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The microstructure and mechanical properties of the alloy CuZn30 after recrystallizion annealing

W. Ozgowicz, E. Kalinowska-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: barbara.grzegorczyk@polsl.pl

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ABSTRACT

Purpose: The aim of the investigations is to determine the influence of the recrystallization temperature on the microstructure and mechanical properties of the brass CuZn30 subjected to cold deformation in the process of rolling at various degrees of strain.

Design/methodology/approach: The brass CuZn30 was recrystallization annealed within the temperature range of 300-650°C after cold rolling with the strain of 15.8-70.2%. The tensile test was carried out by the use of universal testing machine. Metallographic observations were performed on an optical microscope and fractographic tests on a scanning electron microscope. The hardness was also measured.

Findings: The analysis of the results of investigations concerning the mechanical properties permitted to determine the effect of the temperature of recrystallization annealing on the strength and plastic properties of the investigated brass, subjected to cold deformation with a varying strain in the course of rolling. The character of fracture after decohesion in the tension test was determined basing on fractographic investigations.

Practical implications: An increase of the recrystallization temperature within the range of 400-650°C results in a deterioration of the mechanical properties of the brass CuZn30 and an increase of its plastic properties.

Originality/value: The results of the investigation revealed the occurrence of the phenomenon of heterogeneous plastic deformation in the recrystallized alloy.

Keywords: Brass; Recrystallization; Mechanical properties; Plastic cold deformation

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1. Introduction

Besides bronze, the alloys of copper with zinc and brass are the first alloys accompanying the development of mankind. Nowadays, they are widely applied in technology, and next to light metals they belong to the most commonly used alloys in the group of non-ferrous metals. Thanks to the specific properties of brasses they are applied in various domains of industry, among others in civil engineering, armaments industry, aircraft industry, machine building, the production of motor cars, electrical industry, ship building, precision mechanics, chemical industry and many others, even in the production of musical instruments. These alloys are characterized by a considerable ductility and resistance to corrosion, particularly atmospheric corrosion and corrosion in sea-water. They also display good casting properties. In technology CuZn alloys with a zinc content of 45% are applied. A higher content of zinc in the brass increases their brittleness. The optimal mechanical properties display brass containing about 30% zinc. Those are characterized by considerable plastic properties together with high tensile strength and hardness [1-3, 7, 8].

In the electrical industry brass is used, e.g. for the production of the sockets of bulbs and fuses. For this purpose the alloy CuZn37 is used, which displays good plastic properties and can be cold stamped. Brass is used in the production of wire (CuZn36Pb1, 5), gliding elements (CuZn31Si1) and sieve bottoms of condensers in the shipbuilding industry (CuZn38Sn1). Due to the high thermal conductivity and resistance to corrosion brass CuZn20Al2 is often used in the production of heat exchanger tubes. The mechanical properties of brass depend mainly on the content of zinc and the degree of deformation in the course of the production, but also on the parameters of heat treatment, particularly the temperature of recrystallization [1-8].

The investigations concern the influence of the parameters of recrystallization annealing on the microstructure and mechanical properties of the brass CuZn30, cold-deformed in the course of rolling.

2. Experimental procedure

In the investigations brass CuZn30 was used in the form of a flat bar with the dimensions 23x60x600 mm, obtained at the Institute of Ferrous Metallurgy in Gliwice from an ingot after cogging at a temperature of 850°C on compression hammer MS 200 and intermediate annealing in a chamber furnace at 900°C, then cooled down in water. After the intermediate annealing the flat bar was cold-rolled continually on a quarto reversible cold strip reduction mill, repeated several times. The thicknesses of the respective strips and the degree of the reduction (the draft) have been gathered in Table 1. The mechanical properties and hardness of the tested brass are to be seen in Table 2. The degree of the draft was determined basing on quotient of the final height of the strip versus its initial height, assuming that the extension of the sheet due to cold rolling may be neglected. After cold-rolling samples were taken to test their mechanical properties, to measure their hardness and to perform metallographic observations. The samples were subjected to recrystallization annealing within the temperature range from 300°C to 650°C, stepping up the temperature every 50°C and cooling the sample in the air. The samples were heated up and held at the given temperature in an electric chamber furnace with a power rating of 4, 4 kW at a temperature of 950°C. The furnace was equipped with a control unit ensuring an accuracy of measurements of the temperature of ±1°C. The time of heating amounted to 1 hour.

For the determination of the influence of the recrystallization temperature of plastically cold-deformed brass CuZn30 on its microstructure and mechanical properties, the following methods of investigations were applied:

Table 1.
Thickness of the sheet and degree of the draft of the brass CuZn30 after cold-rolling

Designation of sheet strip	Thickness of the strip [mm]		Degree of the draft [%]
	h_0	h_1	
Z0	22.8	-	in the delivered state
Z1	22.8	19.2	15.8
Z2	22.8	16.0	29.8
Z3	22.8	13.1	42.5
Z4	22.8	10.0	56.2
Z5	22.8	6.8	70.2

Table 2.
Mechanical properties of the tested brass CuZn30 after cold rolling

No.	Degree of the rolling reduction [%]	Mechanical properties				HV 50
		R_m [MPa]	$R_{p0,2}$ [MPa]	A [%]	Z [%]	
1	15.8	433	402	21.6	69.2	136
2	29.8	504	483	16.5	66.4	154
3	42.5	577	543	16.3	63.6	165
4	56.2	617	577	16.1	58.7	186
5	70.2	693	644	13.4	49.2	200

- investigations of the chemical composition
- measurements of its hardness
- investigations concerning its mechanical properties
- microscopic metallographic investigations
- fractographic investigations.

