Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 29 ISSUE 2 August 2008

The influence of the temperature of tensile test on the structure and plastic properties of copper alloy type CuCr1Zr

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Received 13.04.2008; published in revised form 01.08.2008

Properties

ABSTRACT

Purpose: The purpose of this paper is to determine the influence of temperature of plastic deformation on the structure and mechanical properties of copper alloy of the type CuCr1Zr during a tensile test.
Design/methodology/approach: The tensile test of the investigated alloy was realized in the temperature range of 20÷700˚C with strain rate of 1.2 • 10^{-3} s^{-1}. 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 alloy as well as the range of occurrence of the Portevin - Le Chatelier phenomenon was determined on the basis of σ–ε curves formed by tensile tests; however the character of fracture during the break of the samples was defined on the basis of fractographic investigations.
Practical implications: In result of tensile tests of copper alloy it has been found that the PLC effect occurs in temperature range of 250÷400˚C. However, the ductility minimum temperature of the alloy equals about 550˚C.
Originality/value: A correlation of temperature of PLC effect was achieved with a qualitative description of the type of "teething" on the σ–ε curves, compatible with the classification quoted in literature.
Keywords: Metallic alloys; Copper alloy; Plastic instability; Portevin – Le Chatelier effect; Tensile test at elevated temperature

1. Introduction

Copper alloys, are currently the most widespread constructional materials besides the iron and aluminium alloys. Copper alloys have numerous uses. The majority of their kinds are applied in electrical engineering and electronics. The plastic properties of copper alloys are in a considerable degree dependent on their chemical composition and the temperature of plastic deformation [1-9].

The plastic deformation conditions the course of basic structural phenomena and the technological processes of plastic forming. During the tensile test in many metallic alloys there occurs the phenomenon of heterogenic plastic deformation in the form of so called "teeth" on the stress-strain curves, generally known as the Portevin – Le Chatelier effect (PLC) [10]. The course of stress changes as a function of deformation is different according to the kind of the alloy and conditions of the process, particularly the rate and temperature of deformation. The nature of responsible processes for showing up this effect hasn't been explained completely so far and opinions referring to the physical reasons of the PLC effect are diversified [10-15]. The oldest and most general explanation of this effect is the theory suggested by

Cottrell. According to this theory the condition of the occurrence the Portevin-Le Chatelier effect is to equalize the rate of dislocations with the speed of the diffusion atoms [11].

The purpose of this paper is to determine the influence of the stretching temperature on the structure and plastic properties as well as the effect of heterogenic plastic deformation of copper alloy type CuCr1Zr during a static tensile test.

2. Experimental procedure

Experiments were carried out on copper alloy of the type CuCr1Zr, applied as electrodes to welders. The chemical composition of the alloy CuCr1Zr is shown in Table 1. The material was supplied after plastic deformations as bars with a diameter of about 10 mm and lengths about 500 mm. The investigated alloy was subjected to solution heat treatment in water from 950˚C after holding it at that temperature for one hour.

Table 1.
Chemical composition of alloys CuCr1Zr

Kind of the alloy	Chemical composition, wt %				
	Cu	Cr	Zr	Al	Fe
CMR16X by ASTM	Melting analysis				
	98.84	0.88	0.19	0.06	0.00
CuCr1Zr by PN-EN 12163	According to the standard				
	res.	0.5÷1.2	0.03÷0.3	-	0.08

Static tensile tests of supersaturated alloy CuCr1Zr were carried out on the universal strength machine INSTRON 4505 within the temperature range of 20 ÷ 700^{o}C and strain rate equal to $1.2{\bullet}10^{-3}$ s^{-1}. Metallographic investigations of the structure were carried out on longitudinal polished sections of copper alloy CuCr1Zr samples applying the light microscope type Leica MEF4A and AXIOVERT 405 with a magnification of up to 1000x.

