INVESTIGATION OF THE MICROSCOPIC DEFORMATION BEHAVIOR AND SURFACE QUALITY OF AUSTENITIC STAINLESS STEEL PLATE DURING HOLES PIERCING PROCESS

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Engineering (Mechanical - Advance Manufacturing Technology)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MAY 2010
To my beloved mother and father
Suid Salleh
Asmah Pawanteh

My beloved wife
Siti Aisah Mohmad Ashari
ACKNOWLEDGEMENT

I would like to thank Allah Almighty for blessing and giving me strength to accomplish this thesis. In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, a special thank to my supervisor, Prof. Dr. Safian Sharif who greatly helped me in every way I need to go through this study, and Haji Shamsudin Man from GMI for being the co-supervisor and also for his encouragement guidance, advices and motivation. Without their continued support and interest, this thesis would not have a success.

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ABSTRACT

The purpose of this study is to investigate the effect of different clearances on smooth-sheared depth, burr height and surface quality. Austenitic stainless steel sheet metal of 316L with 3 mm thickness as used in this study. Experimental results showed that the burr, smooth sheared region and punch force greatly influenced by the clearance value between the die and punch. The results are in agreement with the previous theoretical and experimental works in the literature. The findings is expected to contribute to the process of developing medical implant device made from 316L stainless steel.

The study involved design and fabrication of a medium precision piercing die set of single station with one hole. Most of the die components were fabricated using the various facilities at KKTM Balik Pulau, Pulau Pinang. The punch was made of SKC50 steel with hardness of 64 HRC with diameter of 5 mm. Four different clearances of 5% (0.15mm), 7% (0.21mm), 10% (0.3mm) and 13% (0.39mm). These die clearances variation were obtained by using circular button die of different die diameter.
ABSTRAK

Kajian ini dilakukan bertujuan mengkaji kesan beberapa kelegaan pemotongan kepada kedalaman permukaan licin, ketinggian burr dan kualiti permukaan kepingan keluli austenitik. Kepingan keluli austenitik 316L dengan ketebalan 3 mm digunakan didalam kajian ini. Keputusan kajian menunjukkan kedalaman permukaan licin, ketinggian burr dan kualiti permukaan amat dipengaruhi oleh kelegaan diantara penebuk dan lubang. Keputusan ini selari dengan keputusan kajian ilmiah yang telah dibuat sebelum ini. Penemuan ini dijangka akan menyumbang dalam pembangunan alat implan yang dibuat daripada 316L.

Kajian ini melibatkan rekabentuk dan fabrikasi sebuah acuan tekan kejadian sederhanadengan satu stesen dan satu lubang. Kebanyakan komponen acuan tekan ini di fabrikasi menggunakan berbagai mesin dan alatan di KKTM Balik Pulau, Pulau Pinang. Penebuk di buat daripada bahan SKC50, dengan kekerasan 64HRC dan berdiameter 5 mm. Empat saiz kelegaan iaitu 5% (0.15mm), 7% (0.21mm), 10% (0.3mm) dan 13% (0.39 mm) digunakan. Saiz kelegaan ini ditentukan oleh saiz lubang pada lubang acuan tekan ini.
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LIST OF SYMBOLS

$D, d$ - diameter
$F$ - Force
$g$ - Gravity = 9.81 m/s
$I$ - Moment of inersia
$l$ - Length
$m$ - Mass
$N$ - Rotational velocity
$P$ - Pressure
$Q$ - Volumetric flow-rate
$r$ - Radius
$T$ - Torque
$V$ - Velocity
$w$ - Angular velocity
$x$ - Displacement
$z$ - Height
$\theta$ - Angle
$\rho$ - Density
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CHAPTER I

INTRODUCTION

1.1 Project Background

Sheet metal forming technology has been widely used in many industrial contexts especially in the automotive and electrical industries. Stainless Steel 316L is widely used in various products and is the common material for the manufacture of implant bone plates because it has corrosion resistance and harmless to human body. Bone plates as in figure 1.1 are used to connect fractured bones during healing process. It must be strong enough to withstand the tension in pulling the bones. Presently the bone plates is manufactured using machining operations whereby several jigs and various cutting tool are used in order to minimize the machining lead time and cost, stamping process offer better advantage in terms of manufacturing time as compared to milling and drilling operations. As such an investigation must be made to evaluate and verify the suitability that stamping processes is suitable for Stainless Steel 316L in terms of its deformation behaviour, burr formation and dimensional accuracy The stamping process that under study is hole piercing operation.
Currently, the bone plate requires higher quality and lower cost. The sheared surface is one of the major indicators showing the product quality. This study is focused on the sheared wall surface quality in the piercing process. It is well known that burr and crack usually occur in the conventional piercing process. (as showed in figure 1.2) (Sutasn Thipprakmasa et al., 2008).

