DECARBONISING THE CERAMIC PROCESS WITH ELECTRIC HEATING FROM RENEWABLE SOURCES

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1. ABSTRACT

The ceramic tile and slab sector is one of the industrial sectors most in need of a conversion of its energy-intensive processes, with a gradual changeover from the use of fossil fuels (such as natural gas) to sustainable vectors (such as renewable energies and green hydrogen), in order to meet the emissions reduction demands foreseen in the European Green Deal (reduction of net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels).

Moreover, the recent energy crisis, which has led to a significant increase in the cost of natural gas, is pushing the ceramic sector to seek alternative responses to the use of gas in its thermal processes, particularly those involving high temperatures.

Another factor that should not be overlooked is the constant increase in costs related to CO_2 emissions into the atmosphere, regulated by the EU ETS system, which will probably continue to rise in the coming years, further driving the abandonment of fossil fuels.

At the same time, there has recently been a true race to install solar and wind farms, capable of exploiting renewable natural resources to increase the proportion of available "green" electricity (by 2022, at least 58% of electricity in Europe will be of non-fossil origin).

In ceramic production, two main thermal energy-using stages account for almost all direct CO_2 emissions. In fact, spray drying contributes approximately 40% of those emissions, while the remaining 60% comes from the drying and firing stages.

Spray drying, given its working temperature between 450 °C and 600 °C, is well suited for a partial or total conversion from a fossil fuel (in general, methane gas) heat generator to an electric generator powered by non-fossil energy (and therefore with zero CO_2 emissions).

The aim of this study was to define and develop a heating system, for the air entering the spray dryer, capable of operating in hybrid mode (gas + electricity) with an electricity contribution that varies between 0 and 100% (zero emissions).

In particular, the test focused on three technical aspects: a fluid-dynamic study of the heat generator to optimise the heat exchange geometry in flow rate and flow velocity conditions not found in other industrial applications, modulation of the significant power ratings involved (from 1 to 40 MW), and management of the electric contribution based on the available renewable energy (day/night alternation, partial contribution at sunrise/sunset).

The study has demonstrated the industrial feasibility of a hybrid heat generator that can be applied to both new and existing spray dryers for ceramics, thus enabling substantial decarbonisation of the process while ensuring unaltered productivity and quality of the ceramic tiles and slabs obtained in this way.

2. INTRODUCTION

In order to meet the emissions reduction guidelines of the European Green Deal (reduction by 2030 of net greenhouse gas emissions by at least 55% compared to 1990 levels), the ceramic tiles and slabs sector will be one of the industrial sectors (like cement, glass and steel) obliged to transform its energy-intensive processes (also known as «*hard to abate*» processes) [1].

The first driver of emissions reductions is improving the overall efficiency of processes and installations, which comes naturally as technology development and has already enabled the sector to reduce specific consumption per m^2 product by more than 35% compared to 1990 [2].

The second line of research and development is the gradual replacement of fossil fuels (e.g., natural gas) with environmentally sustainable energy sources (such as electricity from renewable sources or green hydrogen) to ensure a substantial or total reduction of greenhouse gas emissions in the process stages requiring thermal energy.

The EU ETS emissions regulation mechanism has recently led to a considerable increase in the costs of emitting CO_2 into the atmosphere, as shown in **Fig.1** with the value per tonne of CO_2 rising from €20 (in 2020) to more than €100 (in March 2023) in a span of three years and likely to increase further in the near future, which will further drive the shift away from fossil fuels towards carbon-neutral technologies.

