

INFLUENCE OF HARD COLD WORKING ON MICROSTRUCTURE AND PROPERTIES OF ANNEALING COPPER TUBES

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Abstract

This work gives results of influence of temperature and deformation degree on changes in the metal grain growth of drawn copper tubes, because this mutual dependence was observed. Copper tubes samples, chemical content of 99,97 % Cu and 0,024 % P, were exposed to recrystallized annealing after drawing. The annealing was carried out at temperatures of 573, 623, 673, 723, 773, 823 and 873 K, for 60 minutes, in laboratory conditions. Investigation results show that after drawing with high cold deformation degree (96 – 99 %), the annealing leads to the changes in the continuous grain growth with increased temperature. The smaller grain size appears at 823 K in comparison with the lower annealing temperature. Annealing has influence on mechanical characteristics of tested samples and during drawing of copper tubes these characteristics are adequately changed: with regard to the annealing at the 773 K, the characteristics of strength and plasticity increase as a result of decreased grain size. The increase of annealing temperature to 873 K leads to the increased grain size and decreased values of strength and plasticity characteristics.

Keywords: Drawn copper tube, degree of cold work, annealing temperature, grain size.

1. Introduction

Many factors have influence on recrystallization kinetics and structure of recryst-

tallized metal, as well as deformation degree, deformation rate, annealing temperature, annealing time, annealing rate, starting grain size, existing impurities and secondary stages and others [1]. In some cases the increase of recrystallization temperature is associated with a certain texture formation [2].

Due to the different texture formed after high degree of cold deformation in copper, recrystallization temperature is considerably increased [3]. The structure of recrystallized metal depends on annealing temperature and texture. Consequently, recrystallized structure could not be anticipated, but it could be only experimentally established.

Keeping in mind the complex influence of deformation degree, annealing temperature and texture on recrystallization rate and also on recrystallized grain size and mechanical characteristics, the experiments with annealing temperature change on drawn copper tubes with high degree of deformation, was carried out in this work.

2. Experiment

Copper tubes, chemical content of 99,97 % Cu and 0,024 % P, produced by high degree of deformation ($\epsilon = 96 - 99 \%$) were used in the experiment. Copper tubes after drawing were exposed to the recrystallization annealing at temperatures of 573, 623, 673, 723, 773, 823 and 873 K, for 60 minutes, in laboratory conditions. The investigations include testing of influence of deformation degree and annealing temperature on changes in growth of recrystallized grain size and mechanical characteristics of drawn copper tubes, because this mutual dependence was observed. Metallographic investigations and mechanical investigations (determination of hardness, tensile strength and elongations) were carried out on samples, to recognize the existing dependences after annealing.

3. Results

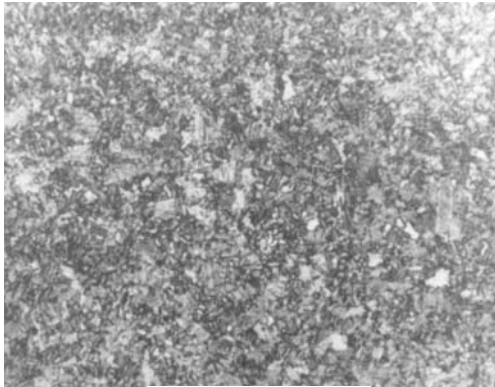
Metallographic test on samples was carried out by optical microscopy. The structure of annealed samples (Fig.1.) showed polyhedral recrystallized grains with clear twins. A method of comparable series by ASTM was used in this work for determination of metal grain size due to recrystallized structure of copper. The results show that the grain size increases with annealing temperature increase. Especially, on samples obtained by drawing the high degree of cold deformation (96 – 99 %), annealing changes the continuous growth of grain with increase in temperature. Considerable fine grained structure with regard to the lower annealing temperature, was observed on samples annealed at 823 K, which is not a common phenomenon (Fig.1d).

Further increase of annealing temperature results again in the grain growth. The details of characteristic sample microstructures after annealing at temperatures 573, 673, 773, 823 and 873 K are presented in figures 1(a-e).

