ABSTRACT

Dr. Taguchi, in his book on quality engineering (A.P.O., Tokyo, 1986), has defined quality engineering as off-line quality control, which effectively is parameter design, using statistical design of experiments, and is carried out with the primary objective of determining the optimal combination of parameter, or factor, levels for the process, differentiating it from on-line quality control which is the control of quality during the production process. This, however, is a myopic view of quality engineering, and the "umbrella that encompasses Dr. Taguchi's overall quality philosophy" should more correctly be called quality engineering. Quality engineering then must necessarily consist of both off-line and on-line quality control, or in other words, it must include both process optimisation and process control. This broad definition of quality engineering is more appropriate, particularly when it comes to tackling real-life industrial problems.

The basic interest with which the project was undertaken was the study of complex processes in continuous process industries with the aim of investigating whether quality engineering can be apliied to such complex processes. A theoretical study could have been undertaken but this was not done. It was felt that a theoretical study would not bring out the actual problems and, therefore, the identifying characteristics of the complex processes would not be known. It was decided that a real-life problem would be taken up for study and based on this, a methodology would be developed for the application of quality engineering to complex processes. Accordingly, a problem in an integrated iron and steel work was identified. The problem was one of rejections of semi-finished product due to existence of cracks. In this plant the rejection due to cracks in one of the crack-prone grade is as high as 22 percent. Such rejections contributed to the significant losses in revenue and profit. Moreover, past research in the area of cracks in semi-finished product and mechanism of cracking had considered one factor at a time, namely carbon, sulphur, teeming temperature or soaking pit practice etc. All the factors taken together have not been considered earlier. Accordingly, the problem of minimisation of cracks in semi-finished product in an iron and steel plant was taken up for study. Thus, there were essentially two aims for the selection of this problem. First was the minimisation of cracks and second was to develop a methodology which can be used in complex processes in continuous process industries.

The study was conducted in different phases. Initially 26 factors were identified. On closer observation, it revealed that some of the factors were uncontrollable. After dropping uncontrollable factors, 15 factors remained. Two alternative designs, considering 15 factors and 8 two-factor interactions were suggested to the management. The proposed experiment could not be conducted as the management felt that it would not be possible to conduct such a large number of experiments and that too with such a large numbers of factors from

different areas of plant. Under the circumstances, a different methodology had to be worked out. It was then decided to conduct the investigation in phases, with the first phase consisting of collection of historical data and analysis of such data to identify the significant factors. Historical data were collected and 193 and 126 data points were available for blooms and slabs respectively. However, it was found that shop data were available for only 7 factors out of 15. It was also found that 5 out of the 7 factors were composition related factors. To save experimentation effort and time, regression analyses were carried out on historical data for both slabs and blooms. Later, on closer observation, it was found that there was a heavy concentration of data points at specific values of factors. Therefore, to ensure analysis with equally spaced data, the historical data were fitted to L27 O.A.s for both blooms and slabs.

In the second phase, the easy-to-control factors were identified. These factors can be distinguished from hard-to-control factor since the available tolerances of variations are larger. Composition related factors, the effect of which had been investigated in phase I, are hard-to-control factors, since once the grades of steels are specified, the amount of variation in carbon and sulphur are limited. In phase II other-than-composition related factors were experimented on. Three crack-prone grades, namely API A & B, Mo and BG 1 & 4 and two routes, namely SMS III and LD were considered for experimentation. 7 factors and 3 two factor interactions were considered for experimentation. A L16 O.A. with all the factors at two levels was chosen and experiments were conducted for all the three grades and two routes. ANOVA revealed significant factors and ANOM, the preferred level of the factors.

In phase III of the investigation, significant factors of the hard-to-control and easy-to-control categories were brought together in a split-plot design. Split-plot design was used with the hard-to-control factors in the main plot and easy-to-control factors in the sub-plot. An equivalent O.A. in which the column placements ensure the requirements of split-plot design was used for experimentation. Experiments were conducted on the same crack-prone grades and the two routes. At the end of phase III, off-line quality control exercise was complete and the optimal combination of factor levels for the process had been determined.

In phase IV, validation runs were carried out and the results obtained showed very significant reduction in rejections due to cracks. At the end of phase IV, it was realised that apart from off-line quality control, soaking pit and rolling mill operations require on-line quality control. In these cases fine tuning is required. Past research had identified two important factors, namely, input rolling temperature and draft per pass. Input rolling temperature can be regulated conventionally. Accordingly, control charting was used for the control of this factor. On the other hand draft per pass cannot be regulated in this manner. It depends upon the soaking practice employed. Thus on-line control on draft per pass requires the optimal combination of levels of factor which affect soaking and rolling. This was done in two stages, using a L27 O.A. to determine the optimal levels of factors from steel melting to soaking pit which affect the process of soaking of ingots and L8 O.A. to detemine the factors involved in the process of rolling of ingots.

The off-line quality control exercise conducted in phases I, II and III enabled the identification of significant factors. It also provided the optimal combination of factor levels. Five factors, namely carbon, sulphur, teeming temperature, pit condition and draft per pass were identified and optimal combination for these five factors were obtained for all three crack prone grades and two routes. The results, thus obtained, were validated with a few experimental runs carried out in phase IV. Rejections were reduced from 8.73 percent to 3.5 percent for API A & B grade. This indicates a reduction of rejections of 59.9 percent. Similarly, rejections were reduced by 70.3 percent and 62.3 percent for BG 1 & 4 and Mo grade respectively. The on-line control phase conducted on the soaking pit and rolling mill processes enabled fine tuning of the factors which affect these two processes. The optimal combination of teeming temperature, soaking temperature, soaking ratio and carbon percent on one hand and heating rate in soaking pit, soaking time, gas flow rate and draft per pass on the other were obtained from this phase. The effectiveness of the use of X-bar and R charts and for on-line control of input rolling temperature was also brought out by phase V of the investigation. It is felt that the implementation of the recommendation for on-line control of soaking and rolling processes as given in Chapter 6 would enable further reduction in rejections due to cracks for all three crack-prone grade noted earlier.

An humble attempt to apply the technique of quality engineering to a complex process in a continuous process industries have been made. A step-wise procedure has been developed. Six steps which form the part of the methodology embrace both off-line and on-line quality control. The methodology which has been developed for minimisation of cracks in semi-finished product in a steel plant and applied to three crack-prone grades produced by two routes can be used for other complex processes in continuous process industries.