EVALUATION OF MECHANICAL PROPERTIES OF ALLUMINIUM FILLED EPOXY COMPOUND FOR RAPID TOOLING APPLICATIONS

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بسم الله الرحمن الرحيم

In the name of God, most Gracious, most Compassionate

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ABSTRACT

In this study, the mechanical properties and microstructure inspection for aluminium filled epoxy including hardness, dimension accuracy, density, compressive test, fracture analysis were evaluated . An investigation measurement for the grain size on the three different temperature was carried out. Result shows that the grain size or G number microstructure for aluminium filled epoxy having a different size and distribution was corresponding with increase in temperature. In term of dimensional accuracy inspection, aluminium filled epoxy tends to have shrinkage experience with rate of 0.05% to 0.06% for round part while 0.15% for pin .The compressive strength shows a better trend during cooling in ambient temperature compared to cooling in an oven. In term of density, there was no significant effect to the hardness when tested with Vickers Hardness Tester , Barcol Impresser and Shore D Durometer . The parameter design mixing and curing for aluminium filled epoxy using Taguchi Method which based on larger is better is optimized .Four control factors are investigated in the study: pre curing time, degassing time, Interval time curing and maximum curing time. The response plot of the control factor shows factor A2 (pre curing at 50ºC), B2 (degassing time at 45 minute) C3 (interval curing at 14 hour) D2 (maximum curing at (165ºC) and factor A2 (pre cuing at 27ºC), B3 (degassing time at 30 minute) C1 (interval curing at 14 hour) D2 (maximum curing at (165ºC) were significant in contributing in mixing and curing to increase the hardness and density of aluminium filled epoxy.

ABSTRAK

Dalam kajian ini, sifat-sifat mekanikal dan pemeriksaan microstruktur untuk *aluminium filled epoxy* termasuk kekerasan, ketepatan dimensi, ketumpatan, ujian mampatan, analisis patah telah dinilai. Ukuran untuk saiz bijian pada tiga suhu yang berbeza telah dijalankan. Keputusan menunjukkan bahawa saiz butiran atau G number mikrostruktur *aluminium filled epoxy* mempunyai saiz yang berbeza selaras dengan peningkatan suhu. Dalam pengukuran ketepatan dimensi, *aluminium filled epoxy* cenderung untuk mengalami pengecutan dengan kadar 0.05% kepada 0.06% bagi sampel bulatan manakala 0.15% untuk pin. Kekuatan mampatan menunjukkan trend yang lebih baik semasa penyejukan suhu persekitaran berbanding penyejukan dalam oven . Dari segi ketumpatan, tidak ada kesan yang ketara kepada kekerasan apabila diuji dengan Vickers Hardness Tester, Barcol Impresser dan Shore D durometer. . Reka bentuk parameter bagi penyediaan bahan untuk *Aluminium filled epoxy* .denagn menggunakan Kaedah Taguchi yang berdasarkan yang lebih besar adalah lebih baik (*Larger the better*) Empat faktor kawalan disiasat dalam kajian ini:. *Curing time*, *Degassing time* masa *Intervel time* dan *Maximum Curing Time* .Keputusan menunjukkan faktor A2 (*Curing time* 50 º C), B2 (*Degassing time* 45 minit) C3 (*Intervel time* 14 jam) D2 (*Maximum Curing* 165 º C) dan A2 (*Curing time* 27 º C), B3 (*Degassing time* 30 minit) C1 (*Intervel time* 14 jam) D2 (*Maximum Curing* 165 º C) adalah faktor penting bagi menyumbang kepada kekerasan dan ketumpatan semasa proses penyediaan bagi *aluminium filled epoxy*.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Increasing global competition, together with the rising number of product variants with shorter life cycles in today's way forcing manufacturing companies and industries to reduce their development time of the manufactured components. Currently, companies are experiencing increasing pressure to produce complex and diverse products in shorter product development cycles, aiming to achieve less overall cost with improved quality (Evans and Campbell, 2003). Besides product costs and quality, the set-up time of a new product is a key factor for the competitiveness of the manufacturing. Due to that, new manufacturing methods such as rapid tooling are becoming increasingly important to save the time, cost and lead time for fabricated tooling for injection moulding mould especially mold and cavity insert. Production of tooling is a slowest and most expensive exercises because of accuracy and quality needed depending on the manufacturing process involved. Rapid tooling processes are now being considered as an option specifically tooling to be developed economically. An idea in this research is to develop accurate process parameters for mixing and curing of aluminium filled epoxy compound for rapid tooling applications. It offers great potential and opportunity in product development especially to mold maker and rapid tooling application.

