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The influence of the temperature of plastic deformation on the structure and mechanical properties of copper alloys CuCo2Be and CuCo1Ni1Be

W. Ozgowicz*, B. Grzegorczyk
Division of Constructional and Special Materials, Institute of Engineering Materials and Biomaterials, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: wojciech.ozgowicz@polsl.pl

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ABSTRACT

Purpose: The aim of the paper is to determine the influence of temperature of plastic deformation on the structure and mechanical properties of copper alloy of the CuCo2Be and CuCo1Ni1Be during a tensile test applied on electrodes to welders.

Design/methodology/approach: The tensile test of the investigated copper alloys was realized in the temperature range of 20-800°C with a strain rate of 1.2•10-3s^{-1} on the universal testing machine. Metallographic observations of the structure were carried out on a light microscope and the fractographic investigation of fracture on an electron scanning microscope.

Findings: The mechanical properties of alloys as well as the range of occurrence of the Portevin - Le Chatelier (PLC) phenomenon was determined on the basis of F-ΔL curves formed by tensile tests; however the character of fracture during the break of the samples was defined on the basis of fractographic investigations.

Research limitations/implications:

Practical implications: In result of tensile tests of copper alloys it has been found that the PLC effect occurs in both alloys in the temperature range of 150-350°C. However, the ductility minimum temperature of the alloys equals about 500°C. At the temperature of stretching of about 450°C the investigated copper alloys show maximum strength values.

Originality/value: The type of ”teething” on the load - displacement curves was defined, according to the classification received in literature. The dependence ε_{kr} = f(t) was marked too.

Keywords: Metallic alloys; Copper alloy; Plastic instability; Portevin – Le Chatelier effect; Tensile test at elevated temperature

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PROPERTIES

1. Introduction

Contemporary technologies used, for example, in electrical engineering and the electronic industry require applied of metals with a high plasticity, electric and thermal conductivity, as also a small chemical affinity with oxygen. Such properties characterize copper, which contributes to a wide application of this metal in the various techniques fields.

Copper alloys composes with different elements, which create new possibilities in the technical demand. Copper alloys are the most widespread constructional materials besides steels and aluminium alloys. Copper alloys have numerous uses in the industry. The content of elements in the copper alloys is very various and mainly depends on the kind of the alloying component. The alloys of non-ferrous metals have a lower strength than iron alloys, but higher resistance to corrosion. They established the group of the constructional materials whose application results from their special properties [1-6].

During the tensile test in many different metals and metallic alloys in define temperatures and with various speeds of deformation there occurs the phenomenon of heterogenic plastic deformation in the form of so called “teeth” (changes of strains) on the stress-strain curves. Generally this phenomenon as known as the Portevin–Le Chatelier effect (PLC). Investigations connected with the appearing effect, are usually made on polycrystalline alloys of non-ferrous metals, rarely on iron alloys. The essence of the occurrence of PLC effect was not fully explained and physical theories on this subject still change [1, 7-16].

The purpose of this paper is to determine the influence of the statically stretching temperature on the mechanical properties and structure of copper alloys CuCo2Be and CuCo1Ni1Be.

2. Experimental procedure

Experiments were carried out on copper alloy of the CuCo2Be (CB4) and CuCo1Ni1Be (CCNB), applied on electrodes to welders. The chemical composition of the tested alloys is to be seen in Table 1. The material was supplied after plastic deformations as bars with a diameter of about 10 mm and lengths of about 500 mm. The investigated alloys were subjected to solution heat treatment in water from 950˚C after holding it at that temperature for one hour.

Static tensile tests of supersaturated alloys CB4 and CCNB were carried out on the universal strength machine INSTRON 4505 within the temperature range of 20-800^{o}C. The tensile test of the investigated copper alloys was realized with a strain rate equal to $1.2•10^{-3}$ s^{-1}. Hardness measurements of the investigated copper alloys were made by Rockwell’s method. Metallographic investigations were carried out on longitudinal polished sections of copper alloys samples applying the light microscope type Leica MEF4A and AXIOVERT 405 with a magnification of up to 1000x.

The fractographic investigations of the fracture after decohesion of samples in a tensile test at elevated temperature were executed in an electron scanning microscope of the SUPRA^{TM}25 produced by ZEISS with the accelerating voltage 20 kV, applying the magnification of 1000-75000x.