**Figure 1.1** Application of bone plate in bone fracture treatment

**Figure 1.2** Conventional pierce-shaving process: (a) piercing step and (b) shaving step.
1.2 Problem Statement

Problems in Piercing Steel 316L can be divided into two segments which are the burr formation on the holes wall and the form accuracy of the holes after piercing.

1.2.1 Burr formation

Burr formation normally depends on the cutting clearance between punch and die opening. Optimum cutting clearance will produce minimum burr. Steel 316L has a high tensile strength which creates high resistance during shearing process. The deformation behaviour of the holes are normally divided into three segments with standard percentage which are plastic deformation, penetration and fracture as shown in figure 1.3.

![Figure 1.3 Burr formation during piercing in three stages and respected load](image)

However due to the high tensile strength of austenitic stainless steel the desired burr formation after piercing may not occur.
1.2.2 Dimensional Accuracy

Surface deformation at the top and bottom of the stamped plate effect the dimensional accuracy of the product. The force from the punch that penetrates the steel plate from top side will affect the top and bottom surface.

1.3 Research Questions

i. What is the burr height on the plate holes area after the piercing process?

ii. Are there any crack occurs on the hole wall?

iii. What are the hole sizes variation after piercing operation?

1.4 Project Objectives

The objectives of this project are

i. To design and fabricate a piercing die set.

ii. To investigate the effect of cutting clearances on the microscopic deformation behaviour of a pierced hole.

iii. To quantify the dimensional accuracy of the pierced holes.

iv. To evaluate the cutting clearances effect on stress and index failure using computer aided engineering analysis.
1.5 Project Scope

i. Pro Engineer stress analysis software will be used to analyze the piercing effect of 4 cutting clearances on the die openings.

ii. To design and fabricate the piercing die set using the available facilities at KKTM Balik Pulau.

iii. To apply the piercing operation using standard punches and dies via hydraulic press machine.

iv. 3 mm thickness austenitic stainless steel 316L plate will be used as strip material.

v. To collect samples and observes with profile projector and optical microscope.

1.6 Significance of the findings

The findings of this study will enable researchers to evaluate the potential of replacing machining by stamping operation in the manufacture of bone plates or other medical devices.
There is a growing incentive to identify alternative renewable energy sources. Among the sources, grains, plant matters (biomass) and their wastes are commonly been used for biofuel production due to their sustainability. Oil palm empty fruit bunch (EFB) is a type of lignocellulosic waste from palm oil mills. Fermentable sugars mainly the glucose from EFB can be further fermented for the production of bioethanol. This study aims to investigate the effect of dilute acid pretreatment and enzymatic treatment for the hydrolysis of EFB to produce optimum yield of glucose. Three parameters for the dilute acid pretreatment, namely the reaction temperature, acid concentration and reaction time whereas two parameters for the enzymatic treatment, namely the substrate concentration and treatment time were investigated to optimise the yield of glucose. Batch reactions were carried out under different combination of operational conditions as proposed by the experimental design produced by the Response Surface Methodology (RSM). RSM was used to determine optimisation for both the dilute acid pretreatment and enzymatic processes in order to obtain the highest glucose yield. An optimised glucose yield of 53.96 % was obtained at the operating condition of 130 °C pretreatment temperature, 6 %w/w sulphuric acid concentration, 37 min of pretreatment time and 96 hours of enzymatic treatment using 6 %w/v of substrate concentration. The optimised yield has also been validated through experiment work.
ABSTRAK

