Journal for Technology of Plasticity, Vol. 27 (2002), Number 1-2

INFLUENCE OF COPPER FINENESS TO WIRE MECHANICAL PROPERTIES AT WIRE FORMING

Michal Tkac[1], *Milan Majernik*[2]
[1]*University of Economics in Bratislava,* [2] *Technical University in Kosice*

ABSTRACT

A production technology of copper products is based on melting of refinery and residual materials in pit furnace with following converter process. Converted copper together with the copper scrap material forms a batch of a tilting refinery furnace. This pyro-refinery process produces copper anodes that are further refined in electrolysis to copper cathodes. The high-grade copper cathodes are then processed by the continuous casting and rolling line to the copper wire with diameter of 8 mm.

1. INTRODUCTION

The wire is further processed by customer by drawing at the tandem machine until diameter of the wire is from 0.4 to 1.87 mm. Mechanical properties of the copper wire play a very important role in this processing. One of the most serious defects occurring in the drawing process is a tear. A tear can result from various causes.

More than 50 % of all input material tears (when the tear is caused by the material failure) are caused by the presence of the ferrous particles in copper. It is not possible to reduce their occurrence completely. Anyway, some actions can be done to reduce the occurrence of these unwanted events, for example increasing the equipment quality or increasing the fineness of the technological process. From the long-term monitoring of the executed actions impacts is obvious that number of tears at the customer's declined with material fineness increasing although the ferrous particles may be still present. Presence of the ferrous particles is a random event and it is hardly identifiable for the production is continual.

2. TORSIONS UP TO THE TEAR

There are many factors in the production that influence individually or mutually desired properties of copper wire. Here are some of them:

- copper cathode fineness
- cooling medium temperature when quenching

– rolling machine setting, pouring and rolling temperatures
– ratio of gas to oxygen, etc.

We suppose that copper fineness has a significant impact on the number of tears decline. For that we have aimed our observations at the measuring the influence of the material fineness (factor *A*) and cooling medium temperature when quenching (factor *B*) on parameter denoted torsion up to the tear.

Torsion up to the tear is one of the characteristics of the copper wire mechanical properties. We can have it by counting the number of turnings of the wire on its axis in one direction. The less number of wire turnings, the higher tear occurrence probability.

To find out the influence of the two major factors on one response (torsion up to the tear) we decided to realise a full factorial designed experiment – a test in which purposeful changes were made to the input variables of a process so that we could observe and identify the reasons for changes in the output response.

Focusing on the two factors results from the very time-consumption of the extensive experiments. Other factors were approximately constant during the experiment. Possible factors' levels are from 95 ± 1 % to 99 ± 1 % for factor *A* (concentration of the pure copper in the cathodes) and from 35 ± 1 °C to 40 ± 1 °C for factor *B* (cooling medium temperature).

The experiment was realised during the routine operations, not in the laboratory conditions. With respect to continual casting of the wire, there were only 1-meter long wire samples available, which were cut after approximately 4 tons of copper wire had been produced. The technology does not allow taking a sample neither during casting nor during drawing the wire before filling up the roll. The minimum number of the torsion up to the tear is 45 as stated by the standard. The sample of copper wire is 80 cm long and is cut after completing roll.

The experiment started with the filling the pit furnace with the cathodes containing approximately 99 % of pure copper exclusively. Values of the output response – number of torsions up to the tear, were immediately recorded and depicted in diagram (Fig. 1).