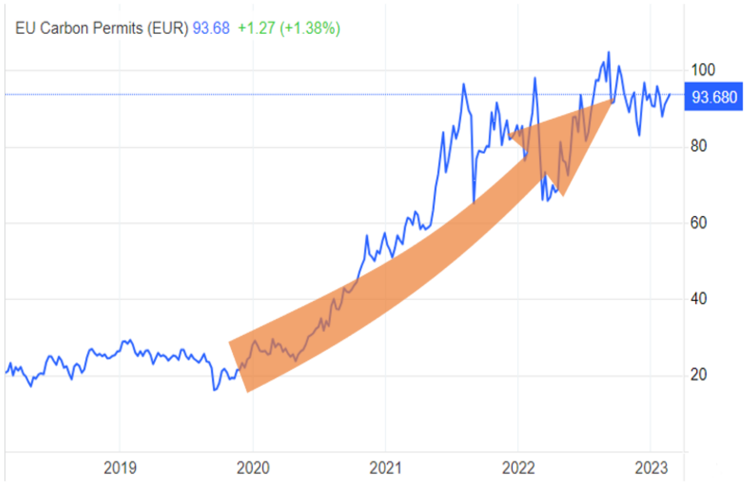

Fig. 1 *– Upward trend in ETS quotations [3]*

At the same time, a true race has taken place recently to install solar and wind farms to exploit renewable natural resources and increase the share of available "green" electricity. Governments around the world have also been encouraging investment in clean energy for some time now through specific policies and tax relief. **Fig 2.** shows the global trend in these investments worldwide; as can be seen, the progression is similar to that of the graph in **Fig.1.**

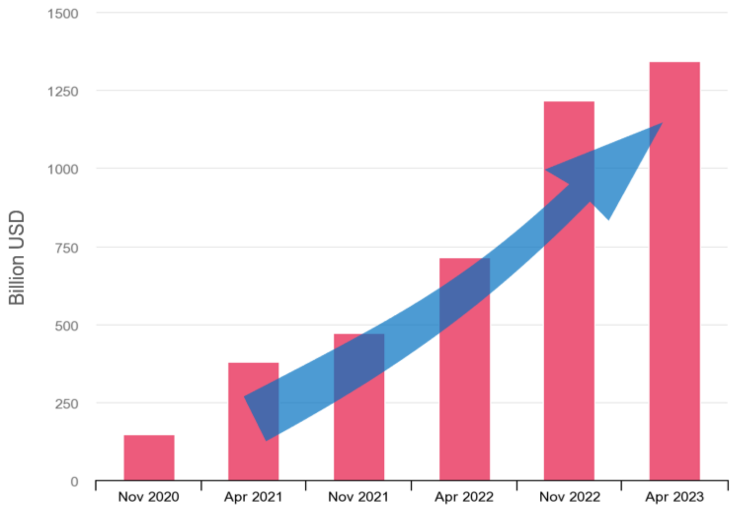

Fig. 2 *– Public spending in support of clean energy investments [4].*

In 2023, for the first time, global investments in clean energy have exceeded investments in fossil-based energy. This means that the cost of green energy will come down in the future and will also become increasingly convenient from an economic point of view.

The European ceramic industry has long been on the path of progressive energy conversion of its production processes. To meet EU requirements, Cerame-Unie has developed an emissions reduction model that combines a series of measures to achieve a gradual reduction that leads to carbon neutrality by 2050.

The graph in **Fig.3** shows cumulative emissions (million tonnes of CO_2) over the decades from 1990 to the present day and forecast up to 2050 (when carbon neutrality is expected to be achieved) for the European ceramic industry. Direct combustion of fuels (blue graph) obviously accounts for most of the total emissions.

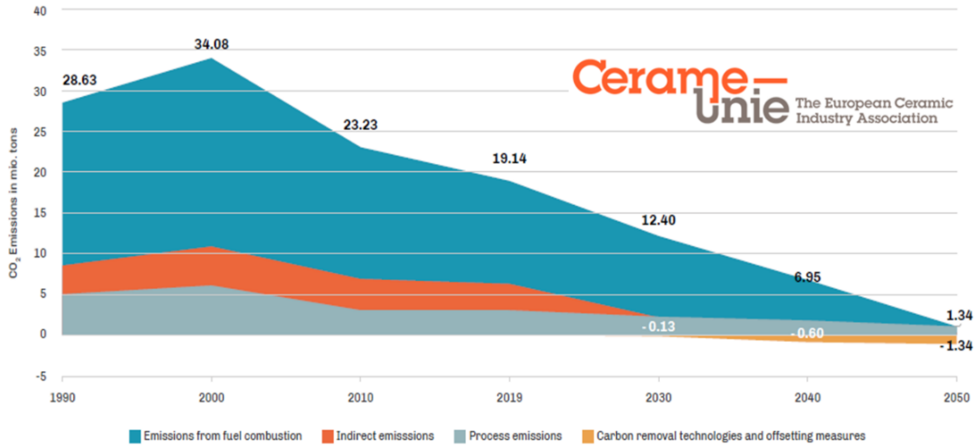

Fig. 3 *– Historical and projected emissions up to 2050 for the European ceramic industry [5]*

3. THE CERAMIC SPRAY DRYER

Analysis of the direct CO_2 emissions in the ceramic tile production cycle [5] yields a CO_2 emissions breakdown by production stages, as shown in **Fig. 4**. Among the production stages that require thermal energy (spray drying, drying and firing), the spray-drying stage contributes approximately 40% (1.86 kg CO_2 out of a total of 5.05 kg CO_2 from thermal processes).