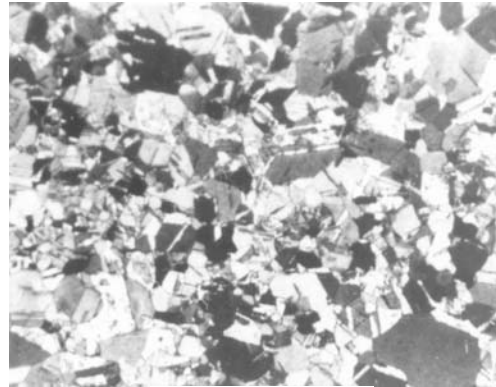
Table 1. Appropriated equations for mechanical characteristics of tested samples

Equation for	Degree of cold work (%)	Values of			
		<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
Tensile Strength (MPa) $ax^2 + bx + c$	97	-0,0714	0,0286	25,16	
	98	-0,0929	0,3071	27,08	
	98,5	-0,1143	0,3657	24,90	
	99	-0,0571	0,1029	25,68	
Vickers Hardness (MPa) $ax^3 + bx^2 + cx + d$	97	-0,2917	2,1821	-6,126	57,98
	98	0,0667	-1,9786	9,054	41,16
	98,5	-0,9333	7,1643	-15,502	60,00
	99	-0,6750	5,6679	-14,957	63,88
Elongation A_{10} (%) $ax^3 + bx^2 + cx + d$	97	-0,1892	0,9818	-1,349	43,58
	98	0,9708	-8,4404	20,708	28,40
	98,5	-0,4450	3,2643	-7,430	50,62
	99	0,5500	-6,1493	20,080	21,33
Elongation A_5 (%) $ax^3 + bx^2 + cx + d$	97	-0,2150	0,5050	1,590	50,10
	98	0,2800	-2,2229	3,677	53,60
	98,5	-1,4992	12,8825	-32,268	75,71
	99	0,1267	-2,3529	8,870	42,15

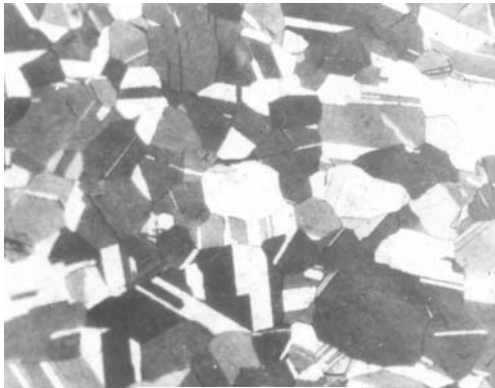
The annealing has influence on mechanical characteristics of tested samples also. Figs.2 – 5 graphically present dependence of hardness (*HV*), tensile strength (*R_m*), and elongation (*A₁₀* and *A₅*) of drawn copper tubes on annealing temperature after cold work. The functional dependence is represented also by appropriate equations (Table 1).



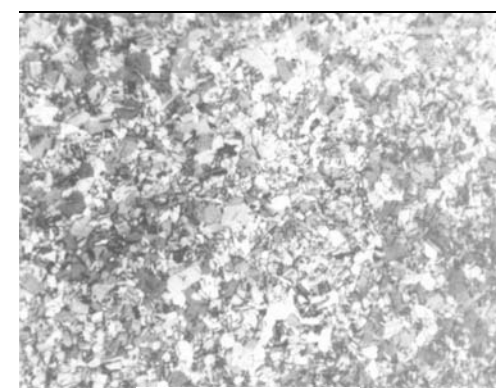
a)



b)



c)



d)



e)

Figure 1. Microstructures of annealed Cu-tubes at (a) 573 K, (b) 673 K, (c) 773 K, (d) 823 K, (e) 873 K. ($\times 100$)