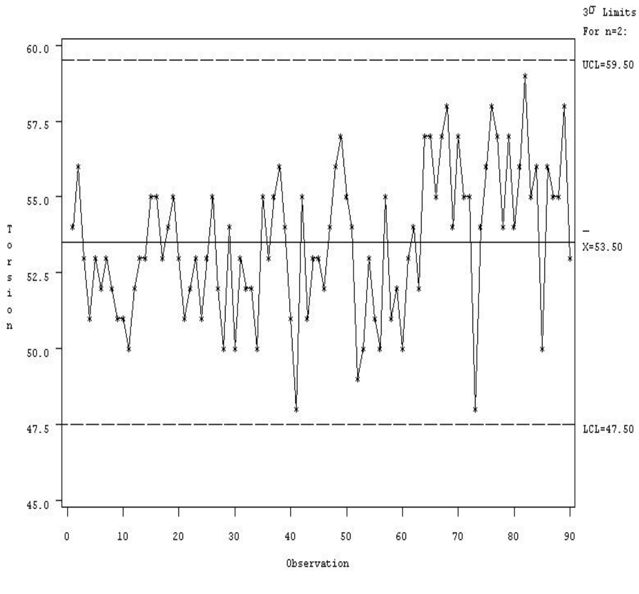

Fig. 1 The diagram of the number of torsions up to the tear for 90 observations

At the same time an operator started to modify the cooling medium temperature. As the common randomisation of the moments of the factor change was impossible in this case, he used the following way:

For every odd consecutive triplet of rolls the cooling quenching medium temperature was adjusted to 35 °C and for every even consecutive triplet of rolls the temperature was adjusted to 40 °C. The change of factor *B* was observed by subgroups of three rolls. Triplets of rolls matched up with the triplets of copper wire samples on which the measuring of the torsion up to the tear was done. The subgroups averages of the torsions up to the tear are showed in diagrams of averages in Fig. 3. Since the change of factor *A*, that is the change of copper content in the wire, did not exhibit immediately after filling up the pit furnace (because of the remainder of copper used before had been still in the furnace and rolling process), it was necessary to estimate the moment of cleaner copper impact using statistical methods.

The problem occurs when determining the moment of change in torsion up to the tear behaviour. Identifying it by the cathodes' fineness change is error loaded; first one is the error of discreteness (wire sample is cut after certain amount of wire has been processed) and another one is caused by the wire non-homogeneity (although the copper cathodes and produced copper wire are of high fineness in average, the test for the torsion up to the tear can be done at the place of ferrous particle presence).

The first problem consist in determining the time response between the pit furnace filling up with the cathodes of higher fineness and starting the copper wire of higher fineness production. Cusum chart seemed to be the most suitable method. The cusum of individuals (or means) chart is sensitive to detecting small shifts in the process mean. We use the cusum of means chart to reduce non-homogeneity impact. When the cusum chart point is outside the arms of the *V*-mask, it means that the process mean has changed by reason of the initiation of the factor *A* impact. That moment is displayed on the figure 2. On the following control charts a vertical line represents this. The space between two lines encloses transitional copper wire production using copper of two kinds of its fineness.

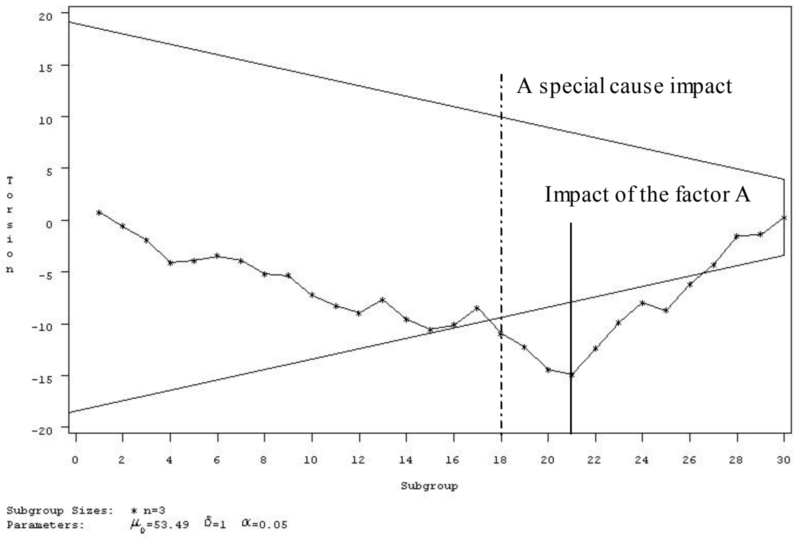

Fig. 2 Cusum chart of the number of torsions up to the tear (all samples). The vertical line demonstrates the situation when the factor A impact has manifested.

