SAIIE25 Proceedings, 9th – 11th of July 2013, Stellenbosch, South Africa © 2013 SAIIE

INVESTIGATION OF THE EFFECTS OF LUBRICANT FAT CONTENT ON DRAWN COPPER WIRES

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ABSTRACT

The Lean Manufacturing goal of reducing waste and increasing productivity has made it a necessity to produce good quality products in manufacturing industries at a low cost. In the cable manufacturing companies this can be achieved by optimising the wire drawing process. One way to meet the desired quality of the drawn wires is to improve lubricant efficiency through installation of an automatic, continuous lubricant fat content control system on the drawing machine. The paper shows a method of finding the optimum lubricant concentration for producing good quality copper wires using Taguchi experiments. Taguchi experiments are employed to analyse the effects of different lubricant fat content levels on the tensile strength and lubricant temperature. The results from the experiments indicated that the tensile strength of the wire is affected by low lubricant fat content. The lower the lubricant fat content: the lower the tensile strength drawing lubricant resulting in numerous wire breakages that affect the quality of the final product, namely the cable

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1 INTRODUCTION

Lubricant is one of the main elements in wire drawing that has a large influence on the quality of the produced wire and efficiency of the tool (die).The introduction of tungsten carbide and diamond dies and the increase in drawing speeds due to drive technology has posed the need to provide sufficient lubrication for long die life and intensive cooling that lessen the effects of higher drawing speeds. Most researches done in the past focused on provision of effective lubrication but overlooked the monitoring of its effectiveness during wire drawing process. Ineffective lubrication results in compromised drawn wire mechanical properties and in turn this causes frequent wire breakages and poor surface finish. The efficiency of a lubricant is measured by its emulsion strength and the focus of this paper is to provide a means to continuously control the lubricant fat content. This paper investigates the effects of low lubricant fat content on the mechanical properties of copper wire and its quality.

2 WIRE DRAWING PROCESS

Wire drawing is an operation done to produce wires of various sizes within certain specific tolerances. The process involves reducing the diameter of rods or wires by passing them through a series of wire drawing dies with each successive die having a smaller bore diameter than the one preceding it as stated by Yoshida, Ido, and Denshi [1]. According to Byon et al [2] wire drawing can also be defined as a process that pulls the rod manufactured in the groove rolling process through a die with a hole by means of a tensile force applied to the exit side of the die. According to Vegas, Imad and Haddi [3] the drawing capability process depends on three main parameters: (i) the wire material properties, (ii) the die geometries (such as die angle and die length) and (iii) the processing conditions such as drawing speed and friction at the interface between the die and the wire. The friction phenomenon has a major influence over the wire quality and the die wear in the wire drawing process.

2.1 Lubrication in wire drawing process

Lubrication is a determining parameter for productivity in cold heading. Therefore, the lubricating strategy adopted must be defined in the product design phase. The product geometry, certain client specifications, the materials involved and the various surface stresses in the wire drawing process all influence the choice of the lubricating systems to be used. Once the lubricating strategy has been defined, the performance level must be maintained to ensure a reliable process as shown by Dubois et al [4]. Lubricant performance is important in wire drawing processes as it acts as a coolant that helps reduce the temperature at the die thus prolonging die life. According to Yoshida et al [1] two primary variables that control die life in any metal forming operation are pressure and temperature and consequently, temperature is often a far more critical factor in controlling die life. According to Wright [5] increased drawing speed can increase drawing temperature thus impacting lubricant stability and performance. Beyond this, drawing speed generally has a direct effect on lubricant film thickness and the related coefficient of friction. This is shown generically by way of the Stribeck curve displaying generic dependence of lubricant film thickness and coefficient of friction on drawing speed as shown in Figure 1.

