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The influence of the chemical composition and temperature of plastic deformation on the PLC effect in tin bronzes

W. Ozgowicz*, B. Opeldus
Division of Constructional and Special Materials Engineering,
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.p

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Materials

ABSTRACT

Purpose: The aim of the present paper is the determination of the effect of the chemical composition and temperature of deformation of standardized tin bronzes and bronze modified with zirconium on the Portevin – Le Chatelier (PLC) phenomenon, mainly basing on the shape of stress-strain curves within the temperature range of 100÷300°C and observations of their structure. The reasons of the occurrence of such en effect are so far no fully known and explained and the opinions concerning is physical basis vary.

Design/methodology/approach: Of essential design in this research is determination of the dependence of PLC effect on the chemical composition, temperature and strain rate and the preliminary heat treatment and grain size. The main method used in this investigation is tensile test at elevated temperature.

Findings: The main conclusions are following: the PLC effect on tin bronzes with a miero-addition of zirconium in an amount of 0.01÷0.05% depends the temperature of deformation in the tensile test in the range of 100÷300°C and the chemical composition of the alloys; the type of serration revealed on the δ–ε curve depend mainly on the temperature of deformation and can be differ during the respective stages of the analyzed curves.

Practical implications: In this paper implications for practice are not taken into consideration.

Originality/value: In this paper an additive type of serration observed on the curves δ–ε, denoted by the symbol D, is new.

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

1. Introduction

During the tensile test of many metals and alloys at elevated temperature there occurs the phenomenon of the heterogeneous plastic deformation, characterized by the presence of irregularities the so called "teeth" along the tensile curve, recorded in the system δ–ε. This phenomenon is generally known as the so-called Portevin – Le Chatelier (PLC) effect [1]. The nature of the processes responsible for the occurrence of this effect has not been fully explained and the opinions concerning its physical basis still vary [2÷12].

The aim of the paper is, therefore, to determine the effect of the chemical composition and temperature of plastic deformation of single – phase model tin bronzes type CuSn7 and tin bronzes with a comparable chemical composition of alloy elements with a micro – addition of zirconium in an amount of 0.01÷0.1% wt. on the PLC phenomenon basing on the shape of the curve δ – ε, recorded in the course of tensile test within the temperature range of 100÷300°C and metallographic tests.

2. Experimental procedure

Experiments were carried out on tin bronze samples, mainly of the type CuSn7 resulting from and laboratory casting shaped as bars and plates, with a chemical composition as shown in Table 1.

Comparative investigations were carried out on model bronzes modified with zirconium in amount of 0.01÷0.1% wt. displaying a high purity and comparable alloy components. Tensile tests were carried out within the temperature range of 100 ÷ 300°C at strain rate of $1.19 \cdot 10^{-3}$ s^{-1} on a strength machine INSTRON (4405) with a loading range up to 100kN with computer control of the tensile test and numeral recording of the results. Investigations of the mechanical properties were carried out applying round sample with a diameter of 6mm and a length of 28mm with threaded heads.

Table 1.
Chemical composition of the studied alloys

Kind of the alloy		Chemical composition, wt %							
		Sn	P	Zr	Bi	Pb	Si	Zn	Cu
1	CuSn7	6.07	0.0037	-	0.0003	0.0052	0.001	0.0130	res.
2	CuSn7Zr0.01	6.86	0.0006	0.020	0.00004	0.0049	0.002	0.0130	res.
3	CuSn7Zr0.05	6.8	-	0.001	-	-	-	-	res.
4	CuSn7Zr0.1	7.16	0.0001	0.0005	0.0008	0.004	0.012	0.0220	res.
5	CuZr0.01	0.0001	0.0008	0.015	0.0001	0.0004	-	0.0001	res.
6	CuZr0.05	0.0006	0.0001	0.0665	0.0001	0.0003	-	0.0013	res.

3. Experimental results

The results of the analysis of tensile curves of the investigated model copper alloys within the temperature range of the PLC effect hav e been gathered in Table 2 and in the diagrams presentedin Fig. 1÷6.