Table 1.
Chemical composition of copper alloys

Material		Chemical composition in mass %					
Mark	Feature	Co	Ni	Be	Fe	Rest	Cu
CuCo2Be	CB4	According to the standard PN-EN 1216 3/2002					
		2-2.8	max. 0.3	0.4-0.7	max. 0.2	max. 0.5	Rest
		check analysis					
		1.99	0.3	0.4	0.065	-	Rest
CuCo1Ni1Be	CCNB	According to the standard PN-EN 1216 3/2002					
		0.8-1.3	0.8-1.3	0.4-0.7	max. 0.4	max. 0.5	Rest
		check analysis					
		1.1	1	0.5	-	0.2	Rest

3. Experimental results

The results of static tensile tests permitted to qualify the influence of elevated temperature of deformation on the mechanical properties of copper alloy. Simultaneously the range of temperature occurrence was determined to underrate plasticity of alloy.

The results of investigations on the mechanical properties after a tensile test have been shown in Table 2. Within the temperature range 150-350^{o}C, load–displacement curves with characteristic “teeth”, were obtained testifying the occurrence of the Portevin–Le Chatelier (Figs. 1 and 2) effect in the investigated copper alloy CB4 and CCNB. It was noticed that the temperature of deformation influences essentially the character of ”teething” on the curves σ-ε of the investigated alloys. At the beginning of the occurrence of the PLC effect, " teeth” of A and A+C type are forming. At 250^{o}C and 300^{o}C, “teeth” of B type prevail, however the temperature of 350^{o}C results in regular “teeth “ of B+C type.

On the basis of the analysis of the diagrams of stretching of alloys CCNB and CB4 it was found that the beginning of the heterogeneous deformation (ε_{kr}) is changes with the change of tensile test temperature and its shape reminds the letter U (Fig. 3). The value of the critical deformation ε_{kr} for alloy CCNB in 150^{o}C carries out 5.2%. With the increasing tensile test temperature the ε_{kr} decreases and at a temperature of 250^{o}C the obtained minimum amounts to about 3%. After the crossing of the temperature 250^{o}C, the ε_{kr} increase and at a temperature of 350^{o}C of amounts to about 4.2%. Similarly for the alloy CB4, at a range of temperature from 150°C to 250°C the value ε_{kr} decreases and takes values from about 13% to about 3.3%, however at a temperature of deformation amounting from 150°C to 400^{o}C the ε_{kr}, increase from 3.3% to 14.8%.

On the basis of graphs of stretching of investigated kinds of alloys at 300°C in the delivery state it was the affirmed, that these diagrams have a homogeneous character opposite to alloys subjected to solutioning before the tensile test. In the delivery state the investigated copper alloys have a strength about three times higher than the supersaturated ones, and their lower plasticity amounts to about 35 %.

Table 2.
Results of the mechanical properties of copper alloys CB4 and CCNB after tensile test at elevated temperature

No.	Deformation temperature [^oC]	Mechanical properties							
		CB4				CCNB			
		R_m [MPa]	$Rp_{0,2}$ [MPa]	A [%]	Z [%]	R_m [MPa]	$Rp_{0,2}$ [MPa]	A [%]	Z [%]
1	20*	891	857	11.7	28.1	836	768	18.9	40.3
2	300*	705	681	9.7	17.7	683	582	18.4	35.7
3	20	317	109	42.6	61.2	315	130	41.5	75.0
4	100	278	104	30.9	67.8	311	100	38.5	74.6
5	150	287	84	41.1	71.3	302	112	39.2	77.0
6	200	278	67	39.8	70.0	289	77	36.3	76.7
7	250	271	55	35.7	65.4	285	78	40.7	75.0
8	300	268	54	38.4	52.8	289	55	36.9	60.2
9	350	275	63	29.4	56.3	343	67	35.9	54.3
10	400	317	239	10.3	16.8	448	371	9.6	13.4
11	450	399	389	6.5	0.7	484	460	3.0	5.5
12	500	334	320	0.7	0.4	410	387	4.4	1.4
13	600	249	-	5.7	2.5	314	294	5.6	5.1
14	700	125	-	15.6	32.1	137	-	31.6	49.9
15	800	41	-	36.0	66.8	47	-	78.0	77.4

