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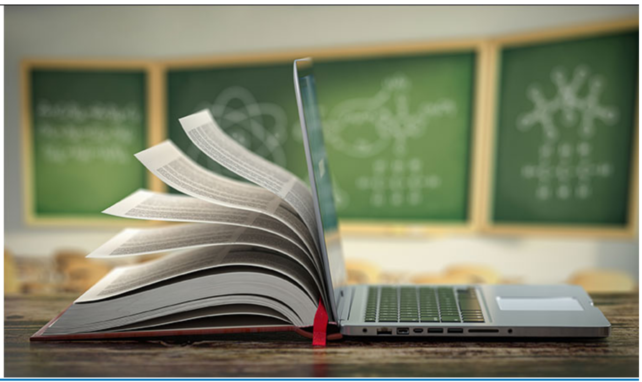

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Flow capacity of the capillary copper tube as its figure of merit

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Abstract. The use of capillary copper tube is popular for manufacturing of gauges and evaporators of refrigeration units. Its main feature is a small inner diameter (no more than 0.9 mm), which makes it difficult to measure it along the whole length of the tube, thus, indirect test methods are used for its determination. Main problem in manufacturing of quality tubes is providing the necessary flow capacity. This article features these under-investigated issues by determining correlation between technological parameters and figures of merit of the capillary copper tubes. Specifically, it was found how flow capacity changes by the influence of such parameters as heat treatment (annealing), tube channel diameter and length of the treated product.

1. Introduction

Capillary tubes (Figure 1) are characterized by their small inner diameter, and the ratio of wall thickness to average diameter may be different. According to this ratio, tubes may be either thin-walled or thick-walled. As a result of this grading, there are various technological schemes for their manufacture [1]. Since the inner tube channel is small in size, close attention is paid to the possibility of this channel to create low resistance to gas or liquid flow [2]. This is ensured by the purity of the channel and rough surface [3]. Most frequently, capillary tubes are made from corrosion resistant steels [4, 5], and heavy nonferrous metals, including copper [6, 7, 8, 9]. Quality of the inner and outer surface depends a lot on the applied lubrication regimes [10, 11], tool surface configuration [12] and its wear stage [13].

Purpose of this work is to study the changes in capillary copper tube flow capacity in the manufacturing process.

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Figure 1. Capillary tube coil, the profile of the tube is shown in the left corner.

2. Description of the applied method

Tube flow capacity (FC) has a tendency to fluctuate in manufacturing environment. If the tolerance is exceeded, tubes can be rejected, which affects the performance of the enterprise. The following describes the methodology of an industrial experiment.

Two sizes of capillary tubes made of M1p copper were selected for measurements: 1.85x0.66 mm (sample size is 190) and 1.85x0.71 mm, sample size is 160. The length of the 1.85 x 0.66 mm tube samples was 2.5 m, and the length of the 1.85 x 0.71 mm tube samples was 3.5 mm. The measurement procedure included the determination of the reference sample FC, the calculation of the tolerance limits, and the determination of the FC of the reference tube segment. The tube flow capacity was checked at room temperature by a flow meter at 0.101 MPa nitrogen pressure.

3. Measurement results

As a result of measurements, four FC value groups were obtained:

1. Coil head before annealing FC, marked as hba,
2. Coil head after annealing FC, marked as haa,
3. Coil tail before annealing FC, marked as tba,
4. Coil tail after annealing FC, marked as taa.

Thus, variables in an industrial experiment are:

- Two workpiece sizes,
- Measuring point (at the beginning of the drawing – head, at the end of the drawing - tail),
- Heat treatment: yes / no.

The FC values are important for the further analysis, since they determine the quality of the product and the possibility of its usage. Figure 2 shows the results of the FC measurement in chronological sequence. In particular, it's clear that FC fluctuations can be significant. In manufacturing environment, the tolerance on the FC value is 5% of the value measured using the reference tube segment. Thus, the lower and upper limits of the tolerance (in the amount of 10%) are formed. The limits are measured from the reference nominal value in these test conditions.

At this stage of processing the results, it was revealed that the solid trend lines in all cases go above the dashed lines, i.e. the FC is somewhat higher before than after the annealing. It is difficult to justify statistically because of the high amplitude of FC oscillations, however, this fact was observed not in one, but in four series of measurements.