The chemical composition of brass CuZn30 was investigated spectrographically on monolithic samples with the dimensions Ø30x5 mm, using an X-ray spectrometer ZSX Prymus produced by the Rigaku Co.

In order to determine the mechanical properties a static tension test was carried out in compliance with the standard PN-EN-10002-1, applying the testing machine INSTRON type 4505, within the range of tensile forces up to 100 kN at a rate of 2 mm/min. After cold rolling and recrystallization annealing the mechanical properties were tested on a rolled specimen with threaded ends, the dimensions of which are to be seen in Fig. 1.

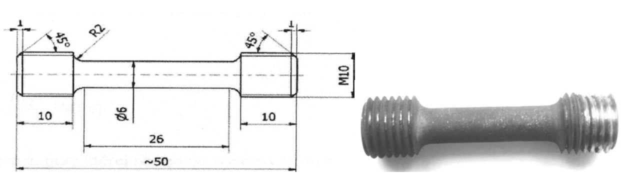

Fig. 1. Sample for tests of mechanical properties

The hardness was measured making use of Vicker's method in compliance with the standard PN-EN ISO 6507-2:1999, on etched metallographic sections of the brass after cold rolling and recrystallization annealing, applying a hardness tester from the firm Hauser and a load of 50 N in the time of 15 second.

The microhardness was tested on metallographic sections, using for this purpose a microhardness tester PMT 3 at a load of 50 g in the time of 15 sec.

Metallographic scanning was realized on an optical microscope LEICA MEF4A, provided with a digital camera and computer system of image analysis, permitting the recording of the results. The metallographic tests were accomplished on longitudinal microsections of CuZn30 after cold rolling and recrystallizion annealing. The microsections were etched in the reagent Mi19FE, containing 3 g ferric chloride ($FeCl_3$), 10 cm^3 hydrochloric acid (HCl) and 90 cm^3 ethanol (C_2H_5 OH). These tests were carried out at a magnification of 100-500 times. After the recrystallization in the microstructure of the brass, the grain size was determined in compliance with the method of sections according to the standard PN-EN ISO 643:2005.

Fractographic investigations were accomplished on specimens of brass CuZn30, cold-deformed and after recrystallization annealing. The fractography of the fractured specimens after decohesion in the tension test were scanned in the scanning microscope SUPRA 25 from ZEISS with a resolution of 2 μm at an accelerating voltage of 20kV. The scanning was performed at a magnification of up to 4000 times. Before the fractographic tests the fractures were cleaned for 3 minutes in an ultrasonic washer in ethanol. The X-ray microanalysis of the chemical composition of the precipitations revealed on the fractures was realized by means of the attachment EDAX, being a part of the scanning microscope.

3. Experimental results

The chemical composition of the investigated brass has been presented in Table 3. The concentration of copper and zinc in the investigated brass amounts to 69.03 % and 30.3% respectively. The concentrations of nickel, iron, lead and tin, contaminating the brass, are lower and, therefore, not taken into account in the standard PN-EN 12163 concerning the brass CuZn30. The content of aluminum amounts to 0.039% exceeding the value quoted in the standard by 0.019%. Aluminum influences considerably the mechanical properties of the brass, affecting a higher tensile strength, a higher yield point and hardness without reducing the elongation and necking.

The results of investigations concerning the mechanical properties have made it possible to determine the influence of the temperature of recrystallization annealing on the strength and plasticity of the investigated cold-deformed brass with a differentiated reduction in the process of rolling. Basing on the results of the static tension test the values of the tensile strength (R_m), the yield point (R_e), elongation (A) and necking (Z) were determined. Exemplary, tension curves of brass CuZn30 have been gathered in Fig. 2-7, and. the results characterizing the tension curves in Table 4. The results of investigations concerning the mechanical properties are to be seen in Table 5 and in Fig. 8-12.

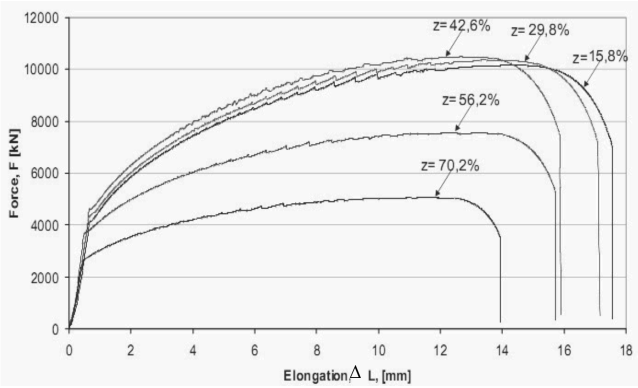

Fig. 2. Tension curves of brass CuZn30, cold-deformed and recrystallized at a temperature of 400°C

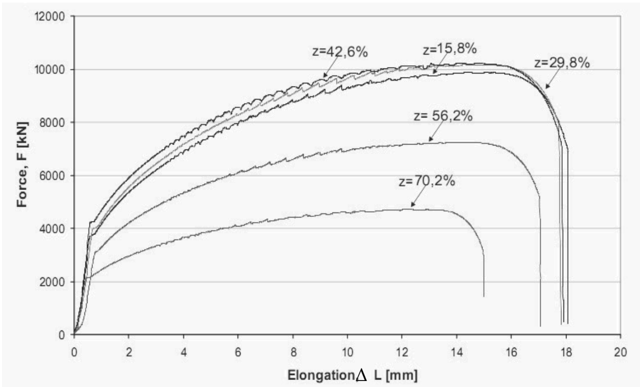

Fig. 3. Tension curves of brass CuZn30, cold-deformed and recrystallized at the temperature of 450°C

