Journal of Ceramic Processing Research. Vol. 16, No. 5, pp. 596~600 (2015)

JOURNAL OF
Ceramic Processing Research

Development of a semi-wet process for ceramic wall tile granule production

Emrah Durgut[a,]*, Çiğdem Yiğit Pala[a], Kağan Kayacı[a], Ali Altıntaş[a], Yıldız Yıldırım[a] and Hasan Ergin[b]
[a]*Kaleseramik R&D Center, Çan, Çanakkale, Turkey Hasan Ergin*
[b]*Mining Engineering/Faculty of Mines, Istanbul Technical University, Istanbul, Turkey*

In ceramic tile manufacturing industry, the wet process includes wet grinding and spray drying, is widely used for preparing granule. However, due to the high energy consumption for the water evaporation in spray dryer has become a major problem in wet process. In recent years, there have been vast amount researches for developing of dry granulation processes that consist of dry mills such as vertical roller mill or pendular mill and a granulator, have various problems on the granule shapes and granule size distributions that cause quality problems in the final products. In this research, it is aimed to develop a new production system, called as Semi-Wet Process. The new system consists of a horizontal dryer, dry ball mill, separator and additional high speed mixture. The raw-materials having low humidity are ground to the required fineness in dry size reduction process. The other components of recipe, that are prepared in conventional wet process, are mixed with the dry prepared powder in the mixing slurry tank. The addition of dry powder reduces the water ratio of final suspension, in other words, the bulk density of the slurry increases. Hence, a decrease is shown at the natural gas consumption of the water evaporation in spray dryer. The case application of developed Semi Wet System has been carried out in Kaleseramik Factory, which is the largest ceramic manufacturer in Turkey. The sintered wall tile wastes were ground in the developed system to the fineness of under 63 μm sieve. The dry prepared powder was added by 15% to the body slurry in the mixing tank, the bulk density of the wall tile slip has risen from 1632 g/L to 1750 g/L. As a result, the natural gas consumption has reduced from 52,52 sm^3/ton to 37,52 sm^3/ton. The use of Semi Wet System can provide savings around 6.750.000 sm^3/year for the current production rate at the factory.

Key words: Ceramic, Wall tile, Semi-wet process, Energy consumption.

Introduction

Ceramic tiles that are mainly used for wall and wall decoration of buildings have been the predominant products of the world's ceramic industry [1]. The general process of manufacturing ceramic tiles consists of such procedures as preparing the proportioned raw materials into granules, and press forming as-received granules, have a specific water content (usually 5-7%), into green tiles which are then fired into ceramic tile products [2]. Different preparation processes generally produce ceramic powders with different properties. Currently, in the ceramic tile industry, ceramic powders for wall tiles are mainly produced by wet grinding and spray drying, after which the compacts are formed by pressing [3]. Wet preparation system for wall tiles starts with crushing process, where the raw materials such as kaolin, fired ceramic waste and quartz, are reduced to fine size distribution under 1 cm. The raw materials, that compose the body, are ground by a wet ball mill until reaching the 2% residue of 63 μm. In addition, clays are dissolved in a blunger to remove the gang minerals before mixing operation. Furthermore, calcite minerals are ground separately by controlling the final particle size of the calcite, so as not to cause problems that are able to occur by inconvenient particle sizes. These three slurries are homogenized in a mixing pool with the ordered ratios of each material. After screening and removal of iron impurities, the suspension is pumped to spray dryer, based on the directions of air and product flow through the drying chamber [4-7]. The slurry makes a contact immediately with 400-550 °C hot air for instantaneous drying into fine granules [5-6].

The technical command of raw material wet grinding and the excellent performance of spray-dried powders have led to wide-scale industrial application of the spray drying process in the last 40 years. However, the high energy and water consumption involved in spray drying, in addition to emissions, remain major issues [7-8]. The prepared ceramic slurry has water content of about 36%, which is evaporated in spray dryer by 400-550 °C hot air that is generated by natural gas. Hence, the evaporated water content of the ceramic slurry directly affects the natural gas consumption in spray dryer. Especially after drying work, the hot air is cooled down into tail gas with temperatures between 90 °C and 130 °C. Thus, the air is directly discharged with considerable excess heat energy [4].

A new production system, called as Semi-Wet

*Corresponding author:
Tel : +90530-386-9021
Fax: +90286 416 1740, +90286 416 1741
E-mail: emrahdurgut@kale.com.tr

Process, has been planned to reduce granule production costs. Dry material is ground separately in the dry grinding system and added to the ceramic slurry. Hence, bulk density is increased with the addition of dry material into the slurry. The prepared ceramic slurry has less water content than the original ceramic slurry. This provides less natural gas consumption for dewatering of the ceramic slurry. The production capacity raises and the energy consumption decreases in the use of new developed Semi-Wet System.