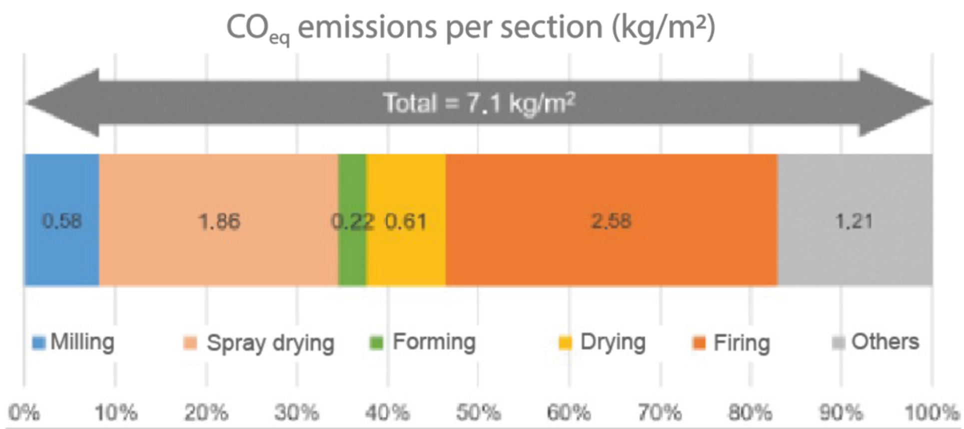

Fig. 4 *– Current CO_2 emissions subdivided between the various sections of a ceramic plant [2].*

The spray-drying stage needs large volumes of hot air at an intermediate temperature (between 450 °C and 600 °C), without any particular purity requirements, and it has long been the subject of energy efficiency solutions, such as recovering combustion fumes from electric cogeneration plants with a gas turbine or alternative internal combustion engine.

***Fig. 5** – A modern spray-drying facility*

Inside the spray-drying tower (see **Fig.5**), heat exchange takes place between the droplets of sprayed slurry and the hot fumes. The ceramic product reaches maximum temperatures of about 60 °C and undergoes no chemical transformation resulting from the atmosphere or temperature, as shown in **Fig.6.**

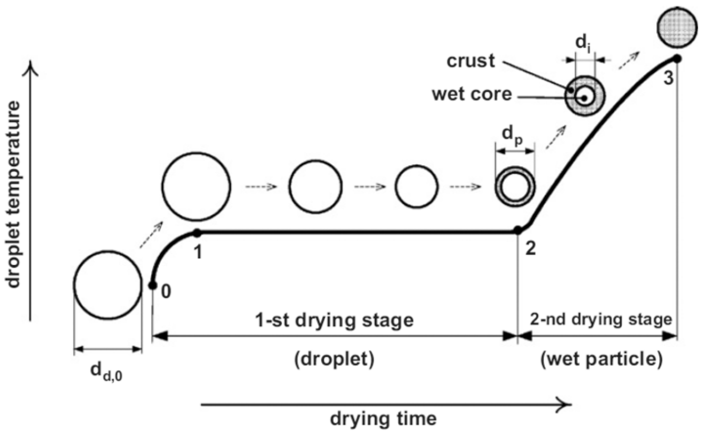

***Fig. 6** – Evolution over time of droplet drying [6].*

The fumes enter the drying chamber unfiltered; any ash or other combustion products do not alter the drying process but may be considered pollutants, depending on the purity required of the spray-dried powder. The spray dryer normally works at full load, with short stops for cleaning and maintenance; therefore, it is a very suitable candidate for coupling to waste heat recovery or self-producing energy systems, for example, via cogeneration.

