Failure model for bioactive degradable composite

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Abstract. This paper presents the failure model for bioactive degradable composite due to degradation in saline solution using static structural. The composite material is chosen as the material for analysis. Composite has specified into polylactide acid (PLA) that have pointed to two different kinds of temperatures of 140°C and 150°C. Then, each one of the materials given different percentage UTS where it is divided into three classes with 2%, 50%, and 75%. Each class is imposed six forces 500N, 600N, 700N, 800N, 900N, and 1000N. The objective is to determine the durability of the materials and how long it can be used. Furthermore, the purpose of this project is to analyses the factor of safety of using Static Structural. Therefore, all data and information related to this project have been sought and recorded in the literature review. Simulation and analysis applied in this project are using ANSYS software. SolidWorks software is used as a CAD software to construct three-dimensional models for the design of the specimen. Static Structural used to simulate the structure of the material changes when a load is applied. Static Structural analysis has been carried out on both types of material and results are calculated based on three parameters such as the life cycles, damage, the factor of safety and buckling. Another goal of this project is to design a model for composite failure analysis. Referring to the results obtained from the analysis, the best composite materials selected to make some comparisons with regard to the material safety factor.

Keywords: Failure, static, bioactive, degradable, composite

1. Introduction

Failure mode and effects analysis (FMEA) is designated as a methodical technique to recognise the failure style of the structure, issue or task, and to measure the result of the failure mode at an advanced level. The objective of FMEA is to define the details for failure style and to remove or decrease the chance of failure. By using the bottom-up practices, such as FMEA, it is an operative technique to classify the faulty module or system failure, and credentials of the system under deliberation [1].

Several studies in Failure mode and effect analysis have been conducted in presenting the framework and methods recently. Another study of multi-criteria decision-making method is offered by Bian et al., 2018. The authors determined the preference rank of failure modes with reverence to hazard [2], a new systematic human error reduction and prediction approach (SHERPA). Is proposed to address human error and detecting failures [3].
The design of composite is restricted by the calculation competences of several enlightened destruction and failure analysis methods. In command to apply the complete possible of these approaches, a dissimilarity among destruction and failure must be recognised. Failure designates a universal adversity, such as macroscopic cracking; consequently, it is an occasion that principals to great variations in the material properties at the unsuccessful material point. Damage primes to a slow decrease in carrying weight ability. In maximum occurrences, damage spreads a serious state and develops unbalanced subsequent in failure. Conversely, these instruments requisite to be preserved distinctly. The reaction of a carbon fibre laminated composite construction can be further precisely categorised by allowing for equally advanced damage and failure [4].

In an engineering industry to produce the material structure the material should be exposed to load. It is important to know the material is strong enough to endure the load. Each type of material has different mechanical properties. Therefore, to identify the mechanical properties the material should be given a test. Mechanical testing is important in engineering to make a new material and also to control the mechanical properties for use in design and manufacturing. Many types of mechanical testing that have been used in engineering such as Tensile Test, Compression Testing, Hardness (Rockwell, Knoop, Vickers, and Brinell), Micro hardness Testing, Impact Testing and Bend Testing. In this project, tensile test or quasi-static tests were chosen. However, to implement the test can obtain several advantages and disadvantages. The advantages are can gain more accurate data. The disadvantages when using the mechanical test such as can increase the material cost, time-consuming and can cause waste. Therefore, the applications of FE software are introduced to the industries.

Failure analysis is an industrial method to control the failure of an equipment or a constituent. Approximately, the universal reasons for failure are mechanical stacking, wear, rust, and hidden defects. The aim of a failure study is to comprehend the source cause of the failure to avoid related failures in the forthcoming. Collective reasons of failure are counting manufacturing defects, design faults, inappropriate material, unsuitable heat treatments, and casting discontinuities. ABAQUS, ANSYS, and MSC Nastran are the main finite element software that have composite modelling competences. In addition, this software capable to user to construct and analyse composite materials. The features investigated in these programs such as progressive damage and failure, ability to have ply-level nonlinearity in the principal and shear directions, progressive ply failure capabilities, provision for an extensive variation of failure standards, and an effective method of imagining this data. This research studies the design and analysis of the progressive damage and failures model which shows how the tensile test is applied to the specimen until failure. This computer-based simulation is used to simulate the fracture of the specimen week by week with the material selected. The result of this simulation is essential to predict the fatigue life of degradable composite without conducting the experiments.