***-** alloy in the delivered state

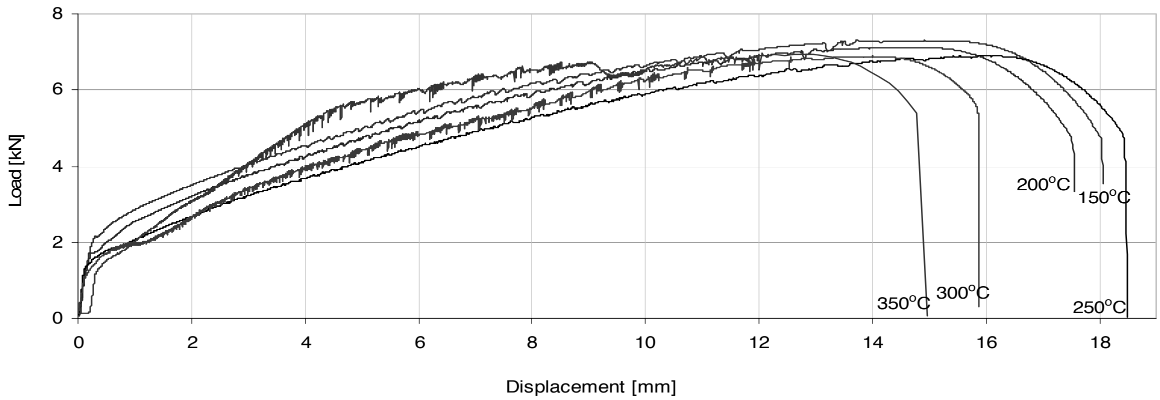

Fig. 1. The tensile test curves of the investigated copper alloy CB4 with the distinctly apparent Portevin-Le Chatelier effect

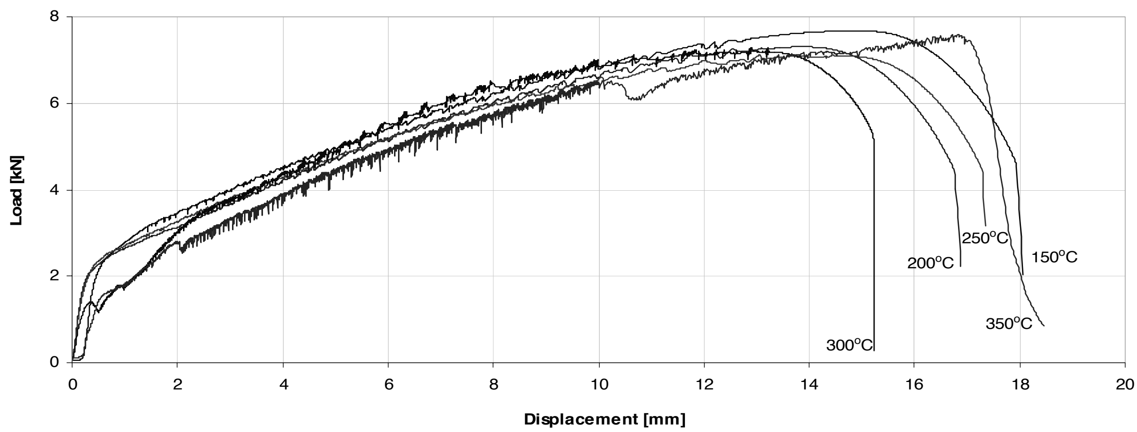

Fig. 2. The tensile test curves of the investigated copper alloy CCNB with the distinctly apparent Portevin-Le Chatelier effect

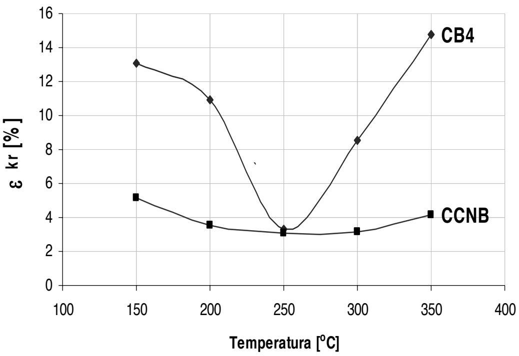

Fig. 3. The influence of temperature in tensile tests on the critical deformation ε_{kr} of copper alloy types CB4 and CCNB