Methodology

Material characterization

There are around nine different raw materials, such as calcite, siliceous kaolins and clays are used in wall tile body composition. The total amount of raw materials used for granule production is around 460.831.703 tons per year. Chemical compositions and sintering properties of the raw materials are listed order in Table 1 and Table 2.

Each material shows different thermal properties and

Table 1. Chemical composition of the raw materials.

Oxide (Mass %)	Kaolin A	Kaolin B	Kaolin C	Kaolin D	Kaolin E	Kaolin F	Tile waste	Calcite	Clay A
L.O.I	5,55	4,22	7,49	2,27	6,52	10,51	0,57	43,04	7,89
SiO_2	77,19	65,8	64,15	75,15	64,52	51,93	63,91	0,79	60,32
Al_2O_3	14,2	21,7	21,87	14,1	22,25	30,24	20,95	0,32	24,35
TiO_2	0,63	0,33	1,1	0,21	1,11	0,66	0,78	0,01	1,21
Fe_2O_3	1,12	1,18	2,67	1,35	2,59	4,34	1,62	0,02	3,04
CaO	0,26	0,52	0,21	0,36	0,23	0,17	8,67	54,9	0,12
MgO	0,11	0,29	0,5	0,32	0,47	0,3	0,71	0,46	0,49
Na_2O	0,18	1,51	0,16	0,83	0,24	0,53	0,74	0,01	0,08
K_2O	0,28	4,14	1,7	5,22	1,67	1,04	2,08	0,03	2,25
TOTAL	99,52	99,69	99,85	99,81	99,6	99,72	100,03	99,58	99,75
SO_4 = (Max.)	1,07	0	0,69	0	0,32	0,15	0	0	0

L.O.I: Loss on ignition.

Table 2. Sintering properties of the raw materials.

Items	Kaolin A	Kaolin B	Kaolin C	Kaolin D	Kaolin E	Kaolin F	Tile waste	Calcite	Clay A
Moisture (%)	9	17	12	11	15,5	26,8	6	3	18
Temperature (°C)	1140	1140	1140	1140	1140	1140	1140	1140	1140
Cycle (minutes)	35	35	35	35	35	35	35	35	35
Shrinkage (%)	-0,8	4,71	-0,08	2,24	3,85	7,43	3,27	0,68	3,61
Water absorption (%)	22,7	11,76	22,04	11,74	12,6	17,6	23,42	-	12,31
L	72,24	66,03	86,55	77,45	67,89	68,43	71,74	90,25	77,6
a	8,32	8,98	3,61	6,46	10,8	10,09	6,65	-1,13	8,61
b	10,97	15,72	5,64	18,56	15,33	12,35	16,53	4,61	19,49

L, a, b: Color measurement values.

Table 3. XRD and dilatometer results of the raw materials.

Items	XRD					Dilatometer ($\times 10^{-7}$ K^{-1})			
						α_{300}	α_{400}	α_{500}	α_{600}
Kaolin A	Quartz	Kaolinite	Alunite	Rutile		83,5	91,4	102,2	135,7
Kaolin B	Quartz	Sanidine	Triydimite	Kaolinite	Muscovite	71,6	72,7	72,6	75,9
Kaolin C	Quartz	Kaolinite	Alunite			70,0	73,3	80,3	105,4
Kaolin D	Quartz	Orthoclase	Albite	Illite	Kaolinite	78,7	84,4	91,9	109,1
Kaolin E	Quartz	Kaolinite	Illite	Anatase		35,3	39,8	46,6	61,5
Kaolin F	Quartz	Kaolinite	Illite			36,8	38,6	41,4	48,2
Tile waste	Quartz	Anorthite	Diopside			63,6	66,3	69,6	78,4
Calcite	Quartz	Calcite						–	
Clay A	Quartz	Kaolinite	Illite	Montmorillonite		53,9	56,2	59,4	69,9

Table 4. Ground and sieved ASTM # 100 mesh wall tile waste.

d_{90}	d_{50}	d_{10}
28,81 μm.	5,23 μm.	0,48 μm.

