STATISTICAL EXPERIMENTAL DESIGN IN THAI CERAMIC AND GLASS RESEARCH

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The word "Ceramic" is derived from the Greek word "keramos" which means "burning stuff" or "burned earth" (Kingery *et al*., 1976). Ceramics are defined as inorganic nonmetallic solid materials. Ceramics are typically crystalline compounds formed between metallic and nonmetallic elements such as aluminum and oxygen (alumina-Al_2O_3), beryllium and carbon (beryllium carbide-Be_2C), and silicon and nitrogen (silicon nitride-Si_3N_4). Glasses are special types of ceramics which have amorphous or non-crystalline structures. Most people think of ceramic as pottery, porcelain, whiteware, tile, brick, cement, enamel, glass, abrasive, and refractory. The above mentioned are referred to as "traditional or silicate-based ceramics". While these traditional products have been and continue to be important to society, a new class of ceramics has emerged in the last 40 years (Kingery *et al*., 1976). This class of ceramic is "new or advanced ceramics". They are of particular interest because they have outstanding properties. Examples of these new ceramic materials are piezoelectric, pyroelectric, ferroelectric, dielectric, ferrimagnetic, glass-ceramic, nitride, carbide, hydroxyapatite, and bone-cement, among others. They were developed in order to fulfill particular needs. These needs were for special electrical properties, temperature resistance, superior mechanical properties, and greater chemical resistance. Advanced ceramics are being used for several applications including computer components, microwave and electronic parts, nuclear fuel, space shuttle tiles, and artificial bones and teeth, among others.

The important goals in ceramic research are to reduce the cost and to improve the specific properties of products. Statistical experimental design and analysis are effective tools to assist ceramists to reach their stated forward looking goals. Statistical design of experiments is the process of planning the experiment so that appropriate data will be collected and statistically analyzed. These methods not only help ceramists to plan and conduct experiments but also assist them in analysis of the resulting data. With good experimental design and analysis, the maximum amount of information can be obtained from a minimum amount of collected data. As an example of such an experiment, suppose that a ceramist is interested in studying the effects of time (x_1) and firing temperature (x_2), as well as chemical composition (x_3), on water absorption

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(y_1) and modulus of rupture (y_2) of light weight concrete. The factors that will be controlled and varied in his study are inputs (x_1, x_2, and x_3) and the properties which will be measured or calculated are outputs (y_1 and y_2). In general, there are always some uncontrollable factors (z_1, z_2, …z_i) in every experiment. Design of experiments is an organized way of conducting and analyzing controlled tests to determine the influence of inputs and their interactions on the output response. Since the inputs are varied and simultaneously tested, causal predictive models can be evaluated. Experiments conducted without design have several disadvantages and can only establish correlation but not causality.

The fundamental principles of experimental design are randomization, replication, and blocking (Montgomery, 2001; Telford, 2007). Randomization is a method that protects against an unknown bias distorting the experimental results. An example of bias is instrumental drift in an experiment comparing a baseline procedure to a new procedure. If all the tests using the baseline procedure are conducted before the test using the new procedure, the observed difference between both procedures might have significantly originated from instrumental drift. By properly randomizing, bias from instrumental drift can be averaged out. This is because both the allocation of the experimental materials and the order in which the individual runs the use of the experimental material are randomly determined.

Replication increases the sample size. It is important to repeat experiments because replication permits researchers to obtain an estimate of experimental error. Moreover researchers can more precisely estimate the factor effect, if the sample mean is used to estimate the factor effect in the experiment. Finally, replication raises the signal-to-noise ratio when noise originates from uncontrollable factors.

Blocking is a method used to improve precision by removing the effect of known nuisance factors. The nuisance factors are factors in which we are not directly interested but which may influence the experimental response. An example of this factor is batch-to-batch variability. Blocking will set each level of the nuisance factor to become a block. The experiment within each block is separately randomized. Therefore blocking is a restriction of complete randomization but it increases precision since the batch-to-batch variability is removed from the experimental error.

The design of experiments was first introduced into agricultural experiments by Sir Ronald A. Fisher in the 1920s. While working at Rothamsted Agricultural Experimental Station in Harpenden, UK, he recognized that the data analysis was often hampered by flaws in the way the experiments were performed. He showed how valid conclusions could be drawn efficiently from experiments, by using the 3 basic principles of experimental design, i.e., randomization, replication, and blocking. He also introduced factorial design and analysis of variance which are significant in designing experimental investigations. Application of statistical design in industries began in the 1930s. George Box developed the response surface methodology (RSM) for optimizing chemical processes in 1951. His RSM and other designs were widely used in research and development work of chemical and industrial processes for more than 40 years.

Many international glass and ceramic researchers have applied statistical experimental design analysis to design and analyze their data for more than 20 years. However, most glass and ceramic researchers in Thailand have not followed this procedure (Fluegel, 2009; Correia *et al.*, 2004; Silveira and Leite, 2010). Recently, statistical experimental design has become a formal course of many ceramic, glass science, and engineering programs at both the undergraduate and graduate levels in Thai universities. For example the ceramic engineering program school in the Suranaree University of Technology has included the statistic experimental design course as its core course for master and doctoral degree studies in its curriculum since 2007. Therefore, currently an increasing number of statistic experimental design and analysis papers are found in Thai ceramic and glass research. One good example of this evidence is that 6 out of 21 ceramic and glass papers published in the **Suranaree Journal of Science and Technology** in the last 2 years were applying statistic experimental design and analysis to design experiments and analyze data (Boonruang *et al*., 2012; Prertkaew *et al*., 2012; Kandananond, 2013; Meethong *et al*., 2013a; Meethong *et al*., 2013b; Nawaukkaratharnant *et al*., 2013; Pee *et al*., 2013; Sriwattanapong *et al*., 2013; Tigunta *et al*., 2013; Ueapiyateeranan *et al*., 2013; Wannakamb *et al*., 2013; Cherdtham *et al*., 2014; Kummoonin *et al*., 2014; Makornpan *et al*., 2014; Onutai *et al*., 2014; Saengchantara *et al*., 2014; Tapasa *et al*., 2014; Tippayasam *et al*., 2014; Wasanapiarnpong *et al*., 2014; Meechoowas *et al*., In press; Srilomsak *et al*., In press). It is expected that statistical experimental design and analysis will be more widely used in ceramic and glass research in Thailand in the future because good experimental design is a key factor for successful research and industrial competitiveness.

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