1.2 Problem Statement

Over the past years, rapid tooling (RT) has been largely seen as complementary technology, for quickly making tools for various kinds of prototype applications, within the tooling sector. Compare with conventional method, the traditional method of developing tool (punch and cavity) takes more time to be ready for production (Rahmati *et al.,* 2007). The use of epoxy resin in aircraft, guided weapons, ships and vehicle construction has increased markedly in the last decade and this dramatic growth rate shows every sign of continuing in shaping the future. Many efforts and attempts have been made to understand the behaviour of epoxy resin in product quality. Research by M.Vaezi *et al.*, (2010) reported that epoxy resin moulds had higher accuracy compared with conventional tooling for injection mould for manufacturing gas turbine blade. Epoxy resin in rapid tooling application can help to reduce both the cost and lead time required for part production by up to 25% and 50%. (Cheah *et al*., 2002)

Like other materials, plastic, can be sensitive and tend to lose the structure integrity when damage. The damage can happen whether at time of manufacture or during in service. Its same goes to epoxy based material. When cured, epoxy resins are highly cross-linked, amorphous thermoset polymers and this structure results in many useful properties, such as high modulus, low creep and good performance at elevated temperature.

However, it also means that the unmodified epoxies are relatively brittle polymers with poor resistance. Cheah *et al*., (2002) reported high pressures were imposed during moulding which caused significant amount of stress to be generated within the mould and causing crack in the epoxy resin mould. Figure 1.1 below shows a crack line observed on the cavity side mould half after series of 400 moulding cycle with PC material.

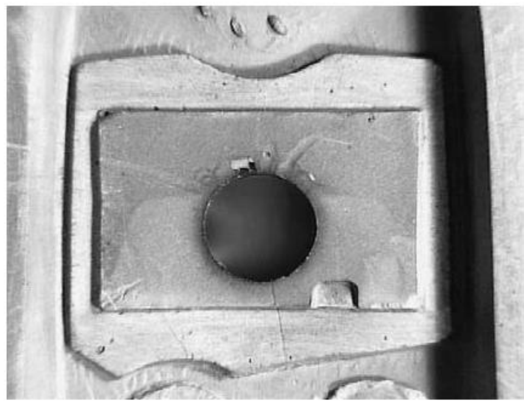

Figure 1.1 Crack appearing on the surface of mould half (Cheah *et al.,* 2002)

Depending on the specific needs for certain physical and mechanical properties, combinations of the right choices of epoxy resin and curing agents can usually be formulated to meet the market demands. The current challenges and issues found in epoxy resin are to combine strength, accuracy, surface finish and thermal characteristics. It is widely acknowledged that not all rapid tooling meet all above requirements. When tooling engineers considers RT to use in functional prototype production, varieties of issues arises. According to Nagahanumaiah *et al.,* (2003) issues in rapid tooling as follows:

i. The accuracy, durability, surface finish and overall performance of tooling
ii. Cost, lead time, process capability (geometric constraints)
iii. The quantity of part produced
iv. The quality of part produced

From previous researches that has been done, the data for curing and mixing is limited. No comprehensive data optimization in mixing and curing of aluminium filled epoxy. Thus, an initiative has been undertaken to conduct this research in order to determine the setting best parameter in mixing and curing for rapid tooling application. The mechanical and metallurgical properties of aluminium filled epoxy will be evaluated. It is expected that appropriate process parameters for mixing and curing of aluminium filled epoxy compound will offers significant benefits to mold maker and rapid tooling industries.