This contradicts the prevailing opinion that the annealing should clean the inner surface of the tube by burning out the grease, wear products of the tool, and the deformed metal itself.

- Structural changes affecting the tube dimensions occur in the metal as a result of a rather long annealing of the tube.

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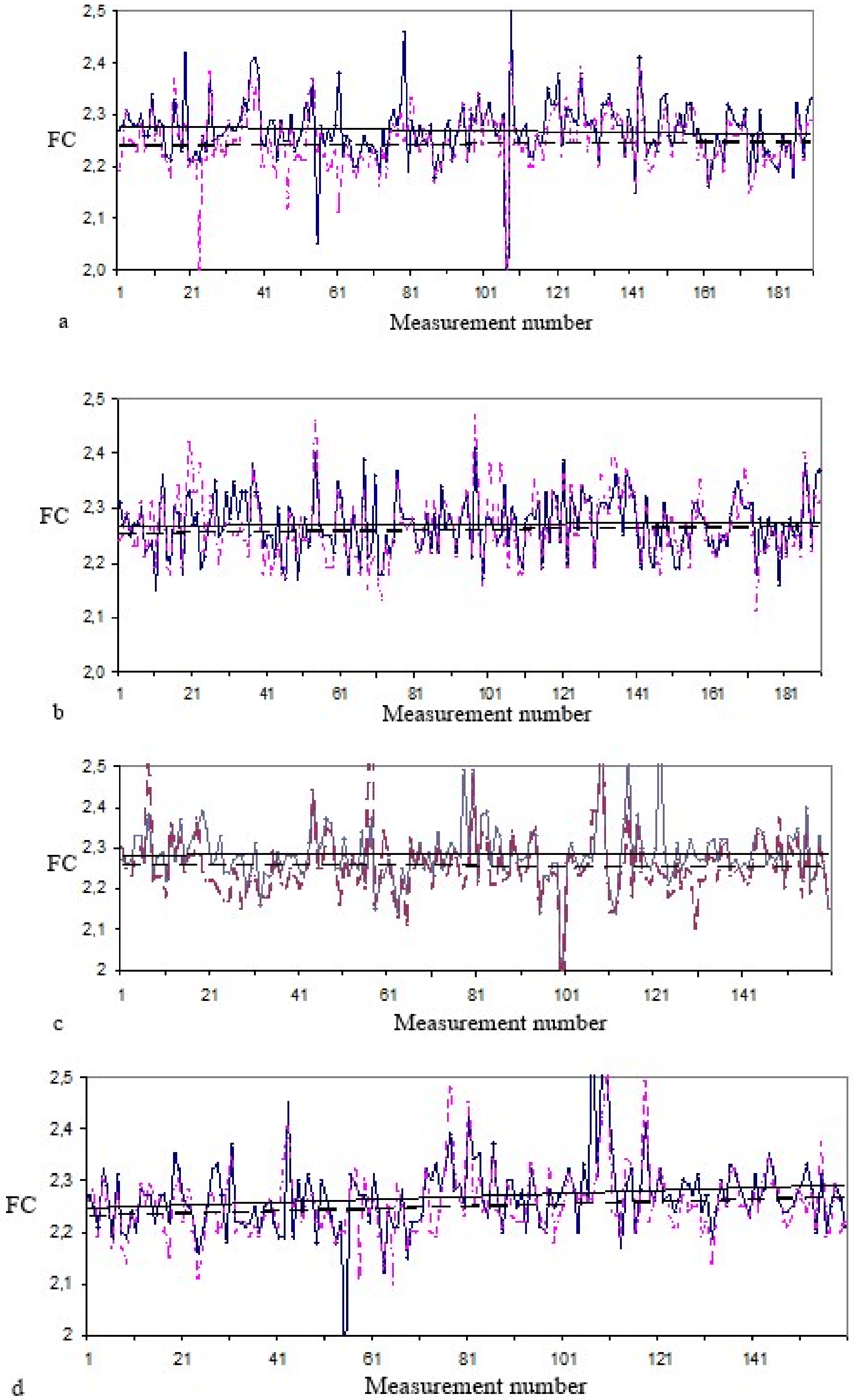

Figure 2. FC measurement results for 1.85x0.66 mm tubes with a sample size of 190 measurements (a, b) and 1.85x0.71 mm tube with a sample size of 160 measurements (c, d) of the head before (solid line) and after (dashed line) annealing (a, c), of the tail before and after annealing (b, d), straight lines are made as trend lines.