In spray drying, the replacement of fossil fuel (of any gaseous, liquid or solid nature) by **hydrogen** does not seem to present particular technical difficulties, provided that suitable technologies and certified components are used.

To truly decarbonise the process, it would be necessary to use green hydrogen as fuel. At present, it is produced by electrolysis of water, using electric power from renewable sources. This makes its use uneconomical, as it costs approximately twice as much as standard electricity and four times as much as natural gas, which today covers almost all of Europe's needs.

The use of hydrogen is only justified for very high temperature processes (over 1000 ºC) or when special conditions of purity of the combustion atmosphere are required.

The possibility of using electricity directly in an electric heater has been studied for thermal processes involving temperatures up to 600 °C, without having to discount energy losses due to the electrolysis process to produce hydrogen.

Therefore, a partial or complete conversion of the heat generator, changing over from fossil fuel to a **hybrid electric heat generator** powered by non-fossil energy (and thus with zero CO_2 emissions), is of interest for spray drying.

4. THE HYBRID HEAT GENERATOR

An innovative spray-drying system for ceramics has been developed (and patented), with an inlet air heating system capable of operating in hybrid mode (fossil + electric), with variable electric contribution from 0% to 100% and, consequently, variable CO_2 emissions.

Fig.7 illustrates the system's three possible configurations/operating conditions:

- 100% fossil generator: this operating condition is equivalent to current installations and is used when, for whatever reason, electricity is not available from renewable sources (self-produced or purchased from the grid). In this case, CO_2 emissions are at a maximum.
- Hybrid generator: When part of the green electricity is available but is not sufficient for the system's total power requirements, the generator draws on a fossil fuel fraction until the required thermal power is reached. The presence of the fossil fuel burner and the electric heater affords the system maximum flexibility, speedy maintenance and efficient adjustment in each of the conditions depending on the availability of the various energy sources. CO_2 emissions are intermediate and related to the amount of fossil fuel used.
- 100% electric generator: when sufficient renewable electric power is available, the system operates only with the electric heater. Under these conditions, CO_2 emissions are zero.

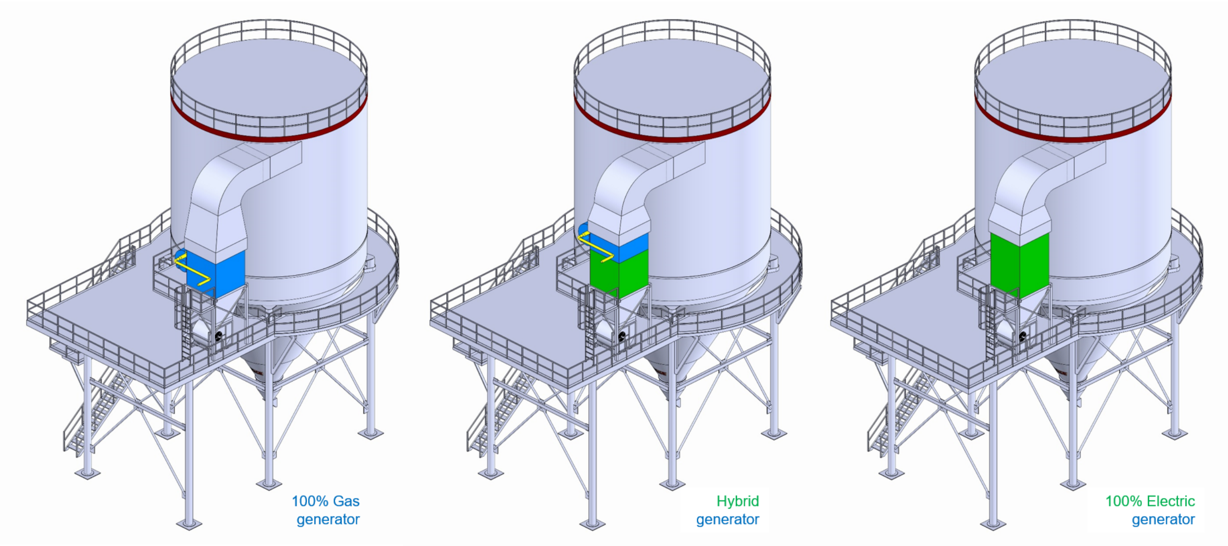

Fig. 7 *– Possible heating system configurations*

The electric generator uses a new class of high-power heaters, which have recently been developed and introduced onto the market. **Fig.8** shows a particular detail of the electric heating elements that make up these heaters.