Terdapat insentif yang semakin meningkat untuk mengenalpasti sumber tenaga alternatif yang sebaiknya dapat diperbaharui dari semasa ke semasa (*renewable*). Di antara sumber tersebut, bijirin, bahan tumbuhan (biojisim) dan sisanya biasa digunakan untuk penghasilan *biofuel* (bahan api berasaskan biologi) kerana kelestariannya. Tandan kosong kelapa sawit (EFB) merupakan sejenis sisa lignoselulosa dari kilang minyak kelapa sawit. Hasilan gula terutamanya glukosa daripada fermentasi EFB dapat ditapai seterusnya untuk penghasilan bioetanol. Tujuan kajian ini bagi menyelidik kesan pra-rawatan asid cair dan juga rawatan enzim untuk menghidrolisiskan EFB bagi memberikan hasilan glukosa yang optimum. Tiga parameter untuk pra-rawatan asid cair iaitu suhu reaksi, kepekatan asid dan masa reaksi manakala dua parameter untuk rawatan enzim iaitu kepekatan substrak serta masa rawatan telah diselidik untuk mengoptimumkan hasilan glukosa. Tindakbalas-tindakbalas berkelompok telah dilakukan di bawah pelbagai keadaan operasi yang dicadangkan oleh rekabentuk eksperimen yang dihasilkan oleh Kaedah Permukaan Respons (RSM). RSM telah digunakan untuk penentuan optimasi gabungan proses pra-rawatan asid cair dan juga proses enzim bagi mencapai hasilan glukosa yang tertinggi. Hasilan glukosa optimum setinggi 53.96 % telah dicapai pada suhu pra-rawatan 130 °C, kepekatan asid sulfurik 6 %w/w, 37 min masa pra-rawatan dan 96 jam proses olahan enzim pada kepekatan substrak 6 %w/v. Hasilan glukosa yang optimum juga disahkan melalui eksperimen.
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CHAPTER 1

INTRODUCTION

1.1 Introduction

Since the beginning of 1970, palm oil industry has emerged as one of the top industries in Malaysia. In order to process the fruits from oil palms, many plants and palm oil mills had been set up. In Malaysia, about 50 million tonnes of palm oil mill effluents and 40 million tonnes of oil palm biomass, in the form of empty fruit bunch (EFB), oil palm trunks and oil palm fronds are generated from palm oil industries, every year. Wastes derived from oil palm industries therefore created a great concern in environmental safety (Kabbashi et al., 2007).

Lignocellulose is the major structural component of woody and herbaceous plants such as oil palm tree. It represents a major source of renewable organic matter. Lignocellulose consists of lignin, hemicellulose, and cellulosic material. The chemical properties of the components of lignocellulose make them a substrate of enormous biotechnological value. Much of the lignocellulosic wastes are disposed by biomass burning, which is not restricted to developing countries alone, but it is considered a
global phenomenon. In addition, the problem arises when all of this biomass is not being treated and left to rot in the plantations to provide some nutrient. Unfortunately, these wastes may create environmental problems due to accumulation of high organic content. Therefore, environmental management is placing greatest emphasis in waste minimisation at source or recycling. Moreover, a growing awareness of the “need not to pollute” has forced this industry to look more closely at the milling operation. It is recommended to treat and manipulate the waste to produce useful product (Kabbashi et al., 2007).

The need for alternative sources of bioenergy is expected to increase sharply in the coming years with the rising prices of crude oil due to increase in fuel demands. The principle fuel used as a petrol substitute for road transport vehicles is bioethanol (Chiaramonti, 2007). Bioethanol is mainly produced by the sugar fermentation process. The main sources of sugar required to produce ethanol come from fuel or energy crops. These crops are grown specifically for energy use and include corn, maize, wheat crops, waste straw, sugarcane and sorghum plants. There is also ongoing Research and Development into the use of municipal solid wastes and agrowastes to produce ethanol in order to reduce the demand of energy crop for biofuel production.

Among the potential alternative of bioenergy resources, lignocellulosic biomass has been identified as the prime source of biofuels and other value-added products. Lignocelluloses, as agricultural, industrial and forest residuals, account for the majority of the total biomass present in the world (Lee, 1997). Therefore, the bioconversion of large amounts of lignocellulosic biomass into fermentable sugars has potential application in the area of bioenergy generation.

EFB was chosen in this study for the monomeric sugars production. Ethanol can be produced from the biomass by the hydrolysis and sugar fermentation processes.
Biomass wastes contain a complex mixture of carbohydrate polymers from the plant cell walls known as cellulose, hemicellulose and lignin. In order to produce sugars from the biomass in this research, the lignocellulosic biomass is milled and pre-treated in order to reduce the size of the feedstock and to open up the plant structure. The cellulosic and the hemicellulosic portions are then hydrolysed, by enzymes or dilute acids, into monomeric sugar which is then fermented into ethanol. There are three principle methods of extracting sugars from biomass. These are concentrated acid hydrolysis, dilute acid hydrolysis and enzymatic hydrolysis (Chandel et al., 2007).

