Reducing waste in casting with a predictive neural model

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This paper describes an interactive neural network model that predicts the quality of cast ceramic products using multiple quantitative and qualitative inputs. This has been done to enable a major sanitary ware manufacturer to reduce product waste by better control of the slip casting process. The input variables describe the raw materials, ambient conditions and line settings for the ceramic casting process. The neural network predictive model assigns one of seven quality categories to the cast based on the input data. This prediction is used by the quality control engineer to make a priori adjustments to materials and line settings so that a good quality cast is produced without trial and error. The neural model can also be used to determine optimum settings of each adjustable input variable in the light of values of non-adjustable input variables.

Keywords: Neural networks, ceramic casting, quality control, predictive modelling

1. Introduction

The manufacture of ceramic products consists of the following ordered steps: (1) preparation of slip; (2) casting slip in a mold; (3) drying the slip and removing the mold; (4) spray glazing the dried product; (5) firing the glazed product; and (6) inspection of the finished product. Step 2 of the process is slip casting, where a suspension (the slip) is poured into a casting mold and the liquid phase is separated by capillary phenomena, leaving a solid piece that takes the shape of the mold. This piece is later glazed and fired inside a kiln. Although there have been a few computer aided improvements in the slip casting process, such as an expert system aimed at slip particle effects (Dinger, 1990), it still remains basically an art. This is because there are no analytical descriptions of casting dynamics, it is affected by many human and non-human variables, and the effects of the interdependencies of these variables are only manifested at the end of the process, after the firing of the cast. This latent manifestation causes wasted product.

The primary factor in cast fractures and/or deformities that cause product waste is the distribution of moisture content inside the cast before firing. When the moisture differential, or moisture gradient, inside the wall of the cast is too steep, it results in stress differentials that cause the piece to deform and eventually fracture. In order to have a good cast, and therefore a solid durable product, the moisture gradient should be as uniform as possible. A poor quality cast identified before firing may be recycled by retrofitting the cracked or deformed cast to the beginning of the process. Although the raw material (clay) is saved and reused, the labor and overheads are irretrievable. It is more common for defects to be identified after firing, which causes complete product waste.

The moisture gradient present in the cast is a result of different interrelated parameters. There are raw material characteristics such as rheological behavior, gelation behavior, viscosity, flow, specific gravity, etc. There are the mold's conditions, such as water retention and environmental conditions. There are ambient conditions
such as plant temperature and humidity. They all impact the behavior of the cast, as will be discussed in more detail in Section 2.3.

The objective of this project was to model the interrelations of all the parameters involved and make some a priori assessments on cast condition using actual data from a ceramic products manufacturer. This was aimed at reducing product waste caused by the trial and error approach to adjusting manufacturing parameters, and the latent manifestation of substandard casts. The authors chose a neural model for two main reasons. First, there are no known analytical models for the slip casting process. Second, there are many related stochastic variables with non-specified probability distributions. Measurements of these variables and their effects were available, but known to contain human bias and data collection imperfections.

2. The slip casting process

2.1. How casting is achieved

As the casting takes place, the displacement of water from the slip to the mold's wall is accelerated by the capillary effect. When water is discharged into a container the water molecules closer to the container walls 'climb up' these walls due to water's surface tension. In a capillary tube, the diameter of the tube is so small that the water molecules closer to the tube's walls climb higher. In slip casting, the capillary tubes formed by the casting process and the mold's pores help to drain out the water from the slip (Lambe, 1958).

As more water is drained from the cast, clay particles build up against the mold forming a solid structure. If the rate of casting is too high, particle build up will be very fast and can clog the capillary tubes. Once the capillary tubes begin to become obstructed, the movement of water out of the cast becomes more difficult. The resultant cast will have a steeper moisture gradient because there will be a very wet part near the drain face and a very dry part near the mold face. This creates a bad cast, which could crack either before or after glazing and firing. This moisture differential or moisture gradient is represented in Fig. 1.

2.2. Assessment of cast quality

The difference in moisture content, or moisture gradient, produces a difference in consistency in the walls of the cast. So far there is no computerized substitute for the considered assessment of an experienced ceramic engineer in deciding whether a particular slip has cast properly. The manufacturer we worked with estimated product quality by producing pilot casts. The engineer strips off the pilot cast, or cuts a piece from larger pilot casts, and judges plasticity by forming or working the material with his or her fingers. This is the so-called 'feel test'. The ceramic engineer performs the feel test and then grades the quality of the pilot cast into one of seven categories (-3 to +3). These categories go from hard (-3) to good (0) to soft (+3), where the two extremes (hard and soft) represent undesirable quality of the cast. This pilot cast procedure is a human dependent, trial and error method for establishing the necessary values of the raw material parameters. Once a pilot cast of acceptable quality is obtained (a quality category near the mid-point of hard and soft), the production batch is started with the same properties as the acceptable pilot product. This trial and error procedure causes waste in itself, but more importantly, if not done properly, results in whole batches of inferior grade (too hard or too soft) products which are not recognized until post-firing. This large scale waste is impossible to recover.

2.3. Variables impacting cast quality

The quality of the cast depends on the chemical properties of the slip, the ambient conditions in the plant and the mold conditions. Ceramic engineers run a series of tests that emulate the behavior of the slip during casting.