Development of an automated system for ceramic powder process

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1. Introduction

Autonomous experiments on functional ceramics offer significant potential for accelerating materials development but have not been widely implemented to date. This is due to the complexity and cost of automating ceramic processing steps, as well as the difficulty of powder handling and automation [1]. Currently, commercial systems that automate tasks such as powder weighing and several new methods for processing milling and mixing are available. However, significant human intervention is required, particularly for powder preparation and moulding, and several bottlenecks remain, particularly in materials development.

In material synthesis, the preparation of diverse mixtures of particles through grinding and mixing into a homogenous and fine powder represents an important step for material fabrication [2]. Especially, dispensing of different powder should be weighed correctly within a tolerance, and the grinding process should be controlled properly as the smaller the particle size of the powder, the greater surface area in contact with other particles, which affect the microstructures of composites and or activates the uniform chemical reactions.

Here we outline the automated system for powder process which is prototyped and introduce its application to materials processing currently under development.

2. Ceramic Powder Process

We have automated the powder raw material dispensing/weighing and grinding/mixing process in the powder raw material sample synthesis process by using a robot arm. Figure 1 shows the workflow of ceramic powder process.

Depending on the target composition, raw powder materials are weighed in stoichiometric or designed proportion, followed by automated powder dispensing module and robot arm which handles the sample vials.

A set of mortar and pestle is a simple and widely used method for preparing powders by crushing and grinding. However, grinding by mortar and pestle often is dependent on the experience and intuition of the operator, as will the applied force, time, and speed. Processes relying on manual labour are prone to variations in reproducibility and accuracy, which make it difficult to achieve a reproducible process. Additionally, manual processes increase time and cost, which slows research progress and efficiency [3]. To overcome these problems, a robot arm is applied to automation of this process, and it is expected that the improvement of accuracy and reproducibility.

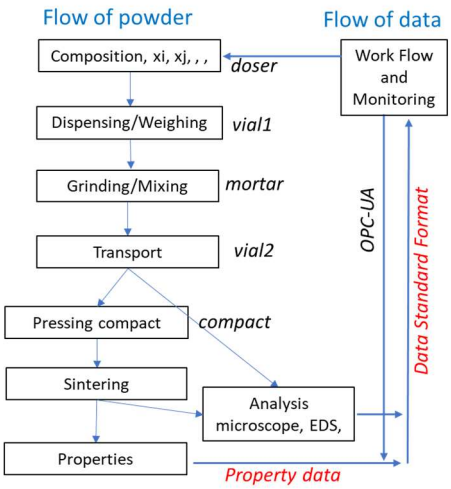

Fig. 1: Workflow of powder processing followed by characterization including the containers for each stage and the flow of data.

Finally, the powders are formed into the pellet and then heated to an elevated temperature to initiate a solid-state reaction that results in a new phase as well as grain growth, which is referred as calcination and sintering. In the series of the process, the pressing compact and sintering is under design and manually processed. Each process is automated by the concept of automated module, and the many tasks previously done manually, such as transporting and setting sample bottles or vials, have been replaced by using a robotic arm, and the process data are stored by semiautomatic methods. This trial of total automation in this study for process, analysis, data collection and formatting is making great advantages accelerating materials development [4].

3. Automation Process

Mainly powder weighing, grinding, and mixing processes are automated using a robot, and modules are communicated by the main server.

3.1 Powder Dispensing

The precise weighing is a typical manual process that takes quite a long time. If a human were to prepare 24 samples for a two-component system during the weighing and crushing process, it would take 10 to 15 minutes of weighing time and 30 minutes of crushing time per sample, and taking breaks into account, it would take approximately 24 hours. If this work were to be automated using a robot, it is expected that it would be about 3 to 4 times faster and work efficiency would be greatly improved. The automated powder dispenser module is shown in Fig. 2.

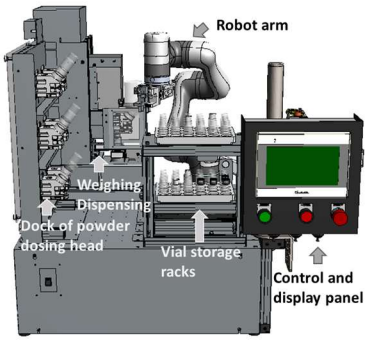

Fig. 2: Image of powder dispensing system with robot arm handling dosing heads and vials.

3.2 Grinding and mixing

By attaching a torque sensor to the robot arm, the system performs grinding and mixing operations based on force control in addition to position control (Fig. 3). The movement of the pestle can be controlled appropriately without using auxiliary tools.

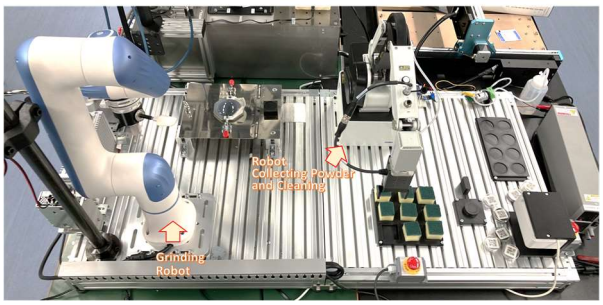

Fig. 3: Image of the grinding and mixing robot and cleaning robot system.

3.3 Transfer and cleaning

The powder collection process involves: Collection: A spatula of the grinding robot gathers the powder from the mortar and dops into the new vial. Cleaning: Wet sponge of the transfer robot cleans the inner surface of the mortar. Transport: The collected powder is stored in vail container for next process.

Automation of powder collection by robot arm is performed by the robot arm equipped with spatula collecting fine powder from the mortar. The motions of robots were manually adjusted, ensuring efficient collection of mixed powder.

When collecting powder, the entire platform is inclined and the spatula is used to gather and scrape the powder, causing it to fall into the bottle. After the powder has been collected, the bottle is returned to its initial position. After transfer, any powder remaining in the mortar is removed using a wet sponge (Fig. 4). Figure 4 shows the mortar before and after wet sponge cleaning. The contamination level of the mortar after cleaning is within the acceptable for simple composite mixing process, and the system can process the next sample without replacing the mortar.

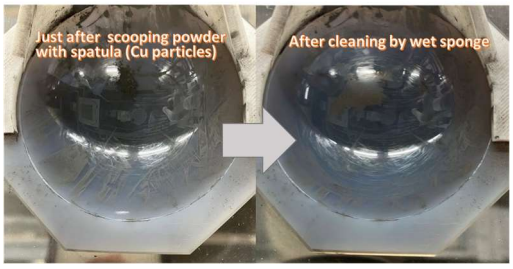

Fig. 4: Snap of mortar before and after wet sponge cleaning.

3.4 Pressing compact

Preparing the pressured compact from the powder is currently under construction. The automated press and robot arms are designed for gathering and pressing the mixed powder.

3.5 Framework of workflow and data

Not only the direct control of automated modules but both workflow management and data acquisition are essential. In this study, a simple user interface is tried to set-up monitoring the process and collecting experimental data (processes variables and measured physical properties with measurement conditions) for powder materials, based on the concepts of OPC-UA and MaiML [5]. The data are temporarily stored on a PC and uploaded in MaiML format in our private network.

Acknowledgments

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