1.3 Research aim and objectives

The aim of the study is to establish and to evaluate the aluminium epoxy compound for rapid tooling application. In order to achieve the above goal, the specific objectives and scope were set for this research as follows:

1.4 Objectives of the study

i. To determine the appropriate process parameters for mixing and curing aluminium filled epoxy compound for rapid tooling applications.
ii. To evaluate the metallurgical and mechanical properties Aluminium filled epoxy compound.
iii. To establish the optimum parameters for mixing and curing aluminium filled epoxy using Taguchi approach.

1.5 Research Scopes

i. The resin used is aluminium filled with epoxy.
(Rencast © CW47 / Ren © HY 33)

ii. Develop appropriate process parameters using Design of Experiment (DOE) approach.

iii. To evaluate the metallurgical and mechanical properties of aluminium filled epoxy using Scanning electron microscope (SEM) and others mechanical testing equipment was used to plan the experiments and identify the significant parameters that affect the responses..

REFERENCES

Antonio J. Pontes ,Miguel P. Queirós ,Pedro G. Martinho , Paulo J. Bártolo and António S. Pouzada (2010). Experimental assessment of hybrid mould performance. *International Journal Advance Manufacturing Technology*.50: pp 441–448

Ariyanti Sarwono , Zakaria Man and M. Azmi Bustam (2012) .Blending of Epoxidised Palm Oil with Epoxy Resin: The Effect on Morphology, Thermal and Mechanical Properties. *Journal Polymer Enviroment* 20:540–549

A Rosochowskia and A. Matuszak (2000). The state of the art . Rapid tooling. *Journal of Materials Processing Technology* 106 ,pp191 – 198.

ASTM F2792 - 12a *Standard Terminology for Additive Manufacturing Technologies.*

ASTM 695-96 – *Standard Test Method for Compressive Properties of Rigid Plastic*

ASTM G99-95a – *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*

Brush Wellman Inc. (2010) Grain Size and Material Strength: Technical Issue No 15 March 2010.

Chil-Chyuan Kuo, Zhi-Yang Lin and Wang-Lin Tsai (2012). A New Environment Friendly Process For Making Green Epoxy-Based Composites Mold Advanced Materials Research Vols. 341-342 (2012) pp 194-198

C. M. Cheah , C. K. Chua and H. S. Ong (2002) Rapid Moulding Using Epoxy Tooling Resin. *International Journal Advance Manufacturing Technolpgy* (2002) 20:368–374

Daniel H. Herring. Grain Size and Its Influence on Materials Properties. August 2005 – Industrial Heating.com.

D T Pham and S S Dimov (2003) Rapid Prototyping and Rapid Tooling- The Key Enablers for Rapid Manufacturing. Proceedings of the Institution of Mechanical Engineers, Part C: *Journal of Mechanical Engineering Science* 217:1

Eric Radstok (1999*)* Rapid tooling *Rapid Prototyping Journal*. Volume 5 . Number 4 . 1999 . pp. 164-68

Evans, M.A. and Campbell, R. I. (2003). A Comparative Evaluation of Industrial Design Models Produced Using Rapid Prototyping and Workshop-Based Fabrication Techniques. *Rapid Prototyping Journal*, Vol. 9

J.C. Ferreira and A. Mateus (2003) A. Studies of Rapid Soft Tooling With Conformal Cooling Channels For Plastic Injection Moulding. *Journal of Materials Processing Technology*. pp 508–516

H. Brull 1959 Anti-Corrosion Methods and Materials Volume: 6 Issue: 10 1959

H.Muller and J.Sladojevic (2001) Rapid Tooling Approaches For Small Lot Production Sheet-Metal Parts .*Journal of Materials Processing Technology* 115 (2001) 97-103

I. M. low, C. SHI (1998) Vickers Indentation Responses of Epoxy Polymers .*Journal of Materials Science* Letters 17 (1998) pp 1181-1183

Ismet Ilyas , Chris Taylor, Kenny Dalgarno and John Gosde. (2010). Design and Manufacture of Injection Mould Tool Inserts Produced Using Indirect SLS and Machining Processes, *Rapid Prototyping Journal*. Vol. 16, No. 6, pp. 429-4

Jack G. Zhou, Monnappa Kokkengada, Zongyan He, Yun S. Kim and Ampere A. Tseng (2004). Low Temperature Polymer Infiltration for Rapid Tooling , *Materials and Design* 25 (2004) pp145–154.

