A Study on Injection Moulding of Two Different Pottery Bodies

M. Y. Anwar[1], M. Zubair[1], M. Ajmal[1], and M. T. Z. Butt[2]

1. Department of Metallurgical & Materials Engineering, UET Lahore.
2. Faculty of Engineering & Technology, Punjab University Lahore.

ABSTRACT

Injection moulding of a conventional high clay pottery body and an unconventional low clay pottery body has been described. The Sheffield Binder System comprising of a major component of PEG and a minor component of PMMA was used. The behavior of these pottery bodies during various stages of injection moulding has been analyzed. Optical and scanning electron microscopy was used to examine the structure of the green and sintered specimens.

Key Words: Injection moulding, conventional pottery body, unconventional pottery body. Binder System

1. INTRODUCTION

Pottery is sometimes used as a generic term for ceramics that contain clay and are not used for structural, technical, or refractory purposes. The definition of pottery used by ASTM is "all fired ceramic wares that contain clay when formed, except technical, structural, and refractory products" [1]. Whiteware refers to ceramic ware that is white, ivory, or light gray in color after firing. Whiteware is further classified as earthenware, stoneware, chinaware, porcelain, and technical ceramics [2].
Traditionally, Pottery bodies and tableware ceramics are formed both plastically and by slip casting. Mostly, plastic forming is carried out using the roller-head technique and slip casting using plaster moulds. Powder pressing is used to automate production of parts such as plates, saucers and bowls etc. In 1990s, Powder Injection Moulding was employed to make relatively complex shapes such as tea pots and cups with handles [3].

Powder injection molding (PIM) is a technology for manufacturing complex, precision, net shape components from either metal, ceramic and cermet powders. The potential of PIM lies in its ability to combine the design flexibility of plastic injection molding and the nearly unlimited choice of material offered by powder metallurgy, making it possible to combine multiple parts into a single one [4]. Furthermore, PIM overcomes the dimensional and productivity limits of isostatic pressing and slip casting, the defects and tolerance limitations of investment casting, the mechanical strength of die-cast parts, and the shape limitation of traditional powder compacts [5].
In the present study, Injection moulding of a conventional high clay pottery body and an unconventional low clay pottery body has been discussed.

2. EXPERIMENTAL PROCEDURE

In this set of experiments two types of pottery bodies were used:

1) **Conventional body**: this consisted of 25 wt. % ball clay E. C. C. Hymod Prima, 25 wt. % E. C. C. Super Standard Porcelain china clay, 25 wt. % feldspar (Forshammer, 10 µm median size) and 25 wt. % quartz (10 µm median size).

2) **Unconventional low clay body**: this consisted of 7.5 wt. % W. B. B. Ukrainian ball clay, 7.5 wt. % E. C. C. Super Standard Porcelain china clay, 25 wt. % finely milled pre-fired body (~ 2-3 µm median size) and 60 wt. % coarsely milled pre-fired body (~20 µm median size). The pre-fired body was composed of 76 wt. % anorthite, 17 wt. % glass and 7 wt. % mullite.

The pre-fired body was prepared using19.35 % $CaCO_3$, 40.60 % $Al(OH)_3$, 37.70 % SiO_2 and 2.30 % $MgCO_3$ (by weight) and was fired at 1350 °C for three hours.

Feedstocks were prepared from the conventional pottery body and binder (80 wt. % PEG_{1000} and 20 wt. % PMMA) and were mixed according to the Method described in the flow diagram, Figure 1. The detailed procedure of feedstock preparation has been discussed elsewhere [6]. Initial injection moulding experiments were conducted using feedstocks with 65 vol. % and 62 vol. % powder loading, but these could not be moulded. However, feedstock with 60 vol. % powder loading produced mouldings free of defects. Therefore, for both conventional and unconventional pottery bodies 60 vol. % powder loading was used for subsequent study. The moulded specimens were water leached at about 60 °C for four hours and dried at the same temperature for one hour. The following firing schedules were used.

a) Heating at a rate of 3 °C/min. up to 1200 °C, held at this temperature for 3 hours and cooled within the furnace.

b) Heating at a rate of 4 °C/min. up to 1300 °C, held at this temperature for 4 hours and cooled within the furnace.