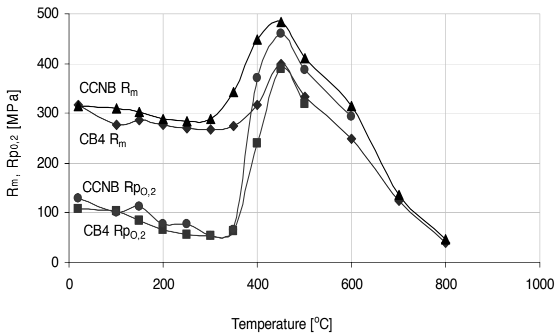

Fig. 4. The influence of temperature of plastic deformation on the mechanical properties (R_m, $R_{p0.2}$) of investigated copper alloys CB4 and CCNB

The influence of temperature of deformation on tensile strength (R_m) and yield point ($R_{p0.2}$) of the investigated copper alloy CB4 and CCNB has been gathered in the curves presented in Fig. 4. With the increasing temperature of deformation from about 250^{o}C, the value of the R_m and the $R_{p0.2}$ decrease. After the crossing of the temperature 250^{o}C the curves rise up and the tensile strength and yield point reach the maximum value of R_m=399 MPa and $R_{p0.2}$=389 MPa for alloy CB4 and adequately R_m=484 MPa and $R_{p0.2}$=460 MPa for alloy CCNB. Above to the temperature of 450°C the mechanical properties of both alloys decrease.

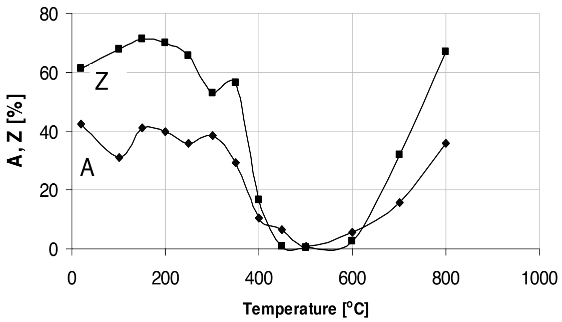

Fig. 5. Elongation (A) and reduction of area (Z) versus the temperature of deformation of copper alloy type CB4

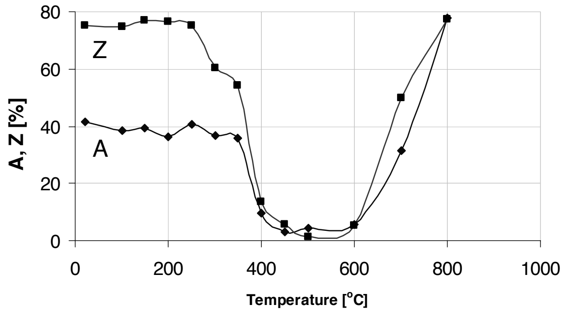

Fig.6. Elongation (A) and reduction of area (Z) versus the temperature of deformation of copper alloy type CCNB

The influence of temperature of deformation on the plasticity of copper alloy CB4 and CCNB have been gathered in Figs. 5 and 6. Copper alloy CB4 after deformation at elevated temperature amounts to about 500^{o}C shows a minimum values of plasticity, namely: elongation A<1% and reduction of area Z=0.4%. In the case of copper alloy type CCNB after deformation temperature 450^{o}C the values of elongation stay on the level A=3%. Reduction of area for this kind of alloy after deformation temperature 500°C amounts to Z=1.4%.

The results of metallographic investigations of copper alloy CB4 and CCNB were introduced on microphotographies (Figs. 7-16). In the structure of the investigated alloys in the delivered state fine-grained of α solution with numerous precipitates with diverse morphology were observed (Figs. 7-8).

It was found that after stretching at a temperature of 950˚C in the structure of both investigated alloys the deformed grain α solution with precipitates about different size occurs (Figs. 9-10). The occurrence of precipitates in the supersaturated state of alloy proves about their primary character.

After deformation at a temperature of 20˚C to 800˚C in the structure of the investigated alloy CB4 and CCNB the elongated grains of α solution with numerous precipitates with diverse morphology and twins of deformation were observed (Figs.11-16). At a temperature above 500˚C voids and crystalline crackings were observed and the effects of beginning dynamic recrystallization on the grain boundaries (Figs. 15-16).

