Combination of Particle Shapes to Enhance Sanitaryware Production Yields

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The ceramic sanitaryware industry is constantly increasing its competitiveness based on technology changes. The move from plaster casting, such as bench, battery or capillary casting techniques to high pressure casting using polymer moulds results in a more demanding sanitaryware production. Most manufacturers use various combinations of the above techniques with different level of automation to produce their full range of pieces. Some are now pressure casting heavy, complex, and truly one-piece water closets using automated de-moulding. In this environment, raw material properties and consistency are key to manufacturers who create more complex formulations to obtain the maximum benefit from each technique.

Dewatering of raw material suspension

Whichever forming technique is used, the objective remains the same: from a water based suspension of raw materials, a piece is shaped at the surface of the mould by water extraction. The dewatering is made by the suction of the plaster mould, which corresponds to 1,5–2 bar or by the pressure applied by the casting machine, 12–15 bar. The characteristics of the cake formed at the surface of the mould influences the extraction rate of the water and the cake properties, such as firmness, drying behaviour, etc. The cake has to present a high permeability while giving the mechanical properties to the piece. Therefore, the structure of the cast cake driven by the pore volume, size and distribution is key to optimise the dewatering of the suspension.

As a consequence, the packing of the particles remains critical to improve the body performances. In traditional casting systems, i.e. plaster based, the mould has a constant suction pressure, however the increasing thickness of the cast build up means that the cast rate is not constant and actually reduces over the casting period. Thus, the cast body has to generate and maintain a high degree of permeability and the pore size distribution has to be developed so that the flow of water remains at the highest level possible.

In high-pressure casting, the mould is actually acting as a support and the process of cake build up is governed by the water movement under constant, higher pressure, through the cast piece; hence a different pore distribution can be managed, allowing production of more demanding pieces.

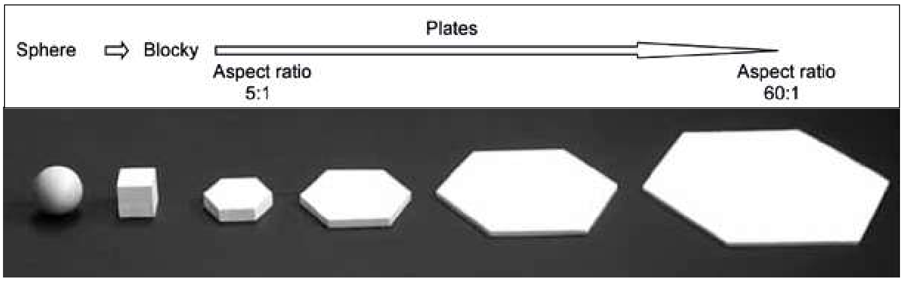

Fig. 1 **Idealised example of particle shape**

Controlling casting properties through the adjustment of suspension parameters

The casting body performances remain driven by the raw materials used in the formula. Three types of materials can be defined:

- The non-plastics, i.e. quartz and feldspars, nepheline syenite, etc., are the less complex. They mainly contribute through particle size and shape distribution, fusibility and coefficient of thermal expansion. These parameters are relatively easy to measure.
- The plastics, i.e. ball clays and kaolins, provide the main properties of the cake and contributes to the plasticity, particle size distribution, fluidity, shrinkage and strength. These parameters are interdependent and not always easy to measure. The characterization of clay mineral particles remains complex with the mineralogy, the particle size, shape and electrical charge density.
- Auxiliary materials, i.e. dolomite, talc or chamotte, can be added in small quantities to adjust specific parameters, such as the point of vitrification or coefficient of thermal expansion.

The particle size distribution measurement is heavily influenced by the shape of the particle, whatever the technique used. In terms of particle shape, particles can resemble spheres, blocks, known as blocky clays, or more plate-shaped (Fig. 1).