J. C. Male (1996) The Accuracy and Surface Roughness of Wax Investment Casting Patterns from Resin and Silicon Rubber Tooling Using a Stereolithography Master. *Second National Conference on Rapid Prototyping and Tooling Research*, pp. 43-52

J. D. N. Shaw (1972) Epoxy Resins -Materials For The Engineer Pigment and *Resin Technology Volume*: 1 Issue: 12 1972

J.L. Massingill Jr. and R.S Bauer 2000) Epoxy Resins *Applied Polymer Science*: 21st Century, Pages 393-424

J. Zhang, Y. C. Xu and P. Huang (2009) , Effect of Cure Cycle on Curing Process and Hardness for Epoxy Resin *eXPRESS Polymer Letters Vol.3, No.9 (2009) pp 534–541*

Khairur Rijal Jamaludin , Mohd Shahriman Adenan , Mohd Yusof Md Daud and Norazmein Abd Raman (2012) Delaminating Control on Drilling the Medium Density Fiber Board with Robust Optimization. *Jurnal Teknologi (Sciences & Engineering)* 59 (2012) Suppl 1, 99–103

.

Krikorian, G. (1996) IEEE Conference Publications WESCON/96 Digital Object Identifier: 10.1109/WESCON.1996.554006 Year: 1996 , pp 312 - 316

K.P. Karunakaran , P. Vivekananda Shanmuganathan,Sanjay Janardhan Jadhav,Prashant Bhadauria and Ashish Pandey.P. Karunakaran et al., (2000) Rapid Prototyping of Metallic Parts and Moulds. *Journal of Materials Processing Technology* 105 (2000) 371 – 381

Gayle Ramdeen Linka, John Fesslera, Alex Nickela and Fritz Prinza (1998) Rapid Tooling Die Cast Inserts Using Shape Deposition Manufacturing. *Materials and Manufacturing Processes* 13, pp263–274.

M. H. Irfan Chemistry and Technology of Thermosetting Polymers in Construction Applications 1998, pp 8-77 Springer Netherlands

M.S. Bhagyashekar, Kavaitha Rao and R.M.V.G.K. Rao (2008) Studies on Rheological and Physical Properties of Metallic and Non-metallic Particulate Filled Epoxy Composites.*Journal of Reinforced Plastics and Composites* Vol. 28, no. 23/2009

M.S. Bhagyashekar and R.M.V.G.K. Rao (2010). Characterization of Mechanical Behaviour of Metallic and Non-metallic Particulate Filled Epoxy Matrix Composites *Journal of Reinforced Plastics and Composites*, Vol. 29, No. 1/2010

Mueller, T (1995). Stereolithography-Based Prototyping: Case Histories of Application in Product Development. *IEEE Technical Application and Conference Workshops*, Portland, Oregon, 10 October pp. 305–309.

