UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FATIGUE PERFORMANCE OF ADDITIVE MANUFACTURED POLYMER WITH DIFFERENT COMPOSITION OF RAW AND RECYCLE MATERIAL

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APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Selective Laser Sintering adalah prototaip pantas yang boleh menghasilkan produk berkualiti tinggi. Konsep utama adalah dengan memejalkan bahan serbuk secara berterusan lapisan demi lapisan bagi menghasilkan sesuatu produk. Ciri-ciri bahan dan sifat lesu akan berbeza oleh kerana kaedah pemprosesan bahan. Serbuk nilon dipilih sebagai bahan untuk menghasilkan produk kerana ia mempunyai banyak ciri yang bagus. Terdapat tiga jenis bahan yang akan dikaji iaitu bahan mentah, campuran dan bahan kitar semula. Kebiasaannya, bukan sahaja polimer mentah yang digunakan tetapi juga bahan yang sudah dikitar semula, atau bahan yang sudah melalui proses pemanasan berulang kali juga diguna pakai. Oleh kerana polimer menjalani proses yang berbeza, sifat-sifat bahan akan berbeza. Jika komponen dikenakan pembebanan dinamik, sifat kelesuan adalah penting untuk dikaji. Ujian tegangan, ujian kelesuan dan Fraktografi telah diuji pada produk untuk menentukan dengan lebih terperinci mengenai sifat kegagalannya. Bagi ujian tegangan, spesimen dari bahan mentah dan campuran mempunyai ciri-ciri hampir sama iaitu 47.757 MPa dan 49.143 Mpa, manakala sampel dari bahan kitar semula adalah 37.193 MPa. Ujian kelesuan juga menunjukkan trend yang hampir sama bagi specimen bahan mentah dan campuran. manakala ujian kelesuan untuk spesimen dari bahan kitar semula adalah 55% lebih rendah. Walaupun bahan kitar semula pada mulanya mempunyai sifat yang kurang bagus, tetapi dengan gabungan yang baik antara bahan mentah, kitar semula dan bahan panas semula, sifat-sifat itu dapat dipertingkatkan.

ABSTRACT

Selective Laser Sintering is a rapid prototyping that can manufacture high quality product. The main concept is by solidifying powder material continuously layer by layer to create a product. Due to production method, the property differs from normal material as well as fatigue properties. Nylon powder is chosen as the material of the product since it has many good characteristics. There are three types of material that will be investigated which are raw, mixture and recycle material. In practice, not only raw polymer is used but also recycle, or reheat material. As the polymer undergo different process, the properties of the material also differ. In case of component subjected to dynamic loading, fatigue properties of the material is important to be studied. Tensile, Impact, Fatigue and Fractography test were tested on the product to determine more detail about its failure properties. As for tensile test, specimen from raw material and mixture has almost same properties which are 47.757 MPa and 49.143 Mpa, while sample from recycle material is 37.193 MPa. Fatigue life also show the same trend which specimen from raw material and mixture has almost the same fatigue life, while fatigue life for specimen from recycle material is 55% lower. Although recycle material initially has poor properties, but with good combination with raw, recycle and reheat material, the properties can be improve.

DEDICATION

To my beloved parents Zulkifli Abdullah, Norr Aizan Mohd Nasib and my beloved family members.

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AM	-	Additive Manufactured
CAD	-	Computer Aided Design
HCF	-	High-cycles Fatigue
LCF	-	Low-cycles Fatigue
MPa	-	Megapascal
N	-	Cycles
SLS	-	Selective Laser Sintering
STL	-	Stereolithography
S	-	Stress
s	-	Strain
S-N	-	Stress-Cycles
UTS	-	Ultimate Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 Introduction

Fatigue failure was widely investigated recently. The capability to know the conditions which cracks or defects are effectively no propagating are good for design and failure analysis (Newman & Piascik, 2000). With rapid growth of processes of additive manufacturing for these days, as example, powder beds or direct powder projection with laser or electron beam energy sources. Optimum structure design can now be built easily as virtually everything seems to be possible to produce. One of the most important issues to deal with is the durability of such structures as fatigue or fracture phenomenon will be implemented in many industrial fields such as in aeronautics field, aerospace fields, ground transportation and energy. Several research has been done on assessing the impact of process parameters on lifetime fatigue (Günther et al., 2017). There are several parameters that has been evaluated during lifetime fatigue processes such as roughness of the surface, ultimate heat treatment solution. The properties of fatigue are analysed with respect to the mechanisms of crack initiation found on the micrographs post-mortem of each specimen. As for result, when surface defects are extracted, the machined specimen will have stronger fatigue properties. Due to various defect shapes with respect to the loading axis, small differences are observed among horizontal and vertical construction directions.

1.2 Background

Selective Laser Sintering (SLS) or also called as 3D Printing is one of technologies of rapid prototyping and additive manufacturing which can produce high quality product directly from computer-aided design (CAD). The advantages of SLS are it can produce complex and organic geometries that other manufacturing techniques cannot produce. Nowadays, SLS has been use widely because it can cooperate almost any material such as polymers, ceramics, metals and several sort of composites. The material will process to powder first that sometimes contain sacrificial polymer binder to be removed later. Main concept of SLS is that by solidifying powder material continuously on top of one another. The solidification is done by sintering or fusing the selected areas of powder layers by thermal energy that is gained by laser beam.