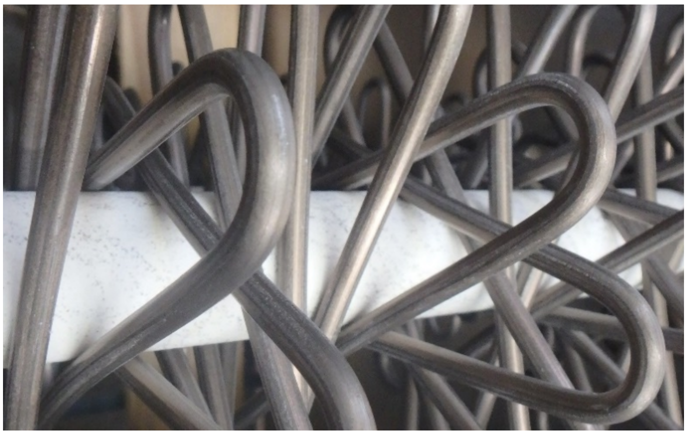

Fig. 8 *– Close-up of the elements that make up the electric heater.*

In view of the high thermal power required by industrial spray dryers - a typical range of machines for ceramic industries goes from 1 to 40 MW thermal -, a modular solution has been adopted, which allows a suitable number of heaters to be combined until the project's required power output is reached. The modular construction of the electric heater means it can be sized according to the green energy available to the plant and allows possible future extensions to be planned.

To maximise the equipment's efficiency and contain its costs, an electronic system for regulating the thermal power has been developed, which guarantees a conversion efficiency of over 98%.

The design and testing activities have focused on three technical aspects:

- The fluid-dynamic study of the heat generator to optimise heat exchange geometry under flow rate and flow velocity conditions not found in other industrial applications.

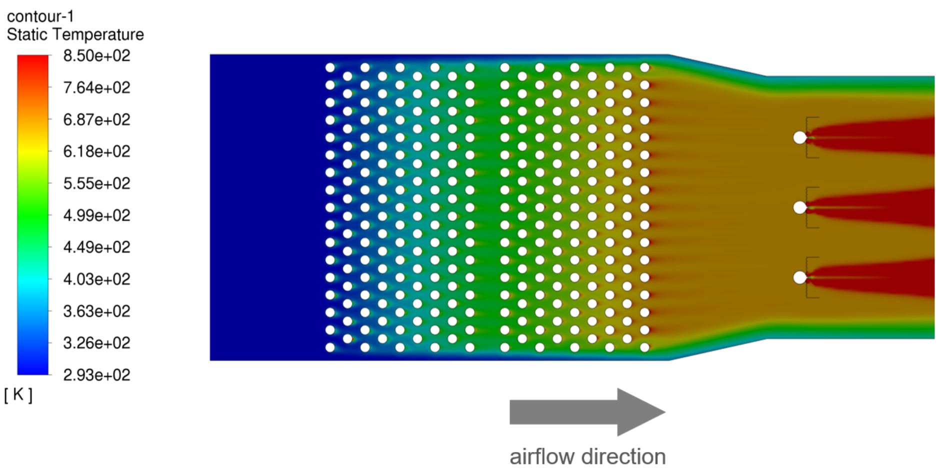

Fig. 9 *– Fluid-dynamic analysis of the hybrid generator: it shows the cross-section of the heating elements followed by three fuel burners. Temperature rises progressively from 20 °C to about 600 °C.*

- Modulation of the significant power ratings involved: the modular design allows the various modules to be inserted sequentially according to the system's thermal demand. The use of the most advanced power supply systems enables the electricity contribution at each individual stage to be partially implemented, with maximum temperature control accuracy.

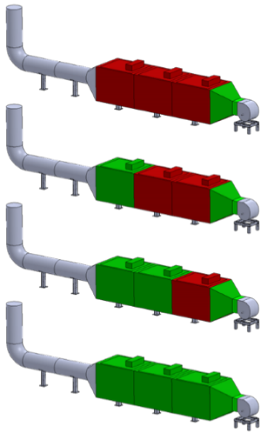

Fig. 10 *– Example of the modular construction of a (3 module) generator*

- Management of the proportional contribution by the thermal burner and/or the electric heater based on the instantaneous availability of both energy sources (day/night alternation, dawn/dusk partial implementation). Sophisticated automatic control programmes have been implemented to better manage transitions, avoiding any technological disturbance in the finished product (the spray-dried powder).