Dilute acid hydrolysis is among the oldest method for sugar extraction process. This process dates back to 1800 that the first commercial plant was set up in year 1898 (Chiaramonti, 2007). The dilute acid hydrolysis process first hydrolyses the hemicellulose in mild process conditions to recover the 5-carbon sugars. The reaction has to be controlled under mild conditions in order to avoid sugar degradation during the hydrolysis process. This not only reduces yield but also causes the formation of inhibitors such as furfural and other byproducts of the fermentation process. Cellulose in the remaining solids is then hydrolysed in a more strict condition at temperature more than 200 °C. The liquid hydrolates are then neutralised and recovered from the process (Sasaki, 2005). Dilute acid hydrolysis is a simple process and no acid recovery is needed after this process. Unfortunately, the yields of fermentable sugar are low and it has high potential for the production of degradation product.

Apart of using acid to hydrolyse the biomass into monomeric sugar, enzymes can be used to break down the biomass in a similar way. Enzymatic processes use selected cellulase and hemicellulose degrading enzymes to break the polymeric chain of the cellulose and hemicellulose, leaving the monosaccharide available for fermentation. It performs a higher hydrolysis yields than the chemical hydrolysis process (Chandel et al., 2007). However, a barrier for these processes is represented by its costs that accounts for approximately 40 % of the total costs. As only 20 % of the biomass’s pore volume
can be reached by the large cellulase enzymes molecules, biomass pretreatment becomes an essential step in the enzymatic hydrolysis processes and thus increasing the cost (Chiaramonti, 2007). Enzymatic treatment however can be considered as a mild hydrolysis process. A clean and clear sugar solution can be produced which consists higher amount of fermentable sugars. In this study, combined dilute acid hydrolysis pretreatment and enzymatic hydrolysis treatment were used. Various variables among the combined hydrolysis processes were studied to obtain the maximised yield of glucose.

To prepare a successful experimental design for this research, response surface methodology (RSM) was chosen. Among the RSM, there are several types of models that can be used. Central composite design was chosen due to the usefulness of this model without the need of using a complete three-level factorial experiment (Montgomery, 1997). Through the RSM, the experimental runs were proposed. The analysis of the data after the proposed condition of experiment can also be evaluated accordingly. The optimised condition for the highest yield can be obtained after the analysis of experiments.

### 1.2 Research Objective

Due to the cost but the good efficiency of the enzymatic treatment, it is desirable to incorporate enzymatic hydrolysis treatment with the existing acid hydrolysis pretreatment to further enhance the conversion of oil palm empty fruit bunch into the sugar products. The objective of this research is to optimise the parameters or the operating conditions for both the acidic pretreatment and the enzymatic treatment to maximise the yield of glucose.
1.3 Research Scopes

i. To investigate the effect of the key parameters for dilute sulphuric acid pretreatment, these parameters include:
   - reaction temperature
   - acid concentration
   - reaction time

ii. To investigate the effect of substrate concentration and reaction time for the enzymatic hydrolysis of pretreated oil palm empty fruit bunch at a specific enzyme concentration.

iii. To optimise the combined process of acid hydrolysis pretreatment and enzymatic treatment in order to obtain highest glucose yield using the statistical model of RSM.

1.4 Organisation of Thesis

This thesis consists of five chapters. Chapter one introduce the research background, problem statement, objective and scopes of the study. Besides, the organisation of the thesis is also included in this chapter.
Chapter two presents the detailed literature survey concerning the main elements involved in this study as well as researches involved in this area. It reviews the related studies on biofuel, oil palm and its waste, lignocellulosic biomass and the statistical optimisation model.

Chapter three describes the materials and the methodology involved in this study. The analytical methods including characterisation and testing procedures for the determination of total solids content and sample composition, the design and analysis of experiments and the experiments of hydrolysis procedures are discussed in this chapter.

Results and Discussion are presented in chapter four. The results on sample characterisation are firstly presented and discussed. The total solids content and main composition of EFB is reported. The effectiveness of the hydrolysis treatments is compared and the highest yield of glucose is identified and discussed statistically. The optimum values for the variables are obtained respectively.

Chapter five concludes the study. It presents the conclusion for the objective and the scopes of this study. Recommendation and suggestions are presented for further improvement of this work in the future.