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FORMATION OF HOLLOW SHAPE PORCELAIN BY USING A NEW INTEGRATED SLIP ROTARY MOULDING TECHNIQUE

Nor Hayati Saad[a*], Abdul Rahim M. Sahab[b], M. Moza M. Mohtar[b], Farrahshaida M. Salleh[a], Izdihar Tharazi[a], Juri Saedon[a]

[a]Faculty of Mechanical Engineering, Universiti Teknologi MARA 40450 Shah Alam, Selangor, Malaysia.
[b]Advanced Materials Research Centre, SIRIM Berhad, No 1. Persiaran Dato' Menteri, P.O. Box 7035, 40700 Shah Alam, Selangor, Malaysia.

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*Corresponding author
norhayatisaad@salam.uitm.edu.my

Graphical abstract

Abstract

Hollow ceramic product is fabricated generally using slip casting technique. The conventional processes produce slip and mould waste which require for disposal schedule. A rotary moulding technique is a feasible process for producing hollow shape ceramic product and eliminates the waste. This paper focuses formulation of the slip and process parameters of the rotary moulding for hollow ceramic product fabrication. The formulated ceramic slip is poured inside the mould rotated at 2-axis system inside a controlled chamber with specific temperature, speed and time for producing green body hollow ceramic product. This process uses minimum amount of ceramic slip and long lasting mould material which will reduce ceramic waste to environment and simplify the manufacturing process for mass production. Using small amount of polymer based dispersant and coagulant agents, experimental analysis resulted the green hollow porcelain product which was successfully removed during de-moulding process without any breaks. The hollow product produces homogeneous forms of ceramic structure after firing procedure and 1.9 MPa green strength with addition of small amount of binder.

Keywords: Hollow shape ceramic, rotary moulding, ceramic waste, green product, firing product.

1.0 INTRODUCTION

Rotational moulding is a manufacturing method of hollow plastic product. New market sector of hollow product are opening up the rotary moulding to deliver high quality and high performance parts. Since many technical advances have been made and new type of machines and mould material are becoming available, [1] developing new material for rotary moulding process is possible. Polymer rotary moulding can be adapted in producing hollow shape ceramic product to maximize engineering application and to reduce production costs [2]. In conventional process, the slip casting was used to produce hollow shape product from ceramic slip formulated [3, 5]. In slip casting, degradation of plaster mould and excess slip removed from mould will generate a lot of ceramic waste and need to depose. Since the ceramic waste is scheduled waste we need a lot of space to store the waste materials. Storage, shipping and disposal of the wastes increase production cost [2]. Introducing rotary moulding for production of hollow ceramic product from ceramic slip is feasible [4]; it will minimize use of ceramic slip where the ceramic slip poured inside the mould will become end product and no excess ceramic slip

removal is required from the mould. The amount of ceramic slip poured inside the mould is calculated to form hollow ceramic product as thickness required [2,4]. Slip formulation, rotating parameters and mould material are considered for the successful of the slip rotary moulding process for producing hollow ceramic product [4, 7]. Clay based material such as porcelain vitrified and fine-grained whiteware are produced from natural raw materials comprised of clays, quartz and feldspar. It is dense, vitreous and the strongest of clay bodies and important materials in ceramic industries [6]. Slip formulation such as advanced technique of gel casting, coagulating casting and in-situ coagulating casting were used as a reference for developing slip for rotary moulding process [8, 9]. The slip formulation required high solid content of powder to suit the rotary moulding process [4, 8]. Type of dispersant agent plays an important role in high solid content of ceramic slip preparation. Increasing solid content requires consistent fluidity of ceramic slip which is important technical parameter [7, 8] in development of hollow ceramic product by rotary moulding technique. Gel casting and direct coagulation casting are well-established method for fabrication of solid components from concentrated ceramic powder suspension by the gelation approach [9, 10,11,12,13].

2.0 MATERIALS AND METHODS

In this study porcelain material No. 180 was used as main powder. The porcelain material is in a form of cakes phase. The polymer based dispersant in liquid form was selected to disperse the porcelain slip particle where solid and water contents are 46 wt% and 54 wt% respectively. Binder Duramex B 1022 was added inside the porcelain slip compound. The coagulant agent glucono-delta-lactone was added and mixed together with the porcelain slip. Table 1 shows the chemical analysis of porcelain powder used in this experiment.

