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ScienceDirect
Journal of the European Ceramic Society 27 (2007) 1889–1892
www.elsevier.com/locate/jeurceramsoc

Wet-pressing of handles in table porcelain manufacturing

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Available online 5 July 2006

Abstract

Due to the need of cost reduction in table porcelain manufacturing new processing techniques like injection moulding, microwave drying or fast firing are of interest. Especially the manufacturing of handles are in the focus of research. Cups and handles are separately produced by jiggering and slip casting, respectively. While jiggering is a profitable technique for rotation-symmetrically parts, slip casting is a very expensive technology, because of degradation of gypsum-moulds, long production time and the necessity of bin location. Thus, wet-pressing is an interesting alternative to avoid these disadvantages. To use this forming technology, a conventional porcelain mass was modified concerning water content and organic additives, and the effects of these modifications on the rheology of the mass, the workability, the sticking behaviour of the mass to the tool, the strength of the green body, and the shrinkage behaviour were analysed.

Keywords: Pressing; Traditional ceramics; Porcelain; Plasticity; Rheology

1. Introduction

In recent years research activities in tableware manufacturing are focussed on two subjects. On the one hand there is the demand for a better quality of products and on the other hand there is the necessity of cost reduction in the manufacturing process.

Above all, slip casting is a technology which has to be replaced for cost reasons in some areas by other manufacturing processes which additionally can be better automated. Slip casting is a very expensive technology, because of degradation of gypsum-moulds, long production time and the necessity of bin location. For example, in case of handles, which are produced by slip casting technology, different research groups developed possibilities to produce handles or cups with handles by avoiding slip casting. This was achieved by using technologies like pressure casting[1,2] and injection moulding.[3,4]

With pressure casting cups and handles can be produced fully automated by robot units. In these units cups and handles are fabricated separately and joint together by applying vibrations. Compared with jiggering, pressure casting allows to produce cups, which may be also asymmetrical.[1]

Injection moulding of porcelain (PIM) is an advanced technology which was also used for the manufacturing of cups with handles.[3] The manufacturing of non-rotation-symmetrically pieces is possible. By conventional injection moulding of porcelain, handles and cups were fabricated separately and than joint together manually, but problems can occur with fettling and cutting. A new way of injection moulding offers the possibility to produce cups with handles in one forming step.[4] This is realised by injection moulding of aqueous porcelain suspensions with gelling agents.[4] This technique should allow the reduction of manufacturing costs, even this process technology is very expensive. However, up to now pressure casting and injection moulding could not be established in industry as manufacturing processes.

A further alternative method to fabricate handles by avoiding slip casting is wet-pressing. Wet-pressing is used for the production of a wide variety of small porcelain pieces and refractory materials.[5] Usually wet-pressing is characterised by a water content of 10–15 wt.%. With these water contents the mass becomes free flowing and fills the space in the pressing tool through plastic deformation.[6] Higher water contents cause adherence of the ceramic masses in the pressing tools and cracks occur in the pressed green body.

For assembling of wet-pressed green handles to green cup bodies it is necessary to adapt specific properties of handles to those of the cups. For example, handles and cups must have the

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0955-2219/$ – see front matter
doi:10.1016/j.jeurceramsoc.2006.05.074

Table 1
Overview of different porcelain raw materials, which are used in this work

	Density (g/cm^3)	Particle size, d_{50} (μm)	Specific surface area (m^2/g)	Shape
Porcelain 1	2.62	307.04	9.25	Plate-shaped
Porcelain 2	2.64	86.70	9.02	Plate-shaped
Porcelain 3	2.44	373.42	11.93	Spherical

same shrinkage behaviour to avoid cracks in the joining area. Therefore, there is the demand for wet-pressed green bodies with a higher water content of nearly 17 wt.%. To achieve this, the mass has to be optimised by organic additives to get a suitable workability. The used organic additives consist of pressing agents to avoid mass sticking in the pressing tool, of binders for improving green strength and of plasticisers which control the flexibility of the pressed handles for a better fettling and assembling.

2. Experimental procedure

In this study different porcelain raw materials and commercial available organic additives were tested for their suitability for the wet-pressing forming technique. The influence of individual organic components on the rheology was analysed by rheological measurements. The workability of wet-pressed handles was investigated by 3-point-bending tests. The wet-pressed handles were assembled to cup bodies and fired, to achieve information about the assembling behaviour of pressed handles and about the quality of the interface between handle and cup.