Fig. 7. Structure of copper alloy CB4 with grains of α phase and numerous precipitates, in delivery state; Mag. 1000x

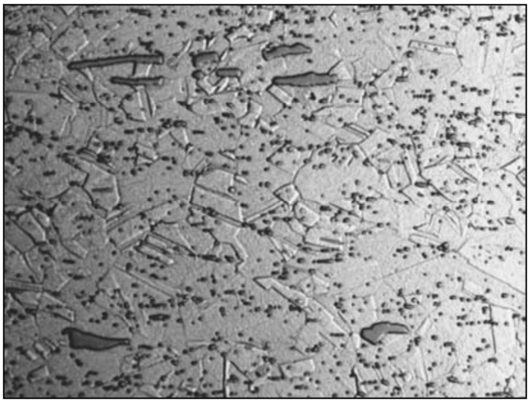

Fig. 8. Grains of α phase with precipitates and annealing twins in structure of copper alloy CB4 stretched at a temperature 950°C; Mag. 1000x

Fig. 9. Structure of copper alloy CCNB with grains of α phase and numerous precipitates in delivery state; Mag. 500x

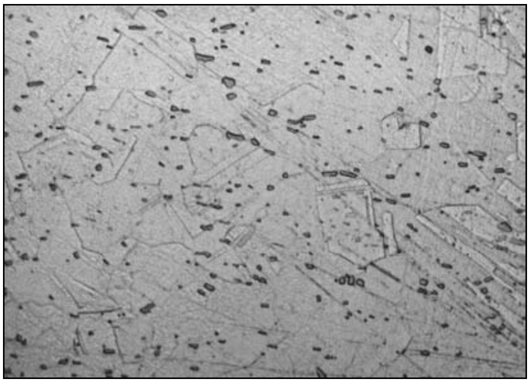

Fig. 10. Grains of α phase with precipitates and annealing twins in structure of copper alloy CCNB stretched at a temperature 950°C; Mag. 1000x

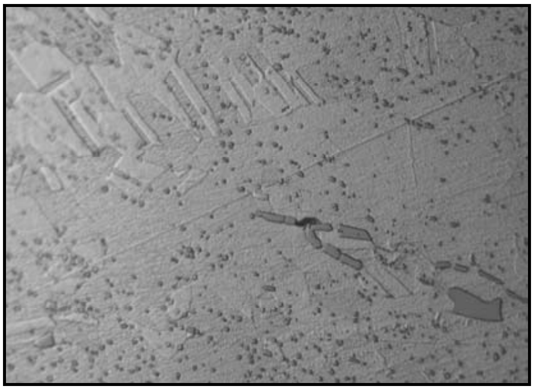

Fig. 11.Grains of α phase with twins and precipitates in structure of copper alloy CB4 after tensile test at 200°C; Mag. 1000x

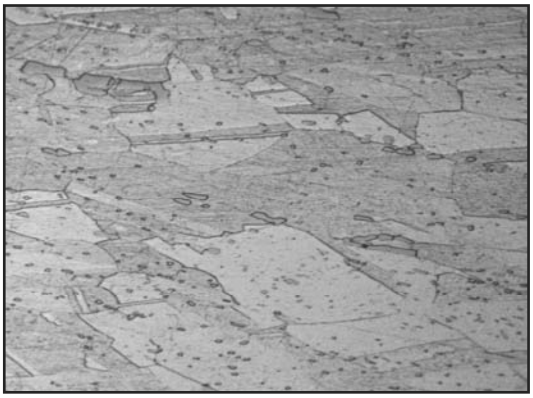

Fig. 12. Deformed grains of α solution with twins and precipitates in structure of copper alloy CCNB after tensile test at 200°C; Mag. 1000x

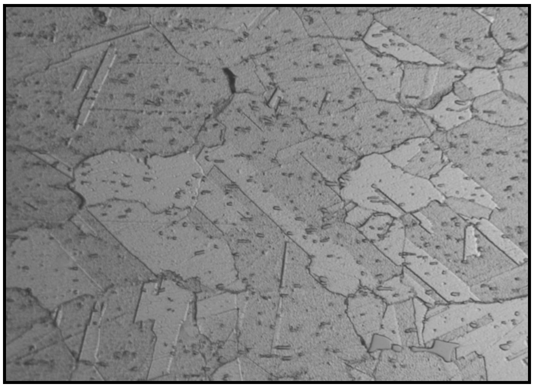

Fig. 13. Deformed grains of α solution with twins, precipitates and microcracks on the grain boundaries in structure of alloy CB4 after tensile test at 500°C; Mag. 1000x

