EFFECTS OF DAMAGES ON THE FATIGUE PROPERTIES OF GLASS REINFORCED PLASTICS

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BORANG PENYERAHAN TESIS

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This project report attached hereto, entitled **"EFFECTS OF DAMAGES ON THE FATIGUE PROPERTIES OF GRP "** , prepared and submitted by Tiong Siing Kieh as a partial fulfilment of the requirement for the degree of Bachelor of Engineering with Honours in Mechanical and Manufacturing System is hereby read and approved by:

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Date: 17 MARCH 2001

EFFECTS OF DAMAGES ON THE FATIGUE PROPERTIES OF GRP

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Report submitted as partial fulfillment of the requirements for the degree of Bachelor of Engineering (Hons) in Mechanical and Manufacturing Systems Engineering
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ABSTRACT

Glass Reinforced Plastics (GRP) have been widely used in various applications in the engineering field and many studies on their mechanical properties have been done. The effects of damages such as drilled holes on the tensile and compressive properties of GRP have been very well established. However, there have been little studies of their effects on their flexure fatigue properties. This project investigates the effects of damages, in particular drilled holes on the fatigue properties of GRP. The project looks into both the inherent fatigue behaviour of GRPs, as well as how the introduction of drilled holes affects its fatigue properties. This paper also include an attempt to identify the best machining conditions for the drilling of holes and correlate the fatigue properties to the conditions of the damages.

ABSTRAK

Plastik yang diperkukuhkan dengan serat kaca (GRP) telah banyak digunakan untuk pelbagai aplikasi dalam bidang kejuruteraan, dan banyak kajian ke atas ciri-ciri mekanikalnya telah dibuat. Kesan-kesan lubang yang digerudikan ke atas ciri-ciri tegangan dan mampatan statik GRP telah dikaji dengan menyeluruh. Namun hanya terdapat sedikit kajian terhadap ciri-ciri fatig lenturannya. Projek ini mengkaji secara menyeluruh kesan lubang-lubang yang digerudi ke atas ciri-ciri fatig GRP. Projek ini juga mengkaji ciri-ciri fatig GRP itu sendiri, dan juga bagaimana penggerudian lubang-lubang memberi kesan kepada ciri-ciri fatignya. Kajian ini juga termasuk percubaan untuk mengenalpasti keadaan penggerudian yang terbaik, dan mencari perkaitan antara keadaan lubang-lubang yang digerudi dengan ciri-ciri fatignya.

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CHAPTER 1

INTRODUCTION

1.1 Background.

During the last few decades, there have been many significant advances made in the research of composites. Composites have found their way into many applications in the engineering field, replacing more traditional materials, as well as enabling designers to create and design things previously impossible due to materials constraint.

Among the numerous types of composites available today, Glass Reinforced Plastics (GRPs) remain the composite that is most widely used. There are several reasons why this material is so popular, for example:

i) glass is easily drawn into fibers from the molten state

ii) glass is readily available, and can be fabricated into GRPs via economical processes.

iii) GRPs has very high specific strengths.

iv) GRPs are chemically inert, highly corrosion-resistant and inflammable.

Presently GRPs are used extensively in many applications, including automotive components, plastic piping, storage containers, industrial floorings etc.

As in any component or structure, GRPs that are used in the industry are susceptible to fatigue. Fatigue is loosely defined as a form of failure that occurs when a material is subjected to repeated dynamic or fluctuating stresses [1]. As a result of these repeated stresses, a material can fail at stress levels considerably lower than its yield strength under a static load. Its importance in materials design and selection can be seen in the fact that it is responsible for 90% of all metallic failures, as well as being a major cause of failure for plastics, composites and ceramics.

Engineers began studying fatigue damage in Europe during the 19^{th} century, and subsequently, fatigue was incorporated into design criteria in the late 19^{th} century. Since then, much research into fatigue had been conducted with many notable discoveries coming in the 1950s. However, little study has been made on the effects of damages on the fatigue properties of GRPs.

Therefore this project aims to investigate the effects of damages, specifically drilled holes, on the flexure fatigue properties of GRPs. Besides this, this project will also correlate the effects of machining conditions of the holes on the fatigue properties of the specimens. Holes are extremely significant because they have to be drilled in order to incorporate mechanical fasteners when adhesive bonding becomes unsuitable, such as when the joints are subjected to high levels of stresses.

1.2 OBJECTIVES.

This project has the following objectives:

i) To investigate the effects of drilled holes on the flexure fatigue properties of GRPs.

ii) To identify the best machining conditions for the drilling of holes in order to minimize their effects on the fatigue properties of GRPs.

iii) To investigate the relationship between the machining conditions of the drilled holes and the fatigue properties shown by the GRP specimens.