In slip preparation the porcelain powders is dried in an electric oven at 110^{O}C temperature for 24 hours. After drying the porcelain powder is crushing with mortar and pestles and filtering with 300 µm of sieves. In slip preparation, both composition solid and water contents are 75 wt% and 25 wt%. Both composition is mixed with an electric mixer at reasonable speed and added with small amount of polymer dispersant to ensure the compound producing acceptable viscosity and appropriate for slip rotary moulding process. Small amount of binder also was added inside slip compound to ensure the strength of green body is sufficient to hold especially during de-moulding and transportation process. The mixture was mixed homogenously for about 1 hour. The slip compound is closed with aluminium foil and kept for 1 day before viscosity measurement. The viscosity of the slip compound is measured by Brookfield Digital Viscometer DV-11 (with *spindle no. 5 selection).

In producing hollow porcelain product, the slip compound was added with small amount of coagulant agent (DGL) prior to rotating process. The rotating process uses two axis Integrated Slip Rotary Moulding System to produce hollow shape porcelain product. Before rotating process, the slip prepared is weighted and the appropriate slip amount is poured inside a close mould in order to produce 2-3 mm thickness of hollow product. The closed mould was installed and fixed at the system and simultaneously rotated the mould following the setting process parameters. Table 2 shows the main parameters of the system for producing porcelain hollow product. In this process porous resin mould is selected for the mould material. In strength measurement of green body, the slip compound is cast in test bar mould. The dry test samples are tested with Autograph AG-X/R Universal Testing Machine. In SEM analysis, the dry and fired sample was measured by Hitachi S-2500 Scanning Electron Microscope.

Table 1 Chemical analysis of porcelain powder used for producing hollow shape product.

Elements	Weight %
SiO_2	67.44
Al_2O_3	21.32
Fe_2O_3	0.29
TiO_2	0.09
CaO	0.12
MgO	0.93
Na_2O	3.06
K_2O	0.70
IG. Loss	6.05

Table 2 Main setting parameters of system for producing green hollow shape porcelain product

Main Parameters	Data input
Rotation Speed, RPM	20-25
Chamber temperature, ^{O}C	80
Rotation time (forming), minute	60
Rotation time (cooling), minute	60

3.0 RESULTS AND DISCUSSION

3.1 Result

Table 3 Viscosity measurement of slip formulation for slip rotary moulding process

Solid Content of Slip, %	Dispersant Amount, %	Viscosity Measurement, CPS
75	0.13	$26.4x10^3$
75	0.15	$21.6x10^3$
75	0.16	$12.8x10^3$
75	0.20	$56.0x10^3$

Table 4 3 points bending test for drying sample hollow porcelain product with and without binder

Sample condition	Strength, MPa
Without strengthen agent	1.1
1.0 wt% with strengthen agent	1.9

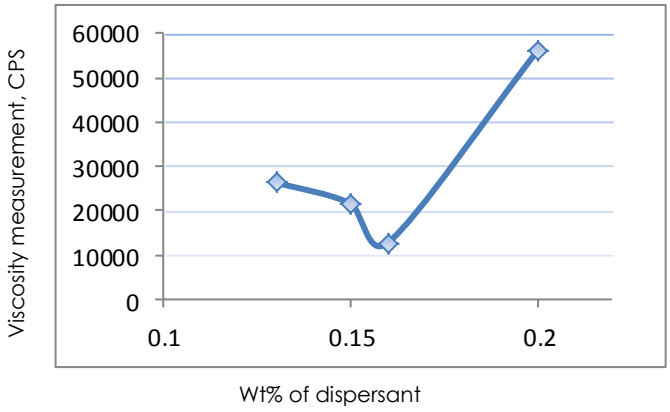

Figure 1 Weight percent of dispersant amount versus viscosity measurement of slip