The fractographic investigation of the fracture after decohesion of samples in a tensile test at elevated temperature were executed in electron scanning microscope of the JEOL JXA-50A company with 10nm resolution at the accelerating voltage 30kV, applying the magnification of $500\text{-}2{\cdot}10^{3}$x.

3. Experimental results

The results of static tensile tests permitted to qualify the influence of elevated temperature of deformation on the mechanical properties of chromium-zirconium 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 gathered in Table 2 and in the curves presented in Fig. 1. Within the temperature range 250 - 400^{o}C, load –displacement curves with characteristic “teeth”, were obtained testifying the occurrence of the Portevin – Le Chatelier (Fig. 1) effect in the investigated copper alloy. At 250 ^{o}C, the temperature of beginning occurrence of the PLC effect, " teeth” of C type are forming. At 300 ^{o}C and 350^{o}C, “teeth” of B type prevail, however the temperature of 400^{o}C results in regular “teeth “ of A type.

Table 2.
Mechanical properties of copper alloys CuCrZr after tensile test at elevated temperature

No.	Deform. temp. [^{o}C]	Mechanical properties			
		R_m [MPa]	$Rp_{0,2}$ [MPa]	A [%]	Z [%]
1	W – 20*	623	619	14.9	49.5
2	20	277	98.4	36.9	45.8
3	100	239	72.7	45.8	59.3
4	150	230	83	42.8	64
5	200	211	78.7	39.7	56
6	250	207	75.4	42.1	70.1
7	300	204	69.6	41.9	63.1
8	350	220	66.7	32.6	67.2
9	400	249	141	35	59.1
10	500	166	139	28.4	55.6
11	550	109	106	18.7	17.3
12	600	140	131	18.5	20.4
13	650	67.3	64.4	23.9	24.8
14	700	68.5	64.9	43.5	57.8

* In the delivered state

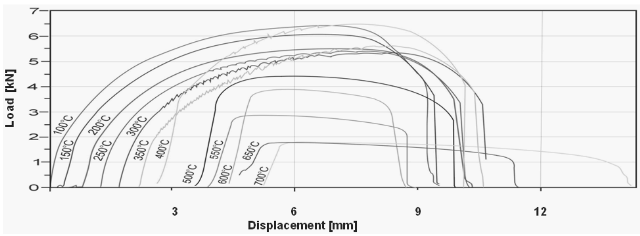

Fig. 1. Typical load – displacement curves for CuCr1Z copper alloy at temperature range of 100-700˚C

It was found, that the value of the critical deformation ε_{kr}, is changing with the change of tensile test temperature. At a temperature of 250 ^{o}C, 300 ^{o}C and 350^{o}C the value ε_{kr}, decreases and amounts to about 11.5 %, 3.84 % and 1.92 %, however at temperature of deformation 400^{o}C ε_{kr}, it grew up to 7.7 % (Fig. 2).

The influence of temperature of deformation on R_m and $R_{p0.2}$ of the investigated copper CuCr1Zr has a similar character. Together with the increasing of temperature from 100 to 300^{o}C, R_m and $R_{p0.2}$ drop from 239 to 204 MPa and 73 to 67 MPa. At temperature 300^{o}C and 350^{o}C the minimum of these properties reaches R_m = 204 MPa and $R_{p0.2}$ = 66.7 MPa. At 400^{o}C R_m and

$R_{p0.2}$ reach the maximum value of 249 MPa and 141 MPa. A considerable decrease of these properties is observed at temperatures of 500°C ÷ 700°C.

