REVIEW OF STUDIES AND REFERENCES ON PARAMETERS THAT CAN PRODUCE COLOUR VARIABILITY AND SURFACE DEFECTS IN CERAMIC TILE MANUFACTURE

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SUMMARY

After reviewing the articles and references indicating the origin of the factors that produce colour variations and surface defects in floor and wall tiles, over 150 factors have been gathered as causes of these variations. The presentation, knowledge and use of the studies and work carried out in this respect can enable improving the form of working and the quality of the resulting product.

By performing a literature survey on the process variables (over 70 national and international articles are listed in the poster), exhaustive analysis was conducted of the most important factors and causes generating changes in colour and surface defects. The different ceramic manufacturing stages were considered: clay extraction, spray drying, pressing, drying, engobe, glaze, fumé, brushing, printing, fixative, transparent glaze, granular, firing and sorting.

In the clay extraction process and subsequent spray drying, it is fundamental to know and control the chemical and mineralogical composition of the clay (proportion of aluminium and iron oxide, organic matter and moisture content humidity, amongst other), as well as primary particle size distribution and agglomerate size distribution. As for the pressing stage, it is fundamental to control the mechanical variables, and at the same time perform bulk density tests on the compact, as well as conducting tests on powder moisture content and flowability before this stage. In the drying stage, tile temperature and moisture are mainly determined, while control of such conditions as drying air flow and temperature are of vital importance.

The printing process has been analysed with regard to the main systems currently found: flat screen printing, rotating screen printing, rotogravure, flexography, pad printing and even ink-jet, in each case keeping in mind the pre-printing variables (preparation of the photolitho, production of the applicator, etc.) and those of printing itself in the production plant.

Fixative variables are set out (typically used for screen printing), together with transparent glaze, granular and firing. The firing stage is perhaps one of the key stages, since this is when melting and crystallisation of the engobe-glaze-inks occur, producing the final colour of the piece and such well known defects as black core, pre-heating cracks or dimples, etc., as well as tile expansion-shrinkage, particularly of wall tiles. To control and to avoid these problems and the defects relating to tile colour and surface defects during firing, it is necessary to principally control firing rate, temperatures in the different modules, cooling rate, pressure curves, and oxygen concentration.

Finally the different factors have been considered that affect tile end sorting, bearing in mind that this is generally carried out visually by trained personnel. Three factors are distinguished, lighting conditions (type of illumination in sorting and in glazing to guarantee colour stability in the two sections), observation conditions (tile arrangement in the panel and lighting), and lastly the criteria and human component in the sorting stage.

At the present time, few companies carry out controls on the variables that affect colour changes, and in many cases these controls focus on the printing system. Nevertheless, in the companies where controls are conducted along the whole glazing line, viscosity, grammage, density of the engobe, glaze and inks etc., are measured. These measurements are performed by weighing or indirect measurement of the variables. Many other important variables such as squeegee lift-off, angle and pressure, tile temperature and moisture content should be measured in a regular way in each and every production series, ensuring they remain constant throughout the whole production. To achieve and hold production quality as well as sustained output, it is important for manufacturing to take place with standard methods, which makes systemising each production stage indispensable.

The variation sources mentioned are based on the knowledge or expertise of their authors, and having a clear list of these tests in each production system stage is an important help in anticipating and discovering the origin of production problems. The experiences indicated have neither been evaluated nor verified by repeating the tests, only the factor involved is clearly indicated, together with the author or authors that signal this as a cause, with the references in which all this is found.

Given the importance and benefit that it can mean to co-ordinate and set out the works to be found in this sense, the poster will present a list of the variation sources together with the corresponding references, as well as other sources generally dealing with control and measurement in the companies, even though the corresponding references are unavailable. The main benefit is to have a single work with all the sources for study and consideration, by researchers and also by the companies in the ceramic sector.