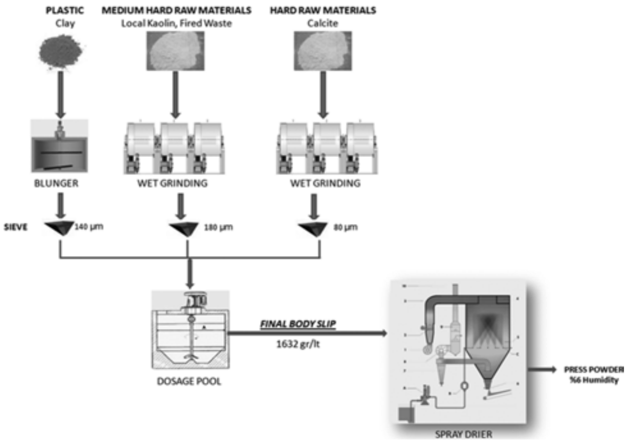

Fig. 1. Current wall tile granule preparation systems.

mineralogical structure. XRD results and thermal expansion values of the raw materials are shown in Table 3.

Cracked pieces of wall tiles, which were taken from Kaleseramik raw material storage area, were crushed and ground by a dry ball mill. Moreover, dry ground tile waste was passed through an ASTM # 100 mesh sieve and particle size distribution of the sample was checked by Malvern Microplus Mastersizer (Table 4).

The wall tile wastes of which chemical and physical analysis are presented in both Table 1 and Table 2, were used in this study.

The current wet process

The water absorption ratio must be more than 10% by mass for wall tiles [9]. Firstly, the recent process for wall tiles starts with crushing-screening unit. At that part, the aim is to prepare raw materials, such as siliceous kaolin, calcite and wall tile wastes for wet grinding feed down to 1 cm particle size. In addition, clay materials are prepared at a homogenizing process plant. Secondly, the raw materials and wall tile wastes that are crushed down to 1 centimeter particle size are moved to silos for wet grinding in wet system ball mills. On the other hand, clay materials are dissolved and removed from such impurities in a blunger system. These three slurries are homogenized in a mixing pool at ordered ratio and the bulk density of the final slip is 1632 g/L for wall tile. The mixing ceramic slurry is separated from iron impurities in a wet magnetic separator and sieved on a vibrating screen. The final ceramic slip is pumped to spray dryer, where ceramic granule is produced in. The flow chart of the process is shown in the Figure 1.

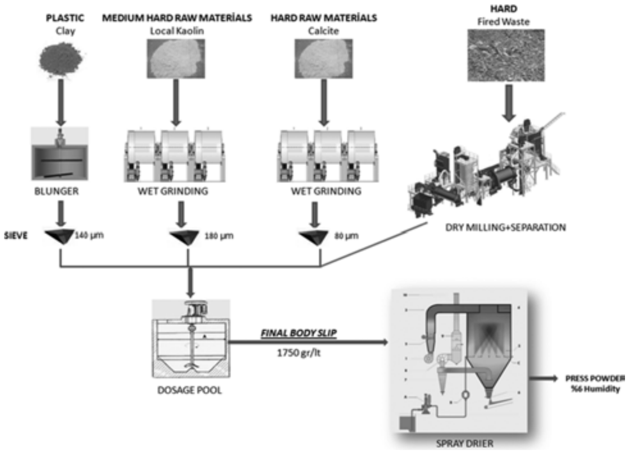

Fig. 2. Developed **s**emi-wet process.

Developed semi wet process

A new production system, termed as Semi-Wet Process, has been developed in order to reduce natural gas consumption in dewatering of slurry. The Figure 2 shows the flow chart of semi-wet process.

As it's indicated in the Figure 2, hard raw-materials such as tile waste and siliceous kaolins that contain humidity less than 10% are crushed down to 3 mm particle size by a hammer crusher, which is suitable for crushing of hard materials. After crushing process, raw materials that are crushed under 3 mm size, are dried in a horizontal dryer until containing a humidity less than 1%. Moreover, dry materials such as wall tile wastes are ground by a continuous dry ball mill until reaching the 1,5-2,0% residue of 63 μm sieve. In addition, particle size separation is supported by a separator, which works closed circuit with a ball mill to keep the particle size in ordered ratio.

Finally, dry material is added to the mixing pool, where clay slurry and other materials that contains humidity more than 10% are homogenized in. The pool is modified to achieve homogenous mixing of wet and dry particles with addition of a turbo rotary wing. A piston pump is used for efficient pumping of the slurry that has water content under 36%. The spray drying process is needed to modify on nozzle parts because of the high bulk density of the slip. The atomizers are spray pressure nozzles, through which slurry is pumped at high pressure. The spray nozzles are mounted on a series of radially arranged lances in the middle of the chamber, hot air being fed into the top of the chamber [5]. Hence, bigger nozzles are needed to pump the high density slurry into the chamber.

