STUDY OF SURFACE FINISH OF STEREOLITHOGRAPHY (SLA™) PRODUCTS

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ABSTRAK

Sekarang pengembangan Teknologi *Rapid Prototyping* mengacu pada *Rapid Tooling*. Tetapi, karena keterbatasan dari teknologi ini dan material yang tepat, penelitian-penelitian lebih ditekankan pada pengembangan metoda berdasarkan teknologi dan material yang tersedia saat ini. Tetapi itu bukanlah satu-satunya masalah, masalah lain yang dihadapi adalah kesulitan untuk mendapatkan produk dengan kualitas yang baik. Oleh karena itu pada penelitian ini dititik beratkan pada kualitas produk terutama kekasaran permukaan. Hal utama yang mempengaruhi kekasaran adalah arah penyusunan lapisan. Pada penelitian ini dilakukan perubahan susunan. Dari hasil penelitian didapat bahwa produk yang dibuat dengan mesin *Stereolithography*, akan mempunyai kekasaran yang baik pada sudut kemiringan lapisan, 16,875^o dan 22,5^o.

ABSTRACT

Recently, development of Rapid Prototyping technique refers to Rapid Tooling (RT) application. Unfortunately, considering the limitation of technology available and suitable material, the research activities are respectively stagnating on improvement the method using building tool with recent technology and material. However, the problem being faced by researchers are not only limitation pre-mentioned above but also due to difficulties to gain tool with high part qualities. Therefore, in this present research, the part qualities especially surface finish would become primary consideration. Moreover, the obstacles in gaining the part with high surface finish on RP technology is the staircase effect, which is influenced by orientation angle. So, to reach the aim of research in observing the orientation angle for which part would have good surface finish, the orientation angle will be varied. The result shows that surface roughness of SLA built on 0^o and 11,25^o considerably have good impact on surface finish of the part building directly from Rapid Prototyping machine..

Keywords *: Rapid Tooling, Part Orientation, Surface roughness, SLA (Stereolithography)*

1. INTRODUCTION

1.1 Background

Rapid tooling is the primary dream on development of Rapid Prototyping techniques to visualizing the final product design directly from design tooling applications. The advantages of this method is its ability to make the initial prototype directly from the actual final product material so it is easy to assess all requirements needed for final product. However, this method, certainly has several limitations in efforts to: (a) reduce time-to-market, (b) obtain high complexity of the models, and (c) reduce the use of very labour intensive work [23]. Along with increasing customer demand for high-quality product delivered on time in today's globally competitive manufacturing arena, the product design must have short life-cycle. In other words, product design will be changed and updated more frequently than ever before. This concept called Rapid Response Manufacturing (RRP) [6]. This method has been pursued by many companies to shorten time-to-market, improve quality-to-cost and enhance product reliability. In addition, this method also has prompted research and development in order to find the suitable and sufficient new technique in prototype production process for the implementation of rapid response manufacturing. The implementation of RRP methods makes product realization cycles shorter and in turn, will lead to rapidly product entry into market. A 20% reduction in product realization cycles time translates to roughly 20% reduction of the product is the operating costs of product development [1].

However, in many cases, this also leads to reluctance of firms to change existing technologies and ends up with product stagnation. Desktop manufacturing, in the design case, provides design engineers with easy and economic tools to build a prototype or even a functional part in order to considerably reduce the process time [6]. Principally, this technology includes desktop numerical (NC) machining and solid freeform fabrication. Desktop numerical machining is apparently based on common machining process, which could provide products with high surface finish and dimensional accuracy. However, this technology still has weakness especially in producing the complex hollow parts. Solid Freeform Fabrication (SFF) could overcome the weakness of desktop numerical machining. Although surface finish and dimensional accuracy is further problem being faced by using this technology as commonly known as Rapid Prototyping (RP). However recent research results indicate that this barrier can be eliminated.

Among the rapid prototyping processes, researches tend to be focus on exploration of improvement of prototype quality, prototype cost and build time. The research is concentrated on the processes, which have machine available commercially such as stereolithography (SLA), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Three-Dimensional Printing (3DP) and Laminated Object Manufacture (LOM).