M. Vaezi, D. Safaeian and C.K. Chua (2011). Gas Turbine Blade Manufacturing By Use of Epoxy Resin Tooling and Silicone Rubber Molding Techniques *Rapid Prototyping Journal* 17/2 pp 107–115

Nagahanumaiah , K. Subburaj, B. Ravi (2003). Rapid Tooling Application in Functional Prototype Production: Towards Modeling RT Issues Technical paper presented at the RPSI Conference, Bangalore, June 2003

One-Part Epoxy Resin Three Bond Technical News Issued October 1, 1987

R.A. Harris, R.J.M. Hague and P.M. Dickens (2004) .The Structure of Parts Produced by Stereolithography Injection Mould Tools and The Effect on Part Shrinkage. *International Journal of Machine Tools & Manufacture* 44 (2004) 59–64

Prashant K. Jain , K. Senthilkumaran, Pulak M. Pandey and P. V. M. Rao (2006) Advances in Materials for Powder Based Rapid Prototyping *Proceeding of International Conference on Recent Advances in Materials and Processing* Dec. 15-16, 2006, PSG-tech. Coimbatore, INDIA

P.S. Grant, S.R. Duncan, A. Roche, and C.F. Johnson (2006) Scientific, Technological, and Economic Aspects of Rapid Tooling by Electric Arc Spray Forming *Journal of Thermal Spray Technology* Volume 15(4) December 2006—801

P.V. Vasconcelos , F.J. Lino, A. Magalh˜aes and R.J.L. Neto (2005). Impact Fracture Study of Epoxy-Based Composites with Aluminium Particles and Milled Fibres. *Journal of Materials Processing Technology*.170 (2005) 277–283

Sadegh Rahmati and Phill Dickens (2007) Rapid Tooling Analysis of Stereolithography Injection Mold Tooling. *International Journal of Machine Tools and Manufacture* , 47,pp 740–747.

R.J.M. Hague, and P.E. Reeves (2000) *Rapid Prototyping, Tooling and Manufacturing* Rapra Technology Ltd pp. 17

Sayana John P , Jyothish Kumar P and Bejoy Francis (2009) Mechanical and Morphological Analysis of Epoxy Resin/San Blends. *ISSN: 0973-7464 Vol. XVI:* No.1 & 2 SB Academic Review 2009: 91-100

S Bal (2010). Experimental Study of Mechanical and Electrical Properties of Carbon Nanofiber/Epoxy Composites *Materials and Design* .31 (2010) 2406–2413

S.I Chung, Y.G Im, H.D Jeong and T.Nakagawa (2003) The Effect Metal Filler On The Characteristic of Casting Resin for Semi-Metallic Soft Tool. *Journal of Materials Processing Technology* 134 pp 26-34.

S. Kashima and J.E Breen (1974) Epoxy Resins for Jointing Segmentally Constructed Prestressed Concrete Bridges. Center for Highway Research The University of Texas

Shyam Kumar Karna and Dr. Rajeshwar Sahai (2012) An Overview on Taguchi Method *International Journal of Engineering and Mathematical Sciences* Jan.- June 2012, Volume 1, Issue – 1, pp.1-7

S. Maa (2007) Rapid Tooling With Particulate Reinforced Epoxy Composites For Low Volume production *SIMTech Technical Reports* Volume 8 Number 1 Jan - Mar pp 11-17

Somerville, G. R. and Jones, P. D. In: Applied Polymer Science"; Graver, J. K., Ed.; American Chemical Society, Advanced in Chemistry Series: Washington, D. C. (1975)

Rencast CW47 Datasheet March 2007 Huntsman Advanced Material GmBH, Switzerland

T.M Goulding , Epoxy Resin Adhesives *Taylor & Franciss Group*, LLC 2003

Tosin Tomori, Shreyes Melkote and Mahesh Kotnis (2004) Injection mold performance of machined ceramic filled epoxy tooling boards *Journal of Materials Processing Technology*. 145 (2004) pp 126–133

Xiaoping Jiang , Xingyang Liu and Chao Zhang (2005) Feasibility study of a new rapid tooling process *International Journal Advance Manufacturing Technology* (2005) 27: 296–304

Yonggwan Im, Hoyoun Kim, Sunjoon Park and Haedo Jeong (2005) Evaluation for Micro Scale Structures Fabricated Using Epoxy-Aluminium Particle Composite *A*nd Its Application. *Journal of Materials Processing Technology* pp 168-1173

Yuin Wu and Alan Wu (2000) *Taguchi Methods for Robust Design* , The American Society of Mechanical Engineers