NCKU-YAGEO Research Collaboration

The fabrication of MLCCs involves several ceramic powder processing including the addition of polymeric binders that enhances the strength of formed ceramic powder. As these polymers can give defects in the final ceramic product, they are then removed in later processing steps by decomposing them at elevated temperature into gas-phase products (1, 2). MLCC binder burnout typically occurs by initially raising the temperature quickly to a level where binder burnout starts and is subsequently programmed at a very low constant rate up to a level where burnout is almost complete (3). The binder burnout is a process that takes a long time and plays an important role in the defect formation of the ceramic body during the ceramic manufacturing process (4).

From the perspective of environmental load reduction, it was stated that industries which involve ceramic industry produce about 40% of the greenhouse gas generated by energy consumption. The changes of energy consumption in ceramic industry is also higher than those iron and steel, paper and pulp, and chemical industries (5). Heat is necessary for the removal of the organic binder in the green body, the conversion of exhaust gas to vapor or carbon dioxide, and for the ceramic firing. Moreover, the energy efficiency is low. Several parameters involving heated temperature also have been mentioned to affect the dielectric properties of MLCCs (6, 7).Therefore, optimizing the heating strategy is necessary to obtain better quality and a higher yield of the product.

Superheated steam has been recognized as one method in heating and drying the ceramic materials. During the whole process, the steam stays above its condensation temperature (8). The superheated system is enclosed and reuses the same steam and heat to dry the part. Superheated steam has some advantages over drying the ceramics with hot air. Superheated steam has a higher capacity and much higher heat transfer quotient. The ceramics can also be dried more evenly throughout its volume at the same rate. Drying with superheated steam is also more efficient in usage of energy and time. Less enthalpy is lost with superheated steam since a new air supply is not continuously heated as with a hot air dryer. The drying cycle is also shorter for superheated steam, thereby requiring less energy. Possible emissions from the drying process, presented in the drying medium, can be effectively removed by condensation.

As one of fluidic devices, superheated steam machine has significant influences on overall performance of things such as rate of mass/heat transfer, conversion, or choice of reaction. Flow maldistribution is generally caused by poor design and imprecise fabrication of the distributor (9). The advances in computational fluid dynamics (CFD) over years and the rise of computing power, allow one to solve the governing equations of fluid dynamics for the complex geometry (10). CFD has recently been used to successfully analyze superheated steam (11). It has been proved that CFD could accurately predict flow patterns, temperature, and humidity in dryer. Currently, the binder burn-out test is being undergone between Yageo and NORITAKE. As particular gas flow system applied in their collaborated test, it is necessary to have simulation that enhance the experimental results. It is stated that combining the numerical and experimental approaches is necessary for designing of novel drying process (12).

The residual pore might appear after binder burnout. A pore structure created by the burnout process and a relationship between the pore structure and the burnout process are to be important for the reliability and dielectric property of MLCCs (13). The pressure-driven gas-phase flow of the binder decomposition products can occur in bodies highly loaded with binder after interconnected porosity is created in the early stages of binder removal (14). It is common knowledge that a change of temperature in solid body induces a stress or a strain, depending on the boundary constraint. For porous medium, the heat effect is applied to two material phases, a solid and a fluid, and even more complicated physical phenomena can result from their interaction. The theory that couples thermal-hydraulic-mechanical issue is called porothermoelasticity (15). This theory has been correlated with the application of binder burnout process from several papers (1, 16, 17). The governing and constitutive equations cultivated from this theory thus can generate equilibrium equation of stress tensor and strain tensor. It can be done by differentiating displacement vector, the partial differential equation of displacement components for obtaining the deformation, and stresses occurred in a porous elastic solid, which is treated by superheated steam in this study case.

Therefore, we proposed to investigate the gas flow generated by the superheated steam, which is part of collaboration between Yageo and NORITAKE. The study will use commercial software named CRADLE to generate the CFD simulation. Besides, we proposed to utilize porothermoelastic model to investigate several parameters during such heating process that might affect the dielectric properties of MLCCs.

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