The primary benefit of utilizing RP technologies are its ability to produce high quality and complex pattern such as used in investment casting, lower cost and shorter leading time [12]. This technology is very suitable for low volume production such as building a tool directly or indirectly from rapid prototyping models. Tooling is one of the main goals in RP technologies, which is intended to be achieved in work related to improvement of RP technologies nowadays. This application is referred to as Rapid Tooling (RT) technique. Currently, tooling is one of the slowest and most expensive steps in manufacturing because of its requirement for extremely high quality. In some extent, tools have complex geometries, yet must be dimensionally accurate. Moreover, tools also must be hard, wear resistance and very low surface roughness. Traditionally, tools is made by using CNC machining, Electro Discharge Machining or by hand, which are obviously expensive and time consuming as well. **Peter Hilton**, President of Technology Strategy Consulting in Concorde, MA, believes that tooling costs and development time could be reduced by 75% or more by implementing rapid tooling and related technology [15].

According to **Rosochowski** and **Matuszak** [24], Rapid Tooling technologies practically can be classified into three main methods as shown in figure (1). In rapid tooling techniques, creating a tool directly from rapid prototyping machine is the ultimate challenge. Therefore, most researches in improving rapid prototyping technologies being done and probably for future development tend to be concentrated on improving quality such as surface finish and dimensional accuracy as well as part strength and stability.

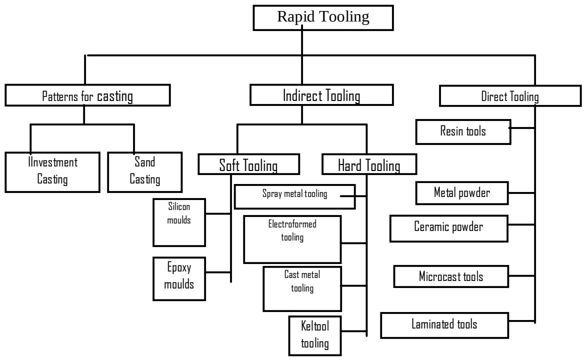

Figure 1 Classification of Rapid Tooling

1.2 Research objectives

This present paper involves theoretical and experimental investigations of the quality and surface finish of part built in SLA machines. This is to assist in determining the suitability of parts built by this machine in RT applications. It is also expected that empirical model developed in this studies will help in assessment of part quality and surface finish.

Five (5) prototypes are built by using Stereolithography (SLA™) machine. Subsequently, the surface roughness is assessed by for each prototype. The process is carried out to help achieve the objectives of this present study, which are:

1. To investigate the effect of build parameter on surface roughness.
2. To investigate the characteristics of surface roughness of prototypes built by Stereolithography (SLA™) due to variation of part orientation.

2. LITERATURE STUDY

2.1 Processes overview

Prototyping is an essential part of product development and has been used for many years to visualize the final product design. The advantage of this method is its ability to make the initial prototype directly from the actual final product material so it is easy to assess all requirements needed for final product. However, this method, certainly has several limitations in efforts to: (a) reduce time-to-market, (b) obtain high complexity of the models, and (c) reduce the use of very labour intensive work (Root 1999). Along with increasing customer demand for high-quality product delivered on time in today's globally competitive manufacturing arena, the product design must have short life-cycle. In other words, product design will be changed and updated more frequently than ever before. This concept called

Rapid Response Manufacturing (RRP) (Dong 1998). This method has been pursued by many companies to shorten time-to-market, improve quality-to-cost and enhance product reliability. In addition, this method also has prompted research and development in order to find the suitable and sufficient new technique in prototype production process for the implementation of rapid response manufacturing. The implementation of RRP methods makes product realization cycles shorter and in turn, will lead to rapidly product entry into market. A 20% reduction in product realization cycles time translates to roughly 20% reduction of the product is the operating costs of product development (Ajay 2001). However, in many cases, this also leads to reluctance of firms to change existing technologies and ends up with product stagnation. Desktop manufacturing, in the design case, provides design engineers with easy and economic tools to build a prototype or even a functional part in order to considerably reduce the process time (Dong 1998). Principally, this technology includes desktop numerical (NC) machining and solid freeform fabrication. Desktop numerical machining is apparently based on common machining process, which could provide products with high surface finish and dimensional accuracy. However, this technology still has weakness especially in producing the complex hollow parts. Solid Freeform Fabrication (SFF) could overcome the weakness of desktop numerical machining. Although surface finish and dimensional accuracy is further problem being faced by using this technology as commonly known as Rapid Prototyping (RP). However recent research results indicate that this barrier can be eliminated.

