

Experimental Design in Tribological Testing to Support Component Lifetime Estimation

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INTRODUCTION

The performance of a component depends on the properties of the component and their response under the load spectra (mechanical, chemical, thermal) the component is subjected to during its operation. There are numerous factors that may affect the properties of the component, such as the material, the manufacturing process, heat treatments, surface engineering and geometry, to mention a few. In many instances the performance can be estimated by theoretical considerations and calculations, but often the effects of various parameters on the performance can only be found out experimentally. When investigating the effect of a number of parameters it is common to study the effect of one parameter at a time. If several parameters are changed at the same time in order to reduce the number of experiments, their separate effects may remain unexplained. Experimental design, based on statistical principles, is a way to select the test parameters and their combinations in a systematic manner so that the effect of a number of factors may be studied simultaneously with a considerably reduced number of experiments, and still obtain reliable information both on the individual as well as interactive effects of the parameters studied. However, since the statistical treatment does not pay any attention to any mechanisms of the influence of the various factors, care must be taken in the selection of the parameters and their levels in order to ascertain their relevance to the problem in question. The presentation consists of two case studies in which experimental design has been applied to tribological testing.

CASE 1

The first case study was an examination of handheld cutting tools which was carried out in three stages. In the first stage, used tools were examined in order to identify the prevailing wear mechanism of the cutting edge. The second stage involved the development of a laboratory test method to produce similar wear mechanism as observed in the used tools. This stage was extremely important, since the results from the laboratory tests would not be relevant to the application if the correct wear mechanism could not be reproduced. The third stage of the examination involved a large number of specimens, made from two different steels using three different hardening procedures, each with various heat treatment parameters. The objective was to determine the optimum combination of the tool

material and heat treatment, with respect to the wear resistance or, in other words, the lifetime of the tools. The two steels were, of course, such that the heat treatment parameters used in the experiments were appropriate to both of them. The experiments were designed using orthogonal matrices, in accordance to the Taguchi method [1], applying the case 'smaller-is-better'. The wear of the tools was measured after the tests by scanning electron microscopy, and the correct wear mechanism was verified at the same time. Figure 1 gives the results of the vacuum hardened specimens. Similar orthogonal matrices were applied for the other two hardening procedures.

The average, standard deviation and signal-to-noise-ratio was calculated from each test and its repetition. The signal-to-noise ratio was calculated according to the equation

$$S/N = -10 \log \{ 1/n \sum_i (y_i^2) \}$$

where n is the number of experiments (in the example $n=2$) and y is the test result. From the average and the S/N values of each test, the response of each parameter, at each level, was calculated as an average value of the tests including the respective parameter levels, see the response tables in Figure 1. For example, the S/N response of parameter B at level + was obtained as the average of the S/N -values of tests T1 and T3. The difference between the response values of the different levels of a parameter indicates the importance of the parameter: the bigger the difference, the stronger is the influence of the parameter on the results. From the response tables the recommended level of a parameter is obtained as the one giving the lowest absolute value (smaller-is-better).

In all the test series, the steel grade was found to be the most important factor, steel 2 giving the cutting tools a clearly better wear resistance than steel 1. In addition, the same recommended levels of the austenitising and quenching temperatures were obtained for each hardening procedure, i.e. 1060 °C and 20 °C respectively. This is advantageous since quenching to room temperature can be carried out at a lower cost than to -76 °C. Regarding the resulting wear resistance or lifetime of the tools, the difference between the hardening procedures was rather small, and the selection of the procedure to be used in the

manufacture of these cutting tools should be based on a compromise between the improvement in performance and the cost effects. The use of experimental design reduced the number of experiments to about half of that

which would have been needed to examine the effect of each factor separately. It can be concluded that the application of orthogonal matrices in this case was very successful.

Parameters		Levels	
		+	-
A. Steel grade		Steel 1	Steel 2
B. Austenitising		1020 °C	1060 °C
C. Quenching		-76 °C	20 °C

Test	A	B	C	Results, μm	Ave	s	S/N	
T1	+	+	+	25	25	25.0	0.000	-27.96
T2	+	-	-	20	21	20.5	0.707	-26.24
T3	-	+	-	19	18	18.0	0.000	-25.11
T4	-	-	+	17	18	17.5	0.707	-24.86

RESPONSE - S/N			
Factor	A	B	C
Level +	-27.10	-26.53	-26.41
Level -	-24.98	-25.55	-25.67
Difference	-2.11	-0.98	-0.74
Order	1	2	3
Recommendation	-	-	-

RESPONSE - AVERAGE			
Factor	A	B	C
Level +	22.75	21.50	21.25
Level -	17.75	19.00	19.25
Difference	5.00	2.50	2.00
Order	1	2	3
Recommendation	-	-	-

Figure 1. The parameters, their levels and the orthogonal matrix with results and response tables of the tests with vacuum hardened specimens.

CASE 2

The second case study involved friction and wear tests with our new pin-on-disc test equipment which allows the tests to be carried out also at elevated temperatures of up to 500 °C. Tests can be performed both with unidirectional or reciprocating sliding with sliding diameters of up to 40 mm, rotational speed of 20 to 3000 rpm and a normal load of 2 to 100 N. The objective was to test the suitability of a software (MODDE by Umetri, Sweden [2]) to be used for experimental design and modelling in tribological testing, giving the possibility to predict friction and wear values on the basis of experimental results. The tests were carried out using M50 steel balls with a diameter of 10 mm, sliding against a steel disc made of AISI D2 steel, quenched and tempered to 60 HRC. The test parameters were normal load of 5 to 25 N, sliding velocity of 0.1-1 m/s, furnace temperature of 22 to 250 °C and number of reversions 0 in unidirectional sliding and up to 100 in reciprocating sliding. The sliding distance was 250 m in each test. The friction force and the wear scar diameter of the ball were measured. Reciprocating sliding tended to increase the friction force variations, and in some of the tests there was a considerable difference in the friction to opposite directions. The friction coefficient measured at the end of the tests varied between 0.4 and 1.3, being mostly between 0.6 and 0.9. The unusually low and high friction values are believed to be a result of transfer material and wear debris entrapment between the pin and the disc, which is supported by optical microscopy of the wear surfaces. The friction values did not directly correlate with the wear of the ball: the lowest friction was measured at the highest normal load whereas the wear increased with the load. A decrease in sliding speed increased both wear and friction. The

software will be used to generate a model based on the results obtained and to predict friction and wear values at different parameter levels. The predicted values will then be compared to experimental results from verification tests in order to verify the model. The modelling and model verification remains still to be completed. This kind of predictions, based on a limited number of experiments at certain levels of parameters, can be used to support lifetime estimation of components subjected to different combinations and levels of parameters.

CONCLUSIONS

By using experimental design the number of experiments in the first case study could be reduced to about half of that which would have been needed to examine the effect of each factor separately. The application of orthogonal matrices in accordance to the Taguchi method was very successful in selecting the optimal combination material and heat treatment parameters in this case study.

In the second case study the objective was to test the suitability of a software for experimental design and modelling in tribological testing. If such models produce satisfactory predictions of friction and wear based on a limited number of experiments, this approach could be used to support lifetime estimation of components

REFERENCES

- [1] Taguchi G., Taguchi on Robust technology Development: Bringing Quality Engineering Upstream, 1993
- [2] <http://www.umetri.se>