The tables in **Fig.11** show a comparison between the main characteristics and performance features of the heat generator in the three configurations shown in **Fig.7**, sized to evaporate up to 9,000 litres/hour of water (ATM90). The hybrid version has been considered here with 30% thermal power supplied by the electric heating element modules.

Type of generator		Full carbon	Hybrid	Full electric
Share of electricity	%	0	30	100
Total nominal power rating	kW	8,720	8,720	8,720
Nominal power of gas burner	kW	8,720	6,100	0
Nominal power of electric elements	kW	0	2,620	8,720
Ambient air flow rate	kg/h	63,300	63,300	63,300
Operating temperature	ºC	550	550	550
Spray-dried powder production (*)	kg/h	21,200	21,200	21,200
Total power used	kW	7,850	7,850	7,850
Heat load coefficient	%	90	90	90
Power used by gas burner	kW	7,850	5,230	0
CO_2 emission (**)	t/yr	11,460	7,630	0
(*) with slurry moisture content of 34% and powder output moisture content of 6% (**) considering 7,000 hours' running time per year				

Fig. 11*– Main characteristics of the heat generators*

5. CONCLUSIONS

The new spray dryer with hybrid heat generator developed by SACMI not only allows progressive reduction of CO_2 emissions into the atmosphere (up to 100%, when fully powered by green electricity), but it also provides the following advantages:

- **Better overall efficiency** (>98%) compared to hydrogen hybrid solutions: no conversion losses in the electrolysis process (currently at least 30%), and therefore higher efficiency in the conversion of electricity into thermal energy.
- The **general characteristics** of these new spray dryers (such as air velocity and air volumes) remain the same as those of traditional facilities, which makes them easy to regulate.
- Unlike conventional and hydrogen systems, electric heating systems do not generate **additional combustion water**; therefore, the hot fumes are drier, which benefits the machine's drying efficiency.
- The generator's **modular design** and control allows the user to regulate power consumption precisely, important in the case of self-generated green energy (e.g., with photovoltaic systems).
- The innovative generator can be installed in combination with any other **heat recovery system** (e.g., hot fumes from the kiln, cogeneration plant, etc.).
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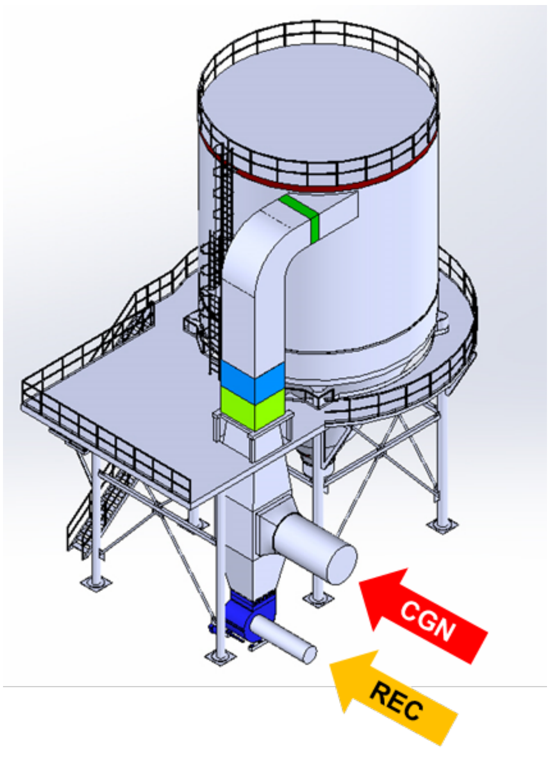

Fig. 11 *– Innovative generator with hot flue gas feed from kilns (REC) or from cogeneration plants (CGN)*

The new hybrid heat generator can be fitted in both new and existing ceramic spray dryers, thus enabling substantial decarbonisation of the process, while ensuring that neither productivity nor the quality of the resulting ceramic tiles and slabs is altered.

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