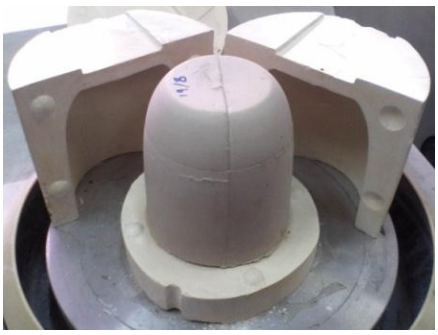

Figure 2 De-moulding of hollow product

Figure 3 Dry green body of hollow products

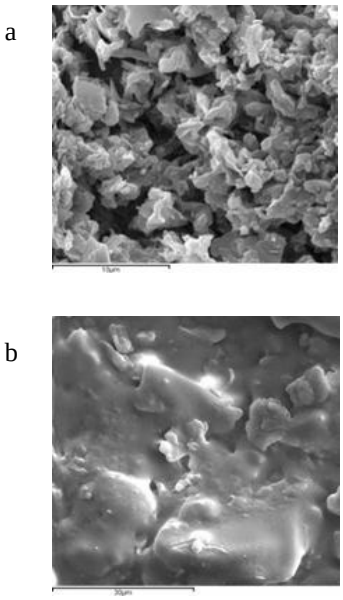

Figure 4 SEM photo of dried (a) and fired (b) hollow product

Figure 5 Final hollow shape porcelain product

3.2 Discussion

The green hollow shape porcelain product is produced by using slip rotary moulding technique. To ensure the process is successfully implemented there are variables and parameters have to be considered. The porcelain slip viscosity and rotation parameters play important role for producing hollow shape product. Appropriate combination of parameters (slip viscosity and rotary process parameters) allows rotary process to produce green hollow shape porcelain product in good quality, and possibly reduce production and manufacturing time.

In this experiment 75 wt% of solid content is selected to produce the green hollow ceramic product. Referring to Table 3 and Figure 1, using polymer based dispersant agent only 0.16 wt% amount added inside slip will produce the minimum slip viscosity around 12.8 x 103 CPS. Less amount of dispersant added inside porcelain slip, the viscosity of slip is high. In this experiment 0.13 wt% and 0.15 wt% of dispersant agent are still suitable for rotary moulding process where the viscosity only 26.4x103 CPS and 21.6 x 103 CPS respectively. Adding more than 0.16 wt% dispersant agents, the viscosity of ceramic slip started to increase and is not suggested for the process.

In this slip rotary molding process, the most preferable mould is porous resin mould. By choosing the type of mould the green hollow product was successfully produced and de-moulded the product from mould as shown in Figure 2. Figure 3 shows the drying hollow products which produced by the rotary moulding technique. The hollow products were successfully produced according to parameters setting as shown in Table 2.

Figure 4 shows the SEM analysis of dried and fired hollow ceramic products. The surface of dried sample shows the powder particles agglomerated together and formed hollow green body product (Figure 4a). After sintering process at 1250^{0}C the surface of the fired product shows the powder particles formed together and produced hollow product body homogenously as shown in Figure 4b. Figure 5 shows the final hollow product after sintering process. The hollow product was formed nicely without any clear or visible defect. Table 4 shows the 3 point bending test of green hollow product with and without strengthen agent (binder) material. With 75 wt% solid content, test result indicates that without strengthen agent, the green hollow product has strength about 1 MPa. With binder the strength of the green hollow product increases about 2 MPa. The binder added is about 0.15 wt%. Increasing amount of binder material will increase body strength and will be convenient for the green hollow product during de-moulding process and transporting green product to other place for other processes. However 1 MPa of green strength of green body is still acceptable condition for de-moulding the hollow product from mould.

4.0 CONCLUSION

Green body and sintering of porcelain hollow product were successfully produced using rotary moulding technique with 75 wt% of solid content. Process parameters and slip viscosity are related to each other for the successful of the slip rotary moulding process. Using polymer based dispersant agent helped in producing high solid content with low viscosity of ceramic slip. Strengthen (binder) material added inside slip will produce high strength green body of hollow shape and minimize the possibility of hollow product to break during de-moulding process. Coagulant agent inside ceramic slip assisted the ceramic slip to be formed uniformly and reduced processing time in producing green hollow shape ceramic product

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