The Conceptual Framework of Hydroxyapatite Fiber Structure by Slip-Casting Techniques

Norhidayah Md. Zainuddin, Shahriman Zainal Abidin, Oskar Hasdinor Hassan and Rusmadiah Anwar

Abstract Hydroxyapatite (HA) has been studied in many fabrication techniques for skull reconstructive material. In previous studies, the study has accomplished fabricating the HA through the conventional slip-casting technique. The study revealed that it is challenging to control the casting due to the fast-drying composition of HA when dispersed in sodium hexametaphosphate. Through another observation on titanium mesh application for skull reconstruction and characteristic of slip-soaked fiber, the study proposed a similar technique by combining these study findings. Fiber mesh material, soaked in HA slip, could have the potential to duplicate the application of titanium mesh. However, the study parameters, especially the selection of the fiber mesh material and the desired thickness, need careful rationalization.

Keywords Slip-soaked fiber · Fiber mesh · Hydroxyapatite · Fiber structure · Slip casting

1 Introduction

Hydroxyapatite (HA) is one of the most often considered substitutes for bone. There were various studies on its method application with attempts to produce porous structures. This includes ceramic foam technique, polymeric sponge

N.Md.Zainuddin (✉) · S.Z. Abidin · O.H. Hassan · R. Anwar
Formgiving Design Research Group, CoRe Humanities Design and Creativity,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
e-mail: norhidayahmz@yahoo.com

S.Z. Abidin
e-mail: shahriman.z.a@salam.uitm.edu.my

O.H. Hassan
e-mail: oskar@salam.uitm.edu.my

R. Anwar
e-mail: rusma935@salam.uitm.edu.my

S.Z. Abidin et al. (eds.), *Proceedings of the 2nd International Colloquium of Art and Design Education Research (i-CADER 2015)*,
DOI 10.1007/978-981-10-0237-3_2

method, gel casting of foams, starch consolidation, microwave processing, cement paste, slip casting, and spray drying [1]. This fabrication method will play a significant role towards particular application of the synthetic bone. Among the most utilized methods of fabrication is through colloidal processing such as the tape-casting, gel-casting, or slip-casting technique [2–5]. Colloidal processing especially slip casting has been notable to be among the applicable methods to construct complex forms [6].

Manufacturing and fabricating are among the design considerations in most product design [7]. The ease of fabricating factors may be influenced by the method and materials used [8]. This strategy is also applicable in ceramic design studies, where possible method options are constrained by the material's limit as summarized by research [9], based on the compatibility matrix suggested by Boothroyd et al. [10]. These researchers classified the fabricating method into three categories consisting of primary, primary and secondary, and tertiary processes. A process that is capable of producing the main component form is considered the primary processes, and casting falls under this category [11]. The second process category defines the method that can be achieved by producing the main shape of a component with improved features [12]. On the other hand, the finishing processes of a component are considered the tertiary processes [9, 10]. A product that can be fabricated with optimum performance and be cost effective would be the main requirement to compete in the current market scenario. Therefore, design consideration should be evaluated in a systematic way to assist designers in selecting the appropriate materials and fabricating method.

In a previous paper, the author has studied the casting ability of HA material with the conventional slip-casting method. This casting method successfully produced a semi-sphere cast form that has the potential for frontal cranial reconstruction design.

2 Issues of HA Slip Casting

2.1 Cast HA

In the previous work, the synthesized HA obtained based on the microwave synthesis technique referred to a study [13] and was castable in semi-sphere form in order to replicate the general frontal skull, although in actuality the radius curve would require some alteration. This form was also applied in a similar study [14]. The cast HA was also successfully sintered at the temperature of 1100 °C.

The HA samples were cast with two different techniques, solid casting and also hollow casting. The dispersion agent used in this HA slip was sodium hexamethaphosphate $(NAPO_3)_6$. The casting approach was the conventional slip-casting technique that did not involve any compression mechanism. The drawback of this method was it produced uneven casting thickness due to the fast-drying HA slip.

Thus, in this chapter, the author would like to propose incorporating fiber material and form structure in the achieved HA slip. Fiber composite materials are widely used to reinforce strength in bone substitute development [15]. Although it seems that in the case of applications for frontal skull reconstruction, load bearing is almost not required, the fiber structure could aid in achieving the mesh-like structure.

