

DEWAXING OF ABS RAPID PROTOTYPE PATTERN FOR CERAMIC INVESTMENT  
CASTING OF PROXIMAL HUMERUS

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

Faculty of Mechanical Engineering  
Universiti Teknologi Malaysia

SEPTEMBER 2014

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Most importantly; I would like to thank God and dedication this thesis to my sweet parents, Azam Nabizadeh and Mohhamad Iranmanesh for their patience and praying. Also my appreciation dedicated to my beloved husband, Alireza Esmailzadeh for his sincere patience, sacrifice, inspiration, understanding and constant help and encouragement. Also my appreciation dedicated to my lovely sisters Saideh and Somayeh and my brother Amir for their patience, invaluable supporting, encouragement and praying for me, as well as Dr.Khoshnezhad for valuable helping and encouragement. Also I want to dedication to my husband's family for their constant support and encouragement. I could not have done it without you! Thank you for your love, support, great expectation and patience while I finished this project...

“This Is Our Success”

## ACKNOWLEDGEMENT

I Thank GOD the Almighty with whose blessings I have completed the whole of my final year project and this thesis. I would like to express my sincere appreciations to my Husband for his encouragements, advices and support during my studies. I was in contact with many people, academicians and practitioners. They have contributed towards my understanding and thoughts.

In particular, I wish to express my sincere appreciation to my supervisor, Prof.Dr.Mohd Hasbullah Bin Hj. Idris for his encouragement, guidance, advices and motivation. Without his continued support and interest, this thesis would not have been the same as presented here.

I also want to express my appreciations to technicians and lab assistants especially thank Cast Metal Lab technicians Mr. Wan Mazian and Mr. Mohd Saleem for their ideas, guidance, cooperation and help me to experiments using all the available facilities. I also thank Mr.Sukari Mamat of Production Department, for his help and contribution.

Last but not least, I would like to thank my parents, family members and friends for their assistants and encouragement in completing this thesis.

## ABSTRACT

Orthopedic implants can be defined as medical devices used to replace or provide fixation of bone or to replace articulating surfaces of a joint. Many proximal humerus bone cases require almost immediate/short lead time surgery. Thus rapid response from the manufacturer is very crucial. The manufacture of surgical implant often requires the use of machining process. Current trend shows that preform either from casting or forging is preferred to reduce machining cost and time. It is expected that by employing rapid manufacture using rapid prototyping and investment casting process could expedite the manufacturer to surgery time. The objective of this project is to evaluate the effect of dewaxing time on collapsibility characteristic of solid and hollow constructed rapid prototyped proximal humerus ABS pattern. FDM2000 machine was used to build the ABS patterns. Acrylonitrile Butadiene Styrene (ABS) P400 was used for pattern material in this study. Output responses investigated were collapsibility, expansion defects. ABS hollow and solid pattern are prepared and are subjected to dewaxing in different time and temperature. The ABS hollow and solid pattern were compared based on the dewaxing process results, ceramic shell defects. The best pattern material according to the optimum time and temperature was chosen based on the results and compared with the reference process. This study is expected to assist the investment caster to estimate the decomposition temperature and allowance required in preparing a mould from ABS pattern as well as in the initial CAD drawings to produce a final casting with minimal dimensional inaccuracy. It is hoped that the outcome of this study will assist the casting industries especially in biomedical in using the advanced product support tools using CAD and RP technology for higher productivity and quality products.