Table 3.
Chemical composition of the investigated brass

Feature	Components of the alloy, %									
	Cu	Zn	Pb	Sn	Fe	Mn	Si	Al	Ni	Rest
CuZn30 check analysis	69.03	30.3	0.01	0.003	0.024	0.001	0.015	0.039	0.001	0.3
CuZn30 According to the standard EN121613:1998	max 69-71	max 28.3-0.3	max 0.05	max 0.1	max 0.05	-	-	max 0.02	max 0.3	max 0.1

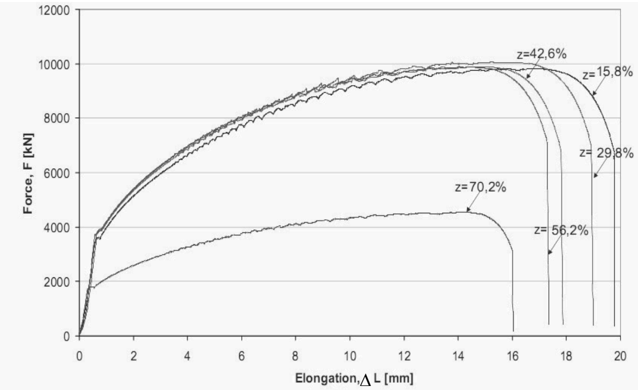

Fig. 4. Tension curves of brass CuZn30, cold-deformed and recrystallized at the temperature of 500°C

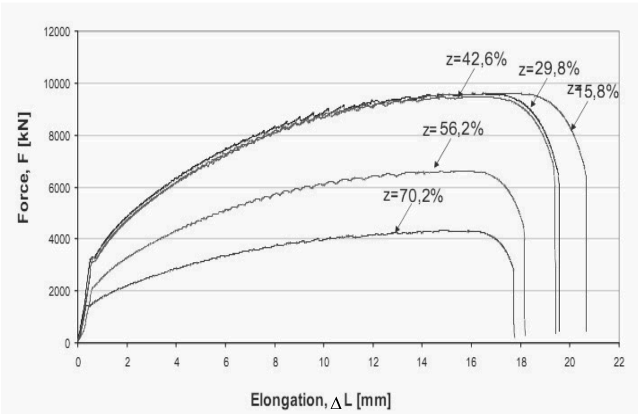

Fig. 5. Tension curves of brass CuZn30, cold-deformed and recrystallized at a temperature of 550°C

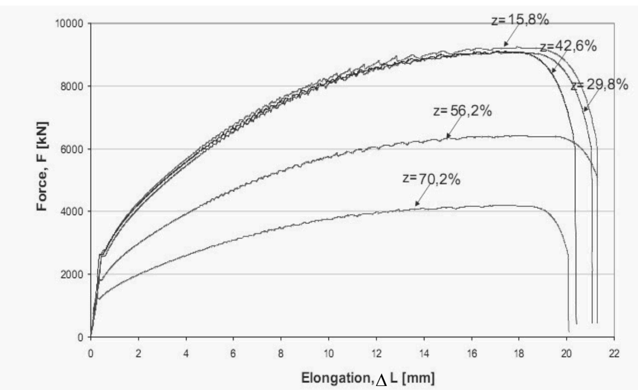

Fig. 6. Tension curves of brass CuZn30, cold-deformed and recrystallized at a temperature of 600°C

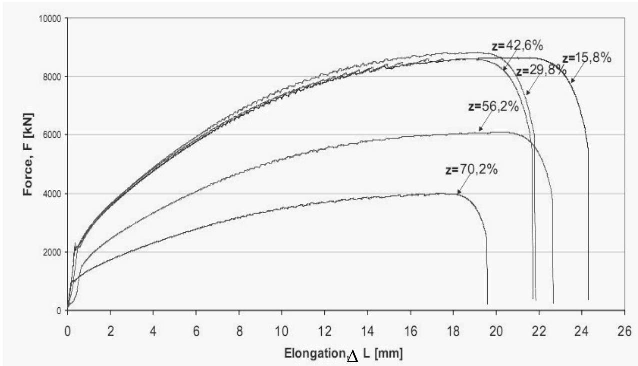

Fig. 7. Tension curves of brass CuZn30, cold-deformed and recrystallized at the temperature of 650°C

The tension curves of brass CuZn30, recrystallized within the range of temperature 300°C-650°C, obtained at ambient temperature display a differentiated character and shape. On the curves F-ΔL of brass annealed at 400°C-650°C quite visible are oscillations of the force indicating the occurrence of the Portevin-Le Chatelier phenomenon (PLC) - Fig. 2-7. The values of the amplitude of oscillation of the force ΔF, the character of the oscillation and the value of critical deformation ε_{kr} , initiating the phenomenon PLC differentiate depending on the temperature of recrystallization annealing of the investigated brass - Table 4. The highest amplitude of oscillation ΔF = 130N occurs on the tension curves of brass deformed with the reduction of 15.8%, recrystallized at the temperature of 600°C, whereas at 400°C ΔF amounts to 23N and 19N, respectively, for the reduction of 15.8% and 70.2%.

