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Optimizing convexity defect in a tile industry using fuzzy goal programming

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ABSTRACT

In most designed experiments, the main focus is to find the factor settings that optimize a quality response regardless of engineer's preferences about factor settings. Further, in tiles industry convexity defects result in huge quality costs as well as production losses. This research, therefore, aims at optimizing convexity defect while considering process engineers' preferences using fuzzy goal programming (FGP). Three two-level key process factors are considered, including below-rollers temperature, above-rollers temperature, direct blow air. Experiments are conducted with two repetitions; in each the convexity is measured on four tiles. Two optimization techniques are employed to determine the combination of optimal factor settings, including the Taguchi method and latter technique. The Taguchi approach and FGP approach provide relative improvements of 61.2% and 41.2%, respectively. Although the former technique reduces convexity larger than latter approach, it failed to satisfy the preferences on the settings of process factors. In contrast, the optimal factor settings obtained using FGP completely satisfy engineers' preferences. In conclusion, FGP successfully optimizes process performance and completely satisfies process engineers' preferences in tiles industry.

1. Introduction

Ceramic tiles are produced by pressing clay and other ingredients into shape then firing it at high temperatures. It may then be glazed, or left unglazed depending on its intended use [7]. In ceramic tiles industry, defects result in huge quality costs as well as production losses. Hayajneh et al. [5] used a subtractive clustering fuzzy identification method and a Sugeno-type fuzzy inference system to monitor tile defects in tile manufacturing process. Xianghua [10] implemented texture analysis techniques for the detection of abnormalities in color texture surfaces of ceramic tile on which patterns are regularly of a random nature. Farooq et al. [4] developed a new methodology to detect defects in ceramic tile. The concept of photometric stereo is adopted and extended for application in manufacturing environments. High speed inspection of ceramic tiles is utilized for the analysis of surfaces at production line rates.

Designed experiments have been found effective in optimizing process performance [8]. In these techniques, the process factors are assigned specific levels; for example, high and low. Then, the optimal settings will be restricted at each of these levels. The Taguchi method [9] has been found only effective in optimizing a single response [2,3,6]. In some cases, process engineers prefer setting the levels of process factors within specified ranges depending on setup time and operation cost constraints. As well as, they may have preferences on the optimal value of a response. This in return transforms a single-objective optimization problem to multi- objectives problem. The goal programming (GP) model is an optimization technique enables the decision maker to take multiple objectives simultaneously into account. In general, GP models consider the model parameters and objective values as

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precise and certain. However, in most real applications these values are not known precisely. Under such a circumstance, fuzzy GP (FGP) models can be employed [1,11,12]. Therefore, this research aims at improving the performance of a tiles manufacturing process by reducing convexity defect using the Taguchi method and FGP approach. The remainder of this paper is outlined in the following sequence. Section 2 maps tiles manufacturing processes and explores tiles defects. Section 3 proposes FGP optimization model for convexity reduction. Section 4 conducts experimental design. Section 5 summarizes research results. Finally, conclusions are presented in Section 6.

2. Tiles process mapping and main defects

2.1. Tiles process mapping

The production process of ceramic tiles is illustrated briefly in Fig. 1.

The production process starts from batching determined amounts of raw materials. The raw materials are tabulated with their chemical compounds in Table 1.

Then, the mixture is fed inside large mills of about 50 tons weight, where the milling operation takes place, where ceramic stones are placed in. After milling, the mixture looks like a milky slip called slip, stored in large tanks underground. The slip is pumped up an atomizer for the spray drying operation to produce a very fine powder with humidity between 5.5% and 6%. Now, the fine powder is fed into for pressing, where the tiles take their initial shape. Tiles are fed into a dryer for increasing their strength by loosing water content from their body, where the humidity after drying is almost 0%. During tiles production, painting, decorating and surface treatments are carried out on the upper surface of the tiles. At the end of the production line, there exists a short dryer. This dryer causes the temperature of the tiles bodies to rise up. The purpose of rising up the tiles temperature is to avoid thermal shocks that may occur during the firing process in the kiln due to high water content. The final stage of tiles production is the firing process, in which physical, chemical and structural changes take place. Due to the lack of proper techniques for monitoring, controlling, and correcting the kiln some defects may be produced.

2.2. Ceramic tiles defects

In the production process of tiles, the most common defects are the planarity defects that occur in the firing process; especially the convexity defects of the fired tiles. To experimentally investigate the convexity defect of fired ceramic tiles, a factory specialized in the production of wall and floor ceramic tiles is selected, where the average production rate is 900,000 m^2 of tiles/year and the average of defective tiles is 8% from the annual production, 40% of the average of defective tiles result from the firing process. The types of defects result during the firing process are planarity defects, holes (pin holes, holes, or bubbles in the glaze), crazing, cooling breakage, breakage during preheating, black core, and tile bursts in the prekiln. Fig. 2 illustrates the percentages of these defects, in which the planarity defects are the most common defects that occur during the firing process. Fig. 3 illustrates the percentages of the various kinds of the planarity defects, where it is clear that the company is facing a real problem in the form of the tile's convexity defect (50% of the total number planarity defects). Fig. 4 depicts a tile with convexity defect. Two hundred samples are randomly selected and tile convexity is measured then shown in Fig. 5. It is noted that there are many points exceeding the upper limit value for convexity of 10 mm; the threshold for acceptable tile. The annual average production of final fired ceramic tiles that contain convexity defect is about 27,000 m^2 of tiles/year. This large quantity of tiles defects, increases the wastage and decreases the company financial returns.

Table 1
Ceramics tiles raw material with their chemical compound.

Raw material	Chemical compound
Kaolin	$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$
Silica	SiO_2
Feldspar	$K_2O{\cdot}Al_2O_3{\cdot}6SiO_2 + Na_2O{\cdot}Al_2O_3{\cdot}6SiO_2$
Calcium carbonate ($CaCO_3$)	$CaCO_3$

3. Proposed fuzzy satisfaction model

This research adopts a weighted additive GP model for optimizing convexity as follows:

Step 1: let y represents the value of tile convexity defect and x_j is the value of the jth process variable. Formulate the multiple linear regression function, $f(x_1, x_2, \ldots, x_j)$, between the y and process controllable factors using regression model; that is,

$$y = f(x_1, x_2, \ldots, x_j), \quad (1)$$

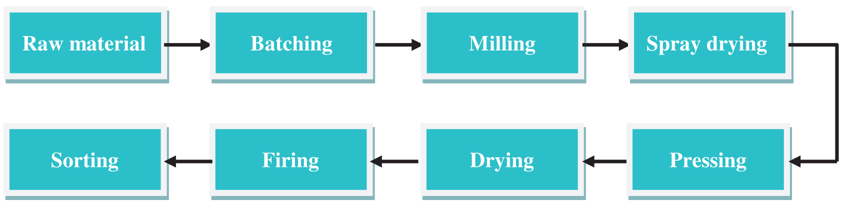

Fig. 1. Production process of ceramic tiles.