## ABSTRAK

Implan ortopedik boleh didefinisikan sebagai peranti perubatan yang digunakan sebagai pelekapan pada tulang atau gantian pada permukaan artikulat sendi. Kebanyakan kes tulang humerus proksimal memerlukan pembedahan yang serta merta/masa pendulu pendek. Oleh itu, respon yang pantas daripada pengilang pembuatan adalah amat penting. Pembuatan dalam pembedahan implan selalunya menggunakan proses pemesinan. Aliran semasa telah menunjukkan proses prabentuk samada daripada penuangan atau penempaan menjadi pilihan kerana dapat mengurangkan kos dan masa pemesinan. Justeru itu, pembuatan deras yang menggunakan prototaip deras dan proses penuangan lilin oleh pengilang berupaya menyegerakan masa pembedahan. Objektif kajian ini adalah untuk menilai kesan masa penyahlilinan pada sifat keboleh-runtuhan binaan prototaip deras bagi bentuk humerus proksimal ABS iaitu dalam keadaan pejal dan berongga. Mesin FDM2000 digunakan untuk membina bentuk ABS. Acrylonitrile Butadiene Styrene (ABS) P400 digunakan sebagai bahan bentuk dalam kajian ini. Respon output yang dikaji adalah keboleh-runtuhan dan kecacatan pengembangan. Bentuk ABS berongga dan pejal ini disediakan melalui penyahlilinan mengikut masa dan suhu yang berbeza. Bentuk ABS berongga dan pejal ini juga akan dibandingkan berdasarkan keputusan proses penyahlilinan dan kecacatan pada kelompok seramik. Bentuk yang terbaik pula ditentukan mengikut masa dan suhu optimum dan dipilih berdasarkan keputusan dan perbandingan melalui proses rujukan. Kajian ini dijangka dapat membantu pekerja tuangan lilin untuk menganggarkan suhu penguraian dan ruang kelegaan yang diperlukan dalam penyediaan acuan pembentuk daripada bentuk ABS dan juga didalam lukisan asal CAD. Oleh itu, tuangan dapat dilakukan mengikut ketepatan dimensi yang minimal. Selain daripada itu, hasil daripada kajian ini juga boleh membantu industri penuangan terutamanya dalam bio-perubatan yang menggunakan sokongan produk alatan termaju CAD dan juga teknologi pembuatan deras untuk meningkatkan produktiviti dan kualiti produk.

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

Shoulder arthroplasty is a successful procedure for the treatment of degenerative and traumatic conditions. The use of shoulder arthroplasty has grown significantly in recent years, with an annual increase of approximately 10%. The number of primary total shoulder replacements is expected to increase by 200% to 300% by the year 2015 (Day et al., 2010). This rapid increase in the number of shoulder replacement surgeries has been accompanied by an increased need for revisions with rates of revision shoulder arthroplasty increasing from 4.5% to 7% since 1993 (Petersen & Hawkins, 1998).

The etiology of a failed shoulder arthroplasty includes problems with soft tissues, bone, infection, and component malposition or wear. The success of revision shoulder arthroplasty depends on the reason for failure, with better results after revision for component related problems, and worse outcomes after soft tissue reconstructions (Y Joshua and S. Dines, 2006).

## LIST OF SYMBOLS

2D	-	Two dimensional
3D	-	Three dimensional
A	-	Ampere
ABS	-	Acrylonitrile Butadiene Styrene
C	-	Celsius
CAD	-	Computer Aided Design
CS	-	Ceramic shell
F	-	Fahrenheit
FDM	-	Fused Deposition Modeling
In	-	Inch
kg	-	Kilogram
QS	-	Quick Slice
RP	-	Rapid Prototyping
mm	-	Milimeter
gms	-	Grams
M	-	Meter
i.e.	-	In Example

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Investment casting is a key technique among a range of modern metal casting techniques that is capable of providing an economical means of mass production of shaped metal parts containing complex features such as thin walls, undercut contours and inaccessible spaces which are difficult or impossible to create using other fabrication methods (Beeley, 1995).

Despite the wide range of applications in many industries, the standard (conventional) investment casting process practice in modern foundries has its drawbacks. High tooling costs and lengthy lead times are associated with the fabrication of metal moulds required for producing the sacrificial wax patterns used in investment casting (Sachs, Cima, & Cornie, 1990). The high tooling costs involved in conventional investment casting result in cost justification problems when small numbers of castings are required.