2.2 Conceptual Casting Methods

Mesh structure could achieve precise architecture in a study conducted on patients of cranial reconstruction compared to normal bone grafts. This is due to the certain cranial contour that needs to be accomplished [16]. Mesh structures are normally produced with titanium material. It is commonly used in cranial surgery, as per Fig. 1. However, unlike HA, although titanium is a bioactive material, it is not able to develop as natural bone throughout time. An ideal bioactive material should be able to become natural bone as it tolerates and encourages bioactivities to take place in the body [1].

A technique on fiber material soaked with ceramic slip was shared by Robin Hopper, as applied for his art piece decoration [17, 18] and managed to retain the structure after sintering. Another similar method was also reported as the main body of a ceramic lamp. In this study, the fiber used was treated by scouring and bleaching leaving the fiber up to 90 % cellulose before it was soaked with ceramic suspension. This method concluded that the application may not be appropriate for intricate forms due to its low endurance [19, 20].

Based on this evidence, it may be possible to apply this method to replace the slip-casting technique in the HA that was employed in the previous work. This is due to the uncomplicated form of the frontal skull itself. However, based on several

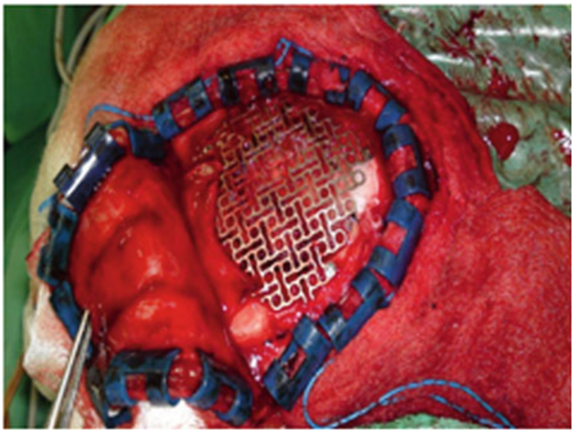

Fig. 1 Burr hole being covered with titanium mesh in a cranioplasty surgery. Courtesy of Dr. Ahmad Khan bin Ibrahim Khan, Neurosurgeon Consultant, KPJ Johor Specialist Hospital

studies on cranial reconstructive work, it would be a huge advantage if the dimension of the specific area were able to be comprehended before the surgery. This is due to the appearance of aesthetic [21, 22] imperfection that could occur by the nonconforming surface on the application area. Such a consequence may occur if the curvature of the implant does not fit well to the original skull [23].

Arising from this point, it relates back to the importance of design and fabrication of a product. Therefore, in this work a conceptual study of fiber-soaked HA slip technique is proposed as another technique for skull reconstructive design. In the ceramic sintering process, it was acknowledged that organic materials such as carbon, inorganic carbons, or sulphate would burn off at about the temperature of 900 °C, leaving the structure influenced by the organics deposited in the clay [18]. This information is in line with the sintering temperature for the obtained HA in the previous study, where the samples were sintered at the temperature of 1100 °C.

3 Proposed Technique

In this study, fiber mesh is proposed to replace the role of the plaster of Paris mould in the slip-casting process. However, prior to that, the dimensions of the mesh opening need to be determined. This is important in order to predict the allowances for the bioactive when implanted in the human body. The porosity distribution is the main aspect of design consideration in bone graft applications. Each porosity dimension character carries a certain ability, where small surface pores could constrain body fluid movement and reduce bio performance [20]. A study revealed that in order to enable surrounding bone augmentation as well as blood distribution, the minimum requirement is between 100–150 μm for macrospores, whereas 50 μm pores are acceptable for osteoconductivity [23].

Similar to the slip-casting absorption mechanism, this technique will manipulate the advantage of the fiber character to absorb the slip to the fiber mesh. In slip casting, the plaster of Paris porosity facilitates the withdrawal of water from the slip leaving the form [24], and this is known as capillary action. The slip-casting technique is an advantage especially in producing intricate forms. However, for a less-complicated radius curve such as the frontal skull, we propose that the soaked fiber mesh be placed on a semi-sphere template to copy and achieve the intended curve. This is referenced from a study that reveals a similar template approach [25], known as “contouring mould shaping” (see Fig. 2).

The common aspects of these techniques are it requires the liquid to be eliminated through dehydration and form a green body. Careful actions need to be taken by ensuring the slip has been fully absorbed into the fiber mesh. Failure in this could lead to “nonsoaked” fiber and break the mesh chain threads once sintering is conducted.