2.1. Raw materials and organic additives

Three different raw materials were used. Porcelains 1 and 3 were spray dried granulates. Porcelain 2 was delivered as a dried filter cake, so it was milled before processing. The different porcelain raw materials were characterised by measuring the density (Heliumpycnometer Accu Pyc 1330, Micromeritics, USA), particle size (sieve analysis) and specific surface area (ASAP 2000, Micromeritics, USA). The results are shown in Table 1. The complete particle size distributions can be seen in Figs. 1 and 2.

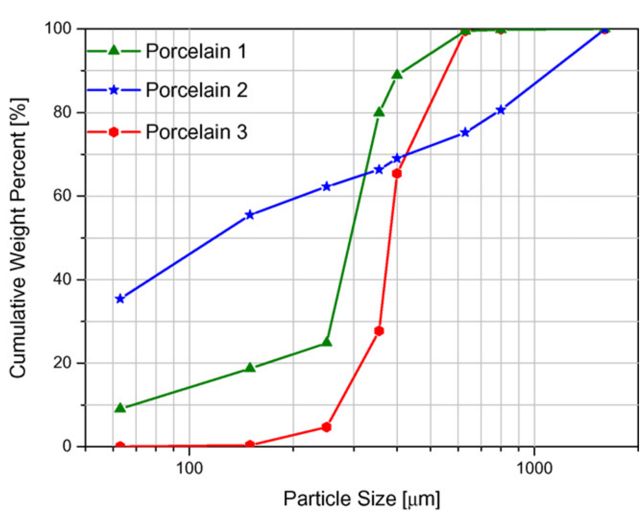

Fig. 1. Particle size distribution of the used porcelain granulates, cumulative distribution.

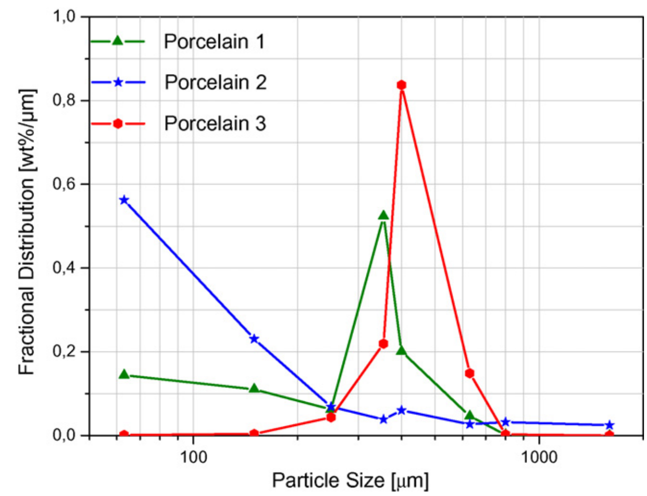

Fig. 2. Particle size distribution of the used porcelain granulates, frequency distribution.

For the optimisation of the porcelain mass a variety of oils were tested as pressing agents in the wet-pressing mass. They were characterised by their viscosity (Rheometer Physica UDS 200, Paar Physica, Germany). The diagram is shown in Fig. 3.

A commercial binder was used in all cases, which was found to be the most suitable binder for this work. Some relevant data of this binder can be seen in Table 2.

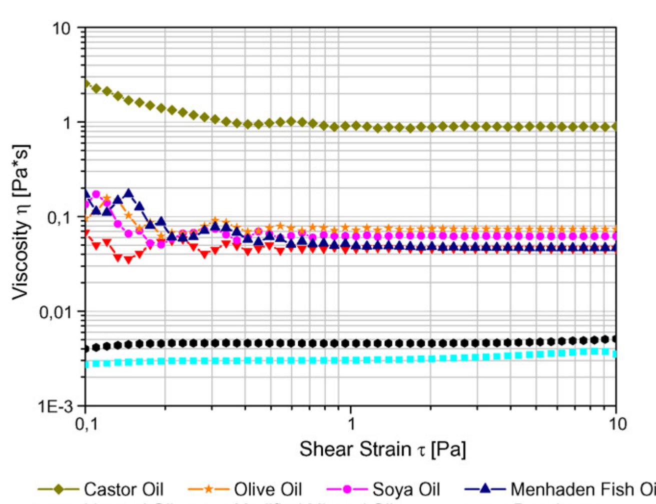

Fig. 3. Diagram with the viscosity curves of different oils tested as pressing agents in wet-pressing masses.

Table 2
Binder characteristics, manufacturers instructions

Chemical bases	Water-based polymeric solution
Viscosity (20 °C)	2000 mPa s
Density (20 °C)	approx. 1.05 g/cm^3
Solid content	approx. 60 wt.%

2.2. Manufacturing process

To achieve a wet-pressing mass approximately 80 wt.% porcelain granulate is mixed with 15 wt.% water and 5 wt.% organic additives by a common mixer at room temperature in a few minutes. This wet-pressing mass is characterised by water content, determined by thermogravimetric measurements. For every mass the rheological behaviour is also determined. The masses are processed promptly. Handles are formed by using an uni-axial press.