Investment casting could do the following (Horton, 1988):

1. Produce complex shapes that are difficult to make by other means.
2. Reproduce fine detail, high dimensional accuracy, and smooth surfaces requiring only minimal finishing.
3. Adapt to most metal alloys.
4. Allow control of metallurgical properties, such as grain size and grain orientation.

Rapid prototyping (RP) techniques are fast becoming standard tools in the product design and manufacturing industries. With the capability of rapidly fabricating of 3D physical objects, rapid prototyping has become an indispensable tool employed for shortening new product design and development time cycles (Chua , 1997; Hilton , 2000). Rapid prototyping techniques are unlimited neither by the geometry nor by the complexity of the parts to be fabricated.

In addition, rapid prototyping techniques involve no tooling or fixtures, resulting in simpler set up, lower overhead cost and shorter production lead times compared to other fabrication methods. With rapid prototyping, parts that were previously impossible or extremely costly and time-consuming to fabricate can be built with ease.

The application of rapid prototyping -fabricated patterns as substitutes for the traditional wax patterns employed in investment casting stems from the fact that rapid prototyping materials can be melted and burned out from the ceramic shell (ceramic shell casting) without damaging it (Beaman, 1997). Most commercialized rapid prototyping techniques are capable of producing such patterns that can be used directly in investment casting. Most of the limitations encountered with earlier applications of RP-fabricated investment casting patterns include damage to the ceramic shells due to excessive thermal expansion of the pattern or the release of corrosive degradation by-products during pattern burn out, which cracks or attacks the cavity surface of the shell.

Ceramic shell cracking is attributed to a mismatch in the coefficient of thermal expansion (CTE) between the rapid prototyping and ceramic materials. Most rapid prototyping materials have CTE values that are larger than the ceramic material and as such, the expansion of the pattern during heating imposes significant amounts of stress on the ceramic shell. Shell cracking occurs when the stresses imposed by the expanding pattern are greater than the modulus of rupture (MOR) of the shell material (Yao & Leu, 2000).

In some cases, residual ash can also cause defects in the final castings when present in relatively significant quantities. Also, due to the high operating and material costs of rapid prototyping techniques, the utilization of rapid prototyping techniques has been reported to be beneficial only when five or fewer castings are required (Smith, 1996).

The application of rapid prototyping techniques to produce sacrificial investment casting patterns can be classified under two methods: the direct rapid prototyping method, and the indirect rapid prototyping method. The direct rapid prototyping method covers the

application of rapid prototyping techniques for producing plastic, wax or paper investment casting patterns for fabricating ceramic moulds that can be employed directly for metal casting e.g. direct shell production method (Beeley, 1995). For the indirect rapid prototyping method, alternative moulds for example is produced by silicone rubber molding in conjunction with an rapid prototyping -fabricated master pattern of the final desired casting are employed for the injection of investment casting patterns from foundry wax.

## **1.2 Problem Statement**

Many proximal humerus cases require almost immediate/short lead time surgery. Thus rapid respond from the manufacture is very crucial. The manufacture of surgical implant often requires the use of machining process. It can either be machined from metal block or preform produced from investment casting or forging processes. Current trend shows that preform either from casting or forging is preferred to reduce machining cost and time. It is expected that by employing rapid manufacture using rapid prototyping and investment casting process could expedite the manufacturer to surgery time. Finding a new way in manufacturing process (near net-shape) and material maybe can help to manufacture that produce joint implants faster.

## **1.3 Project Objectives**

Two specific objectives have been defined to clarify the general purpose of the project. The objectives of the project are:

- i. To determine the workable flash dewaxing parameters of solid and hollow rapid prototyped ABS patterns.

## **1.4 Project Scope**

The scopes of works for this project are as follows:

- i. The flash dewaxing parameters investigated will be the firing temperature and duration. The firing temperatures and duration investigated will be in the range between 300°C and 600°C.
- ii. The thickness of the ceramic investment casting mould will be of 4 layers thick with slurry viscosity of approximately 15-20s.