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2.2 Stereolithography

Stereolithography is a three-dimensional printing process, which produces copies of solid object or models in plastic materials. This process could build a part or prototype quickly. By using a computer-controlled laser to trace cross-sections of the prototype on the surface of a vat of a photocurable polymer, plastic or resin material is hardened. The hardened layer is lowered by moving Z-stage elevator automatically leaving a new layer of the liquid polymer over cured material. Movement of Z-stage elevator is depended on layer thickness being set for every models or even every section (refer to adaptive slicing methods). This process could be left unattended until the whole part has been built completely. Stereolithography process is regarded as the process, which provides prototype or product with extremely accurate part with very good surface finish. However, there are still some limitations associated with process such as. Some prototypes require complex geometries, which are design to have overhang sections to meet customer or market demand for final product. Because the part is built in a liquid environment, support structure may be necessary to support the overhang sections from sinking to the bottom of platform or floating freely in the vat. This supporting sections, which is also called as support structure has function to support the overhang sections as well as to increase the rigidity of the prototype. The support structures are usually removed manually after the prototype is taken away from platform. The shape and angle of support structure is depended on type of overhang section required to be supported. The support structure design is fully depended on operator experience.

Fortunately, although it is still restricted to certain application, Lan (1997) has tried to introduce methods, which can be used to design suitable support structure for prototype built on SLA machine.

Beside build parameters and support structure, the quality of product built by SLA is also depended on how the prototypes are set up to be built, commonly referred to as the build styles. The build styles chosen dictates the size of the hatch, as well as the amount of overcure needed (Diamant 2001a). There are several build styles that have been created currently such as StarWeave™, ACES™, the Tri-Hatch, the Weave and QuickCast™ styles. In addition, Onuh and Hon (1998) have also developed another hatch styles based on the StarWeave: Divergent StarWeave (DSW) and Diagonal Divergent StarWeave (DDSW). These build styles; in turn can greatly influence surface finish and accuracy of the build (Diamant 2001b).

Finally, the quality of the product is not only influenced by selection of the optimal setting parameters and of perfect machines available, but also is depended on the material, which is used to produce a part. Currently, SLA process normally uses photocurable resin, which can be classified as epoxy, vinylether, or acrylate. Fortunately, may researches nowadays have been working to develop new material suitable for SLA process in achieving the goals of RP application technologies as to implement this technologies as Rapid Tooling (RT) or even as Rapid Manufacturing (RM). In addition many research institution such as Cubital, The Institute for Polymer Testing and Polymer Science at The University of Stuttgart and many more have been doing research in improving the mechanical properties of the stereolithography resins and plastic currently being used.

2.3 Previous related works

In order to implement rapid prototyping technique as rapid tooling, improvement of accuracy and surface finish are the primary consideration for user of rapid prototyping machines. Unfortunately, most of research studies have been focused on improving technique in rapid prototyping related with RP machine like stereolithography, fused deposition manufacturing (FDM), Selective Laser Sintering (SLS) and Laminated Object Manufacturing (LOM). **Pham** and **Gault** [22] in their research concluded that Three Dimensional Printing (3DP) methods could provide a high accuracy of built prototype, whether for solid or hollow parts, however, researches in this new method have not been widely published. This is probably caused by the weakness of 3DP systems, which could not achieve good part strength for large part. Unfortunately, Pham and Gault, did not assess the surface roughness that could be achieved by 3DP methods. Therefore, it still has a chance to work on this technique.

In term to achieve the objective of this present research, this investigation will mainly refer to the problem faced by most rapid prototyping techniques in relating to its future development to produce tooling directly from rapid prototyping machines. This problem, as identified by **Rosochawski** and **Matuszak** [24] in their publication about state of art of rapid tooling, are primarily related with the initial dimensional accuracy and dimensional stability of prototype patterns as well as its surface finish.

