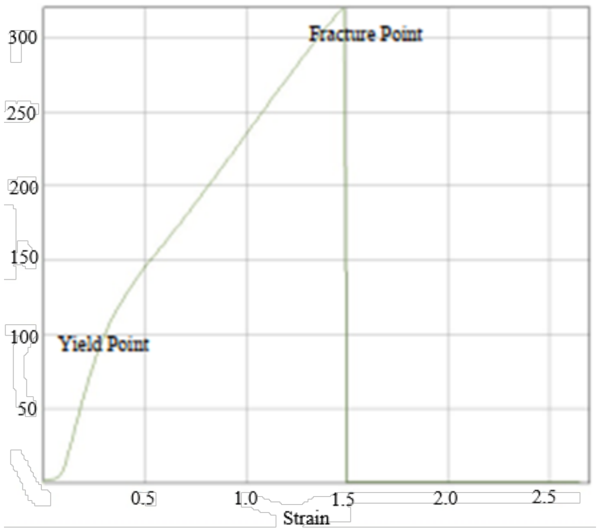
(a) **(b)** **(c)**

Fig. 6 *Tensile test failure of (a) Sample 1; (b) sample 2; and (c) sample 3*

3.2 Stress-Strain Relationship

In the tensile tests, the mechanical properties of zinc plates including maximum tensile failure stress and stiffness are exhibited in the form of stress-strain curves. **Fig. 7** shows that the stress-strain curves for the laminated samples are bi-linear up to the ultimate stress until the fracture point. From the findings, it has been presented that the material property based on the slope of stress and strain curve when subjected to increasing loads. **Fig. 7(a)**, the change of slope location point took place at a strain level around 0.7% which corresponds to 75-90MPa until the ultimate strength of 348MPa. While, **Fig. 7(b)** undergone the transition of stress-strain curve from first linear to second linear behavior at 0.4% of strain level to 105-115MPa until the ultimate strength of 320MPa.





(a) **(b)**

Fig. 7 *Stress-strain curves of (a) Sample 1; and (b) Sample 2*

Fig. 8 shows the change of slope at a strain level around 0.3% which approximately reached 100 MPa to ultimate strength of 250 MPa. Based on the result, it is shown that the laminated zinc plate possesses a high ultimate strength, however the brittleness remains as it ruptures instantaneously without significant deformation under the increasing stress over strain.

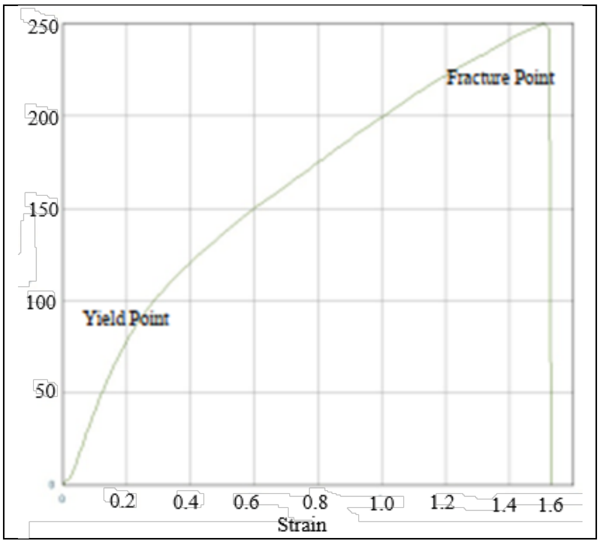


Fig. 8 *Stress-strain curves of sample 3*

3.3 Modulus of Elasticity

Modulus of elasticity, also known as young's modulus, is analysed and discussed based on the stress-strain relationships from the test to measure the stiffness of zinc based composite plate. It illustrates that the ratio of stress to strain within its elastic limit by finding the gradient slope of linear elastic region. The slopes of curve indicating the young's modulus (E) of the samples during the elastic deformation in the form of stress versus strain graphs. According to the slopes, the modulus of elasticity can be directly calculated by using the formula which is stress over strain (σ/ε).