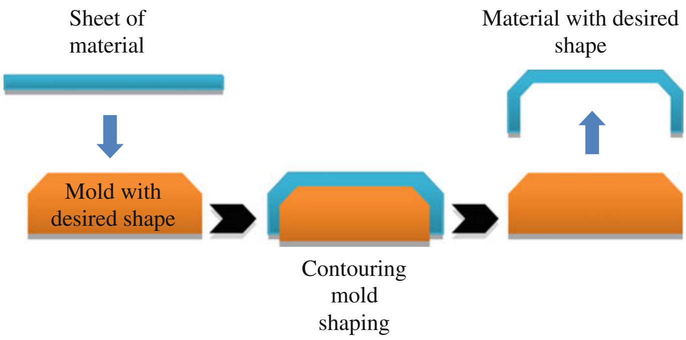

Fig. 2 Contouring mould-shaping technique

The parameters of studies should include the thickness of fiber required to achieve appropriate skull thickness. This would also include the shrinkage percentage of the soaked fiber after the sintering process [26]. Careful consideration needs to be given to rationalization as the mesh opening could be affected by the shrinkage rate. Another factor that needs to be considered is the fiber material selection itself as the material may vary in its absorption ability, the mesh opening as well as the thickness of the thread. Lastly, to achieve the desired specific form or shape using the contouring mould shape approach, the accuracy of the radius curve needs to be addressed [26, 27].

4 Summary

HA slip casting is a promising material for skull reconstructive work. Many aspects have been studied including the design engineering, the fabrication, and the material selection such as the HA composition itself. Based on the findings from previous attempts on HA slip casting, the study proposed another approach to fabrication by replacing the slip-casting technique with slip-soaked fiber to achieve the titanium mesh structure that is commonly used in cranial reconstruction surgery. The technique has potential, based on the findings of previous studies with similar approaches. This new technique was anticipated to counter the challenges of uneven casting thickness faced in previous studies.

Acknowledgment We would like to acknowledge the generous participation of the interaction designers in the research. This study was conducted in the Formgiving Design Research Lab. Our full appreciation also goes to the Universiti Teknologi MARA (UiTM) for the financial support under Formgiving Design Research Entity Initiative and Research Management Centre for their administrative support.

References

1. Sopyana, I., Melb, M., Rameshc, S., & Khalidd, K. A. (2007) Porous hydroxyapatite for artificial bone applications. *Science and Technology Advanced Materials, 8*(1–2), 116–123.
2. Arita, I. H., Castano, V. M., & Wilkinson, D. S. (1995). Synthesis and processing of hydroxyapatite ceramic tapes casting with controlled porosity. *Journal of Material Science Materials in Medicine, 6*(1), 19–23.
3. Toriyama, M., Ravaglioli, A., Krajewski, A., Galassi, C., Roncari, E., & Piancastelli, A. (1995). Slip casting of mechanochemically synthesized hydroxyapatite. *Journal of Material Science, 30*(12), 3216–3221.
4. Padilla, S., García-Carrodeguas, R., & Vallet-Reg, M. (2004). Hydroxyapatite suspensions as a precursors of pieces obtained by gelcasting method. *Journal of Europian Ceramic Society, 24*(8), 2223–2232.
5. Zainuddin, N. M., Rahim, Z. A., Anwar, R., Mujir, M. S., Hassan, O. H. (2012). Conceptual framework of hydroxyapatite for damaged skull through design approach. I*n IEEE Business, Enginering & Industrial Applications Colloquim* (BEIAC), Kuala Lumpur.
6. Begam, H., Chanda, A., & Kundu, B. (2011). fabrication of fine grained dense HAP through slip casting route. *International Journal of Engineering Science and Technology, 3*(2), 1258–1265.
7. Anwar, R., Hassan, O. H., & Abidin, S. Z. (2015). A pattern in formgiving design: Giving priority to a principle solution in industrial design situation. In M. Gen, K. J. Kim, X. Huang, & Y. Hiroshi (Eds.), *Industrial engineering, management science and applications 2015*. Berlin: Springer.
8. Roy, R., & Riedel, J. C. (1997). Design and innovation in successful product competition. *Technovation, 17*(10), 537–548, 593–594.
9. Nilsson, M. (1998). *Component design: A theoretical study of form synthesis, materials selection and process selection*. Sweden: Unitryck, Linkoping.
10. Boothroyd, G., Dewhurst, P., & Knight, W. A. (2011). *Product design for manufacture and assembly* (3rd ed.). United States: Taylor & Francis Group.
11. Anwar, R., Kamarun, H. R., Vermol, V. V., & Hassan, O. H. (2011). Marble dust incorporate in standard local ceramic body as enhancement in sanitary ware products (pp. 355–357). In *IEEE Colloquium on Humanities, Science and Engineering (CHUSER)*, Penang.
12. Abidin, S. Z., Sigurjónsson, J. B., Liem, A., & Keitsch, M. M. (2008). On the role of formgiving in design. In *10th International Conference on Engineering and Product Design Education-New Perspective in Design Education*, DS46-1-365-370.
13. Ramli, R., Omar Arawi, A. Z., Talari, M. K., Mahat, M. M., & Jais, U. S. (2010). *Synthesis and structural characterization of nano-hydroxyapatite biomaterials prepared by microwave processing*. Penang, Malaysia: American Institute of Physics.
14. Zanott, B., Verlicchi, A., Indiani, S., Scarparo, S. A. Zingaretti, N., & Parodi, P. C. (2015). Spontaneous fractures in custom-made porous hydroxyapatite cranioplasty implants: Is fragility the only culprit? *Acta Neurochirurgica The European Journal of Neurosurgery*.
15. Von Gonten, A. S., Kelly, J. R., & Antonucci, J. M. (2000). Load-bearing behavior of a simulated craniofacial structure fabricated from a hydroxyapatite cement and bioresorbable fiber-mesh. *Journal of Materials Science Materials in Medicine, 11*, 95–100.
16. Ellis, E. B., & Tan, Y. (2003). Assessment of internal orbital reconstructions for pure blowout fractures: cranial bone grafts versus titanium mesh. *Journal of Oral and Maxillofacial Surgery, 61*(4), 442–453.
17. Hopper, R. (2004). *Making marks: Discovering the ceramic surface*. New York, USA: Krause Publications.
18. Rhodes, D. (1974). *Clay and glazes for the potter*. New York, USA: Thomas Nelson & Sons Ltd.
19. Lawanwadeekul, S., & Bunma, M. (2014). Using natural fibers in forming the body of ceramic lamp. *Key Engineering Materials, 608*, 331–334.