The dimensions of the green, leached and fired specimens were measured using a digital micrometer. The linear shrinkage was calculated after each processing step. The fired samples were examined for defects and pore structures using optical and scanning electron microscopy.

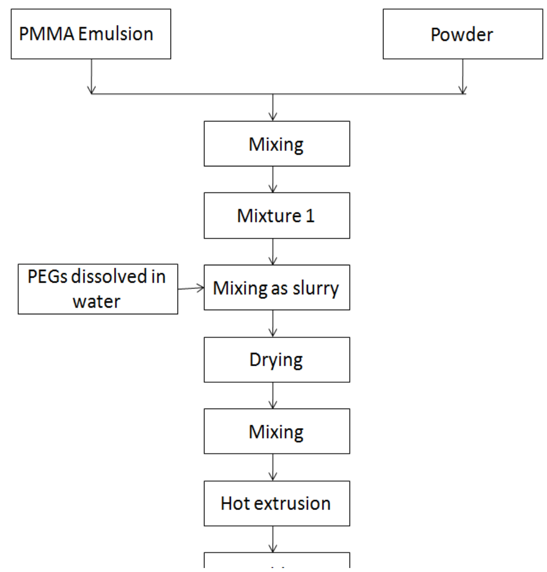

Figure 1: Flow Diagram for mixing of the feed stock.

3. RESULTS

The feedstocks made from conventional pottery body using 60 vol. % powder loading were easily moulded in the temperature range of 140-150 °C and 45-50 MPa pressure. Green shrinkage was ~ 0.2 % relative to the mould dimensions. The green strength of these samples was about 13 MPa. The binder was removed by a combination of solvent and thermal debinding. The method of debinding has been discussed in detail in another publication [7, 8]. There was always a decrease in length and increase in width and thickness after water leaching. The changes in dimensions calculated for samples water leached at 60 °C for four hours were as follows:

Length = ~ 1.2 - 1.6 %, contraction.
Width = ~ 3.0 - 3.25 %, swelling.
Thickness = ~ 1.0 - 1.2 %, swelling.

Due to swelling, most of the samples were split along the mould joint line. On drying, there was always a contraction in all dimensions. The shrinkage in dimensions of the dried samples, taking the dimensions of green samples as initial, was as follows:

Length	=	4.4 - 4.6 %
Width	=	3.8 - 4.0 %
Thickness	=	2.0 - 2.3 %

On firing, cracking was observed in most of the samples produced using conventional pottery body.

The mouldings produced from unconventional pottery body had a green strength ~13 - 14 MPa. A representative SEM micrograph of a fractured surface of a green bar is shown in Figure 2. After water leaching, there was always a small decrease in length but no swelling was observed. The samples leached at 60 °C for four hours showed a contraction of about 0.4 - 0.6 % but no significant change in width and thickness. After drying, shrinkage compared to green dimensions was as follows:

Length	=	1.2 - 1.5 %
Width	=	0.2 - 0.4 %
Thickness	=	0.2 - 0.3 %

The samples fired at 1200 °C for three hours showed a linear shrinkage of about 12 % and density of 92% of the theoretical density. Whereas, the samples fired at 1300°C for four hours showed a linear shrinkage of about 15 % and density of 95 % of the theoretical density. The fired samples did not show any swelling or cracking. The maximum variation in shrinkage in length, width and thickness of the same sample was about ±0.5 %. A representative SEM micrograph of a fired sample is shown in Figure 3.

Figure 2: SEM of a fractured surface of a green bar made from an unconventional pottery body, illustrating the packing behavior of particles and distribution of binder.