	CERAMIC PROCESS			
	CLAY (raw mat.)	**SPRAY DRYING**	**PRESSING**	**DRYING**
VARIABLES THAT AFFECT COLOUR (of the body and finished product)	* Iron oxide content [1,2,69]. * Silica or aluminium oxide content [1,70]. * Organic matter content [3,17,20,69].	* Chemical and mineralogical composition of the raw materials [2,4,10,26]. * Primary particle size distribution [2,4]. * Agglomerate size distribution [2].	* Pressing conditions [6]. * Powder moisture content [2,7]. * Powder flowability [2]. * Forming pressure [2,7,19]. * Bulk density of the compact [2,4,69]. * Tile thickness. * Tile roughness.	* Drying conditions [6]. * Tile exit temperature [2,7]. * Humidity in the dryer [4,21]. * Drying temperature [4,21]. * Drying air flow rate [21].
VARIABLES THAT PRODUCE SURFACE DEFECTS (SYSTEMATIC DEFECTS and UNFORESEEN DEFECTS)	* Organic matter content and particle size [9,17,20]. * Calcium carbonate content [17,20]. * Sulphide, sulphate and fluoride content [17,20].	* Chemical and mineralogical composition of the raw materials [16,17,18,71]. * Powder moisture content [5,64]. * Powder particle size distribution [9,13,10,17].	* Lubricant composition [12]. * Binder composition [11]. * Powder moisture content [5,11,12,14]. * Granule size [11]. * Tile thickness [5]. * Tile weight [5]. * Forming pressure [14,15,19]. * Tile bulk density [10,14,20].	* Drying cycle [8,15,20]. * Drying temperature [15]. * Tile exit temperature [5]. * Tile residual moisture content [8,20].

Table 1. Raw materials, spray drying, pressing and drying.

	CERAMIC PROCESS/GLAZING LINE			
	ENGOBE	**GLAZE**	**FUMÉ**	**BRUSHING**
VARIABLES THAT AFFECT COLOUR (of the body and finished product)	* Formulation and composition [1,21,31]. * Density [1]. * Grammage [1,6,7,21,35]. * Viscosity [1]. * Particle size distribution [2]. * Stock change [6,7]. * Stirring [2]. * Lot change [7]. * Engobe flow rate [2]. * Line speed [2].	* Formulation and composition [1,26,31]. * Density [1,4,25,26]. * Grammage [1,6,7,23,24,25,35]. * Viscosity [1,25,26]. * Particle size distribution [2,4,26,27,34] * Homogeneous mixing [26]. * Glaze pH [23]. * Water hardness [23]. * Nature and properties of the additives [23]. * Effect of common salt [23]. * Deflocculant content [23,28]. * Change of stock [6,7]. * Line speed [2]. * Lot change [7]. * Nozzle [25]: compressed air quantity and quality. * Bell [25]: suspension flow rate, deflocculant content. * Rotogravure [25]: shape and dimensions of the cavities, adjustment, shape, angle and hardness of the blade. * Opaque coloured glazes: frit and glaze transparency [29].	* Density. * Viscosity. * Grammage. * Nozzle application: pressure and direction. * Control of stopping time and fumé emission.	* Brushing speed. * Brushing pressure
VARIABLES THAT PRODUCE SURFACE DEFECTS (SYSTEMATIC DEFECTS and UNFORESEEN DEFECTS)	* Formulation and composition [33]. * Surface drying time [33].	* Lumps, pinholes, cracks, etc. - Rheological parameters [32] * Bell [25]: deflocculant content, stirring, glaze viscosity [5] and density [5], grammage [30], tile surface roughness [30], body material (redware, whiteware)[30], chamfer shape [30], tile temperature [30]		

Table 2. Glazing line: engobe, glaze, fumé and brushing.