Each example has a different aspect ratio and a different surface charge density which affects how the particles interact. These parameters also influence rheology, casting rate and particle packing. The optimization of the suspension parameters has to consider the particle shape. The addition


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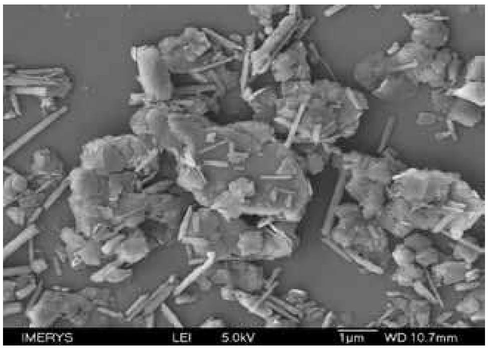

Fig. 2 Imerys Ceramics' Thai kaolin

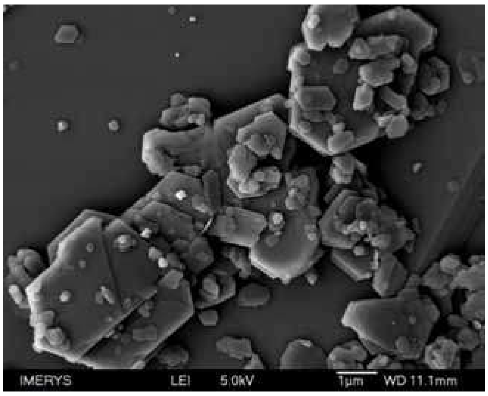

Fig. 3 Imerys Ceramics' GB kaolin

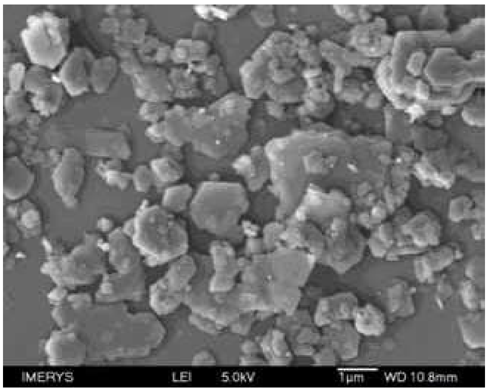

Fig. 4 Imerys Ceramics' US kaolin

of plate particles to blocky ones will change the particle packing and the global performance of the formulae. The interest lies in using several ball clays and kaolins from different deposits with processed clays, which parameters can be controlled.

Understanding and utilising the different properties of the raw materials is key. Imerys Ceramics has developed a number of different clays over the years which incorporate all the above factors and enable the manufacturer to manipulate the body performance.

Large variety of kaolins for the sanitaryware industry

Imerys Ceramics developed its portfolio around three main deposits. Each deposit presents a specific mineralogy and production processes have been adapted to deliver consistent raw materials focusing on particle characterisation and performance, when combined with the other minerals present in the sanitaryware formulae.

Imerys Ceramics Thailand's kaolins are primary in origin and derived from a granite source (Fig. 2). They are composed of a mixture of kaolin and halloysite, together with some mica, feldspar and a small amount of quartz. This kaolin product range has a naturally coarse particle size distribution, around 18 % of the particles being finer than 1 µm.

By combining the selection of the kaolin matrix in the mine with a modern wet refining process, Imerys Ceramics Thailand is able to offer a range of kaolin products for the sanitaryware industry (Tab. 1). The particle size and the specific particle shape, resulting from the mineralogy allow manufacturers to obtain a high permeability and increase the productivity of the casting shop. However, due to their nature, they provide a narrow range of fluidity.

Imerys Ceramics' kaolins from Great Britain (GB) are also primary in origin and derived from a granite source (Fig. 3). They are composed of mainly kaolinite, together with some mica, feldspar and a small amount of quartz. The GB kaolins are more platy in nature and more fluid. Due to more intense processing, they are available in a wider range of particle sizes.

Imerys Ceramics' kaolins from USA (US) are from secondary deposits (Fig. 4). They are mainly composed by kaolinite with a small amount of quartz and anatase. These kaolins are very fluid and they present a fine particle size distribution and a blocky shape.

Ball clay product range for the sanitaryware industry

Imerys Ceramics Thailand's ball clays are relatively low in carbon and composed of kaolinite, illite, mica and quartz (Tab. 2). They are characterised by exhibiting high strength, combined with a fine particle size distribution, where approximately 50 % of particles are finer than 0,6 µm (measured by sedigraph).

These characteristics endow the ball clays with good properties for the production of sanitaryware; such as reasonable fluidity and rheology, medium permeability, high plasticity and high dry mechanical resistance combined with controlled shrinkage. They are available in both blended and refined forms: the blended forms are produced under specific selective mining conditions, whilst the refined forms are prepared by wet processing and provide more fluid options combined with better slip stability and lower levels of contaminants.