Now it is possible to continue with the experiment and determine the relevancy of the two factors changes on the copper wire mechanical property. Omitting the data of the transitional production and selecting them by the factor combinations we have following diagrams (fig. 3).

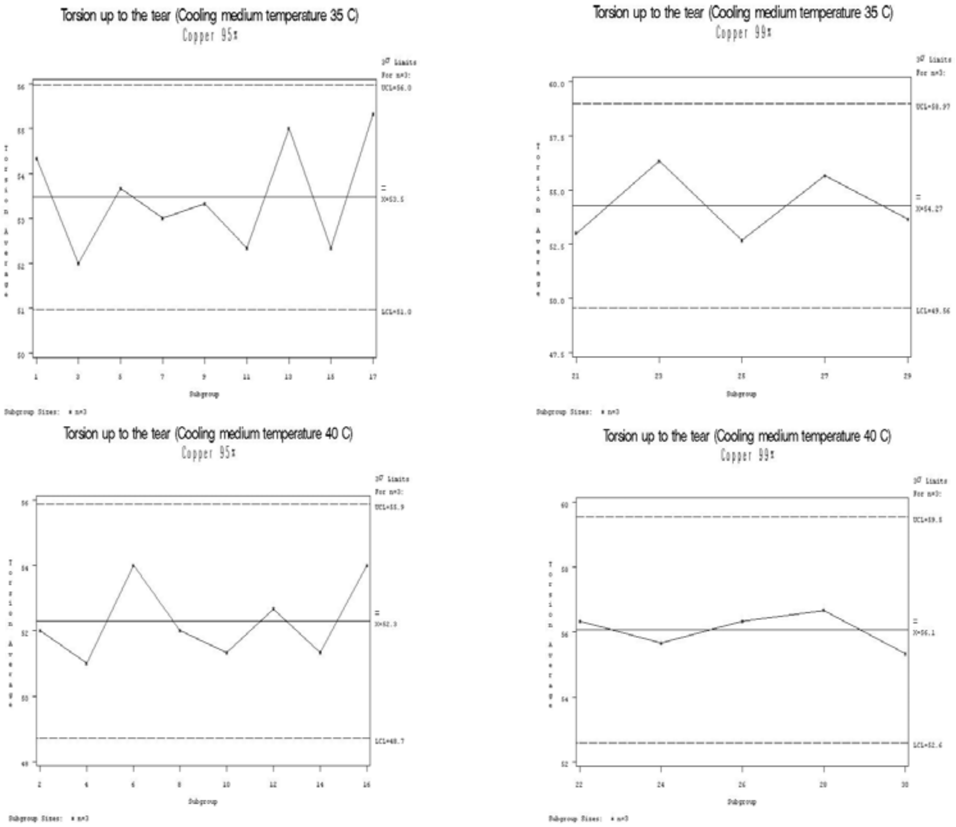

Fig. 3 Diagram of the number of torsions up to the tear for different levels of the 2 factors.

Diagrams (fig. 3) of the wire sample subgroups means in different conditions enables to estimate means of the two factors' levels. Response computations are summarised as follows:

$$y_1 = 53.5$$
$$y_2 = 54.27$$
$$y_3 = 52.3$$
$$y_4 = 56.1$$

y – denotes the response of the experiment – torsion up to the tear.

The impacts of the certain factors are changes of the factors' responses. In this case the response of the factor is a change of the mean of the random quantity y, hence a change of the number of turnings up to the tear.