1.3 DEFINITIONS OF IMPORTANT TERMS AND CONCEPTS

The following terms and concepts will be most significant to the whole idea of the project.

1. Fatigue

Fatigue is the process of cumulative damage in a benign environment that is caused by repeated fluctuating loads [2]. In an aggressive environment, the term used is corrosion fatigue. However environmental effects will not be dealt with in this project.

2. **Composite**

Composites are any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized.[3]

3. **GFRP**

GFRP stands for Glass-Fiber Reinforced Plastics which is a class of composites whereby glass fibers, either continuous or discontinuous are contained within a plastic matrix. GRFPs are more commonly, though not accurately, known by the common term, fiberglass.

4. **Anisotropy**

The behavior of exhibiting different values of a property in different directions. GRPs exhibit this behavior due to the fact that the glass fibers are placed in different orientations within the matrix for each different type of GRP.

5. **Plastic**

A solid material of which the primary ingredient is an organic polymer of high molecular weight.

6. **Polymer**

A long-chain molecule containing one or more repeating units of atoms joined together by covalent bonds.

7. **Drilling speed**

In drilling, the cutting speed is generally referred to as the speed of the revolving drill or spindle. It is defined as the rate that a point on the circumference of the drill will travel in a unit time.

1.4 OVERVIEW OF PROJECT.

This project will generally involve three major parts: Literature review; preparation and execution of experimental procedures; and interpretation and discussion of results.

Firstly, an extensive literature review will be conducted to look into the theoretical aspects of the relevant subject, and previous researches done that are relevant to the objectives and context of the project.

Secondly, the specimens will be prepared and then tested according to the experimental procedures stated in Chapter 3. The test material will be carefully selected, and holes in different configurations will be drilled into the specimens under varying machining conditions. The specimens will then be tested to failure through the *Universal Fatigue Testing Machine*, and analyzed through a metallurgical microscope.

Finally, the results gathered through the experimental procedures carried out will be carefully analyzed and interpreted. Through the analysis process, conclusions will be drawn, and subsequent recommendations, based on the analyses of results will be made.

CHAPTER 2

LITERATURE REVIEW

This literature review deals with three main elements. Firstly, the theory and researches made in the area of Glass Reinforced Plastics. Secondly, literature on drilling operations and other hole-making methods will be studied. Finally, the various theories on fatigue properties of materials will be dealt with.

2.1 Glass Reinforced Plastics (GRPs)

As defined earlier, composites are materials consisting of 2 or more separate materials, combined macroscopically in order to obtain desirable properties. Glass fiber reinforced plastics were among the first composites used in the engineering industry.

Fiber reinforcements were more widely used than particle or flake type reinforcements because of its superior reinforcing effectiveness. Fibrous reinforcements, including glass fibers are effective because these materials possess much greater strength and stiffness in fiber form than in bulk form, as first shown by the research done by Griffith. [4]

fibers are oriented in various directions according to the stress field in the component of interest, as shown in Figure 2.1.