Table 1 shows the statistical characteristics of FC measurements for the 1.85x0.66 mm tube, and Table 2 shows the statistical characteristics for the 1.85x0.71 mm tube.

Table 1. Statistical characteristics of FC measurements for the 1.85x0.66 mm tube

Index	FChba	FChaa	FCtba	FCtaa
Mean	2.27	2.24	2.27	2.26
Median	2.27	2.24	2.27	2.25
Mode	2.28	2.25	2.27	2.25
Standard Deviation	0.068	0.067	0.054	0.061
Sample Variance	0.005	0.004	0.003	0.004
Excess Kurtosis	18.817	24.840	-0.424	0.519
Skewness	-2.093	-2.996	0.129	0.571
Minimum	1.75	1.69	2.15	2.11
Maximum	2.5	2.4	2.41	2.47
Sum	431.21	426.45	431.43	429.74
Count	190	190	190	190

Table 2. Statistical characteristics of FC measurements for the 1.85x0.71 mm tube

Index	FChba	FChaa	FCtba	FCtaa
Mean	2.28	2.26	2.27	2.25
Standard Error	0.030	0.028	0.010	0.012
Median	2.27	2.24	2.27	2.24
Mode	2.27	2.23	2.27	2.22
Standard Deviation	0.075	0.090	0.072	0.064
Sample Variance	0.006	0.008	0.005	0.004
Excess Kurtosis	5.866	13.057	6.931	3.317
Skewness	0.236	1.613	0.714	1.154
Minimum	1.91	1.84	1.93	2.1
Maximum	2.57	2.82	2.6	2.51
Sum	365.58	360.86	362.9	360.06
Count	160	160	160	160

As can be seen from the tables, the values of standard deviation and variance look quite uniform, which allows us to conclude that arrays of numbers adequately describe the processes. The analysis of data shows that the FC value for the 1.85x0.66 mm tube in the aggregate of the mean, median and mode values ranges from 2.27 to 2.28 before annealing, and from 2.24 to 2.26 after annealing, i.e. these intervals do not even intersect. The FC is lower after annealing, which confirms the conclusions drawn from the graphs. For the 1.85 x 0.71 mm tube, respectively, the intervals are 2.27 to 2.28 before annealing, and 2.22 to 2.26 after annealing, i.e. the trend remains the same, and the value decreases after annealing.

In addition to the array of experimental data obtained, the values of the FC change (increment) were calculated as follows:

- ΔFCtib = FCtba - FChba – FC increment while drawing before annealing;
- ΔFCtia = FCtaa - FChaa – FC increment while drawing after annealing;
- ΔFCtt = FCtaa - FCtba – FC increment of the coil tail as a result of annealing;
- ΔFCht = FChaa - FChba – FC increment of the coil head as a result of annealing.