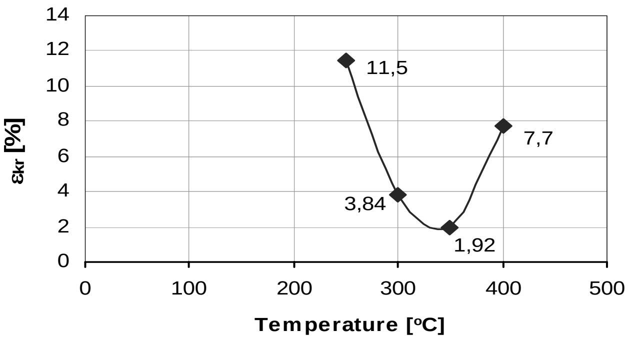

Fig. 2. Critical deformation ε_{kr}, versus the temperature of tensile test at copper alloy CuCr1Zr

A change of elongation and narrowing of the investigated CuCr1Zr alloy in the temperature range 100 - 700°C was plotted on graphs (Fig.3). The curve of the change of extension and narrowing shows a clear minimum in temperature 600°C. The largest value of the elongation in the investigated copper alloys occurs after expansion at a temperature of 100°C and amounts to about 46 %. The minimum value of A = 18.5% was found at 600°C. A violent increase of elongation to about 43.5% follows at a temperature of 700°C.

The curve of changes of narrowing as a function of temperature has a similar character. Within the range of temperature of 100 - 350°C the narrowing amounts to about 63 %. At a temperature 400°C of decrease of reduction of area from about 60% to value about 20% in temperature 600°C was observed. After tensile test at 700°C it was found the increase of reduction of area to the value 57.8 %.

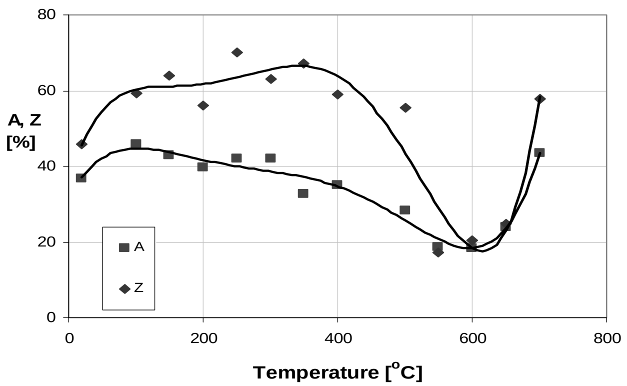

Fig. 3. Elongation (A) and Reduction of area (Z) versus the temperature of deformation of copper alloy CuCr1Zr

The results of metallographic investigations were introduced on microphotographies (Fig.4 and 5). In the structure of the investigated alloys in the delivered state elongated grains of α solution with numerous extractions with diverse morphology were observed. After stretching in temperature to 250˚C it was found that in the structure of deformed grains solution α occurs (Fig. 4) as well as some micropores whose quantity grows at 300˚C and 350˚C.

After deformation at a temperature of 600˚C and 700˚C in the structure of the investigated alloy numerous intercrystalline crackings (Fig.5) were observed and the effects of beginning the dynamic recrystallization on the grain boundaries.

The results of fractografic examinations permitted to determine the influence of the deformation temperature on the character of the fracture of alloys CuCr1Zr obtained during the decohesion of samples. The examined copper alloys showed after the tensile test in the temperature range 20 - 500°C transcrystalline ductile fracture (Fig. 6). At 600°C in the investigated alloy is to be observed brittle crystalline fracture with small areas of plastic deformation according to the minimum growths of the elongation and narrowing (Fig.7).