From the stress-strain relationship, Sample 2 has attained the highest modulus of elasticity which is 17.78 GPa as shown in **Eqn. 2** whereas the modulus of sample 3 is calculated as 12.57 GPa (**Eqn. 3**) which is the lowest value among the samples. For sample 1, it has exhibited an average modulus, 14.3 GPa according to the **Eqn. 1**. The result has proven that sample 3 possesses the lowest modulus of elasticity, experiencing a large amount of strain for a given stress compared to other two samples. According to the strength analysis, it shows the maximum tensile strength and modulus of elasticity for all samples. The result from the tensile test has shown that sample 2 contains excellent potential in term of its mechanical properties especially a high maximum tensile stress (348 MPa) but an average modulus of elasticity (14.3 GPa) or stiffness, making it advantageous in various industry and engineering applications. It provides evidence that the combined effect of zinc-based plates and epoxy glue is beneficial in enhancing the overall properties of composite plate in accordance with the tensile test results.

$$E_1 = \frac{(252.29 - 180.658) \times 10^6}{\frac{1.5}{100} - \frac{1.0}{100}} = 14.3\text{GPa} \quad (1)$$

$$E_2 = \frac{(234.21 - 145.29) \times 10^6}{\frac{1.0}{100} - \frac{0.5}{100}} = 17.78\text{GPa} \quad (2)$$

$$E_3 = \frac{(200.85 - 150.58) \times 10^6}{\frac{1}{100} - \frac{0.6}{100}} = 12.57\text{GPa} \quad (3)$$

3.4 Tensile Strength

Tensile test is used as a mechanical test to measure the behavior of samples especially strength and elasticity under uniaxial tensile force. The detailed results on the physical and mechanical properties of samples according to the tensile tests were shown in **Table 1** as the specimens were applied with a gradually increasing force causing deformations. Tensile strength represents the maximum stress of the samples can withstand before rupture is crucially discussed in order to evaluate its performance in various industry and engineering applications. It can be obtained by dividing the maximum load and thickness multiply with their width.

Table 1 *Result of tensile test*

Sample No.	Maximum Load Point	Maximum Load (kN)	Maximum Extension Point	Maximum Extension (mm)	Stress, σ (MPa)	Strain, ε (%)	Tensile Strength (MPa)
1	307	13.91	340	3.96	348	2.20	347.75
2	258	12.78	343	3.98	320	1.50	249.5
3	196	9.98	199	2.30	250	1.53	319.5

Based on the results calculated, it is shown that the level of maximum tensile strength achieved by the samples is in the range of 250 MPa to 348 MPa. The first sample has achieved the highest maximum tension stress which is 348 MPa as compared to the other samples attained the lowest maximum tension stress which is only 250 MPa. An average maximum tensile strength, 320 MPa. The capacity of the tensile test result shows that the first sample has withstood the maximum load which is 13.91kN with the maximum strain, 2.20%. Sample 3 has the minimum load which is 9.98kN with the 1.53% strain while sample 2 has shown the average maximum load, 12.78 kN and 1.50% strain. This indicates that the zinc material in the form of laminated zinc based composite plate provided a high overall tensile strength until reaching 348 MPa over increasing applied loads. However, the tensile property varies between these samples, showing the inconsistency in the mechanical properties of the zinc-based plates. The variation can be clearly observed between the third sample and the other samples due to several factors such as material inhomogeneity, sample preparation and testing conditions.

4. Conclusions

The goal of this study on zinc metal matrix composites (MMC) was to improve the mechanical characteristics and performance of zinc-based materials for crucial structural applications. Several important advantages were obtained by using zinc sheet as the main material and epoxy adhesive glue as a binding agent. Therefore, the combination of the materials produces a material with qualities unique to the individual components. The composite plate's ingredients include a binder and matrix substance making a strong bond that can be formed between the zinc sheets by combining glue and hardener, allowing them to bear high pressure without delamination. Guarantee effective adhesion of the epoxy adhesive, the surface of the zinc sheet was cleansed of dirt and grease with a soft cloth. The first specimen has the highest maximum tension stress of 348 MPa, while the third sample has the lowest maximum tension stress of just 250 MPa. In the stress-strain relationship, sample 2 has the maximum modulus of elasticity of 17.78 GPa, while sample 3 has the lowest modulus of elasticity of 12.57 GPa. Lastly, the average modulus of elasticity for this zinc sheet combination is 14.3 GPa. This project's successful creation of zinc metal matrix composites offers up new avenues for the use of zinc-based materials into important structural applications. It can fulfill the growing demands of critical structural applications and pave the road for more efficient and dependable structures in numerous industries by continuing to improve the mechanical characteristics and performance of zinc-based materials.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception, design, manuscript preparation:*** *Noorli I.;* ***data collection, analysis and results interpretation:*** *Chong H.Y, Nur Najlah N.D.D, Rivahshini S., Tan K.L and Yeoh Z.H. All authors reviewed the results and approved the final version of the manuscript.*

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