Imerys Ceramics' sanitaryware ball clays from Great Britain are more kaolinitic and contain mica rather than illite. They are finer, with d_{50} around 0,3–0,4 µm, more fluid and contain carbon from 0,7 % up to 2,2 %. The deposits allow to obtain ball clays from coarse to very fine particle size distribution. This large variety of grades is a great asset to adjust the formula on the desired parameter like fluidity, casting rate, dry strength.

Imerys Ceramics' sanitaryware ball clays from USA are composed of kaolinite, mica and quartz. Their composition is a mix of fine and coarse kaolinite, which allows to control and cover a full range of particle size distribution from d_{50} around 0,5–2,5 µm. They also contain a small amount of carbon which help stabilizing the rheology.

Combining kaolins and ball clays to improve production yield

The combination of kaolins from the same deposit, with the same particle shape but with different particle size distribution is adequate to balance the characteristics of the formulae (Tab. 3).

The addition of a coarse kaolin like SPK to the NSC fluid kaolin allows to adjust the performances of the formula by maintaining the fluidity, increasing the casting rate with an acceptable dry strength.

The combination of clays of different particle shapes and particle sizes allows optimising the suspension characteristics.

Using combinations of Thai and GB kaolins and ball clays can help the manufacturer to improve performance. For example, with a traditional casting formulation for plaster casting, initially based on a Thai kaolin and ball clay system, Imerys Ceramics can improve product yield, particularly when producing more complex, heavier one-piece water closets by using their ability to

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Tab. 1 Properties of selected GB, Thai and US kaolins from the Imerys Ceramics' sanitaryware range

		GB							Thailand			US
		SP412	DB225	NSC	Remblend	LPC	Prosper	SPK	MRD SW Standard	MRD LW Cast	MRD Cast	KT Cast
Chemical Analysis [mass-%]	SiO_2	48,0	48,5	48,0	48,0	48,5	49,0	48,5	48,0	48,0	48,0	45
	Al_2O_3	36,5	35,5	36,5	36,5	36,0	35,5	36,0	36,0	36,0	36,0	38,8
	Alkalis	1,85	2,9	2,1	2,1	2,3	2,9	2,1	2,1	1,9	1,9	0,2
	L.o.I. [%]	12,3	11,5	11,9	12,0	11,5	10,2	12,5	12,5	12,5	12,5	13,6
Residue [mass-%]	>53 µm	<0,1	<1	<0,15	<0,25	<1	<0,8	<0,1	<3	<2	<3	–
	<2 µm	68	42	40	39	32	28	12	30	27	24	60
MoR	at 80 % RH [MN/m²]	1,25	1,80	0,70	0,50	0,40	0,30	0,20	0,70	0,50	0,40	0,30
Casting Data	Casting concentration [mass-% solids]	63,5	62,0	69,0	66,5	65,0	65,0	64,5	62,0	61,0	61,0	73,0
	Deflocculant demand [mass-%] 5 P	0,55	0,50	0,45	0,48	0,44	0,34	0,40	1,06	1,06	0,56	0,45
	Casting rate [mm²/min]	0,60	0,75	0,80	1,90	3,00	7,50	11,00	11,00	14,00	21,00	1,40

Tab. 2 Selection of GB, Thai and US ball clays from Imerys Ceramics' sanitaryware range

		GB						Thailand		US	
		Hycast Rapide	Hycast LR	Hycast FFC	Hycast Plastic	Hycast Zodiac	Hyplas 64/S	Thaicast S1	Modicast S4	Martin #5	Old Mine #4
Chemical Analysis [mass-%]	SiO_2	53	53	62	58	56	64	63	63	62	59
	Al_2O_3	30	30	25	27	28	23	22,5	23	24	26
	Alkalis	1,9	2,4	2,2	2,1	2,1	2,5	2,3	2,2	1,7	1,2
	L.o.I. [%]	12,5	12,0	8,2	9,9	11,0	7,0	9,0	8,5	8,5	10,3
	Carbon	2,0	2,5	1,1	1,6	1,9	0,6	0,7	0,7	0,6	1,1
Residue [mass-%]	>125 µm	2,0	0,7	0,9	0,5	0,3	0,4	3	0,5	–	–
	>53 µm	3,0	1,5	4,0	2,5	1,5	3,5	5	3,0	1,6	1
Specific Surface Area	M.B.I. [mg/g]	18,0	24,5	24,0	26,0	28,8	37,0	29,6	31	22	36
MoR	at 80 % RH [MN/m²]	3,5	5,5	6,5	7,5	8,0	8,5	7,0	8,0	3,9	8,2
Casting Data	Casting concentration [mass-% solids]	70	67	68,5	67	66	63,5	64	66,6	66,7	62,4
	Deflocculant demand [mass-%] 5 P	0,8	1,05	0,9	1,03	1,12	0,5	1,2	1,4	0,85	1,18