After recrystallization within the temperature range of 400-500°C, the value of deformation initiating the PLC effect amounts to about 10%. Recrystallization at the temperature of 550°C requires maximum values of deformation amounting to ε_{kr} = 15% and ε_{kr} = 22% corresponding to z = 15.8 % and z = 70.2%, respectively, in order to effect the oscillation of the force. After recrystallization at 600°C the initiation of PLC in cold-deformed brass with a rolling reduction of 15.8% and 70.2 % requires, respectively 12% and about 18 %. In the case of the highest recrystallization temperature, amounting to 650°C, the value ε_{kr} = 19 % at a rolling reduction of z = 15.8 % and ε_{kr} = 21% at a reduction of z = 70.2%.

Table 4.
Quantities characterizing the effect of PLC in the brass CuZn30 after cold deformation and recrystallization

No.	Temp. of recrystallization [°C]	Degree of the rolling reduction					
		15.8%			70.2%		
		ΔF [N]	ε_{kr} [%]	Shape oscillations	ΔF [N]	ε_{kr} [%]	Shape oscillations
1	400	23	9.79	A, B	19	8.05	A, B
2	450	72	8.77	A, B	73	8.99	A, B
3	500	26	9.15	A, B	50	10.28	A
4	550	94	14.68	A	97	21.45	B
5	600	130	11.84	A	45	17.98	B
6	650	119	19.29	A	67	21.07	B

The tension curves of brass recrystallized at 400°C-500°C display two types of oscillation of the forces A and B (classified in compliance with data provided in literature [9-13]), and those recrystallized at 400°C-650°C displayed oscillations of the type A in the case of z = 15.8% and for the type B, when the brass was deformed with a rolling reduction of 70.2%.

Recrystallization annealing of cold-deformed brass CuZn30 influences considerably its strength and plastic properties. A rise of the temperature of recrystallization in the range of 300°C-650°C involves a drop of the tensile strength R_m and the yield point R_e, as well as increased elongation (A) and necking (Z) of the investigated brass (Table 5, Fig. 8-12).

Table 5.
Results of investigations concerning the mechanical properties of brass CuZn30 after cold rolling and recrystallization annealing

No.	Temperature of recrystallization	Degree of rolling reduction	Mechanical properties			
			R_m [MPa]	R_e [MPa]	A [%]	Z [%]
1	300°C	z=15.8%	413.0	357.8	26.8	67.1
2		z=29.8%	463.8	439.5	18.9	62.7
3		z=42.5%	459.0	377.0	30.0	64.2
4		z=56.2%	447.1	311.2	37.9	64.9
5		z=70.2%	452.9	307.0	38.5	57.2
6	400°C	z=15.8%	363.2	148.9	57.0	75.4
7		z=29.8%	370.8	156.0	54.2	70.0
8		z=42.5%	373.2	163.9	51.8	69.1
9		z=56.2%	392.7	193.4	55.4	74.3
10		z=70.2%	403.2	210.7	48.4	62.8
11	450°C	z=15.8%	354.2	133.2	57.5	78.6
12		z=29.8%	362.7	141.7	58.9	68.3
13		z=42.5%	362.7	150.7	59.4	72.2
14		z=56.2%	373.3	164.2	53.9	72.9
15		z=70.2%	380.1	172.6	50.4	58.9
16	500°C	z=15.8%	347.9	125.3	63.7	73.2
17		z=29.8%	351.4	132.9	59.0	75.2
18		z=42.5%	352.3	134.9	60.1	75.7
19		z=56.2%	348.4	140.6	57.4	70.9
20		z=70.2%	355.4	139.2	52.1	69.1
21	550°C	z=15.8%	341.8	117.1	64.0	73.6
22		z=29.8%	340.7	116.3	65.0	75.5
23		z=42.5%	336.0	110.0	65.8	73.5
24		z=56.2%	336.8	109.0	59.8	73.5
25		z=70.2%	336.4	112.3	61.8	76.7
26	600°C	z=15.8%	328.7	97.1	68.6	76.1
27		z=29.8%	322.0	91.3	69.2	75.7
28		z=42.5%	321.0	92.9	70.1	78.1
29		z=56.2%	324.9	91.9	72.7	74.0
30		z=70.2%	330.3	93.4	67.6	77.2
31	650°C	z=15.8%	305.2	72.8	81.8	82.3
32		z=29.8%	310.1	76.2	70.0	78.2
33		z=42.5%	304.0	75.7	72.8	81.7
34		z=56.2%	312.5	78.7	76.0	76.0
35		z=70.2%	315.6	78.5	65.2	76.9

The curves indicating the changes of mechanical properties due to changes of the temperature of annealing display a radical drop of the values R_m and R_e of brass recrystallized in the range of temperature from 300°C-400°C, whereas at the temperature of recrystallization of 400°C-650°C, the curve of changes of the values R_m and R_e, is characterized by a lenient shape (Fig. 8, 9).

The increasing temperature of recrystallization annealing from 300°C to 400°C of deformed brass with a rolling reduction of 15.8% decreases its tensile strength from 413 MPa to about 363 MPa, and the yield point drops from about 360 MPa to about 150 MPa (Table 5). In the case of brass deformed with a rolling reduction of 29.8% and 42.5% and recrystallized in the investigated range of temperature, the value of R_m decreases from about 460 MPa to about 370 MPa (concerning both values of the rolling reduction), and the yield point R_e by about 280 MPa and about 200 MPa, respectively. At a rolling reduction of 70.2 % the tensile strength R_m drops to about 50 MPa, and the yield point R_e to about 100 MPa.