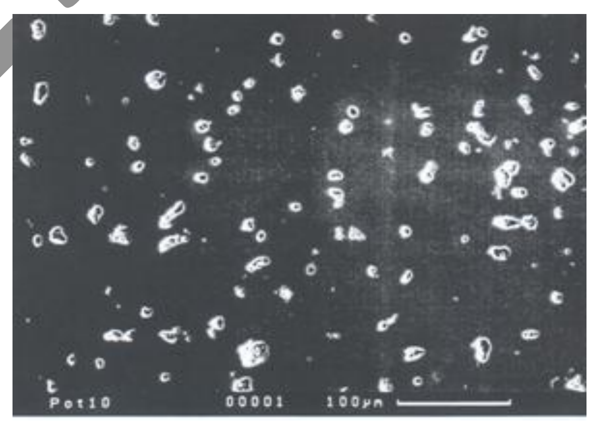

Figure 3: SEM of a polished section of a fired specimen made from an unconventional pottery body.

4. DISCUSSION

Pottery and tableware ceramics have traditionally been formed both plastically and by casting. Most plastic forming is currently performed using the roller-head technique and most casting using plaster moulds. The move to automated production has involved a change from plastic forming to powder pressing. Pressure casting using porous polymer moulds rather than plaster is starting to be employed and more shapes can be produced using this technique than by pressing. Pressure casting is considerably faster than casting in plaster moulds but not as rapid as pressing. These forming processes have certain advantages and limitations associated with them. Without going into further detail of the conventional processes, it is worth speculating on whether injection moulding using the water-soluble binder might not be a better approach to adopt for making complex-shaped tableware with comparatively higher strength and toughness. It is worth mentioning that Arburg [9], a German manufacturer of injection moulding machines has recently shown that it is possible to form tea cups with attached handles by injection moulding (Figure 4) at an acceptably high rate of 120 cups per hour. With conventional plastic forming, the cups are made without handles and these are subsequently attached manually.

During the present study two types of pottery bodies were used.
(1) Conventional body containing a high clay content of 50 wt. % *(25* % ball clay + 25 % China clay).
(2) Unconventional body containing a low clay content of 15 wt. % *(7.5* % ball clay + *7.5* % China clay).

The feedstocks having 60 vol. % powder loading could be easily moulded and produced defect-free mouldings having adequate strength for handling. The green parts produced from conventional pottery body exhibited swelling while leaching in water for removal of the PEGs. This was probably due to the high content of clay, particularly the ball clay, which normally swells as water is absorbed. Most of the leached specimens of the conventional body were split along the mould joint and showed cracking on firing. After water leaching, there was always a decrease in length and an increase in the width and thickness of the bar-shaped specimens. It is thought that injection moulding would have induced some degree of preferred orientation of the clay. There would have been frictional drag on the platy clay particles from the walls of the mould, causing the column to inject more rapidly at the centre than adjacent to the mould surfaces. Probably, the central region would flow as an un-sheared plug and not become preferentially aligned. It is considered that the clay platelets would align themselves with their large plane faces parallel to the nearest mould surface, as illustrated in Figure 5, which represents a cross-section through the bar.

Figure 4: A cup with handle produced in one step, using powder injection moulding process (Arburg, Germany) [9].

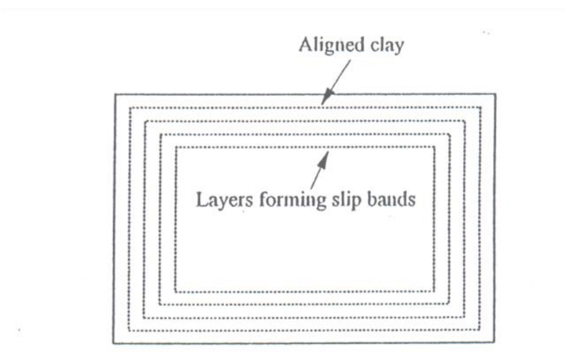

Figure 5: Cross-section of a bar-shaped specimen showing clay platelets aligned parallel to mould walls. Clay platelets are seen edge on and lie in slip bands. The non-clay particles are not sheared and lie between the slip bands.