2.2 Temperature effects on wire drawing process

According to Vegas et al **Error! Reference source not found.** the heat generated for high drawing speeds due to plastic deformation and friction between the wire and die has a major influence on the final wire quality, the lubrication in the process, the mechanical properties of the wire and lastly, the wear of the dies. The unfavourable influence of friction during the drawing process can be observed by the non-uniform distribution of strain intensity and by the redundant strain across the wire. Friction causes the non-uniform distribution of mechanical properties on wire cross section.

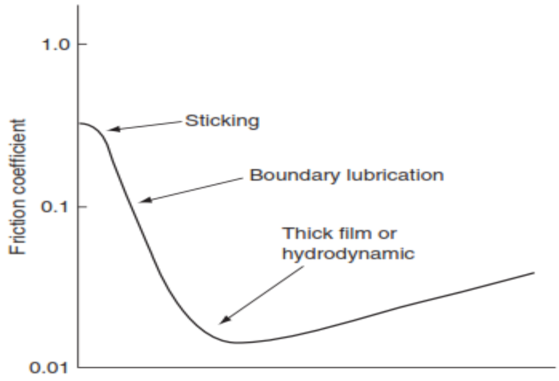

Figure 1: Stribeck curve [5]

The complementary longitudinal internal stresses that remain after the drawing process have a significant influence on mechanical properties of wires, because the stresses from external forces and longitudinal, tensile internal stresses will have an impact on material's plasticity. According to Haddi et al [6] as the die angle becomes larger for the same reduction, the deformation across the part becomes less homogeneous. Under die angle-reduction combinations, a large hydrostatic tension component exists along the wire central axis, which can cause local tensile failure. The effect of the increase of the strain makes the deformation less homogeneous over the cross section, principally near the die-wire interface, causing the damage of wire. The use of high speeds in the wire-drawing process to meet the demands for increased productivity has a considerable effect on the heat generated due to plastic deformation and friction between the wire and the drawing tools. Most of the mechanical energy converts to heat and results in a temperature increase of the order of hundreds of degrees. This temperature rise significantly affects lubrication conditions, tool life and the properties of the final product. The use of a proper lubrication technique substantially reduces the amount of heat generated during drawing and consequently reduces energy consumption.

2.3 Taguchi analytical methodology

Taguchi's techniques are based on direct experimentation. Taguchi defines quality as loss imparted to the society from the time the product is shipped as stated by Feigenbaum [7][7]. The loss includes the cost of customer dissatisfaction that leads to the loss of company reputation.Taguchi methodology is a powerful tool for the design of a high-quality system and it provides a rather inefficient, but systematic approach to optimize designs for performance and quality. The study of the effects of experimental parameters requires extensive experimentation and some statistical techniques for quantitative evaluation of the effects as shown by Rajurkar, Yu, and Tandon [8].

Khamba et al [9] describes Taguchi's approach to the product design process consisting of three stages: system design, parameter design and tolerance design. System design is the conceptual design stage where the system configuration is developed. Parameter design, in some case referred to as robust design, identifies factors that diminish the system sensitivity to noise, thereby enhancing the system's robustness. Tolerance design specifies the allowable deviations in the parameter values, loosening tolerances if possible and tightening tolerances if necessary. The uncontrollable factors that cause the functional characteristics of a product to deviate from their target values are known as noise factors. A standard Orthogonal Array (OA) has been selected in order to accommodate the data. The Signal-to-

Noise (S/N) ratio is used as the quality characteristics of choice in the Taguchi Methodology of optimization.

The Design of Experiment (DOE) methods result in an efficient experimental schedule and produce a statistical analysis to determine easily as to which parameters have the most significant effects on the final results as shown by Jeon, Park and Kwon [10]. Robust design is described as a product or process that is said to be robust when it is insensitive to the effects of sources of variability, even though the sources themselves have not been eliminated. In the design process a number of parameters can affect the quality characteristic or performance of the product. Parameters within the system may be classified as signal factors, noise factors, and control factors. Signal factors are parameters that determine the range of configurations to be considered by the robust design. Noise factors are parameters that cannot be controlled by the designer, or are complex and costly to control and constitute the source of variability in the system. Tarang and Yang [11] indicate that control factors are the specified parameters that the designer has to optimize to give the least sensitivity of the response to the effect of the noise factors.