influence slip density and particle packing (Tab. 4).

The first example, slip 1, used a combination of NSC kaolin from GB with Thai kaolin to increase slip density, improve packing and produce cast pieces with higher wet strength at a lower critical moisture content and higher green strength. The cast rate decreased slightly, but can be offset by increased yield. The second example, slip 2, took this concept further by using some Hycast VC ball clay, combined with fully refined Modicast S4 Thai ball clay, to further increase slip density, reduce critical moisture content and increase wet and dry strength. The cast rate decreased again.

The third example, slip 3, used a combination of Prosper kaolin from GB with Thai kaolin and ball clay to increase slip density and improve overall wet and dry strength. In this case the casting rate was maintained. In all cases production yield of one-piece water closets increased. Manufacturing sanitaryware is more demanding due to the gradual

Tab. 3 Examples of body performance using combinations of Imerys Ceramics' GB kaolins

	Slip 1	Slip 2	Slip 3
Hycast VC [%]	28,5	28,5	28,5
NSC [%]	25	12,5	–
SPK [%]	–	12,5	25
Non-plastic [%]	46,5	46,5	46,5
Slip density [g/cm^3]	1,832	1,838	1,813
Viscosity [P]	6,2	5,4	6,3
TTV fluidity (overswing)	304	314	305
TTV 90 min thixotropy (overswing)	36	26	49
Cast rate [mm^2/min]	0,93	1,2	1,8
Permeability/10^{-14} cm^2	10,3	13,4	20,2
Cast MoR dry [kg/cm^2]	3,1	2,5	2,3
Critical Moisture Content – CMC [%]	14,6	14,4	16,3

Tab. 4 Examples of body performance using combinations of Imerys Ceramics' kaolins and ball clays

	Reference	Slip 1	Slip 2	Slip 3
Thaicast S1 [%]	30	30	0	30
Modicast S4 [%]	0	0	20	0
Hycast VC [%]	0	0	10	0
MRD Cast [%]	26	16	16	16
NSC [%]	0	10	10	0
Prosper [%]	0	0	0	10
Feldspar [%]	27	27	27	27
Quartz [%]	17	17	17	17
Slip density [g/cm^3]	1,800	1,820	1,825	1,815
Viscosity [P]	6,2	6,7	7,0	6,8
TTV fluidity (overswing)	315	314	311	312
TTV 5 min thixotropy (overswing)	75	80	82	79
Cast thickness [mm/h]	9,0	8,6	8,5	8,9
Cast MoR dry [kg/cm^2]	32	35	39	34
Critical Moisture Content – CMC [%]	17,0	16,6	16,0	16,7
MoR at CMC [kg/cm^2]	6,8	7,7	8,0	7,4

transition from standard plaster casting to full pressure casting. It enables time saving, reduced reliance on skilled labour and improvements in yield and product quality.

This transition results in the diversification of demands, better understanding of traditional casting systems and more focus on raw materials.

By importing key components from its major deposits and combining them with or without local raw materials, Imerys Ceramics has developed new products in its new platforms in India, Egypt, Brazil and Indonesia.

Imerys Ceramics offers solutions to help assist manufacturers improve performance thanks to its wide product portfolio combined with detailed understanding of the properties of the plastic materials.

Whilst the example quoted was based on traditional casting, it demonstrates the importance of understanding both how clays work within the body and how the process itself is driven. In this way it can demonstrate how certain properties can be manipulated to give advantages.

Imerys Ceramics is confident that building on these fundamentals with a new, novel, laboratory-scale pressure-casting test rig will enhance their understanding of the process as well as their customers' and improve performance in the future.

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