2.3. Measurements and test conditions

The rheological behaviour of the completed porcelain wet-pressing mass was characterised by a kneader (Rheomix 600p, Thermo Haake, Germany). The kneader offers the possibility to measure over a wide viscosity range. Above all, there is a big advantage for plastic ceramic masses, which cannot be measured by simple shearing viscometers according to high viscosities. The kneader consists of a measuring chamber with two rotors moving non-uniformly with the same preset speed. The sample is transported in the measuring chamber by the given irregular movement. The torque is measured as a value, which describes the internal resistance of the mass. The result is given by a kneader curve, in which the torque is recorded in dependence on time (Fig. 4). The rheological behaviour gives information about the workability of the modified masses.

The sticking behaviour of the mass to the tool was characterised by personal impressions doing tests in the pressing tool. Non-optimised masses tended to adhere in the tool showing a lot of defects in the pressed handles. The influence of a suitable plasticiser appears in the mechanical properties of the wet-pressed green handles. They were measured by 3-point-bending (Universal Testing Machine, Instron Model 4204, Instron Comp., Norwood, MA, USA). The 3-point-bending was chosen because there is nearly the same strain distribution in the handle as well as during assembling. The applied load and the displacement of upper crosshead were determined, until failure occurred. Bending-tests give information about green strength and elastic–plastic behaviour of the green, wet-pressed handles. The results of the 3-point-bending test are shown in Figs. 5 and 6.

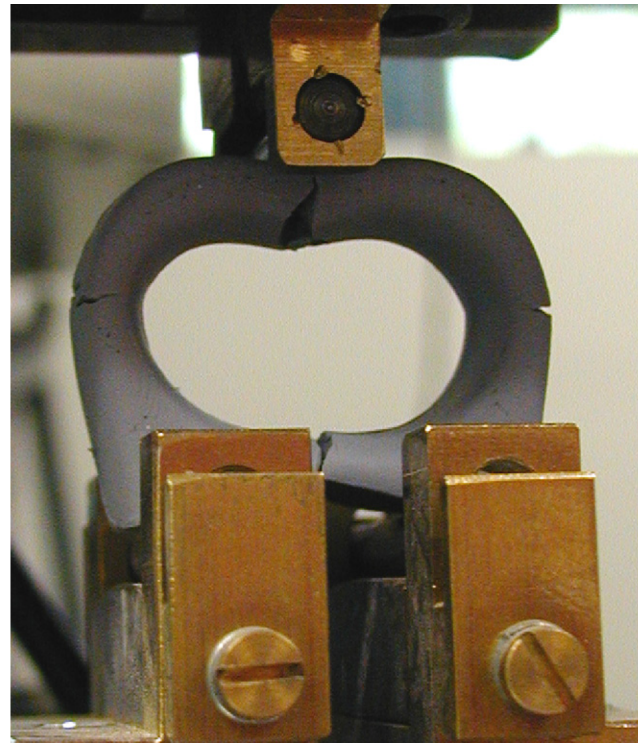

Fig. 5. 3-Point-bending test of a wet-pressed handle.

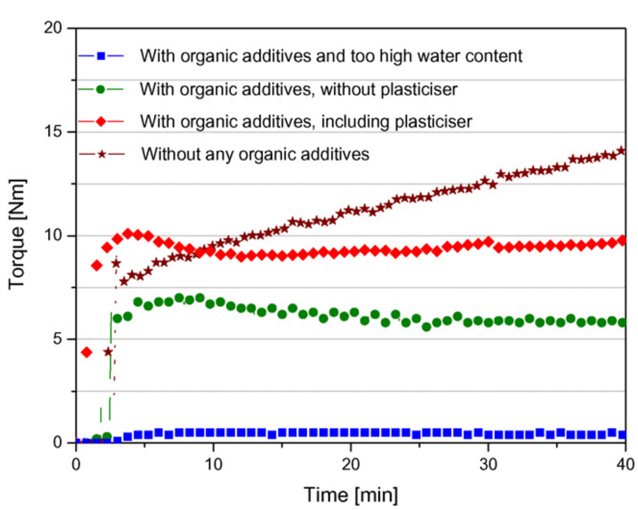

Fig. 4. Influence of organic additives on the rheological behaviour of porcelain wet-pressing masses.