20. Liu, D.-M. (1996). Fabrication and characterization of porous hydroxyapatite granules. *Journal of Biomaterials, 17*(20), 1955–1957.
21. Anwar, R., Hassan, O. H., & Abidin, S. Z. (2015). Theoretical framework for ceramic design studies facing advanced mathematical educational research. In O. H. Hassan, S. Z. Abidin, R. Anwar & M. F. Kamaruzaman (Eds.), *Proceedings of the International Symposium on Research of Arts, Design and Humanities (ISRADH 2014)*. Singapore: Springer.
22. Anwar, R., Hassan, O. H., & Abidin, S. Z. (2015). A framework of empirical study through design practice for industrial ceramic sanitary ware design. In O. H. Hassan, S. Z. Abidin, R. Anwar & M. F. Kamaruzaman (Eds.), *International Colloquium of Art and Design Education Research (i-CADER 2014)*. Singapore: Springer.
23. Sopyan, I., & Kaur, J. (2009). Preparation and characterization of porous hydroxyapatite through polymeric sponge method. *Journal of Ceramics International, 35*, 3161–3168.
24. Groover, M. P. (2010). *Fundamentals of modern manufacturing: Materials, processes, and systems*. New York, USA: Wiley.
25. Leo, S., Tallon, C., Stone, N., & Franks, G. V. (2014). Near-net-shaping methods for ceramic elements of (body) armor systems. *Journal of American Ceramic Society, 97*(10), 3013–3033.
26. Anwar, R., Salleh, M. R., Vermol, V. V., Zakaria, Z. & Hassan, M. R. (2015). Hard ceramic porcelain physical test through potential formulation parameter. In O. H. Hassan, S. Z. Abidin, R. Anwar & M. F. Kamaruzaman (Eds.), *Proceedings of the International Symposium on Research of Arts, Design and Humanities (ISRADH 2014)*. Singapore: Springer.
27. Anderson, M. (2010). *Design for manufacturability & concurrent engineering: How to design for low cost, design in high quality, design for lean manufacture, and design quickly for fast production*. California: CIM Press.

Springer

http://www.springer.com/978-981-10-0235-9

Proceedings of the 2nd International Colloquium of Art and Design Education Research (i-CADER 2015)

Abidin, S.Z.; Legino, R.; Noor, H.M.; Veto Vermol, V.; Rusmadiah, A.; Fairus Kamaruzaman, M. (Eds.)

2016, X, 660 p. 357 illus., Hardcover

ISBN: 978-981-10-0235-9