Table 2.
Parameters analyzed on tensile curve of the investigated alloys displaying the PLC effect

Alloy	Deform. temp. [°C]	Type of serration	ΔF_+ [N]	ΔF_- [N]	Δx [mm]	$\tau_{\Delta x}$ [s]	Δ L [mm]	$\tau_{\Delta L}$ [s]
CuSn7 (1)	150		168	184	0.144	4.33	0.732	21.97
	250	**B**	298	255	0.033	1.01	-	-
	300	**C**	163	243	0.040	1.27	0.084	1.50
		D	131	016	0.055	1.65	-	-
CuSn7Zr0.01 (2)	150	**A**	448	216	0.160	4.87	0.770	23.11
		B	200	199	0.084	2.54	-	-
	200	**B**	230	205	0.039	1.18	-	-
		D	326	189	0.080	2.39	-	-
	280	**B**	283	568	0.033	0.99	-	-
		C	384	384	0.077	2.04	0.612	18.36
CuSn7Zr0.05 (3)	200	**A+B**	506	383	0.126	3.79	0.424	12.71
		B	288	256	0.044	1.32	-	-
	300	**C**	171	177	0.045	1.36	0.122	3.67
CuSn7Zr0.1 (4)	150	**A**	410	502	0.105	3.17	0.692	20.78
		A+B	325	351	0.074	2.23	0.692	20.78
		B	241	201	0.044	1.30	-	-
	250	**B**	371	330	0.051	1.52	-	-
CuZr0.01 (5)	200	**A**	420	29	0.091	2.75	0.133	3.99
		B	299	275	0.041	1.23	-	-
CuZr0.05 (6)	250	**B**	355	335	0.051	1.54	-	-

Δx – quantity of deformation during a single cycle;
ΔL - quantity of deformation in repeated cycles;
$\tau_{\Delta L}$ – duration of single cycle;
$\tau_{\Delta L}$ – duration of repeated cycles;

