

DEVELOPMENT OF EMPIRICAL RELATIONSHIPS FOR THE MECHANICAL PROPERTIES OF COLD-ROLLED STEEL PRODUCTS

New Zealand Steel Ltd, Glenbrook

Industry Representatives:

Mr Philip Bagshaw, New Zealand Steel, Auckland, NZ

Mr Andrew Mackay, New Zealand Steel, Auckland, NZ

Mr Michael O'Connor, New Zealand Steel, Auckland, NZ

Project Moderators:

Assoc. Professor David Scott, University of Auckland, Auckland, NZ

Assoc. Professor Ken Russell, University of Wollongong, NSW, Australia

Student Moderator:

Mrs Judi Scheffer, Massey University, Auckland, NZ

At MISG2005, New Zealand Steel had sought an investigation of the relationship between the mechanical properties of hot-rolled coil and plate products and several input variables such as processing temperatures and steel chemistry. At MISG2006, a similar relationship was sought for cold-rolled steel products, which is a problem with some additional complexity. A relationship was sought between each of four mechanical properties (the main two being yield strength and elongation) and input variables including the steel chemistry, rolling reductions, annealing conditions and upstream variables from the hot mill process. Such relationships will help NZ Steel reduce the percentage of product not meeting specification. Additionally equations that predict output properties in terms of input properties will help the company assess the implications on productivity of drifts in aspects of the process, and also allow it to assess how products with new input characteristics might behave. In producing cold-rolled steel NZ Steel anneals coils of steel in an annealing furnace, a process which restores ductility lost when steel is rolled to reduce its thickness. NZ Steel uses a batch-annealing furnace. A batch consists of nine coils of steel which are loaded into one of three furnaces in a three by three grid arrangement. It may be expected that the mechanical properties of coils processed in the same batch will be correlated. Also the furnace used and the position of a coil within the furnace are likely to have an effect on the mechanical properties of the steel. It is these considerations which are responsible for the additional complexity involved in analysing the cold-rolled steel products compared to the hot-rolled products previously analysed.

The investigators separated the data on the basis of two different ways of measuring mechanical properties (longitudinal and transversal). They performed separate statistical analyses for three different steel types, and for several sub-types. For each (sub-)type, they sought good multiple regression models, to predict an individual mechanical property in terms of the input variables. It is common to use the quantity known as R-squared to assess what proportion of the variation in the response variable is explained by the model. The values obtained varied between about 0.5 and 0.8. These models make specific statistical assumptions about the data (Normally distributed data with constant variance).

Checks were made to see whether the data seemed to meet these assumptions; in general, they did. Another assumption is that the various observations are statistically independent of one another, which *a priori* appeared unlikely in the presence of batch processing. There was evidence of a correlation between some coils, and a more sophisticated analysis should take this into account.

Whilst individual regression models are useful to NZ Steel the mechanical properties being tested are related. In particular, tensile strength and ductility are inversely related. For steel to be within specification for a particular standard generally requires that strength, ductility and hardness are all within given limits. This suggests that models are needed which deal with all response variables together. One means of doing this was attempted which was to use Partial Least Squares regression.

In conventional multiple regression, the parameters are estimated by Ordinary Least Squares, which assumes that the predictor variables are measured without error. The method of Partial Least Squares allows for measurement error in predictor variables so even in the case of a single response variable the results, while generally similar to those from Ordinary Least Squares, can be different. Besides the ability to deal with multiple response variables, another argument for the use of Partial Least Square is that some of the upstream properties of the coil could not be measured accurately; that is, the predictor variables are subject to error.

An alternative technique for dealing with multiple response variables is to use seemingly unrelated regressions. This was not able to be attempted during the conference, but investigation of this method is being undertaken.

To deal with the observed within batch correlation, since there are many batches, use of a batch effect would be computationally expensive. This suggests that the batch effects should be regarded as a random sample of effects from a Normal distribution whose variance needs to be estimated. This suggests a mixed model approach to the modelling problem. An alternative might be to model the correlations using generalized estimating equations.

To deal with both within batch correlations and multiple response variables simultaneously is clearly very difficult and may not be possible without substantial effort. Fortunately, a model which is useful for NZ Steel may not actually need such sophistication however.

The analysis is ongoing.