2. Materials and Methods
In this stage, the material used is Polylactic acid (PLA), a degradable polymer is normally used in biomaterials applications. Calcium phosphate, used as the filler is a bioactive material and also extensively applied to stimulate bone formation. In this study, the materials are in form of three phase composite initially established by Kellomaki [5] and improved by Bleach et al. [6]. The composite contains of drawn PLA fibres in a PLA-calcium phosphate composite matrix.

The matrix polymer was polylactide (PLA70) (Purac Biochem, Holland), in form of fine white granules with inherent viscosity of 6.1 dl. It has L:D L ratio of 70:30 that is 70% PLLA and 30% a racemic mixture of PLLA and PDLA. Polylactide fibres with an L:D ratio of 96:4 of 96% PLLA and 4% PDLA, (PLA96) with an average diameter of 27 m bundled together in 30 filaments was used as the reinforcing phase. The fibers were supplied by Degradable Solution, Switzerland with individual fiber strength of 5.6N. The reported density of PLA is 1.26Mgm⁻³.

Degradation studies and fatigue testing were carried out in saline solution at 37°C. Phosphate buffered saline (sigma-Aldrich Company Ltd, Dorset, UK) in tablet form was dissolved in distilled water to produce a degradation solution with pH range of 7.20 - 7.60. Figure 1 shows the ASTM standard for material E466. Table 1 shows the standard dimension of ASTM standard E466 in this study.
Table 1. Standard dimension of ASTM standard E466

| Symbol | Description          | Dimension (mm) |
|--------|----------------------|----------------|
| L      | Gauge length         | 13             |
| D      | Gauge diameter       | 35             |
| LG     | Grip length          | 35.5           |
| G      | Grip diameter        | 7              |
| R      | Radius of curvature  | 28             |
| TL     | Total length         | 100            |

In this project, the ASTM standard E466 were designed using CAD software (SolidWorks). The design of the specimen should be such that failure occurs in the test section. The acceptable ratio of the areas to ensure a test section failure is dependent on the specimen gripping method is designed using SolidWorks software. Figure 2 shows the solid modelling for ASTM standard E466.

There have several similarities between the material composite and specimen design. Even though, the material specimens are same there are molded at different temperature and different percentage of the ultimate tensile strength. The ultimate tensile strength was divided into three parts with 25%, 50%, and 75%. As listed in Table 2 despite the differences in the ultimate tensile strength for the two different material temperatures molded. Other than that, the specimens were tested by applying the pressure with six different force for each material and ultimate tensile strength. The different pressures exerted on
this experimental is to determine the maximum load factor of safety. Furthermore, the value of buckling can be identified after getting the fatigue value.

### Table 2. The stress level of PLA composite with different moulding temperatures

| Material        | %UTS 25% (MPa) | %UTS 50% (MPa) | %UTS 75% (MPa) 
|-----------------|----------------|----------------|----------------|
| 140°C (T140)   | 25.15          | 50.30          | 75.46          |
| 150°C (T150)   | 39.94          | 69.88          | 104.82         |

### 3. RESULTS AND DISCUSSIONS

In this section, the simulation results shows the contrast of temperature distribution and total heat flux in the transient thermal analysis. Figure 6 shows the contrast amid the global maximum and minimum temperature for stainless steel. The preliminary temperature is 924°C is applied to this fixture outward zone. The green line signifies the maximum global temperature while the red line denotes as minimum global temperature. The temperature rises while waiting for it reaches the maximum temperature of 959.85°C at 3.34 seconds in the global maximum temperature. And for the global minimum temperature, the temperature is extended with 753.56°C. From this figure, it shows that consume a mark of conserving in 10 seconds significantly. The other materials have the similar pattern with stainless steel.

In this study, several simulations based on Table 2 were conducted using ANSYS static structural analysis. In the example for Material 1 UTS 25% and 500N was applied in the simulation. The result shows based on the colored shown in Figure 3, the minimum and maximum value for life is 16 cycle. Based on the colored shown in Figure 4, the minimum and maximum value for damage are 1000.