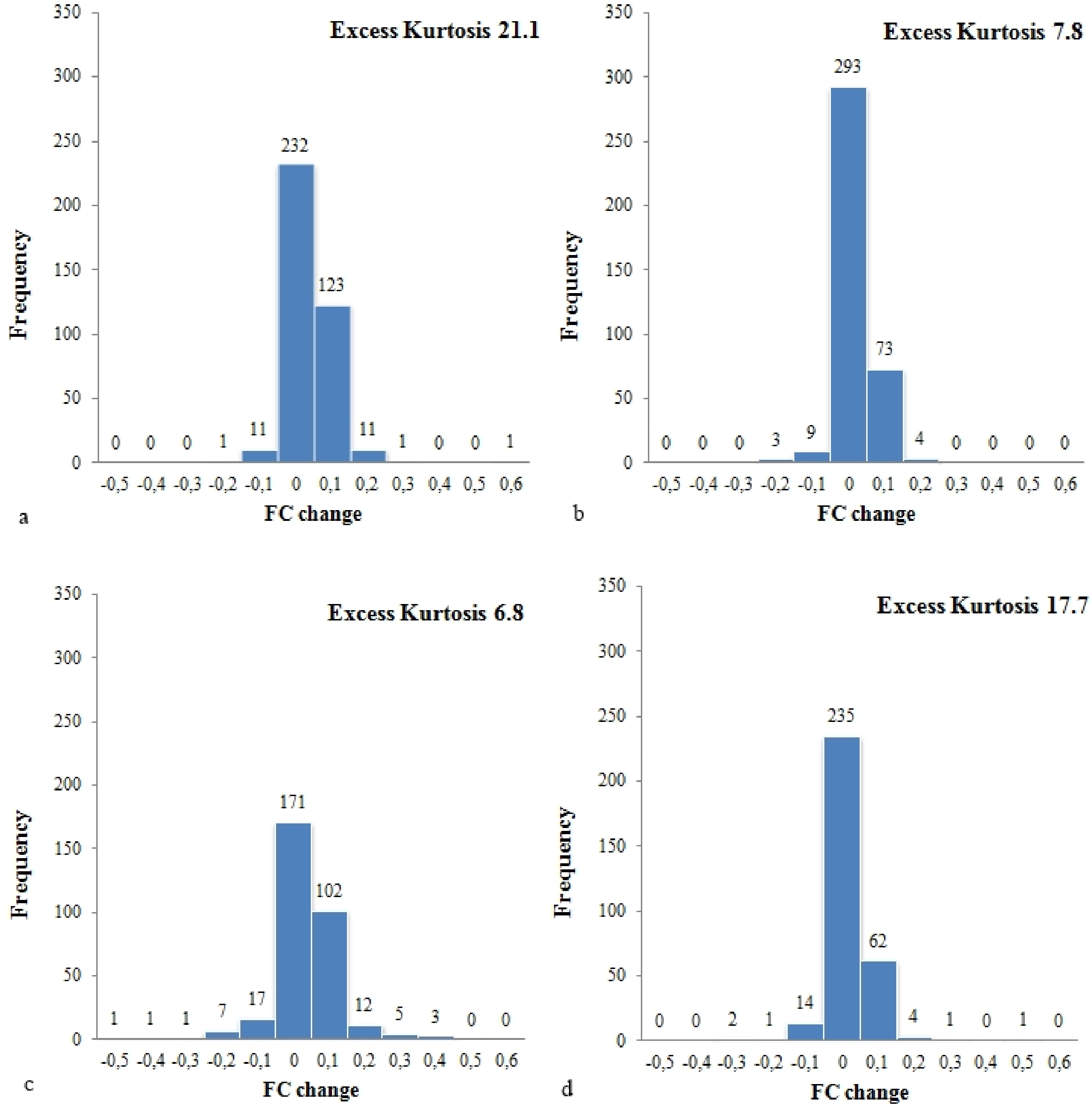

Figure 3. Frequency histograms of FC increases FC for 1.85x0.66 mm tubes with a sample size of 380 measurements (a, b) and 1.85x0.71 mm tube with a sample size of 320 measurements (c, d): from the head to the tail (a, c) and after annealing (b, d); numbers above the columns are frequency for the rage.

Thus, parameter increments were formulated in functional connection with time: the earlier term parameter is deducted from the later term parameter. For example, the coil tail is drawn later than its head, and the result obtained after annealing is always measured later, than the one before annealing.

These increments were calculated within an increased series of results. The FC measurement results before and after annealing were combined in one group for this purpose. Statistical results are shown in Figure 3 as frequency histograms. The same abscissa scales are used for ease of comparison.

According to the histograms, the highest columns correspond to the zero or small FC changes. The next highest column is on the right, i.e. the histogram is asymmetrical, and, basically, does not correspond to the normal distribution function. Thus, we can recognize a physically justified phenomenon. A shift from zero to ΔFC positive values (Figure 3, a) for the 1.85x0.66 mm tubes evidences that the FC increases regularly closer to the workpiece tail. Same trend applies to the 1.85x0.71 mm tubes (Figure 2, c), which proves the mentioned fact. A ΔFC shift to positive values on the histograms (Figure 3, b and d) proves that the FC has shifted to large values after annealing. This phenomenon was noticed earlier with other ways of displaying information.

4. Conclusion

The capacity of capillary tubes is influenced by both deformation processing and heat treatment. The throughput after annealing is reduced, which can be explained by an increase in the coefficient of friction when moving the fluid along the channel. The second version of the explanation of the phenomenon is to change the structure of the inner surface of the capillary tube.

Acknowledgments

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