A quantitative value for response variation comparison is provided by signal-to-noise (S/N) ratio analysis. Maximizing the S/N ratio results in the minimization of the response variation, and a more robust system performance is obtained. The most important task in Taguchi's robust design method is to test the effect of the variability in different experimental factors using statistical tools. The requirement to test multiple factors means that a full factorial experimental design that describes all possible conditions would result in a large number of experiments as shown by Lin [12]. Taguchi solved this difficulty by using OA to represent the range of possible experimental conditions. After conducting the experiments, the data from all experiments were evaluated using the Analysis of Variance (ANOVA) and the analysis of mean (ANOM) of the S/N ratio, to determine the optimum levels of the design variables. The optimization process consists of two steps: maximizing the S/N ratio to minimize the sensitivity to the effects of noise, and adjusting the mean response to the target response.

3 EXPERIMENTAL PROCEDURE

The experiments were performed on a Henrich Maschinenfabrik Rod Breaker wire drawing machine. The first step was the identification of factors contributing to wire breakages during wire drawing process. Lubricant fat content level was identified as one of the factors that causes wire breakages when below the optimum required level. The second step was the selection of the number of levels for the factors to be considered in the experiments. Appropriate Taguchi Orthogonal arrays were selected based on the number of levels and number of factors to be dealt with in the experiment and factors were assigned to the different columns. Experiments and tests were carried out under the various conditions listed in the orthogonal table and calculation of the relevant ratios and means using Minitab software. The last step was the analysis of results using Minitab software to identify the optimal experimental conditions to achieve the optimum wire quality. To verify the results, an experiment was conducted using the optimal experimental conditions obtained using Minitab and no wire breakages were experienced.

3.1 Experiment 1: Effects of high drawing speeds on the lubricant condition

Experiment 1 focused on determining the effects of excessive heat generated due to high drawing speeds on the lubricant condition. The range for the wire drawing speeds was set at 10m/s, 12m/s and 15m/s. The wire size was 1.76mm and the lubricant fat content was varied from 6% to 9% using readings from the refractometer. The temperature of the lubricant was measured on the die exit side using a resistive temperature sensor.

3.1.1 Application of Orthogonal Array (Experiment 1)

In this experiment, two wire drawing parameters, lubricant fat content and drawing speed were used with three different levels of each. The samples were organized into 9 groups to form an L9 orthogonal array with three levels. The orthogonal arrays and response of the various experiments conducted following Taguchi's methodology are shown in Table 1. The results show that at a constant lubricant fat content level, as the wire drawing speed increases, the lubricant temperature increases in turn. As the lubricant fat content level increases the lubricant temperature decreases thus reducing lubricant deterioration rate.

3.2 Experiment 2: Effect of lubricant fat content on the mechanical properties

Experiment 2 focused on determining the effect of lubricant fat content on the mechanical properties of the copper wire in particular tensile strength. The wire drawing process was performed using different input parameters. The lubricant fat content was varied from 6% to 9% and the wire drawing speed from 6.5m/s to 9.5m/s. The entire drawing system (capstans and dies) was immersed in the lubricant. The target population for the study was the rod breakdown machine outlet copper wires and the wire size used for the analysis was the 2.55mm copper wire. A refractometer was used for measuring the lubricant fat content levels and a tensometer for measuring the wire tensile strength drawn at varying lubricant fat content levels and drawing speeds. The lubricant collection point for measurement on a wire drawing machine is shown in Figure 2.