The effects for individual factors and their combinations are then computed.

$$\text{Effect } A = \frac{y_2 + y_4}{2} - \frac{y_1 + y_3}{2} = 2{,}285.$$

$$\text{Effect } B = \frac{y_3 + y_4}{2} - \frac{y_1 + y_2}{2} = 0{,}315.$$

$$\text{Effect } AB = \frac{y_1 + y_4}{2} - \frac{y_2 + y_3}{2} = 1{,}515.$$

From the results above it is evident, that the effect of the factor A is relevant. It means that if the statistical significance of the copper wire sample would be higher, it would prove the substantiation of the further fineness improvement of copper used in the copper wire production. It is one of the solutions of the product mechanical property improving. Since the effect of the factor B is irrelevant, it is not meaningful to adjust the cooling medium temperature when quenching. The effect of the interactions of the both factors AB is relevant. Providing that copper fineness would be achieved at the significant level, it would be meaningful to increase the cooling medium temperature when quenching.

3. CONCLUSION

Difference between the applications of statistical methods in laboratory conditions and common production conditions is sometimes large. As we showed in the article also when Design of Experiment method application in the industry condition there can be a problem to execute such simple acts as randomization of the measurements, or determining the beginning of the factors' level change impact.

The article demonstrates that although with respect to some precision decreasing, we can sometimes effectively use noted statistical methods in practice by utilization of another suitable statistical methods.

4. REFERENCES

1. Montgomery, D. C.: *Design and Analysis of Experiments*. John Wiley & Sons, 3rd edition, USA, 1991.
2. Dietrich, E. - Schulze, A.: *Statistical Procedures for Machine and Process Qualification*. ASQ Quality Press, Milwaukee, Wisconsin, 1999.
3. Sula, A.: *Analyza vzniku vad valcovych plechov vyuzitim vyssej statistickej metody planovaneho experimentu*. Workshop Statistical methods in practice 2000. SSDS, Stara Lesna, Slovakia 2000.

UTICAJ FINOĆE BAKRA NA MEHANIČKE OSOBINE VUČENE ŽICE

Michal Tkac, Milan Majernik

REZIME

Proces vučenja bakarne žice počinje sa prečnikom 8mm. Na tandem mašinama se vrši redukcija na 0,4 do 1,87 mm. Za vreme vučenja (redukcije) mehaničke osobine žice igraju važnu ulogu i imaju bitan uticaj na izvođenje samog procesa. Mogu se tom prilikom pojaviti i defekti a najozbiljniji je pojava unutrašnje pukotine. Ta pojava ima različite uzroke. U više od 50% slučajeva pukotina u bakarnom materijalu se pojavljuje zbog prisustva čestica Fe. Nemoguće je u potpunosti isključiti to prisustvo.
Postoje različiti faktori u proizvodnji koji utiču na mehaničke osobine vučene žice. Najvažniji su:

- finoća katodnog bakra
- temperatura hlađenja
- podešenost valjaoničke mašine, temperatura i dr.

Po mišljenju autora finoća bakra ima odlučujući uticaj na broj pukotina koji se pojavljuju u unutrašnjosti žice. Iznešena su istraživanja u kojima je utvrđen uticaj stepena finoće (faktor A) i temperatura rashladnog sredstva za vreme hlađenja (faktor B) na mehaničke osobine (reprezentant: torzija do pukotine). Ovaj pokazatelj moguće je definisati kao broj obrtaja žice (torzija) oko svoje ose do pojave pukotine.
Istraživanja su realizovana kroz faktorski eksperiment u proizvodnim uslovima. Dužina ispitane bakarne zice bila je 0,8m.
Utvrđeno je da od dva ispitna faktora, faktor A (finoća bakra) ima znatno veću signifikantnost:

efekat faktor A=2,285 (relevantno)
efekat faktor B=0,315 (relevantno)
efekat faktor AB=1,515 (relevantno)