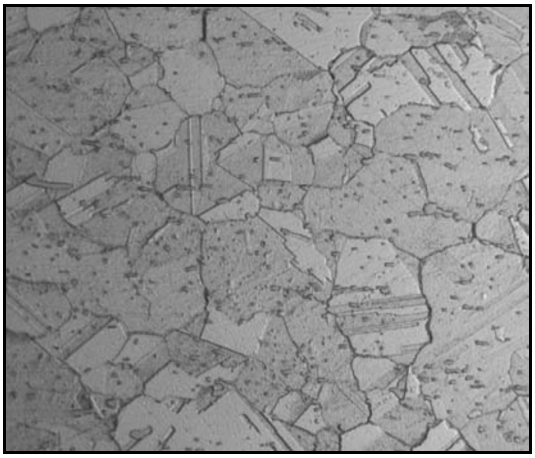

Fig. 14. Deformed grains of α solution with twins, precipitates and microcracks on the grain boundaries in structure of copper alloy CCNB after tensile test at 500°C; Mag. 1000x

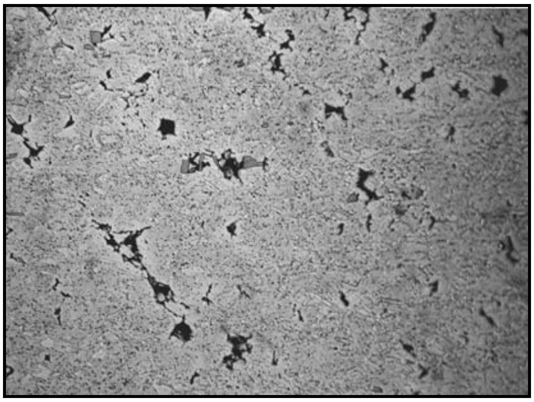

Fig. 15. Grains of α phase with precipitates and microcraking of copper alloy CB4 after tensile test at 700°C;Mag. 200x

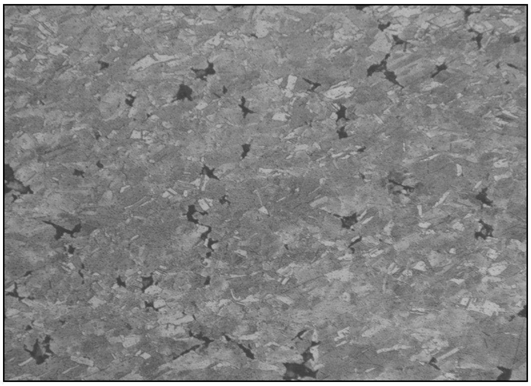

Fig. 16. Grains of α phase with precipitates and microcraking of copper alloy CCNB after tensile test at 700°C; Mag. 200x

The results of fractographic examinations permitted to determine the influence of the deformation temperature on the character of the fracture of alloys CB4 and CCNB obtained during the decohesion of samples. The examined copper alloys showed after the tensile test in the temperature of 20°C transcrystalline ductile fracture with numerous hollows with a diversified diameter. At the bottom of that hollows the inclusions or intermetallic phases is to be occurred (Figs.17-18). At 400°C in the investigated alloys brittle crystalline fracture are to be observed with small areas of plastic deformation according to the minimum growths of the elongation and reduction of area. On the fracture the trace of line and deformation bands with inclusions (Fig. 7) have been seen (Figs.19-20).

The results of hardness obtained in the investigation alloys showed that the alloy copper after supersaturation from 950°C has a considerably lower hardness than alloys in the delivery state. The average hardness of the copper alloy CB4 and CCNB in the delivery condition carried out adequately 100 and 86.4 HRB. After supersaturation the investigated copper alloys show an average value of hardness amount to 23.2 HRB for CB4 and 21.5 HRB for CCNB (Table. 3).

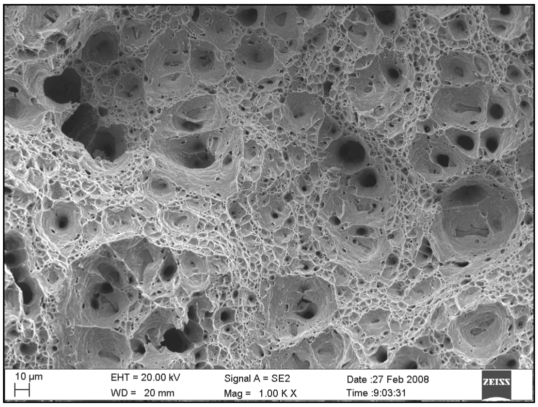

Fig. 17. Ductile fracture with inclusions in the copper alloy CB4 after tensile test at 20°C