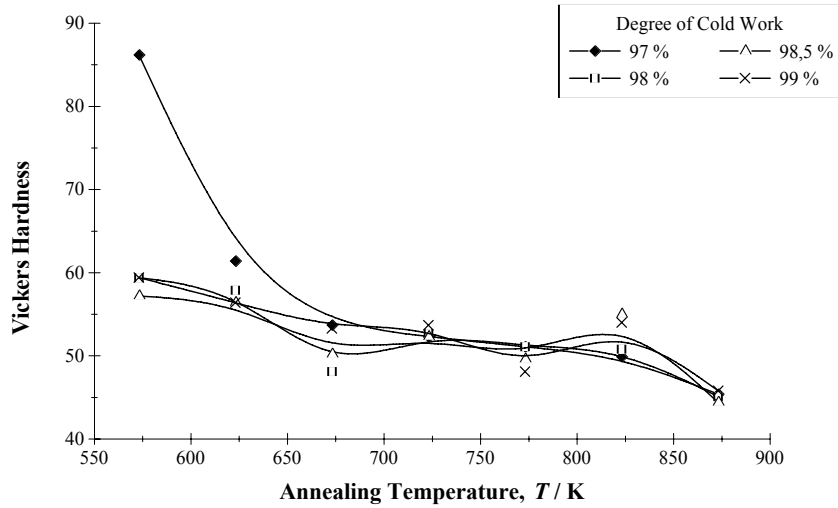


Figure 2. Dependence of Vickers Hardness (HV) of drawn copper tubes on annealing temperature and degree of cold work

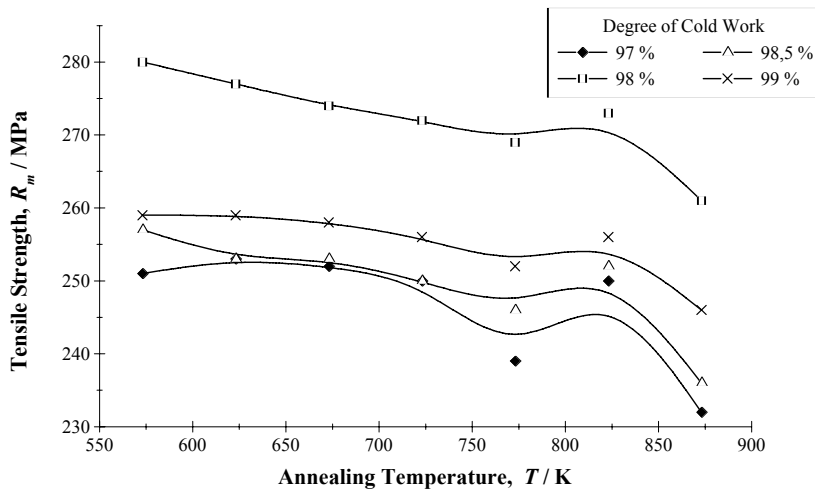


Figure 3. Dependence of Tensile Strength (R_m) of drawn copper tubes on annealing temperature and degree of cold work

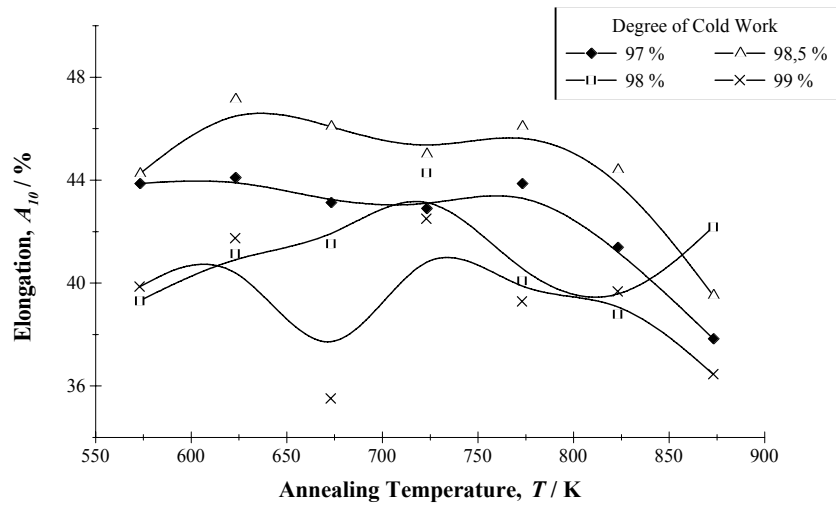


Figure 4. Dependence of Elongation (A_{10}) of drawn copper tubes on annealing temperature and degree of cold work