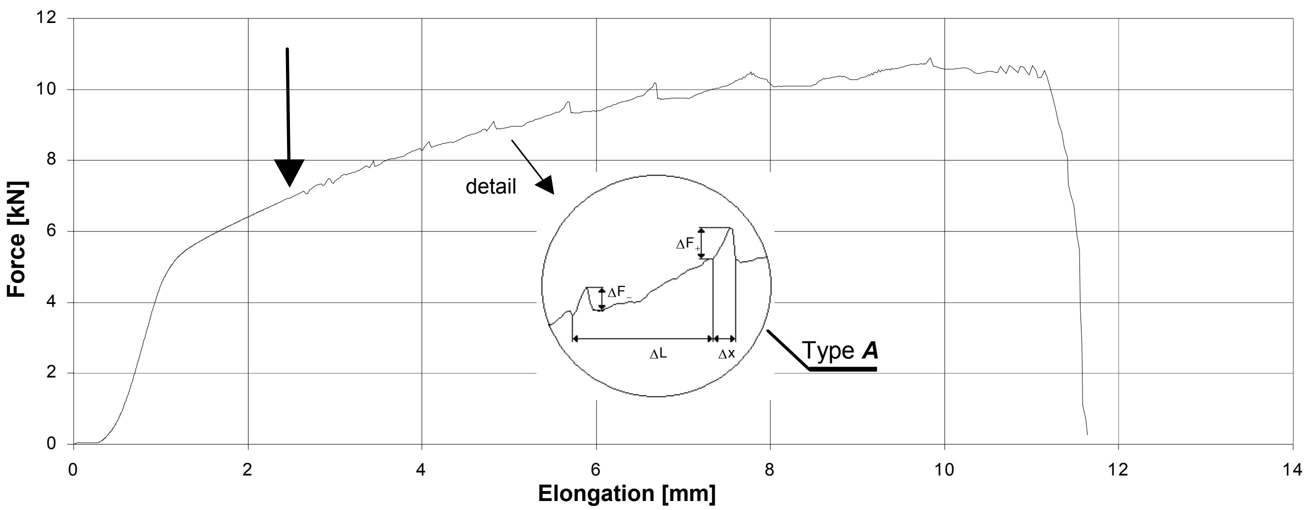

Fig. 1. Tensile stress-strain curve for CuSn7 alloy at 150°C

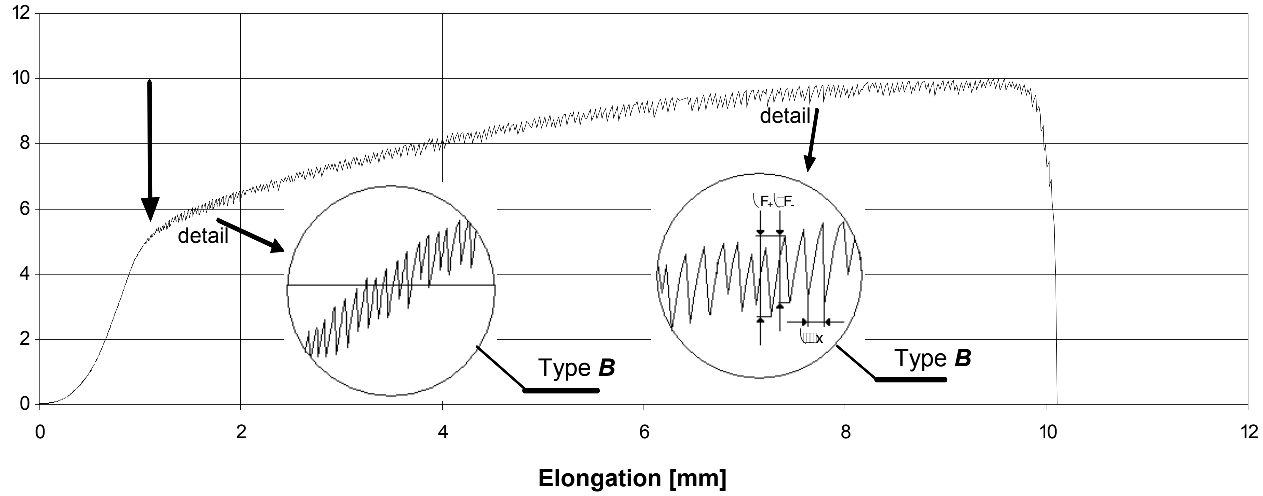

Fig. 2. Tensile stress-strain curve for CuSn7 alloy at 250°C

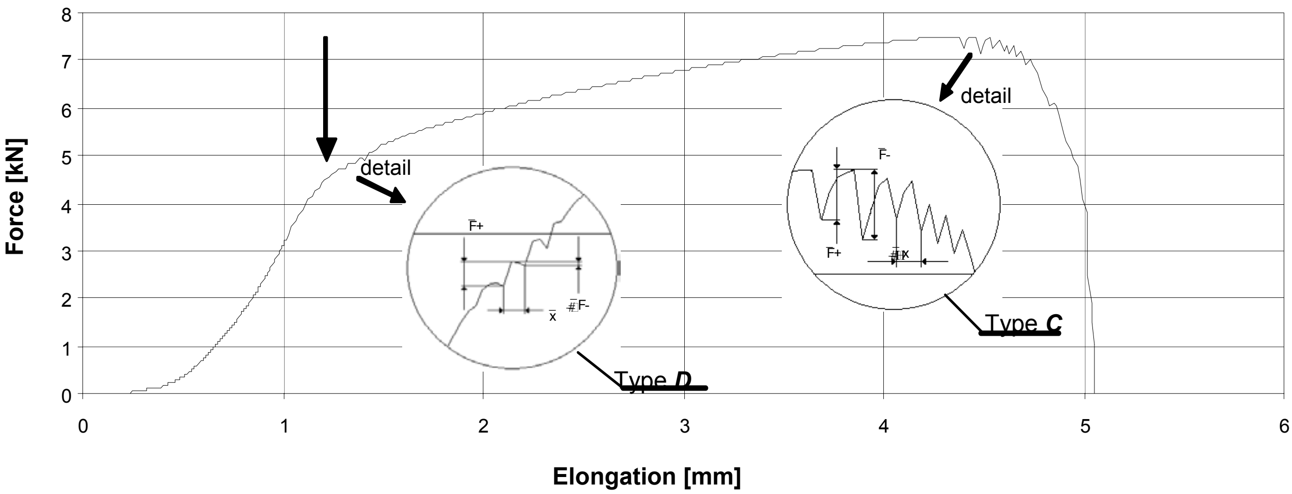

Fig. 3. Tensile stress-strain curve for CuSn7 alloy at 300°C