## **1.5 Overview Of The Thesis**

The remainder of the dissertation is devoted to the development of the previously stated objectives. Chapter 2 describes the theoretical knowledge, literature studies, and previous researches done by the researchers that are used to be a basic ground for the project. In chapter 3, a specific methodology of the project is presented. This would include experimental set up and list of equipment that are required for the performance evaluation of the project. Results and experimental analysis from the experimental data of ABS P400 FDM-fabricated for investment casting process and casting stainless steel 316L are presented in Chapter 4. A summary of the project is given in the final chapter which includes recommendations for future work.

## REFERENCE

- Allen, K. W. (2000). 'Concise encyclopedia of polymer science and engineering. *Materials Science and Technology*, 16(2), 233.
- Batwinder Singh Sidhu, Pradeep Kumar, and B.K. Mishra. (2008). Effect of Slurry Composition on Plate Weight in Ceramic Shell Investment Casting. *Journal of Material Engineering and Performance*.
- Beaman JJ, Barlow JW, Bourell DL, Crawford RH, Marcus HL, McAlea KP (1997). Solid freeform fabrication a new direction in manufacturing *Solid freeform fabrication*. Dordrecht: Kluwer.
- Beeley, Peter. (2002). *Foundry Technology* (Second Edition ed.). Butterworth: Heinemann.
- Beeley PR, Smart RF (1995). Investment Casting. *The Institute of Materials*.
- Chua CK, Leong KF. (1997). *Rapid prototyping*. New York: Wiley.
- Colin Gouldsen , Paul Blake (1998). Investment Casting Using FDM/ABS Rapid Prototype Patterns *Stratasys Inc. USA*.
- Day, Judd S., Lau, Edmund, Ong, Kevin L., Williams, Gerald R., Ramsey, Matthew L., & Kurtz, Steven M. (2010). Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. *Journal of Shoulder and Elbow Surgery*, 19(8), 1115-1120. doi: <http://dx.doi.org/10.1016/j.jse.2010.02.009>
- Degarmo PE, Black JT, and Kohser RA. . (2000). *Materials and Processes in Manufacturing* (9th ed.).
- Dickens PM, Stangroom R, Greul M, Holmer B, Hon KKB, Hovtun R, Neumann R, Noeken S, and Wimpenny D. (1995). Conversion of RP models to investment castings. *Rapid Prototyping Journal*, 1(4), 7.
- Geoffrey Boothroyd , Peter Dewhurst , Winston A. Knight. (2010). *Product Design for Manufacture and Assembly*. New York: Marcel Dekker.

- Harun, Wan Sharuzi Wan. (2007). *Evaluation of ABS pattern produced from FDM for Investment casting Postgraduate*. (Master), Universiti Teknologi Malaysia, Malaysia.
- Hendra Hermawan, Dadan Ramdan , Joy R. P. Djuansjah (2011). Biomedical Engineering -From Theory to Applications. *Metals for Biomedical Applications*, 978(953), 9.
- Hilton PD, Jacobs PF. (2000). *Rapid tooling: technologies and industrial applications*. New York.
- Horton, RA. (1988). *Investment casting* (Vol. 15). Metals Park: ASM International.
- J.Clegg. (1991). Precision Casting Processes. *Oxfords Pergaman Press*.
- KG, Cooper. (2001). *Rapid Prototyping Technology: Selection and Application*. New York: Marcel Dekker.
- Kwon, Y. (2000). *Robust control of Surface Roughness in a Turning Operation*. (PhD Dissertation), University of Iowa.
- Lee CW, Chua CK, Cheah CM, Tan LH, Feng C. (2004). Rapid investment casting: direct and indirect approaches via fused deposition modeling. *International Journal Advanced Manufacturing Technology*, 23, 93-101.
- M. Schwartz Mel. (2002). *Encyclopedia of materials, parts, and finishes*. Ed. Florida: CRC Press.
- Ma'aram, Azanizawati. (2003). *Quality assessment of Hollow Rapid Prototyping Model*. (Master), Universiti Teknologi Malaysia, Malaysia.
- Monsell, Fergal P. (2010). Bone & Joint. Retrieved 07, 2014, from <http://www.boneandjoint.org.uk/>
- Pennington, R. C., Hoekstra, N. L., & Newcomer, J. L. (2005). Significant factors in the dimensional accuracy of fused deposition modelling. *Proceedings of the Institution of Mechanical Engineers*, 219(1), 89-92.
- Petersen, Steve A., & Hawkins, Richard J. (1998). REVISION OF FAILED TOTAL SHOULDER ARTHROPLASTY. *Orthopedic Clinics of North America*, 29(3), 519-533. doi: [http://dx.doi.org/10.1016/S0030-5898\(05\)70026-2](http://dx.doi.org/10.1016/S0030-5898(05)70026-2)
- Pham, DT and Dimov SS. (2001). Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling. *Springer*.
- Prasad K.D.V. Yarlagadda, Teo Siang Hock. . (2003). Statistical analysis on accuracy of wax patterns used in investment casting process. *Material Processing Technology*, 138, 75-81.