It is considered that the aligned structure in the bar-shaped section of the moulding would be similar to that obtained when a pottery body plasticised with water is extruded to form a bar. On drying such a bar, the shrinkage would be larger through the thickness and across the width than for the length. When a dried pottery sample absorbs water, the sample expands, reversing the shrinkage that occurred on drying. The explanation for the anisotropic drying shrinkage and the anisotropic expansion behaviour on being re-wetted is that there are more films of water between aligned clay particles perpendicular to the plane of alignment than parallel to this plane.

It is expected for the injection moulded specimen during leaching that, as water enters the specimen and PEGs are removed, the PMMA attempts to pull the particles closer together whilst the water endeavours to push them apart. The bar undergoes a net expansion across the width and through the thickness, whereas there is a net shrinkage along the length of the bar. In pottery bodies, it is the clay content of the body which is responsible for causing anisotropic shrinkage during drying and also during firing. A body containing very much less clay should, subsequently, shrink more isotropically. No swelling problem was observed when using the unconventional pottery body, which was formulated with a low clay content. Moreover, firing shrinkage was almost isotropic for this body. Thus, there is a good reason to think that low clay pottery bodies could be injection moulded to produce tableware items, such as tea cups with handles, which are otherwise produced by joining separate pieces.

CONCLUSIONS

1. The feedstocks having 60 vol. % powder loading could be easily moulded and produced defect-free mouldings having adequate strength for handling.
2. There was always a decrease in length and increase in width and thickness after water leaching. On drying of the water leached specimens, there was always a contraction in all dimensions.
3. The conventional pottery body, having high clay contents, swells as water is absorbed during water leaching. However, no swelling was observed in the unconventional pottery body (having low clay contents).
4. It is considered that some degree of preferred orientation of the clay plates is induced during injection moulding.
5. The clay contents of the pottery body are responsible for causing anisotropic shrinkage during drying and also during firing. A body containing very much less clay should, subsequently, shrink more isotropically. Thus, the pottery bodies having low clay contents can be injection moulded to produce tableware items.

REFERENCES

1. ASTM International. “Standard Terminology of Ceramic Whitewares and Related Products”’ ASTM C 242–01 (2007)
2. Jian Wang, “Some Critical Issues for Injection Moulding”, InTech Publishers, Rijeka, Croatia, March 2012,
3. M.Y.Anwar, P.F. Messer, H.A. Davies and B. Ellis, "A Novel Approach To Injection Moulding." Ceramic Technology International 1996. Sterling Publications Ltd., London, 95(1995).

4. Hausnerová, B., “Powder injection moulding- An alternative processing method for automotive items”, New Trends and Developments in Automotive System Engineering, InTech Publishers, Rijeka, Croatia, (2011)129.
5. Tandon, R., (2008). “Metal injection moulding” Encyclopedia of Materials Science and Technology, Elsevier Science Ltd, Amsterdam, The Netherlands, 5439(2008).
6. M. Y. Anwar, P.F. Messer, B. Ellis and H.A. Davies, “Preparation of Feedstock for PIM by using a New Binder system”, Advances in Powder Metallurgy-1995, MPIF, Princeton, NJ, USA, Part 6, 2(1995)45.
7. M. Y. Anwar, H.A. Davies, P.F. Messer and B. Ellis, “A Novel Binder System for Powder Injection Moulding”, Advances in Powder Metallurgy-1995, MPIF, USA, Part6, 2(1995)37.
8. M. Y. Anwar, H.A. Davies, P.F. Messer and B. Ellis, “ “Rapid Debinding of Powder Injection Moulded Components”, Euro PM’95, Proceedings of the Euro-PM’95, the 1995 European Conference on Advanced PM Materials, Birmingham, U.K., 1(1995)577.
9. U. Haupt and F. Davies, Euro PM’95, Proceedings of the Euro-PM’95, the 1995 European Conference on Advanced PM Materials, Birmingham, U.K., 1(1995)605.