Experimental

After considering the physical properties such as moisture and hardness of the raw materials, the most suitable material is the tile waste for dry grinding.

Table 5. Dry ground wall tile waste addition to body compositions.

Items	Standard	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Calcite (%)	12,7	12,3	11,7	11,0	10,3	9,6
Siliceous kaolin (%)	53,5	44,8	42,3	39,8	37,3	34,8
Clay (%)	33,8	32,9	31,0	29,2	27,4	25,6
Dry Ground Tile Waste (%)	0	10	15	20	25	30
Total (%)	100	100	100	100	100	100

Hence, dry wall tiles wastes were added to the wall tile body slip compositions with 10%, 15%, 20%, 25% and 30% by mass to evaluate sintering behaviors of the wall tile body. New compositions are listed in Table 5.

After applying the size reduction under 63 microns, ground tile waste was added into the slurry. Moreover, the slurry was dried to reach the 6% moisture in the samples. The granules were pressed for having 5 cm diameter tablets at 325 kg/cm^2. After that, the tablets were dried and then sintered in the conditions of wall tile at 1150 °C, 36 minutes. After thermal treatments, the water absorption of the samples (according to the ISO Standards 10545-3), linear shrinkage that is the difference between the dimensions of the test specimen before and after firing (according to the ISO Standards 10545-2) and color values were measured. Mineralogical structures of raw materials were obtained by XRD (X' Pert Pro MPD 30 mA, 40 kV 0,02 Step Size) and thermal expansion of each raw material calculated by dilatometer (Netzch 402 EP).

Results and Discussion

The physical properties such as firing shrinkage, water absorption and color values of the samples that were prepared by adding 10%, 15%, 20%, 25% and 30% are given both in Table 6 and Table 7.

Figure 3 and Figure 4 refer that dry prepared raw materials such as; fired wall tile wastes that have moisture less than 1% are able to add in wall tile body composition at 15% so as not to have negative effects on technical properties of the body. Moreover, considering the wall tile waste amount of the factory, the most feasible value is 15% tile waste for the process.

There appears to be a significant natural gas saving while adding dry tile waste into the ceramic slurry mix. 1 sm^3 amount of natural gas equals to 8250 kcal energy. 850 kcal of energy is needed to evaporate 1 liter of water from the ceramic slurry. Figure 5 shows the natural gas consumption related to density by adding dry tile waste of different percentages.

Figure 5 indicates that density of the ceramic slurry has risen gradually with the addition of dry tile waste into the slurry mix. Hence, natural gas consumption has decreased considerably.

Total granule preparation costs of the processes that include raw-material costs, crushing-screening, grinding and natural gas consumption (spray drying) are shown in Table 6.

Table 6. Cost distribution of the current wet process for wall tile

Current Situation	(TL/ton)
Raw material composition	39,94
Crushing-screening-transport	5,92
Grinding (wet ball mill)	8,15
Natural gas consumption (1632 g/L) (52,52 sm^3/ton)	38,92
Total	92,93

Table 7. Cost analysis of new granule preparation process for wall tile.

New Situation	(TL/ton)
Raw material composition	39,94
Crushing-Screening-Transport	5,05
Grinding cost	7,5
Natural gas (1750 g/L) (37,52 sm^3/ton)	27,8
Total	80,29

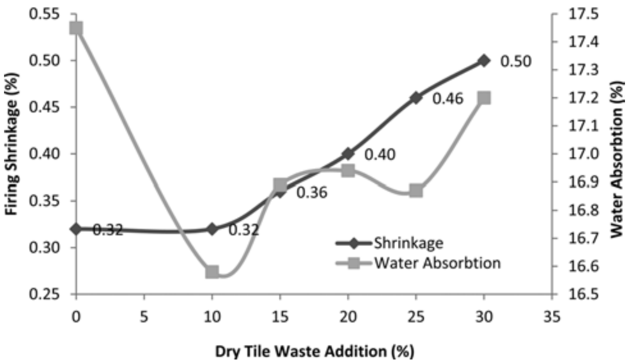

Fig. 3. The changes in both water absorption and shrinkage percentages of the samples.