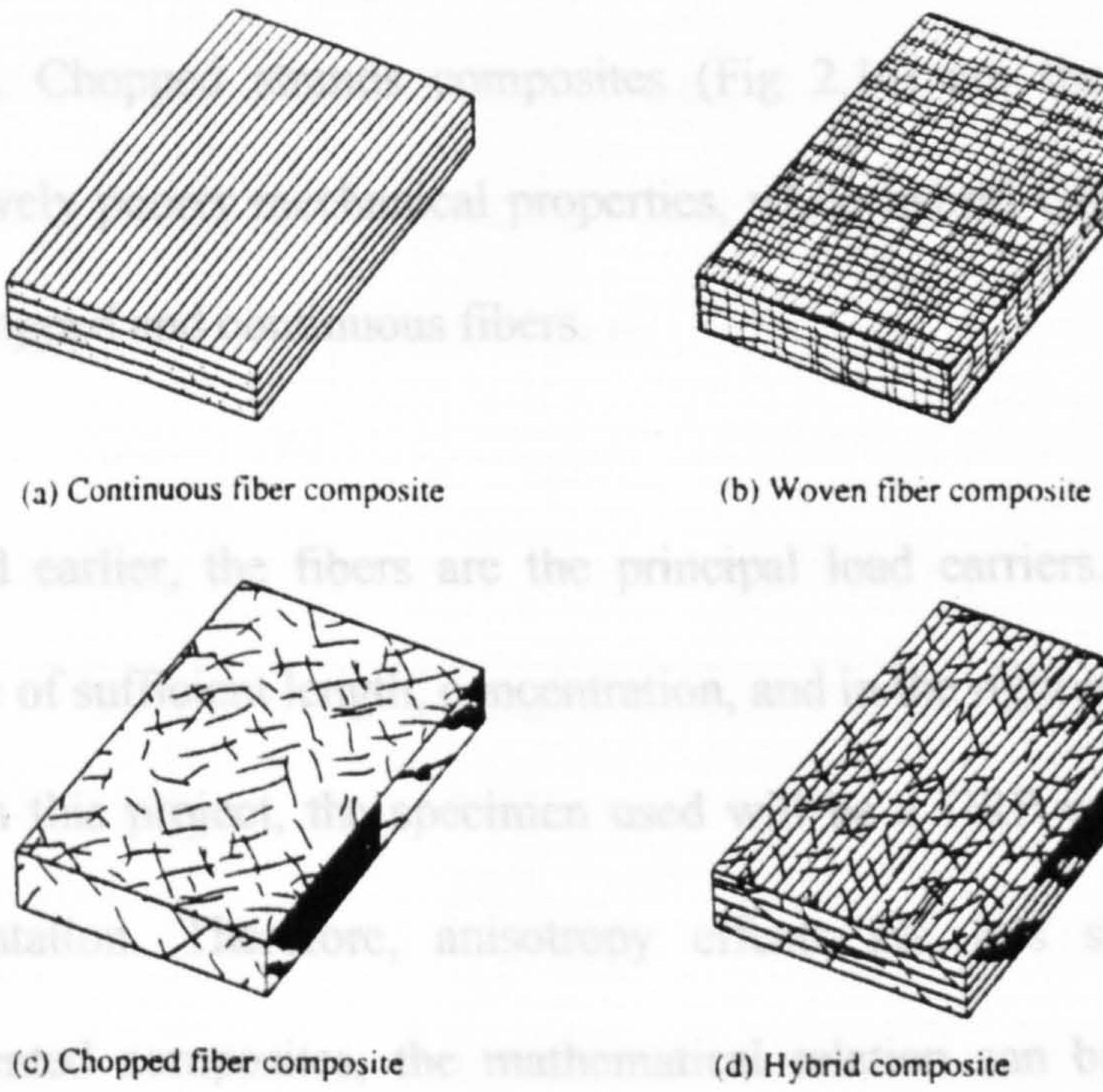

Figure 2.1 : Types of FRPs

The matrix functions to transfer the applied stress to the stronger fibers, as well as to protect and bind the fibers together in a desirable form. On the other hand, the fibers act as the principal load carrying members to enhance the mechanical properties of the material. Fibers also force cracks propagation to follow the fiber orientation, thus minimizing crystallographic failures.

In continuous fiber composite laminates (Fig 2.1a), individual continuous fiber laminates are oriented in a required direction and bonded together with the matrix

In continuous fiber composite laminates (Fig 2.1a), individual continuous fiber laminates are oriented in a required direction and bonded together with the matrix to from a laminate. Woven fiber composites (Fig 2.1b) do not have distinct laminates, thus no delamination occurs during machining, but strength is compromised. Chopped strands composites (Fig 2.1c) are the cheapest, but possess relatively poorer mechanical properties, while hybrid GRPs consist of a mixture of chopped and continuous fibers.

As mentioned earlier, the fibers are the principal load carriers. However, the fibers must be of sufficient length, concentration, and in the right orientation to be of any use. In this project, the specimen used will be a GRP with its fibers in random orientation. Therefore, anisotropy effects are less significant. For randomly-oriented composites, the mathematical relation can be expressed as below:

$$\mathbf{E_c = KE_fV_f + E_mV_m} \qquad \text{where,}$$

E_c, E_f, E_m = elastic modulus of the composite, fiber, matrix respectively,

V_f, V_m = volumetric percent of the fiber and matrix respectively,

K is a fiber efficiency parameter that depends on V_f and the E_f/E_m ratio.

Research done by Krenchel [5] shows that for fibers randomly oriented within 3-D space, the reinforcement efficiency is only 1/5 of an aligned composite in longitudal direction. However, its mechanical properties are isotropic.

Glass fibers primarily consist of silica and metallic oxide modifying elements. E-glass is the most widely used GRP and also the lowest in cost. S-glass has about 30% higher tensile strength than E-glass, but is more expensive. Other common types of GRPs include S2-glass, C-glass, glass/epoxy and glass/polyester composites used in many applications ranging from sports equipment to the aircraft industry. Table 2.1 shows the general chemical composition and mechanical properties of E-glass and S-glass.