- Roux, A., Decroocq, L., El Batti, S., Bonneville, N., Moineau, G., Trojani, C., . . . de Peretti, F. (2012). Epidemiology of proximal humerus fractures managed in a trauma center. *Orthopaedics & Traumatology: Surgery & Research*, 98(6), 715-719. doi: <http://dx.doi.org/10.1016/j.otsr.2012.05.013>
- Sachs, E., Cima, M., & Cornie, J. (1990). Three-Dimensional Printing: Rapid Tooling and Prototypes Directly from a CAD Model. *CIRP Annals - Manufacturing Technology*, 39(1), 201-204. doi: [http://dx.doi.org/10.1016/S0007-8506\(07\)61035-X](http://dx.doi.org/10.1016/S0007-8506(07)61035-X)
- Salonitis, K. (2014). 10.03 - Stereolithography. In S. Hashmi, G. F. Batalha, C. J. V. Tyne & B. Yilbas (Eds.), *Comprehensive Materials Processing* (pp. 19-67). Oxford: Elsevier.
- Sivadasan M, N.K Singh and Anoop Kumar Sood. (2012). *Use of fused deposition modeling process for investment Precision casting a viable rapid tooling*. Paper presented at the second International Conference on advancement in Mechanical engineering, India.
- Smith BJ, St. Jean P, Duquette ML. (1996). *A comparison of rapid prototype techniques for investment casting Be-Al*. . Paper presented at the Proceedings of rapid prototyping and manufacturing '96 conference, Dearborn, MI.
- Stratasys®. (1998). Investment Casting Using FDM/ABS Rapid Prototype Patterns: USA.
- Wikipedi. (2000). Rapid Prototyping. Retrieved 1th May, 2014, from [http://en.wikipedia.org/wiki/Rapid\\_prototyping](http://en.wikipedia.org/wiki/Rapid_prototyping)
- Y Joshua S. Dines, MD, Stephen Fealy, MD, Eric J. Strauss, MS, Answorth Allen, MD, Edward V. Craing, MD, Russell F. Warren, MD, AND David M. Dins, MD. (2006). Outcomes Analysis of Revision Total Shoulder Replacement. *The Journal of Bone and Joint Surgery* 88(1500), 1494.
- Yao, W. L., & Leu, Ming C. (2000). Analysis and design of internal web structure of laser stereolithography patterns for investment casting. *Materials & Design*, 21(2), 101-109. doi: [http://dx.doi.org/10.1016/S0261-3069\(99\)00061-8](http://dx.doi.org/10.1016/S0261-3069(99)00061-8)
- Yarlagadda, Prasad K. D. V., & Hock, Teo Siang. (2003). Statistical analysis on accuracy of wax patterns used in investment casting process. *Journal of Materials Processing Technology*, 138(1-3), 75-81. doi: [http://dx.doi.org/10.1016/S0924-0136\(03\)00052-9](http://dx.doi.org/10.1016/S0924-0136(03)00052-9)