Recrystallization annealing of brass with a rolling reduction of 15.8% within the temperature range of 450°C to 650°C results in a drop of the tensile strength R_m by about 50 MPa and R_e by about 60 MPa. In the case of rolling reductions of 29.8%, 42.5% and 56.2% after recrystallization in this same range of temperature it decreases, respectively, from 362 MPa to 310 MPa, from about 362 MPa to about 304 MPa and from about 373 MPa to about 312 MPa, and the drop of the yield point R_e amounts to about 60 MPa, about 75 MPa and about 60 MPa, respectively. In the case of brass deformed with a rolling reduction of 70.2% an increase of annealing within the range of 450°C to 650°C leads to a decrease of the tensile strength from 380 MPa to 315 MPa, and of the yield point from 372 MPa to 78 MPa.

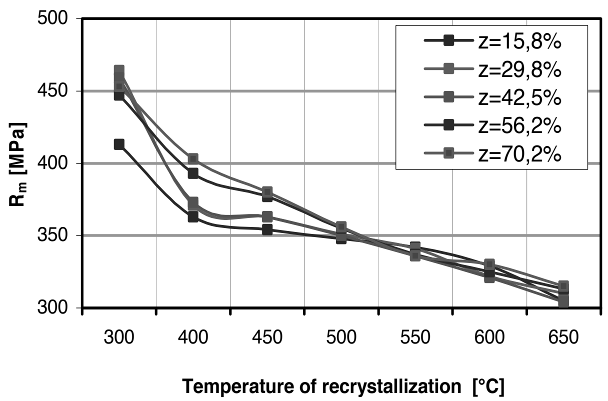

Fig. 8. The influence of the temperature of recrystallization and the degree of the rolling reduction on the tensile strength (R_m) of the brass CuZn30

The increasing temperature of recrystallization annealing within the temperature range of 300°C-650°C increases the plastic properties of the brass CuZn30. The plasticity rises distinctly in this brass after annealing in the range of temperatures from 300°C-400°C where the increase of lengthening amounts to about 50% at a rolling reduction of 15.8% and 29.8%, and about 35% in

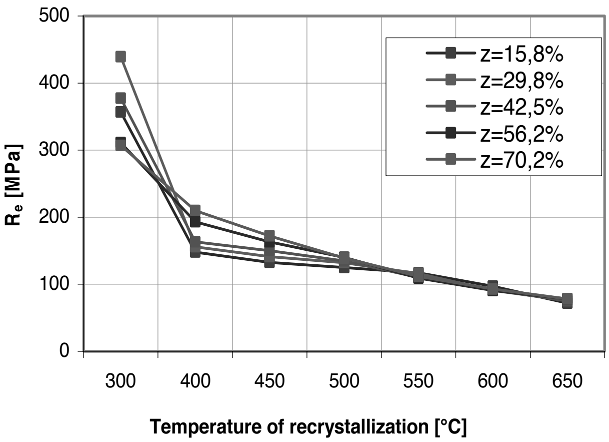

Fig. 9. The influence of the temperature of recrystallization and the degree of the rolling reduction on the yield point of the brass CuZn30

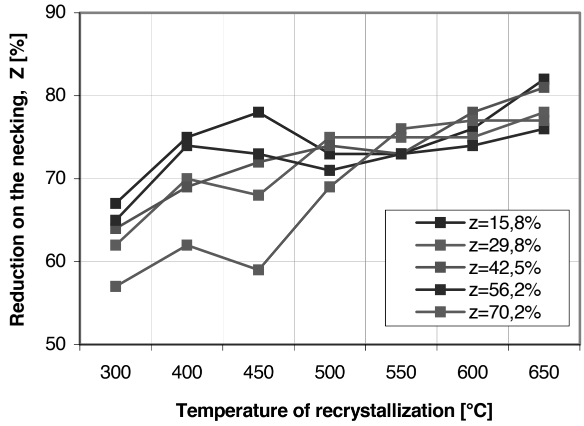

Fig. 11. The influence of the temperature of recrystallization and the degree of rolling reduction on the necking of the brass CuZn30

the case of a rolling reduction of 42.5%, 56.2 % and 70.2% deformed before the annealing with a rolling reduction of 15.8 (Fig. 10). Thus, it may be concluded that the considerable increase of plasticity of the brass CuZn30, cold-deformed before the annealing with a rolling reduction of 15.8% and 29.8% is due to the procedure of the initial stages of recrystallization at a temperature of 400°C. In the case of higher degrees of rolling reduction this process is initiated at lower temperatures.

The relation curve of necking as a function of the temperature of annealing increases with the occurrence of local minimum values (Fig. 11). Minimum values of necking occur in the given brass at 450°C in the case of a rolling reduction of 29.8% and 70.2%, and at 500°C in the case of a rolling reduction of 15.8% and 56.2%. Annealing at a temperature from 300°C to 650°C leads to a necking of the investigated deformed brass with a rolling reduction of 15.8% to 70.2% by about 20%.

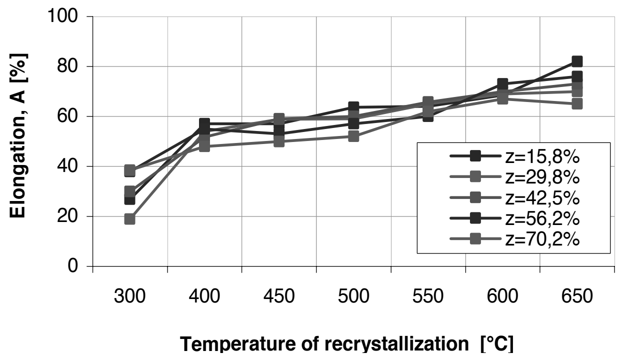

Fig. 10. The influence of the temperature of recrystallization and the degree of rolling reduction on the elongation of the brass CuZn30

The results of measurements of the hardness permitted to determine the influence of the temperature of recrystallization annealing within the range of 300°C to 650°C on the hardness of the brass CuZn30 cold-deformed with a rolling reduction of 15.8 % to 70.2 %. The results of these measurements have been gathered in Fig. 12.