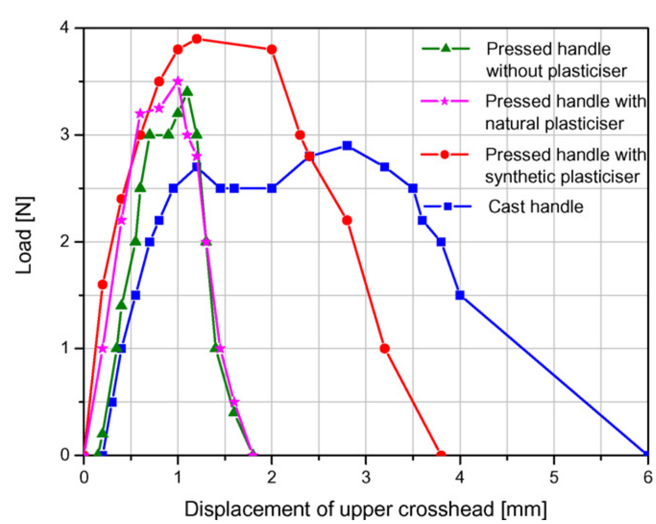

Fig. 6. 3-Point-bending tests of pressed and cast handles.

Furthermore, the shrinkage behaviour was determined by measuring the geometry before and after drying.

3. Results and discussion

3.1. Rheological measurements

The viscosities of oils used as pressing agents to control the flow behaviour of the wet-pressing mass during the pressing process are shown in Fig. 3. The most suitable pressing agent was a modified mineral oil with low viscosity. With this oil the wet-pressing mass shows a good flow behaviour. The viscosity of petroleum was too low, masses including petroleum could not be pressed optimally. Oils with higher viscosity, for example olive oil or castor oil, cause stronger sticking behaviour of the mass in the pressing tool.

The influence of organic additives on the workability of these masses was determined by kneader. There are two extreme cases in which masses were improper. In the first case the mass is too wet and too soft, therefore adherence in the pressing tool occurs. This is the case, if the torque is too low with values lower than 2 N m. In the other case the torque strongly increases if the mass is too dry, which means too stiff, thus, it does not flow into the structure of the pressing tool. In both cases it is not possible to produce handles without any defects. Optimised wet-pressing masses exhibit a constant torque in the middle range (see Fig. 4). The measured torque is higher for masses including plasticisers probably because of higher sticking behaviour of these masses.

3.2. 3-Point-bending tests of wet-pressed handles

3-Point-bending tests give information about the mechanical properties of the green, wet-pressed handles. With the knowledge of the elastic–plastic properties and the green strength, it becomes possible to estimate, whether fettling and garnishing of the handles can be performed easily. Fig. 5 shows the test set-up, Fig. 6 shows the green strengths of wet-pressed and also cast handles. Cast handles exhibit a pronounced elastic–plastic behaviour. Only with suitable plasticisers it is possible to get nearly the same mechanical behaviour for wet-pressed handles. Without any plasticisers the pressed handles are to brittle and a defect-free fettling and assembling of these handles to the cup bodies is not possible. Furthermore, the influence of different plasticisers shows, that only synthetic plasticisers are suitable. Although natural plasticisers are more cheaper, their effect is too low.

3.3. Shrinkage behaviour

The linear drying shrinkage of the wet-pressed handles, which have a water content of approximately 17 wt.%, was 14%. The shrinkage of the wet-pressed handle is a little bit smaller than the shrinkage of the cup body. Despite of this difference, a well cohesion in the interface between handle and cup is obtained after drying and sintering.

4. Conclusion

Handles from modified porcelain masses were successfully produced applying the forming technique of wet-pressing. The properties of the wet-pressing masses are related to the properties of the jiggered cup body. It is necessary to increase the water content of wet-pressing masses compared to common wet-pressing masses. This results in a stronger sticking behaviour of the mass at the pressing tool. This drawback can be controlled by the addition of suitable organic additives. By measuring the rheological behaviour of the wet-pressing masses by means of a kneader and by the characterisation of the elastic–plastic behaviour of the pressed green handles by means of a 3-point-bending test, the workability could be optimised by the addition of proper organic additives. Thus it is possible to estimate their suitability on post-processing like fettling and assembling. Defect-free interfaces between handle and cup could be obtained after drying and firing.

To achieve the well-designed pressing tools for wet-pressing of handles, modern rapid-prototyping techniques are of advantage. They allow to design and fabricate new pressing tools in the shortest time. Thus, in this way handles can be produced fast and with low manufacturing costs by wet-pressing.

Acknowledgement

The authors are grateful to the Bayerisches Staatsministerium für Wirtschaft, Verkehr und Technologie for financial support.

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