A pre-feasibility is studied to determine the economic and technical differences between the current process and planned method. Wall tile waste products, which were added to wall tile body compositions as 15% are ground down to 63 micron with a 1,5-2,0%. As a result, wall tile body slip density increases from 1632 g/L to 1750 g/L while natural gas consumption decreases from 52,52 sm^3/ton to 37,52 sm^3/ton. Cost analysis of wall tile body for the new system is given

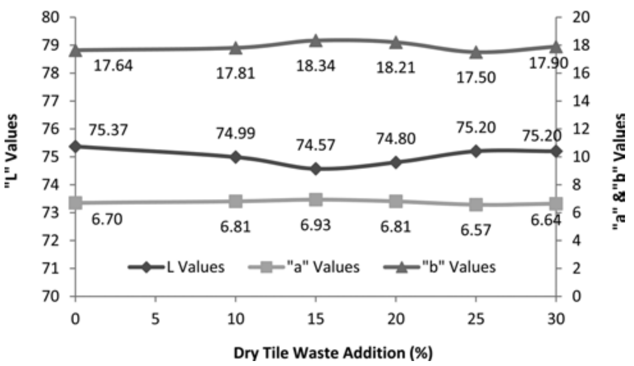

Fig. 4. The changes in color values of the samples.

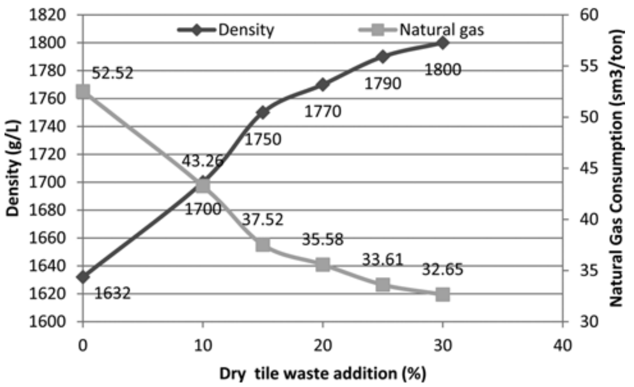

Fig. 5. The changes in both water absorption and shrinkage percentages of the samples.

in Table 7 respectively.

The vast amount of the cost comes from the natural gas consumption except raw material costs. Table 7 indicates that spray drying cost reduces from 38,92 TL/Ton to 27,80 TL/Ton for wall tile body composition. Total granule preparation cost of the body slip decreases from 92,93 TL/Ton to 80,29 TL/Ton.

Conclusions

As a result of the study, the dry prepared powder can be added by 15% to the mixing tank provided that adjusting the body composition, the bulk density of the wall tile slip rises from 1632 g/L to 1750 g/L. Hence, the natural gas consumption reduces from 52,52 sm^3/ton to 37,52 sm^3/ton. The use of Semi Wet System can provide natural gas savings around 6.750.000 sm^3/year for the current production rate at the factory.

Acknowledgments

This research has been done in Kaleseramik Research and Development Center that is supported by Republic of Turkey, Ministry of Science, Industry and Technology.

References

1. Turkish Ceramic Sector Strategy Document and Action Plan 2012-2016, in Proceedings of Turkish Official Gazette, January 2013, edited by Ministry of Science, Industry and Technology p. 14.
2. Liu, D.M., Fu, C.T., Compaction behaviour of spray-dried silicon carbide powders. Ceramics International 22 [1] (1996) 67-72
3. E. Sa´nchez, J. Garcý´a-Ten, V. Sanz, A. Moreno, Porcelain tile: almost 30 years of steady scientific-technological evolution, Ceram. Int. 36 (2010) 831-845
4. European Commission, 2007, Reference document on best available techniques in the ceramic manufacturing ýndustry available from: http://eippcb.jrc.es/reference/cer.html.
5. Walker Jr., W.J. and Reed, J.S., Influence of slurry parameters on the characteristics of spray-dried granules. J. Am. Ceram. Soc. 82 (1999) 1711-1719
6. Lukasiewicz, S.J., Spray drying ceramic powders. J. Am. Ceram. Soc., 72 (1989) 617-624
7. IPTS, 2007, Reference document on best available techniques in the ceramic manufacturing industry, European Commission available from: http://eippcb.jrc.es/reference/cer.html), 116.
8. M.C. Minguillo'n, X. Querol, A. Alastuey, E. Monfort, E. Mantilla, M.J. Sanz, F. Sanz, A. Roig, A. Renau, C. Felis, J.V. Miro', B. Artin~ano, PM10 Speciation and determination of air quality target levels. A case study in a highly industrialized area of Spain, Sci. Total Environ. 372 (2007) 382-396
9. European Committee for Standardization, 2012, European Standard EN 14411, TS EN 1441, p. 41-45.