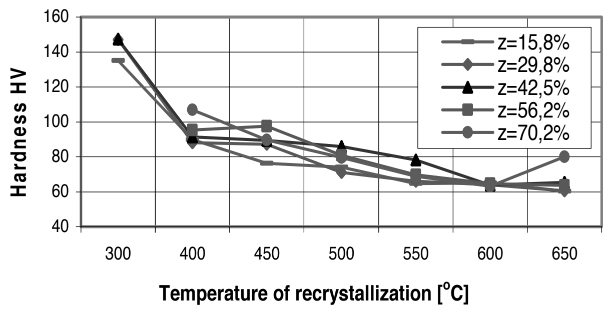

Fig. 12. The influence of the temperature of recrystallization annealing and the degree of rolling reduction on the hardness of the brass CuZn30

After cold-rolling the hardness of the brass CuZn30 increases with the increase of the rolling reduction. At the rolling reduction z = 15.8 % its hardness amounts to 142 HV, and in the case of its maximum deformation of z = 70.2 %, it is 212 HV.

The shape of the curves of hardness in the function of the temperature of recrystallization of cold-deformed brass CuZn30 with rolling reductions of 15.8 to 70.2% is similar (Fig. 12). In the temperature range from 300°C to 400°C the hardness curve suddenly drops, and at higher temperatures of recrystallization, it assumes a softly shape. The hardness of cold-deformed brass with a rolling reduction of 15.3%, 29.8% to 42.5% drops vehemently after its recrystallization in the range of temperature from 300°C to 400°C. After recrystallization at 300°C the hardness of rolled brass with a reduction of 15.8%, 29.8% and 42.5% amounts to 135 HV, 147 HV and 147 HV, respectively, and after recrystallization at 400°C these values are lower, amounting respectively to 89.8 HV, 88 HV and 91.4 HV. In the range of higher temperatures the hardness of deformed brass with rolling reductions of 15.8%-70.2% is mild. Thus, we may conclude that the process of recrystallization starts at a temperature below 400°C. The increase of temperature in this range affects a drop of the hardness of deformed brass CuZn30 with rolling reductions from 15.8% to 42.5% with respect to the value of about 90 HV to about 60 HV, and with a rolling reduction of 56.2% and 70.2% with respect to 95 HV-64 HV and about 107 HV to about 63 HV, respectively.

The results of investigations have made it possible to determine the influence of the temperature of recrystallization annealing on the microstructure of the investigated brass CuZn30, deformed with differentiated rolling reductions. Moreover, they also permitted to assess its microstructure after its intermediate annealing and after cold-rolling. The results of metallographic scanning have been presented in the microphotographs (Figs. 13-20).

In the microstructure of the brass CuZn30 after its intermediate annealing at 300°C and cooling in water the presence of large grains was to be observed in the α solution with a diameter of 0.8 to 1.0 mm and a microhardness of 40 HV (Fig. 13). The grains contained twin crystals of various thicknesses.

After cold-rolling with reductions of 15.8-70.2% the microstructure of the brass CuZn30 is characterized by elongated grains in the solution α with corrugated boundaries and effects of plastic strain in the form of parallel intersecting slip bands (Figs. 14-16). In the region of intersection of these bands the microhardness amounts to 132 HV.

After recrystallization at a temperature of about 400°C in the microstructure of the brass deformed with a rolling reduction of 15.8 % elongated grains have been detected, as well as small regions of minute recrystallized grains of the solution α, occurring at the boundaries and inside the deformed grains (Fig. 17).

In the case of deformed brass with a rolling reduction of 15.8% recrystallized at a temperature of 650°C, recrystallized grains of the α solution with a diameter of 69 μm containing many twin crystals could be detected (Fig. l8).

Recrystallization annealing of cold-rolled brass CuZn30 with a reduction of 29.8% at a temperature of 400°C permits to obtain over the entire volume of the metal, a microstructure of recrystallized grains of the α solution with a size of about 13μm.

After annealing at the temperature of 650°C there are α grains with an average diameter of about 66 μm - about 20 μm and a microhardness of 55 HV. The grains contain twin crystals of differentiated width, from about 5 μm to about 20 μm. The size of the α grains of the solution after recrystallization at the temperature of 400°C to 650°C in the microstructure of cold-rolled brass CuZn30 with a rolling reduction of 42.5% is to be seen in the microphotographs, Fig. 19 and 20. After recrystallization at 400°C the mean diameter of the α grain is 7 μm. The size of the α grain increases with the rising temperature. At 500°C the mean diameter of the grains in the α solution amounts to 17 μm, and at 600°C and 650°C to 41μm and 110μm respectively. After annealing at the temperature of 550°C in the microstructure of the brass strongly etching grain boundaries occur, probably due to the segregation of contaminations at their boundaries.

After annealing the microstructure of brass CuZn30 cold-rolled with a reduction of z = 56.2% and recrystallized at 400°C displays the least average diameter of α grains in the solution. For these parameters of deformation and annealing, the mean diameter of the α grain amounts to 7 μm (Fig. 21).