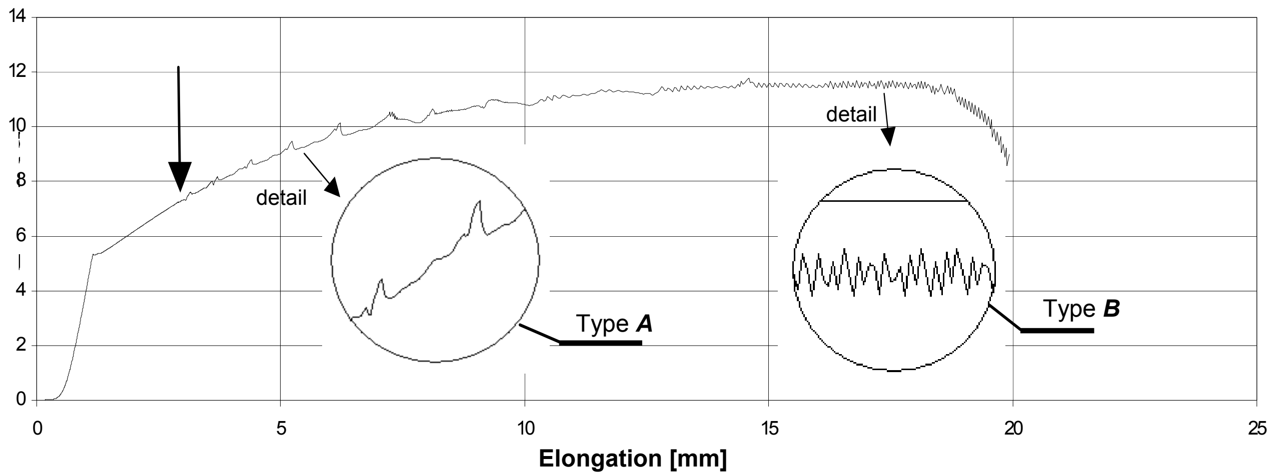

Fig. 4. Tensile stress-strain curve for CuSn7Zr0.01% alloy at 150°C

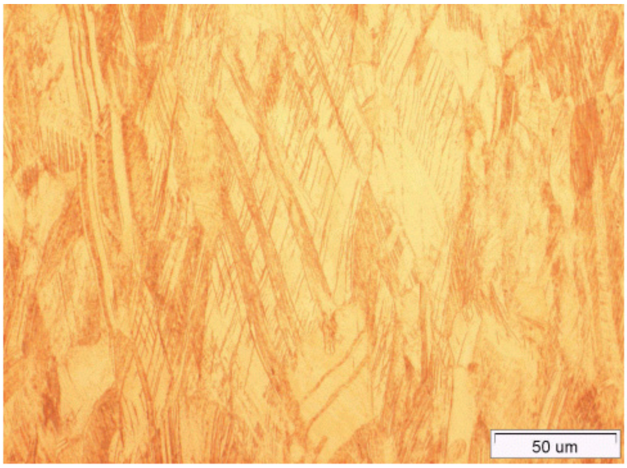

Fig. 5. Single – phase structure of bronze CuSn7 with the shear bands; tensile temp. 250° C, break–off zone of the sample; 500x