Table 1 Effects of lubricant fat content and wire drawing speed on lubricant temperature

EXPERIMENT NUMBER	LUBRICANT FAT CONTENT (%)	WIRE DRAWING SPEED (m/s)	LUBRICANT TEMPERATURE (°C) (RESPONSE)
1	6.0	10	61
2	6.0	12	63
3	6.0	15	65
4	7.5	10	55
5	7.5	12	58
6	7.5	15	60
7	9.0	10	46
8	9.0	12	48
9	9.0	15	52

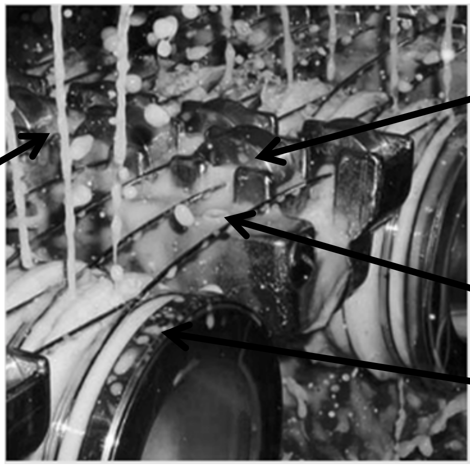

Figure 2: Lubricant collection point on a wire drawing machine

3.2.1 Application of Orthogonal Array (Experiment 2)

In this experiment two wire drawing parameters, lubricant fat content and drawing speed were used with three different levels of each. The samples were also organized into 9 groups. The orthogonal arrays of various groups following the Taguchi methodology are shown in Table 2. The results in Table 2 show that as the drawing speed is increased at a constant lubricant fat content level, the tensile strength of the wire decreases. The increase in lubricant fat content level increases the wire tensile strength in turn due to a decrease in the temperature between the die and wire.

Table 2: Effects of lubricant fat content and wire drawing speed on tensile strength

EXPERIMENT NUMBER	LUBRICANT FAT CONTENT (%)	WIRE DRAWING SPEED (m/s)	TENSILE STRENGTH (kN) (RESPONSE)
1	6.0	6.5	1.370
2	6.0	8.0	1.365
3	6.0	9.5	1.360
4	7.5	6.5	1.385
5	7.5	8.0	1.380
6	7.5	9.5	1.376
7	9.0	6.5	1.393
8	9.0	8.0	1.390
9	9.0	9.5	1.388

4 RESULTS AND DISCUSSIONS

The results for Experiment 1 after computations using Minitab are shown in Table 4 and Figure 3. The effect of the two factors, fat content and wire drawing speed on the lubricant temperature is determined by the signal to noise ratio, the ratio being directly proportional to the effect. From the results shown in Table 3, lubricant fat content level has the highest signal to noise ratio thus it has a greater effect on the lubricant temperature.

Table 3: Response Table for Signal to Noise Ratio

LEVEL	LUBRICANT FAT CONTENT	DRAWING SPEED
1	-35.85	-34.43
2	-35.17	-34.77
3	-33.16	-34.97
Delta	2.69	0.53
Rank	1	2

The most suitable settings for producing wires with the highest tensile strength are obtained from the Main Effects Plot for SN ratios in Figure 3 while lubricant fat content is 9.5% and wire drawing speed is 10m/s.