Type of GRP		E-glass	S-Glass
Composition :	SiO_2	54.5	64
(wt %)	Al_2O_3	14.5	26
	CaO	17	-
	MgO	4.5	10
	B_2O_3	8.5	-
Tensile Strength (MPa)		3448	4482
Tensile Modulus (GPa)		72	86
Density	(g/cm^3)	2.54	2.49

Table 2.1: Typical properties of E-Glass & S-glass
(Adapted from W.D Callister, Materials Science and Engineering,John Wiley & Sons 1994, p 419)

2.2 The Drilling Operation

Drilling is defined as the process of machining a round hole in a workpiece. [6] It is the most common and easiest method used to produce holes in components. The cutting force is generally provided by rotating the drill against a stationary workpiece or vice-versa.

2.2.1 Problems in Drilling GRPs.

Problems arise in drilling GRPs because most of the available tools were designed for metals. For polymer matrix composites, the heat conductivity is generally hundreds of times less than that of metals, causing poor heat removal via the chips. As a result, most of the heat is conducted out via the tool itself, as shown in Table 2.2 below.

Heat removal *medium*	Steel	Boron plastics	Organic plastics	Carbon-carbon *composites*	Glass fiber plastics
Chip	75	7-10	20-25	4-8	8-10
Detail	20-22	10-15	15-20	25-40	10-15
Tool	3-5	70-80	50-60	45-55	70-80
Environment	3-5	3-5	3-5	5-7	3-5

Table 2.2 : Heat Removal distribution in drilling PCM and steels (%)

(Adapted from G.A Krivov, B.V Lupkin. Composite Manufacturing Technology, 1995 Chapman & Hall, p157)

Because of GRPs' poor heat conductivity and its low tolerance of high temperatures, the machining process has to be slowed down in order to avoid excessive heat from building up. For example, if too high a drilling speed is used, the heat build-up will cause the resin to become sticky and produce lumpy chips that can clog the removal system [7].

A study done by Koplev, Lystrup and Vorn showed that a titanium diboride coating on the cutting tool significantly improves performance and drill life when used on glass/epoxy materials. [8]

Research has also shown that the best drilling speed for Boron/glass/epoxy material is around 2000-3000rpm, and the best feed rates are 0.14-0.08mm/s, with a 5% commercial surfactant in water as the coolant.[9] A table of composites and their respective recommended machining conditions can be referred to in the Appendix.

2.2.2 Other Composites Hole-making Methods.

Drilling is obviously not the only method to produce circular holes in composite materials. Due to the complications surrounding the drilling process in composites, a few other processes can be applied as alternatives.

Mechanical and hydrodynamic hole punching has the advantages of high productivity and tool durability. However, this process produces uneven cut surfaces and cracks around the holes due to the separation process.

Adaptive control systems are now widely used in the drilling process. These systems have the ability to sense the hardness of materials and adjust the cutting speed and feed rates accordingly. Throughout the drilling operation, parameters such as speed, torque and thrust are compared to pre-programmed memory in the on-board computers so that the appropriate adjustments can be made.

Laser Beam Machining or LBM is based on the interaction of the material with an intense, coherent beam of light. Drilling is done through melting, vaporization or chemical degradation. The holes produced through LBM are always clean and accurate, as well as demonstrating low deformation and absence of specimen pollution by material and tool destruction products.

2.3 Fatigue.

Fatigue, as mentioned earlier, is the process of cumulative damage in a benign environment caused by repeated fluctuating loads. These fluctuating loads could be torsional, axial or flexural in nature. This project will mainly concentrate on the flexural fatigue behaviors.

2.3.1 Fatigue theory.

Fatigue normally occurs after a lengthy period in which the structure or component is subjected to repeated fluctuating stresses. Fatigue damage initiates from regions which has undergone plastic deformation as a result of the applied fluctuating stresses. The fatigue performance of a material is usually measured in its total fatigue life, which is the number of cycles to cause failure at a specified stress level. For materials which do not exhibit fatigue limits, including composites, another parameter that can be used to specify fatigue performance is the fatigue strength, which is defined as the stress level at which the material will fail for a specific number of cycles.[10]

Fatigue failure happens after a certain number of cycles at certain stresses, when the accumulated damage causes the initiation and propagation of cracks in the plastically damaged regions. These cracks are initiated at regions of stress or strain raisers. The more severe the stress concentration, the less time will be needed to initiate and propagate cracks. These stress concentrations can be notches, small surface scratches, grooves, holes or any other geometrical discontinuities.