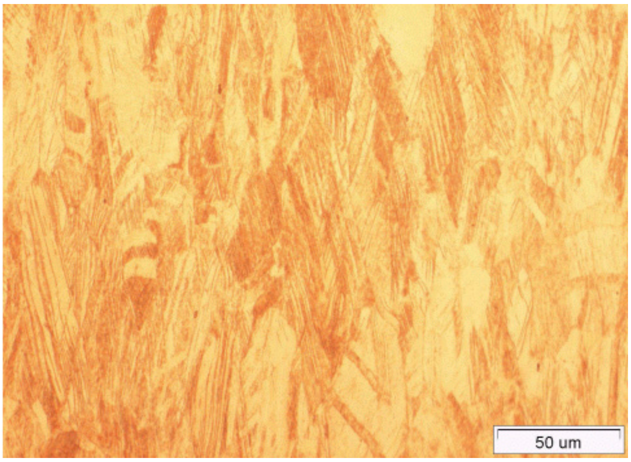

Fig. 6. Single – phase structure of bronze CuSn7 with sliding lines and deformation bands; tensile temp.150°C, deformation zone of the sample; 500x

4. Conclusions

Basing on the investigations the following conclusions may be derived:

1. The PLC effect of the investigated copper alloys and tin bronzes, modified by microadditions of zirconium in an amount of 0.01÷0.05% depends essentially the temperature of deformation in the tensile test in the range of 100÷300°C and the chemical composition of the alloys.
2. The type and serration parameters revealed on the curve $\delta - \varepsilon$ depend mainly on the temperature of deformation and the chemical composition of the investigated alloys and may differ during the respective stages of the analyzed curves.
3. The PLC effect is usually preceded by the homogeneous deformation (ε_s), which decreases distinctly with the growing temperature of deformation of the tested alloys.
4. The amplitude of the serration of stresses (ΔF_{+-}) in the investigated alloys and analyzed types of "teeth" increases with the temperature of deformation.
5. An increase of the content of alloy elements in the investigated copper alloys with Sn and Zr occurs in a larger range of the temperature of deformation.
6. In the investigated model copper alloys with microadditions of zirconium on the curves δ–ε the occurrence of an additive type serration was observed as well as serration denoted by the symbol D.
7. The effect of heterogeneous plastic deformation of model tin bronzes CuSn7 is characterized by the occurrence of a large number of deformation, sliding and shearing bands.

References

[1] A. Portevin, F. Le Chatelier: Cr. Acad. Sci., Paris, 176, 507, 1923.

[2] A. Korbel: Scientific Bulletins of the S.STASZIC University of Mining and Metallurgy, No 474, Metallurgy and Foundry Practice, Bull. 65, "The analyses of the non-uniform deformation in the substitutional solid solutions", Cracow, 1974.

[3] J. Wyrzykowski: „The influence of grain boundary feature on the boundary effect", Research works, Mechanics, No 105, 1987, p. 4-102.

[4] P. Hähner: „On the critical conditions of the Portevin – Le Chatelier effect", Acta Mater. 9 1997, p. 3695-3706.

[5] A. Poznańska, J. Sieniawski: „The Portevin – Le Chatelier effect in the EI-867 nickel super-alloy", Materials engineering, No 1, 1995, p. 15 – 19.

[6] J. Mizera, K. Kurzydłowski: „On the anisotropy of the Portevin – Le Chatelier plastic instabilities in Al-Li-Cu-Zr alloy", Scripta Material, 45, 2001, 801.

[7] J. Balik: „The onset Portevin – Le Chatelier instabilities in tensile testing", Mater. Sci. Eng. A 316, 2001, p 102-108.

[8] Z. Kovàcs: PhD.Thesis; Portevin –Le Chatelier plastic instabilities, Eötcös Loránd Univ., Budapest 2002.

[9] F. B. Klose, A. Ziegenbein, (i in.): „Portevin–Le Chatelier effect in strain and stress controlled tensile tests", Comput. Mater. Sci. 26, 2003, p. 80-86.

[10] F. B. Klose, A. Ziegenbein (i in.): Mater. Sci Eng A369; „Analysis of Portevin–Le Chatelier serration of type B in Al-Mg", 2004, p. 76-81.

[11] Z. Jiang: „Spatial characteristics of the Portevin – Le Chatelier deformation bands in Al-4 at %Cu polycrystals" Mater. Sci. Eng., 2005, p. 154-164.

[12] J. Kong, (i in.): „Effect of type-B Portevin–Le Chatelier bands in uniaxial tension of strip cast AA5754 sheets" Scripta Mater. 53, 2005, p. 499-503.