	CERAMIC PROCESS /GLAZING LINE					
	FLAT SCREEN PRINTING	**ROTATING SCREEN PRINTING**	**ROTOGRAVURE**	**FLEXOGRAPHY [50]**	**PAD PRINTING [51,52]**	**INK-JET**
VARIABLES THAT AFFECT COLOUR (of the body and finished product) - printing variables - pre-printing variables	* Pigment formulation [1,26,31,33,34,37,38,59]. * Screen print density [1,6,26,54,59]. * Deposited grammage [1,4,6,21]. * Screen print viscosity [4,6,26,31,34,35,59,60,62]. * Particle sizes and size distributions [2,9,26,27,31,36,37,34,57]. * Screen print flow on the screen [26]. * Ambient temperature [60]. * Screen printing stock change [6,7]. * Screen change [6,7]. * Average screen life (wear, emulsion loss, clogging, etc.) [26,54]. * Off-contact [6,26,38,39,40,54,61,62]. * Squeegee angle [6,26,38,39,40,42,54,62]. * Squeegee type and hardness [6,26,31,39,40,54]. * Squeegee sharpness, profile and pressure [6,26,38,39,40,54,60,62]. * Squeegee rubber height [31,60,61]. * Squeegee change [6]. * Line and printing speed [6,54,60,61,62]. * Compensator cleanness and use [6,26,54]. * Tile input temperature [43]. * Tile moisture content [43]. * Tile curvature [43]. * Centring and adjustment between printings. * Effect of the operators/line change [6]. * Background noise (company environment)[6]. * Dot density in the photolitho [46,62]. * Dot shape in the photolitho [54,55,62]. * Dot diameter in the photolitho [46,54]. * Dot opacity in the photolitho [54]. * Screen tension [2,26,6,38,39,40,41,54,62]. * Type of gauze [45,2,38,39,40,42,60]. * Gauze ruling [45,54,55,60]. * Gauze colour [41,46]. * Gauze preparation [41]. * Screen size. * Mesh aperture [4,22,25,31,45,46,47,54,55]. * Thickness of the screen and of the emulsion [6,21,31,46,26,47,54,55,60]. * Physico-chemical characteristics of the emulsion [42,55,60]. * Emulsion drying temperature and time [54,55,62]. * Workshop ambient temperature [55]. * Accuracy of the resin application. * Optimum UV-curing time [26,55,62]. * UV-curing intensity [55]. * Lighting system characteristics of the (average life) [44]. * Washing pressure, distance and system [26,55,62].	* Pigment formulation [1,58]. * Screen print density [1,6]. * Deposited grammage [1,4,6,21]. * Viscosity [4,6]. * Particle sizes and size distributions [2,22,36,37,27]. * Screen print flow rate on the screen. * Ambient temperature. * Screen printing stock change [6,7]. * Cylinder tension [2,6,38,39,40,41]. * Torsion angle. * Change of cylinder [6,7]. * Average cylinder life. * Off contact [6,38,39,40]. * Squeegee angle [6,38,39,40,42]. * Type of squeegee [6,39,40]. * Squeegee sharpness, profile and pressure [6,38,39,40]. * Squeegee rubber height. * Change of squeegee [6]. * Line and printing speed [6]. * Tile input temperature [43]. * Tile moisture content [43]. * Tile curvature [43]. * Centring and adjustment between printings. * Effect of the operators/line change [6]. * Background noise (company environment) [6]. * Type of gauze (material) [2,38,39,40,42]. * Gauze ruling. * Colour of the gauze [41]. * Gauze preparation [41] * Cylinder size. * Mesh aperture [4,22,47]. * Thickness of the gauze and of the emulsion [6,21,40]. * Physico-chemical characteristics of the emulsion [42]. * Accuracy of the resin application. * Optimum UV-curing time. * UV-curing intensity. * Lighting system characteristics (average life) [44].	* Pigment formulation [1,48,56,58]. * Ink density [1,25,49,56]. * Deposited grammage. * Ink viscosity [25,49,56]. * Particle distribution and size [2,22,36,37,27]. * Ambient temperature. * Blade angle [25,56]. * Blade pressure [25]. * Blade hardness and profile [25,56]. * Off contact. * Average life of the roller and scraper. * Change of roller. * Line and roller printing speed. * Centring and adjustment between rollers. * Tile input temperature. * Tile moisture content [56] * Tile curvature. * Roller cleanness. * Effect of the operators. * Background noise (company environment)[6]. * Cavity diameter [25,49]. * Cavity depth [25,49]. * Type of cavity [25,49].	* Pigment formulation [1]. * Ink density [25]. * Deposited grammage. * Vehicle viscosity [1]. * Relation vehicle-dry solid. * Surface tension. * Particle distribution and size [27]. * Ambient temperature. * Blade angle and pressure. * Average life of the photopolymer. * Change of the photopolymer. * Line and roller printing speed. * Roller centring and adjustment. * Effect of the operators. * Pressure between rollers. * Profile size and definition. * Photopolymer hardness and thickness.	* Pigment formulation [1,58]. * Ink density. * Deposited grammage. * Ink viscosity. * Particle distribution and size [27]. * Printing and line speed. * Height of pad stroke. * Cleanness of the surface to be printed. * Number of prints. * Air humidity * Cliché profile and print edge definition. * Curing times and type of light. * Screen material * Plate material * Pad shape. * Pad roughness and hardness. * Cliché porosity. * Cliché flatness. * Verticality of the profile. * Blade wear * Blade flexibility * Blade pressure * Electrostatic coefficient of the surface.	* Pigment formulation [1,58]. * Ink density. * Deposited grammage. * Particle distribution and size [27]. *Electric susceptibility of the inks.
VARIABLES THAT PRODUCE SURFACE DEFECTS (SYSTEMATIC DEFECTS and UNFORESEEN DEFECTS)	* Degree of solids and pigment dispersion [36].		* Cylinder stamping process [56] * Slipping or synchrony parameter between roller-mat [56] * Space between pieces [56] * Printing pressure [56] * Roller levelling [56]		* Ink formulation and composition. * Ink viscosity. * Cliché profile. * Type of screen * Type of plate. * Pad shape and hardness. * Pad roughness. * Electrostatic coefficient of the surface. * Cleanness of the surface to be printed. * Height of the pad stroke. * Printing speed. * Air humidity	

