Chapter 6

Integrated Computational Materials Engineering for Determining the Set Points of Unit Operations for Production of a Steel Product Mix

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ABSTRACT

Manufacturing a steel product mix (bar, rod, sheet) involves a series of unit operations - primary steel making, secondary steel making (ladle refining and tundish operation), continuous casting, reheating, rolling and annealing. The properties of the final product depend significantly on how each unit operation is carried out. Each unit operation must be operated to meet the requirements of the subsequent operations. The requirements imposed on a particular unit operation are often conflicting and compromises must be made. Also, there is high degree of uncertainty in the operating parameters of each unit operation, which may lead to considerable deviations from the anticipated performance. To ensure that the final quality specifications of the product is not sacrificed and the customer requirements are met, it is essential to manage the conflict and uncertainty involved in each unit operation of the manufacturing process. In this chapter, we illustrate the use of compromise Decision Support Problem (cDSP) construct and ternary plots to overcome the challenges involved in one of the unit operations, namely, the tundish. The construct can be instantiated for other unit operations to cover the entire manufacturing cycle. Exploring the effects of system variables for each process step through experiments and plant trials is time consuming and very costly. The proposed method allows for faster design exploration of the process and thereby provides a reduced search space to a process designer. The process designer, with

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reduced experimentation requirements, can explore the narrowed search space to find the operating set points for a tundish. This, in turn, reduces the time and cost involved in production of a steel product mix with a new grade of steel in industry.

1. FRAME OF REFERENCE

Consider the following scenario: A steel mill day-in-day-out is involved in production of steel product mix using a particular grade of steel. Due to a change in customer needs, the steel mill has to produce the same product mix with a different grade of steel. To be able to switch the production, the personnel at the steel mill will need to spend a lot of time and money in carrying out experiments and plant trials, to determine the operating set points for each unit operation of manufacturing process chain. In this chapter we propose a method for simulating the behaviour of the unit operation, explore the solution space and determine the operating set points of a unit operation. The method is demonstrated for the tundish.

Manufacturing a steel product mix involves series of unit operations - ladle refining, tundish operation, continuous casting, rolling and annealing. The sequence and flow of information from one unit operation to another is shown in Figure 1. Industry continues to look for ways to reduce development costs and time required when a different grade of steel is to be used for manufacturing a new product mix. To meet this need, we suggest that integrated modelling of the entire manufacturing chain is required (Singh, Pardeshi, & Goyal, 2011). Integration is critical as the processes are linked and the outcome of one unit operation influences the way in which other operation needs to be carried out and there may be alternative paths which yield the same end-product. However before integration, it is necessary to develop models to account for uncertainty and essential trade-offs for each of the constituent processes.

Each unit performs a specified task and meets the requirements of subsequent unit operation. Typically, there is some conflict in the requirements for each unit that constitutes the manufacturing process chain. Further, all the processes are transient and parameters are dynamically adjusted throughout the operation giving rise to significant levels of uncertainty. Typically, in an industrial setting it is difficult to obtain information about batch sizes, exact temperature, etc. As the properties of the end-product are significantly affected by the way each unit operation is carried out, it becomes essential to manage the uncertainty and conflict involved in each unit operation of the manufacturing chain.

The horizontal integration of series of unit operations comes under the umbrella of Integrated Computational Materials Engineering (ICME) (Allison, Li, Wolverton, & Su, 2006). The ICME construct bridges the gap between design and manufacturing by facilitating the horizontal integration of unit operations and the vertical integration of models at different length scales. Several groups have used ICME to enable faster development of materials and manufacturing routes for them. Luo (2013) used computational thermodynamics and CALPHAD modeling in the selection and development of new magnesium alloys. Smith et al. (2013) used the ICME approach for predicting pitting corrosion. Their integrated approach uses thermodynamic modelling to identify the chemistry of the corrosive environment, atomistic modelling to understand the kinetics of corrosion reactions, and experimentation to validate the model predictions. Maiwald-Immer et al. (2013) demonstrated the use of ICME to enable the development of rapid manufacturing technologies by using simulation techniques to understand the effects of process parameters on the properties and quality of the final product. Agarwal and Shivpuri (2013) developed a hybrid computational framework for the integrated process design of high performance parts. They integrated materials and process design to predict the process design parameters for maximizing

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