On the other hand, other researchers have been looking at other aspects, which concentrate on how to apply different layer thickness on the same part or widely known as adaptive slicing method. **Kulkarni** and **Dutta** [13] showed that by means of adaptive slicing methods, cusp-height affects the number of slices that must be built. This can be understood because the highest cusp-height significantly affects the staircase effect. In addition, this will influence the surface finish and part accuracy as well. With this method, build time will be not sacrificed if compared to implementation of uniform layer thickness. Moreover, **Lee** and **Choi** [18] introduced a new method for layered manufacturing by generating optimal slice data. In their study, they investigated a new adaptive slicing algorithm that gives a drastic improvement in computing time. It uses contour line intervals between two consecutive slices instead of calculating the slice thickness at each sampled point. The calculation efficiency is further improved by introducing the vertical lines of the model. This research, therefore, would be useful in calculating the slice thickness of parts built by rapid prototyping technique, because they applied adaptive slicing method that can calculate the thickness of each sampled point using a specific formula created for supporting this method. On the one hand, this method seems to be simplest than any other methods, especially in reducing the calculation time. In addition, this benefit will indirectly make the total time to create a prototype gradually going down especially for large and complex geometry. However, this method would probably give the significant effect to all rapid prototyping process, if contribution of this method to total time of process were investigated. **Ma** and **He [20]**, in related study, gave more focuses on obtaining an accurate and smooth part surface. A new adaptive slicing algorithm introduced in their research operates directly upon a NURBS-based CAD surface model for avoiding possible problems in connection to the commonly used STL interface. This algorithm referred to part tolerance either positive or negative, which is normally occurred for the part built by uniform layer.

By recognising this pattern, the layer thickness suitable for each region of the part to obtain the closest required boundary for final part. This method might be one of the best methods to calculate the optimal layer thickness.

In advanced**, Hope et al.** [9] focused their investigation on sloping layer surfaces combined with implementing the adaptive slicing method, which was an extension to the TruSurf system previously proposed by Hope et al. (1995 and 1996). The advantage of this method is due to its implementation of the Trusurf system in C++ as stand-alone program and operated independently from a CAD system. Therefore, this method does not just stop as algorithm, which is still difficult to apply them in real situation.

All the previous works as discussed above focus on theoretical problem solving, which are related to CAD systems or stereolithography(stl.) format file. In some way, few researchers tend to concentrate on finding out the optimal condition of rapid prototyping technique empirically. In general, they emphasize on exploration of the effect of build methods on part accuracy.

In addition, **Lan et al. [**17**]**, tried to look at the design of the part. They primarily considered the orientation of area, which could fulfil the quality requirement of the part. They analysed the part design, which respectively have to be supported by good supporting structure. In turn, the design of support structure also determines how the built quality is. Although, this result will not provide significant contribution on this present research, however, indirectly this result can give background information for this present research. Finally, to achieve good quality of rapid prototyping product, **Lin et al.** [19] have tried other approaches to minimizing process error in layered manufacturing fabrication. They developed mathematical model to predict the layered process error. Although, it seems more complicated compared to other approach, however in the future this approach may give significant leap on pushing current rapid prototyping techniques as rapid tooling.

3. EXPERIMENTAL METHODS

In this present investigation, Stereolithography (SLA) technique is used to build five (5) prototypes with different variation of part orientation. Moreover, experimental prototypes are measured by using Mitutoyo™ surface roughness testing machine.

Meanwhile the experimental prototype was designed by using Pro-Engineering™ Software (Pro-E) and converted into stl. format. This file is created with 0.02 cord height to avoid future problem in its transfer to SLA machines. The dimensions and features of experimental prototype, as shown in figure (2), are designed by considering part cost; build time; standard engineering features, which are normally appeared on common engineering product; and machine constraints.

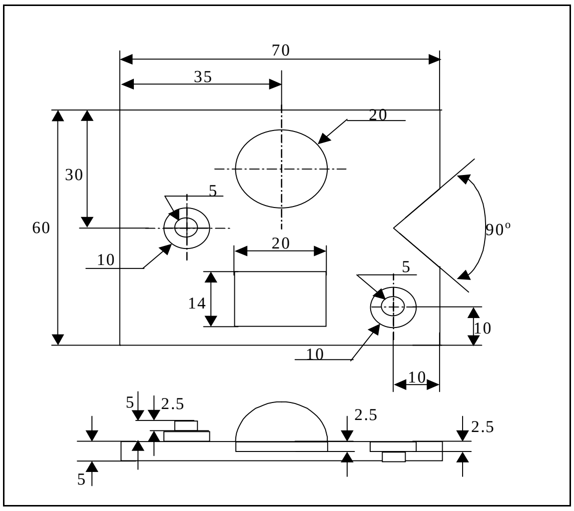

Figure 2 Experimental drawing model

The surface measurement was taken as shown in figure (3), five times for each prototypes. The distance between each point is assigned in order to obtain the measurement data closed to actual characteristic of the surface. In this research, by referring to British Standard [2] about measurement of surface roughness, where is stated that normal surface roughness achieved by product produced by grinding process can be obtained by applying B_{max} 0.8mm and measuring length (maximum) 5mm. In general, all the measurement are done by only part orientation as main consideration .