The product of SLS will faced mechanical fatigue fracture if cyclic load is applied on the product. This fatigue fracture occurs according to the mechanism of macroscopic crack growth. The macroscopic mechanism is that a given polymer specimen's fractional remaining fatigue life is significantly connected to the frictional size of the residual uncracked segment, including the intact craze length at any time during fatigue. Due to the rising of net-section stress amplitude in fatigue, a crack growth functional is proposed and used to represent the progress of cyclic fatigue crack. A crack development equation, which is went along with observations of macroscopic crack growth mechanics by Frost, Dugdale and Weibull's. Fatigue behaviour of polymers is derived by a durable constitutive equation for stress-life (S-N). This fundamental equation accurately represents a large number of polymers mechanical S-N fatigue behaviour under test requirements in which thermal effects were not present. The temperature effect is rationalized, depending on the polymer, based

on beta relaxation, glass transition and temperature strength variation. The fundamental equation is then improved to produce a master equation that includes the effects of mean-stress, allowing for the prediction of stress-life behaviour and limit of endurance for any medium stress based on S-N behaviour of completely backward fatigue data.

Powder material that has been used to produce a product is nylon polymer. One of the reasons of using this material because the excessive powder is recyclable which will cause low cost. Polymer's fatigue behaviour is of critical consideration for the engineering community as plastics have increasingly included in load-bearing implementations over the several decades ago. Polymers offer a wide of unique characteristics involves low density, chemical inertia, lubricity, good specific strength and modulus and cost efficiency. These properties made them perfect to be used for automotive, aerospace, sports goods and medical applications. Polymer's fatigue behaviour is sensitive to the polymer's molecular structure. Molecular parameters include molecular weight, distribution of molecular weight, density of chain interference, crystallinity, existence of fillers or reinforcements and crosslink density. Majority of polymers are sensitive to frequency and viscoelastic, service temperature and waveform. As for molecular factors, a polymer component's fatigue life is monitored by several mechanical factors involve the loading cycle's stress or strain amplitude, component's presence of stress concentrations, cycle's mean stress or earlier defects. For the safety design of structural polymeric subject to fatigue loading, these are all factors are of significant interest and practicality.

1.3 Problem Statement

Fatigue failure happen when a material fails below than the determined yield strength and is generally caused by cyclic loading stress through a duration of time. Since polymers are viscoelastic, some energy will be dissipated in each cycle under cyclic load. This failure will shorten the life time of polymer. To understand this fatigue failure, the polymer needs a thorough testing procedure such as tensile test, hardness test, fatigue test, and fractography test to examine the properties of the polymer and its characteristics. Fatigue failure will start from initiation of a crack and follow by propagation with continuous cycling until fracture takes place. It is normally occurring at intermediate value of oscillating stress and often falling between one-fourth and one-half of the yield of tensile or fracture stress.

There are three types of material that will be tested which are raw, mixture and recycle material. Raw material is where the nylon powder is not been used yet while recycle material is where the excess nylon powder from previous product is reused. From these two materials, they will have different results since the materials do not have the same composition. The rise of recycle campaign cause recycle material will be used in manufacturing. However, recycle material differ from raw material due to multiple reheat process that will cause recycle material will more brittle than raw material. To identify its brittleness, another material will be tested which is the mixture of raw material and recycle material. The purpose of this mixture is to identify and differentiate its result between the other two materials.

There are several discussions, before the polymer faced fatigue failure, it will undergo ductile and brittle fracture. There are several stages of ductile fracture where it is starts from initial necking and follow by formation of small cavity or also called as micro

voids. The next stages are growth of cavity (ellipsoid) by coalescence into a crack and rapid crack propagation around neck area. The shear strain at neck area is at 45°. Cup and cone shape will be seen on final stage. As for brittle fracture, there is no significant deformation as the spread of crack is very rapid. Crack propagation (by bond breaking) occurs along specific crystallographic planes (cleavage planes) in most brittle materials. This type of fracture is trans granular (through grains) which produces grainy texture or called facial texture when the direction of cleavage changes from grain to grain. Fracture is intergranular in certain materials.

1.4 Research Questions

I. What is the different between raw material and recycle material?

II. How to solve the use of recycle material with good properties against fatigue.

III. How the different of ratio of material will affect the fatigue failure.

IV. Why the performance of the type of combination of raw material is difference.

V. Which combination of material will have the best performance against fatigue failure?

1.5 Hypothesis

Basically, recycle material is where the excess material that has been reheat a few times before it is reused. The composition and properties of the material are changes after

undergo heating process that produce by laser during SLS process. Recycle material will affect the fatigue failure since the brittleness is higher than raw material.

As the recycle material has higher brittle properties, it is not good to be used in industry field because it will shorten the lifetime of the product. To overcome this problem, the raw material of nylon powder will be added on recycle material according to suitable ratio. Other purpose of adding recycle material is to reduce the cost of using nylon powder since the price of nylon powder is quite expensive.

The ratio between raw material and recycle material depends on its suitability, if the force acting on the product is high it will cause lower fatigue failure which the higher raw material is needed. Raw material has higher cycle of fatigue failure compare to recycle material.

Fatigue life depends on the toughness of the material. Higher strength of material will lead to higher cycle of fatigue failure. Different mixture of material will have different result of fatigue cycle and by adding raw material into recycle material, the performance of material will increase.

Fatigue failure is very sensitive to stress and by ensuring the accuracy of load and stress estimation is very important for fatigue engineering. Reduction in fatigue cycle can ensure longer lifespan of the material. 100% raw material will have the best performance against fatigue failure since the composition and properties of 100% raw material do not change.