Based on the scattered different contour colour in Figure 5, FOS on green boundary is larger than yellow boundary. This is because of the diameter is larger than yellow boundary. The force 500N was applied is the loading constant amplitude until the part failed. The minimum value of FOS for UTS 25% is 1.6358 and the maximum FOS is 9.4822.
Based on the scattered different contour color as shown in Figure.6, at the end of specimen have a large value of total deformation than the inner part. The red boundary is better than the blue boundary. The force are applied on both ends of specimen is 500N until the part failed. The minimum value of total deformation for UTS25% is $9.274 \times 10^{-5}$m and the maximum value is 1.022m.

Table 3 summarizes the result of safety factor for material 1 with temperature 140°C. It is found that the maximum load is 800N for material 1 in order to withstand with the condition of degradation in saline solution. Furthermore, there is no significant impact for ultimate tensile strength as listed in Table 4. However, the when the force is applied 800N, the ultimate tensile stress meet the best agreement between 25%, 50%, and 75%.

| Force (N) | (FoS) Material |
|-----------|----------------|
| 500       | 1.6358         |
| 600       | 1.3631         |
| 700       | 1.1684         |
| 800       | 1.0224         |
| 900       | 0.9087         |
| 1000      | 0.8179         |
Table 4. Summary of UTS for Material 1

| Force | 25%  | 50%  | 75%  |
|-------|------|------|------|
| 500   | 0.5420 | 0.5379 | 0.6509 |
| 600   | 0.5182 | 0.5263 | 0.5310 |
| 700   | 0.5255 | 0.6313 | 0.7158 |
| 800   | 0.5362 | 0.7391 | 0.8214 |
| 900   | 0.5623 | 0.5329 | 0.5403 |
| 1000  | 0.5919 | 0.5882 | 0.5256 |

Table 5. Summary of UTS for Material 2

| Force | 25%  | 50%  | 75%  |
|-------|------|------|------|
| 500   | 0.7149 | 0.6613 | 0.5357 |
| 600   | 0.5542 | 0.5621 | 0.5743 |
| 700   | 0.6274 | 0.5399 | 0.5346 |
| 800   | 0.7306 | 0.5207 | 0.5843 |
| 900   | 0.5231 | 0.6404 | 0.5562 |
| 1000  | 0.7214 | 0.5426 | 0.5525 |

Based on the overall results found that the material 2 was selected as a good material. The element that considered in the performance are life, damage, FoS, and buckling. The all result are obtained from Static Structural using ANSYS analysis. The performance of material 2 in total deformation is better than other material. This material has the most stable and low value of buckling. That means, the specimen will not deform too much before failed. So that, the lowest value of buckling is better.

The result shows that, when the high force applied to the specimen the FoS value will decreased. Otherwise, different UTS percentage can make the specimen more strength. In the FoS, material 2 performed better than other material. Material 2 produced high FoS compared to material 1. The value of FoS is better when the values on result data are more than 1.

The significant of this research is to contribute in determining the factor of safety for degradable polymer that is commonly used in biomaterials applications. Several load from 500N to 1000N and it is found that the material selected withstand the load. However, the suitable load is proposed less than 800N. Furthermore, the 150°C (T150) material is proposed for bioactive degradable composite due to degradation in saline solution.

4. CONCLUSION

The composite moulded at diverse temperatures and a fraction of the ultimate tensile strength was proposed in this study. The entire material properties are based on CES EduPack 2010. The polylactide (PLA70) is used as a chosen composite material for the specimen. The significant percentage of UTS and force was investigated to provide the accurate analysis result. This project used an engineering quasi-static test. The identified percentage of UTS was refined to give more
obvious impact and differences in each specimen. There has three percent of UTS are needed to evaluate this project which 25%, 50% and 75% that have a different value for two material composite. The static structural analysis has done on the all two type materials and the result is evaluated based on three percentages of UTS. The analysis result shows the material 2 has the good condition in terms of FoS, life, damage, and buckling. The FoS was good because the value is more than 1 at forces 500N, but failed when reached force 1000N. Based on the result, material 2 is selected as the best material for bioactive degradable composite due to degradation in saline solution.

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