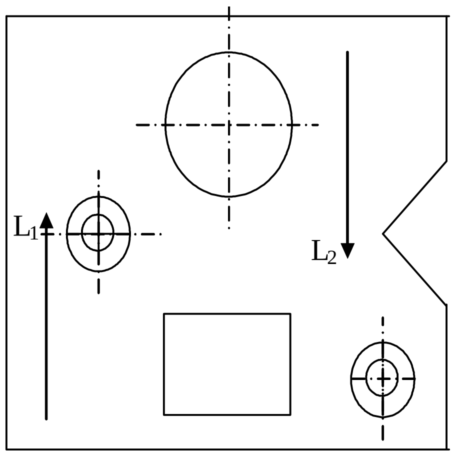

Figure 3 Surface roughness measurement method

In addition, to avoid all the possibility of occurrence of error, as suggested by **Chatfield** [3], randomization method is considered in obtaining the data from measurement process. This is to reduce residual factor caused by uncontrolled factors, which occur during the experiment. Furthermore, the significance test is also done to provide this study with great deal confidential results. Therefore, for whole research activities, several numbers of measurements have to be done as follows:

- 2x3x10 for surface roughness (60 measurements)

4. RESULT AND DISCUSSION

By assuming the data spreading follow normal distribution and by using one-way ANOVA analysis methods with F-test, the result gives 99% confident level. The characteristics of surface roughness of Stereolithography techniques due to variation of orientation angle can be obviously seen.

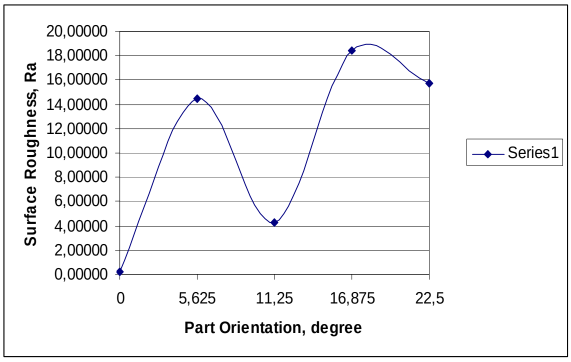

Figure 4 Surface roughness of Stereolithograhy's (SLA) model [10]

From figure (4), by varying the part orientation, characteristics of surface roughness of SLA's models follow parabolic pattern, where the highest roughness is when the model is orientated at 16.875^o and the lowest occurred at 0^o orientation. From 16.875^o to 22.5^o, the surface roughness tends to be flat. Since the process on SLA machine was carried out with only default setting, therefore the only explanation why this tendencies occurred is due to staircase effect created by orientation the angle of the part. Stair case effect generates the cusp-height (δ), which respectively is one of the factors influencing the surface roughness.

This result is in line with our assumption that the roughness of SLA's models on this angle will considerably be higher because the laser beam cut the model not perpendicular to the platform, which would result to good surface roughness.

5. CONCLUSIONS

From this present study, it can be concluded that:

By varying the orientation of the models, SLA gives a better overall result at which models are orientated at 16.875^o, and 22.5^o and worst for models built parallel to platform, Moreover, the characteristics of SLA shows the parabolic pattern. In addition, surface roughness of SLA's models from 0^o to 22.5^o part orientation are lying in a range between ± 0.65μm and ± 19.7μm. Referring to surface roughness table for various manufacturing processes, which was adapted by **Shellabear** [25] from Iuliano et al. (1994), it apparently revealed that the results from this present investigation is in the same range with surface roughness could be achieved by most material removal process methods.

6. RECOMMENDATIONS

To obtain the best results, further investigation is still required in these area highlighted below:

1. Building one part in one process and ensure that the process direction between these two methods are similar, so the effect comes from this process direction could be eliminated and the actual speed of them could be determined precisely.
2. Designing the complex geometry and dimension of the model, which represent the real design of tool, so it might give the actual information about implementation of SLA techniques as Rapid Tooling applications.
3. Using block experimental method to eliminated the unpredicted response.

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Curriculum Vitae

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