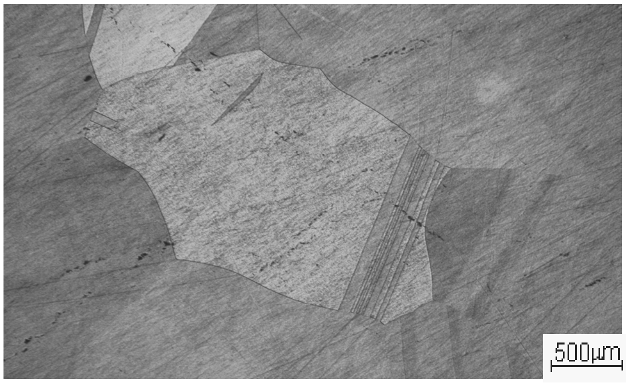

Fig. 13. The microstructure of the supplied brass CuZn30

Fig. 14. The microstructure of brass CuZn30 after cold-rolling. Recurrently grains of the α solution display parallel and intersecting slip bands (z = 15.8%)

Fig. 15. The microstructure of brass CuZn30 after cold-rolling. Elongated α grains in the solution with parallel slip bands (z = 42.5%).

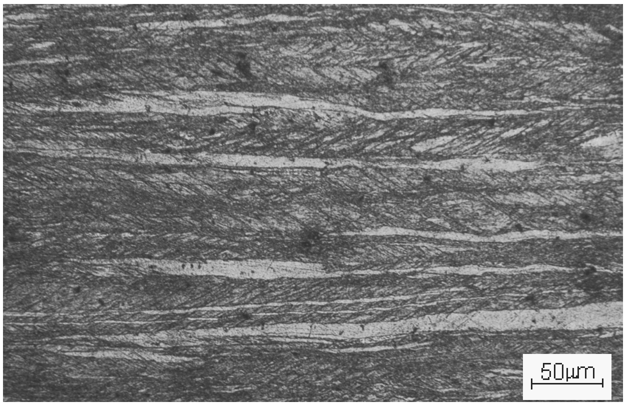

Fig. 16. The microstructure of brass CuZn30 after cold-rolling. Elongated α grains of the solution with slip bands (z = 70.2%)

Fig. 17. The microstructure of brass CuZn30 after cold-rolling and recrystallization. Differentiated sizes of the α grains in the solution (z = 15.8%, t_r = 400°C)

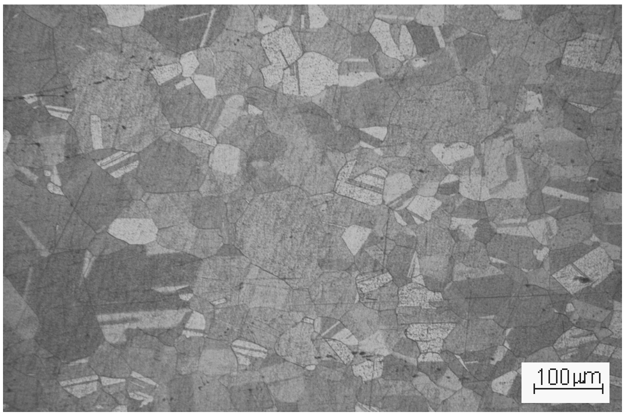

Fig. 18. Recrystallized α grains in the solution containing twin crystals (z =15.8 %, t_r = 650°C)

Fig. 19. Recrystallized small α grains in the solution (z = 42,5 %, t_r = 400°C)

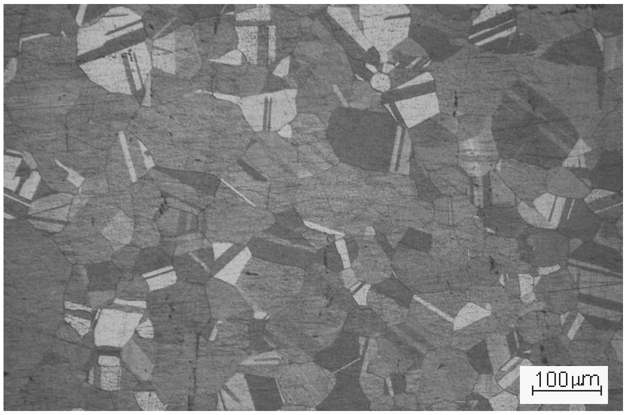

Fig. 20. Recrystallized α grains in the solution with twin crystals due to annealing (z = 42.5% t_r = 650°C)

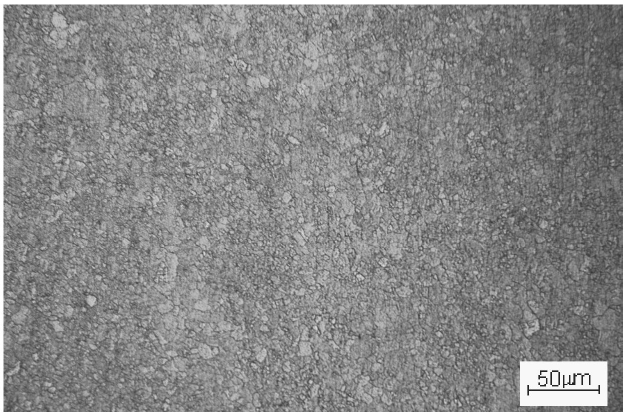

Fig. 21. Small recrystallized grains in the solution (z = 56.2% t_r = 400°C)

The results of fractographic tests permitted to determine the character of the fractures of brass CuZn30 after cold-rolling with a reduction of 42.5% and 70.2% and recrystallization annealing at the temperature of 300°C and 650°C. The results of topographic scanning of the fractures and precipitations at the fractures have been presented in Figs. 22 and 23.