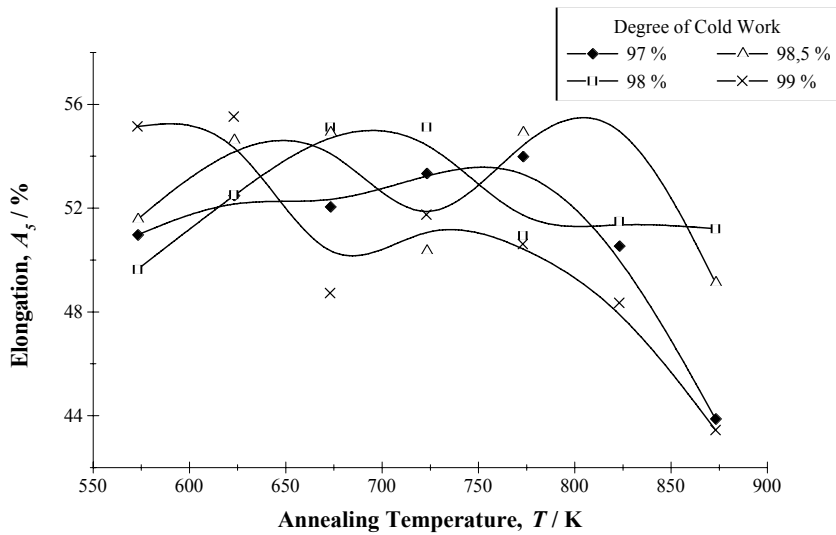


Figure 5. Dependence of Elongation (A_5) of drawn copper tubes on annealing temperature and degree of cold work

The annealing temperature leads to decrease of tensile strength and hardness of the sample up to the temperature of 773 K. As the result of decreased grain size on annealing at 823 K causes adequate changes in the mechanical characteristics of drawn copper tubes, the characteristics of strength and plasticity increases. Further increase of annealing temperature to 873 K results again in decrease of strength and plasticity characteristics. The degree of cold deformation before intermediate annealing [4] has great influence on characteristics and structure of drawn copper wire. High degree of cold deformation during final drawing results in lower values of elongation of copper tubes.

4. Discussion

The change in characteristics and structure during the annealing of tested samples at temperature up to 773 K, is in accordance with common presentations on changes in the characteristics and structure of cold deformed metals during annealing, as found in general literature. The increased annealing temperature speeds up the recrystallization process and, during uniform annealing time, results in the continuous increase of recrystallized grain size [2, 5].

The obtained investigation results are in accordance with general assumptions only for annealing temperatures up to 773 K. The increased of values of characteristics of strength and plasticity is the result of fine grainy structure during annealing at 823 K. The question now is what causes this effect of decreased value of recrystallized grain size.

To explain these phenomena, tests were carried out, but it is necessary to keep in mind that tests were carried out on samples cold worked by high degrees of cold deformation before annealing. It is known that after high degree of cold deformation by drawing, recrystallization temperatures of copper suddenly increases, due to the texture change of deformation [3, 6, 7, 8, 11]. On the other hand, according to the authors [4, 9, 10], the various textures of recrystallization in copper wire, with regard to the texture of deformation, are obtained during the change of annealing temperature from 573 to 873 K. After annealing at 823 K, there is a change of texture, where recrystallization is slower, which has an influence on slow grain growth. Also, it could be expected that the same change of texture of recrystallization in drawn copper tubes would occur, during change of annealing temperature from 573 to 873 K is the reason for fine grainy recrystallized structure of tubes during annealing at 823 K. After high degrees of cold deformation by drawing, the recrystallization temperature of copper increases due to the change of texture type of the deformed metal. So, texture which causes slow recrystallization is formed during high plastic deformation. Starting from this, fine grainy structure in drawn copper tubes, during

annealing in the range of tested temperatures (573 – 873 K) is followed by change of texture.

5. Conclusion

Based on investigation results, it could be concluded that the texture has a great influence on characteristics of the drawn copper tubes, so the change of texture after annealing at 823 K could be of practical importance.

The increased annealing temperature in the range of 573 to 773 K leads to the increase of recrystallized grain size and decrease in the characteristics of strength. Annealing at temperature of 823 K leads to the fine grainy recrystallized structure and evident increase in the characteristics of strength in comparison with annealing at 773 K. The increase of annealing temperature to 873 K leads to the further increase of recrystallized grain size and decrease in the characteristics of strength.

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