Table 3. Printing systems: flat and rotating screen printing, rotogravure, flexography, pad printing and ink-jet.

	CERAMIC PROCESS					
	FIXATIVE	TRANSPARENT GLAZE	GRANULAR		FIRING	SORTING
			WITH SUCTION	WITHOUT SUCTION		
VARIABLES THAT AFFECT COLOUR (of the body and finished product)	* Formulation and composition. * Deposited grammage [6,7,22,54]. * Density. * Viscosity.	* Grammage. * Density. * Viscosity.	* Suction speed and pressure. * Deposited grammage	* Deposited grammage.	* Residence time in boxes. * Change of firing cycle [3,6,7,17,21,31,37,66,67,34] . Firing rate [66]. . Constant firing temperatures [1,4,6, 35,63,66,]. . Peak firing temperature. . Residence time at peak firing temperature. . Preheating: chamber with depression [66]. . m^2/h (drying surface area per unit time) . Cooling rate [35,63,66]. . Kiln channel. . Thermal homogeneity in the different chamber sections. . Pressure curve [4,63,66]. . Firing atmosphere [4,21,66]. . Reduction intensity and duration (O_2 defect) and temperature [65,66].	* Lighting conditions [1,2]. * Human factor (criteria). * Observation conditions
VARIABLES THAT PRODUCE SURFACE DEFECTS (SYSTEMATIC DEFECTS and UNFORESEEN DEFECTS)					* Constant firing temperatures [1,20]. * Tile bloating [31,64,70]: - Firing temperature. * "Wart" defect [9]: - Firing cycle. - Firing curve. * Preheating cracks [20,68]: - Unfavourable temperature conditions. - Very fast rise in preheating temperature. * Black core [17,69]: - Firing cycle. - Oxygen and carbon oxide concentration. * Pinholing: - Firing cycle [17,71]. * Cooling [20]	

Table 4. Fixative, transparent glaze, granular, firing and sorting.

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