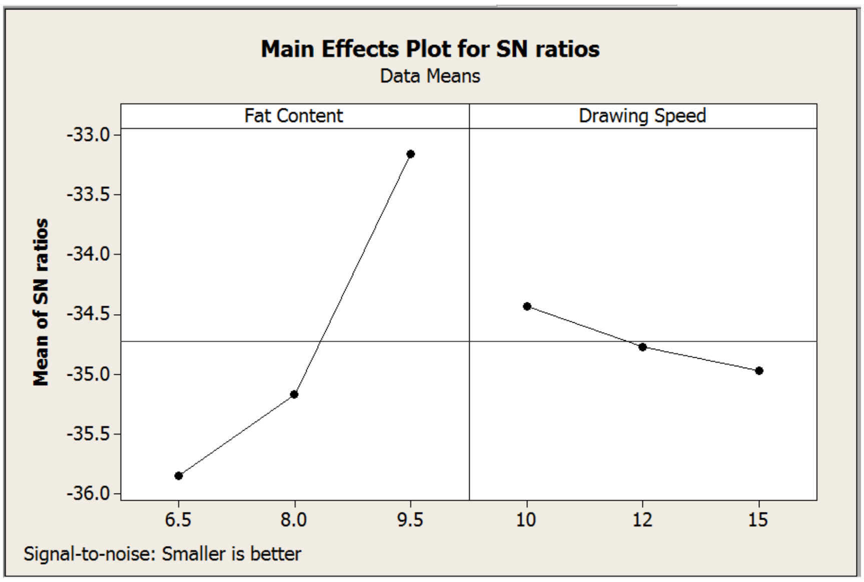

Figure 3: Experiment 1 Main Effects Plot for SN ratios

The results for Experiment 2 after computations using Minitab are shown in Table 4 and Figure 3. The factor that influences the tensile strength of the drawn copper wires is determined by the highest signal to noise ratio and from Table 4, with lubricant fat content having the highest signal to noise ratio. The most suitable settings for producing wires with the highest tensile strength are obtained from the Main Effects Plot for SN ratios in Figure 4 while lubricant fat content is 9% and wire drawing speed is 6.5m/s.

The lower the lubricant fat content the lower the tensile strength and the higher the wire drawing lubricant temperature. For high drawing speeds, excessive heat is generated and this in return accelerates the deterioration of the lubricants used, to the extent that the optimum lubricant emulsion strength is no longer prevailing. From the results obtained in the experiments, it can be concluded that as the emulsion strength of the lubricant becomes weaker, more heat is generated due to friction and the heat generated weakens the metallic bonds in the copper wire.

Table 4: Response Table for Signal to Noise Ratio

LEVEL	LUBRICANT FAT CONTENT	DRAWING SPEED
1	2.703	2.808
2	2.800	2.785
3	2.852	2.762
Delta	0.149	0.046
Rank	1	2

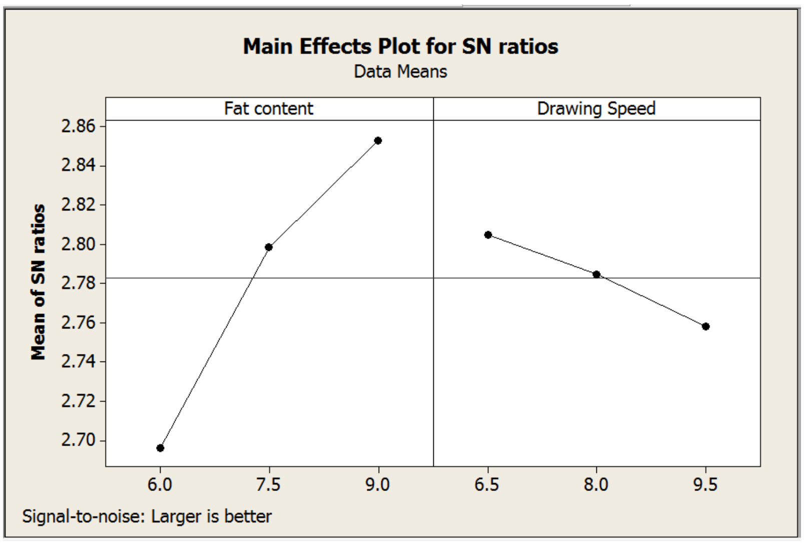

Figure 4: Experiment 2 Main Effects Plot for SN ratios

5 CONCLUSION

The experiments were conducted to determine the effects of drawing speed on the lubricant performance and the effect of the lubricant on the mechanical properties of the wire specifically the strength of the wire. This study confirms that there exists an optimum lubricant level for production of good quality copper wires in the case study company. The author proposes a continuous monitoring system of the lubricant fat content on a wire drawing machine using a Programmable Logic Controller as the next stage of the research. The optimum lubricant fat content level obtained from the Taguchi experiments is proposed to be used as the set point in the automatic monitoring system.

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