The fractures of the investigated brass are circular due to the typical cracking "bottom-cone" characteristic for technical copper, brass and low-alloy steel. The spiral edges on the fractures indicate their helical way of formation. The helical character of the edges may be interpreted as being caused by the fact that while approaching the surface the crack fracture changes its orientation as well as the mechanism of cracking due to the change of the state of stresses to local shearing in the planes of maximum stresses at an angle of 45° versus the direction of tension [16].

After cold-deformation and recrystallization the brass CuZn30 is characterized by ductile fracture without regard to the degree of rolling reduction and the temperature of annealing. Differentiated, however, is the density of craters and their depth.

After recrystallization annealing at 300°C cold-deformed brass with a rolling reduction of 42.5% displays fracture with cavings and craters, differing in depth and diameter from 5 to 19 µm (Fig. 22).

The fracture of deformed brass with a rolling reduction of 70.2% annealed at the temperature of 300°C, has a large number of minute craters and cavings with a diameter of about 0.5 to 2 µm. The craters are arranged regularly or in cascades (Fig. 23).

After recrystallization at 650°C in the investigated deformed alloy with a rolling reduction of 42.5 %, one can find a ductile fracture with numerous craters differing in their depth and diameter. On the bottom of the crater with a corrugated internal surface, fine spherical precipitations are to be observed.

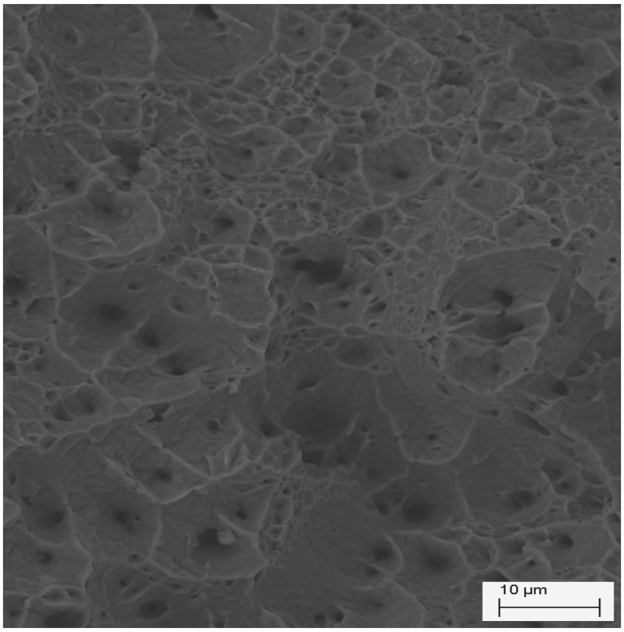

Fig. 22. Ductile fracture in brass CuZn30 (z = 42.5 %, t_r = 300°C)

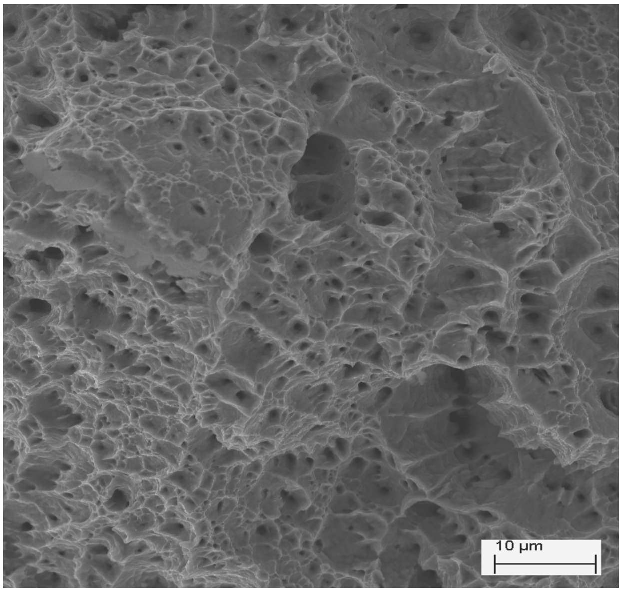

Fig. 23. Ductile fracture in brass CuZn30 (z = 70.2%, t = 300°C)

After cold-rolling with a reduction of 70.2% and recrystallization annealing at a temperature of 650°C on the fracture of the brass CuZn30 there are craters and very shallow cavings, to 10 µm in size, separated from each other distinctly by the edges.

4. Conclusions

Basing on the performed investigations, the obtained results and their analysis, the following conclusions have been drawn:

- Recrystallization annealing of brass CuZn30 within the temperature range of 400-650°C involves a considerable deterioration of the mechanical properties and also a considerable increase of plastic properties
- After cold plastic deformation with a reduction of z - 42.5% and after recrystallization annealing at the temperature of 650°C the investigated brass is characterized by the values R_m about 304 MPa and R_e about 73 MPa, the maximum elongation A amounting to 73%
- Subjected to recrystallization annealing at the temperature of 400-650°C, the investigated brass CuZn30 displays heterogeneous plastic deformation, the so-called Portevin-Le Chatelier effect when stretched at room temperature.
- The hardness of the investigated brass CuZn30 drops with the decreasing degree of the cold-rolling reduction and the rising temperature of annealing.
- After cold plastic deformation and recrystallization annealing within the investigated range of temperature, the brass CuZn30 has a fine-grained microstructure of the α solutions with characteristic twin crystals due to annealing.
- The fractures of recrystallized brass CuZn30 are ductile.

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