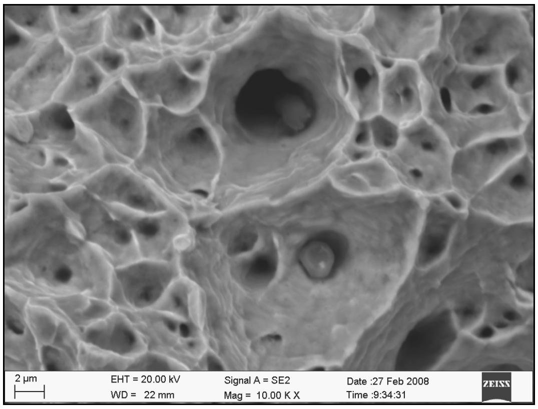

Fig. 18. Ductile fracture with inclusions in the copper alloy CCNB after tensile test at 20°C

Table 3.
Results of hardness measurements of copper alloys CB4 and CCNB

Material	HARDNESS $\overline{HRB}$									
	CB4					CCNB				
Delivery state	99	101	99	101	100	94	85	80	90	83
			$\overline{100}$					$\overline{86.4}$		
After supersaturation from 950°C	20	26	26	23	21	23	21	22	21	22
			$\overline{23.2}$					$\overline{21.5}$		

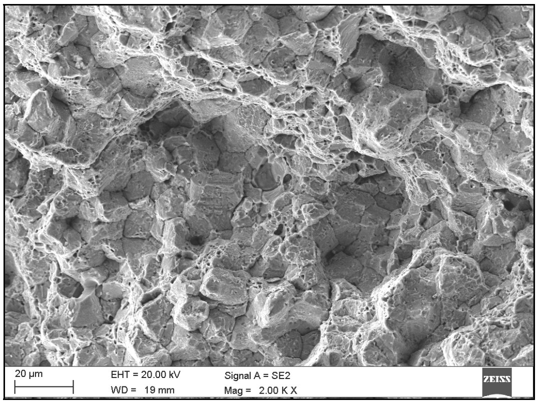

Fig. 19. Intergranular fracture with a share of ductile areas and cracks at the grain boundaries in the copper alloy CB4 after tensile test at 400°C

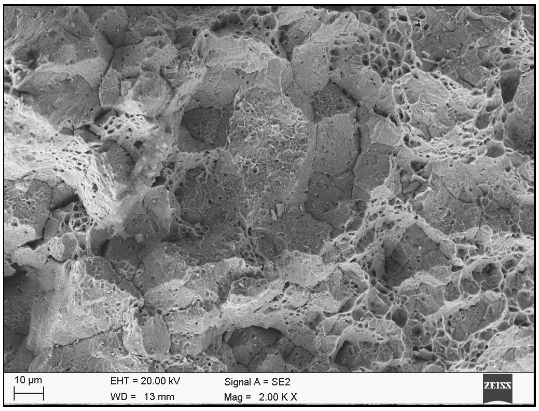

Fig. 20. Intergranular fracture with a share of ductile areas and cracks at the grain boundaries in the copper alloy CB4 after tensile test at 400°C

4. Conclusions

Basing on the analysis of the obtained results of the investigated copper alloy CB4 and CCNB the following statements may be formulated:

- The curves obtained in stretched statically of copper alloy CB4 and CCNB at a temperature of deformation 150-350ºC disclose the occurrence of the phenomenon of heterogeneous plastic deformation, called, Portevin – Le Chatelier effect. The temperature of deformation influences the character of ”teething”.
- In the investigated alloy the value of the critical deformation (ε_{kr}) shows a minimum at the temperature of stretching of about 250°C and the determined dependence ε_{kr} = f(t) defined as a reverse.
- Copper alloys CB4 and CCNB in supersaturated state show lower mechanical properties, hardness and higher plasticity than in the case of the delivery condition of alloy.
- In the structure of investigated copper alloys after tensile test at a temperature 20 - 800ºC elongated grains of α. solution and twins were observed.
- The temperature of deformation influences essentially the character of fracture of the investigated copper alloys. Ductile fragility occurs after rupture at 20°C and 800°C, while the brittle fracture is forming at 400°C.
- Copper alloys CB4 and CCNB stretched statically at a rate of deformation $1.2\cdot10^{-3}s^{-1}$ show of distinct minimum of plastic properties in a narrow range of deformation temperature about 500°C .

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