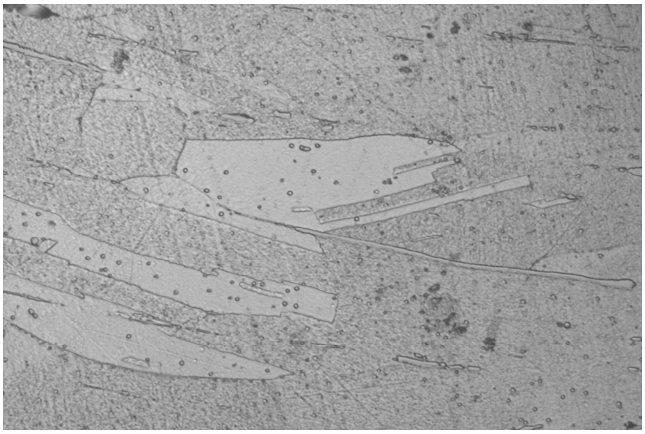

Fig. 4. Structure of copper alloy CuCrZr after tensile test at 250°C Mag.1000x

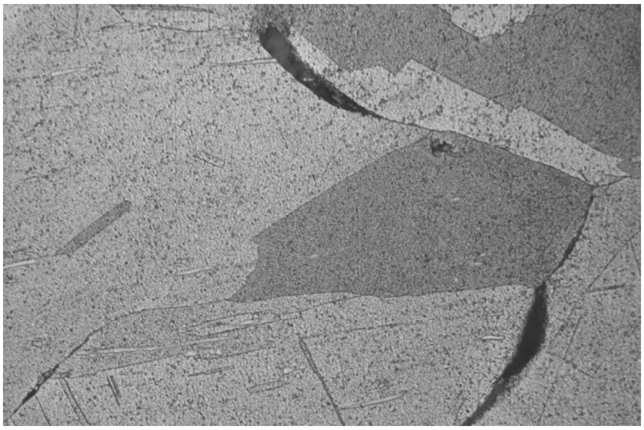

Fig. 5. Microcracks on the grain boundaries and morphologied various precipitations of copper alloy CuCr1Zr stretched at a temperature 700°C Mag. 500x

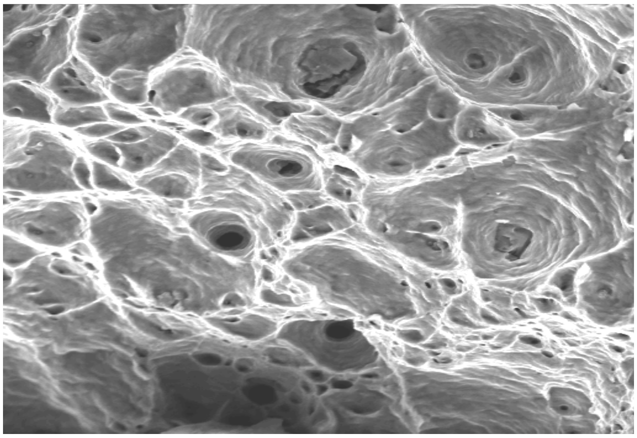

Fig. 6. Ductile fracture of copper alloy CuCr1Zr after tensile test in the temperature 200°C. Mag. 1000x

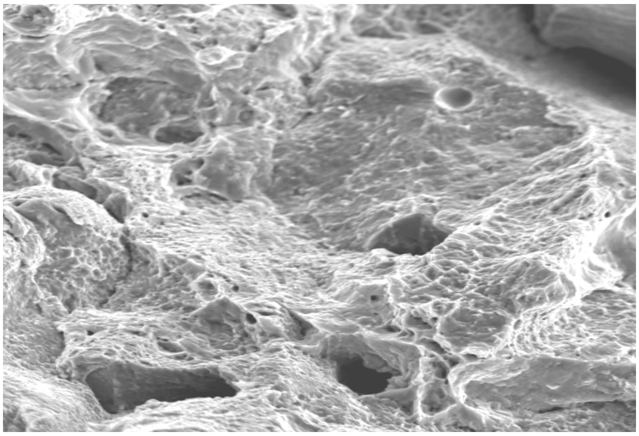

Fig. 7. Intergranular fracture with a share of ductile areas after tensile test at 600°C Mag. 1000x

4. Conclusions

Basing on the investigations the following conclusions may be derived:

1. Copper alloys CuCr1Zr stretched statically at a rate of deformation $1.2 \cdot 10^{-3}$ s^{-1} show distinct minimum of plastic properties in a narrow range of deformation temperature about 550 - 600°C .
2. Intercrystalline fragility is occurring in the range of temperatures of minimum plasticity in the investigated alloys intercrystalline brittleness occurs.
3. The phenomenon of heterogeneous plastic deformation of the investigated alloys (PLC effect) occurs in the range of temperature 250 ÷ 400°C.
4. In the investigated alloy the value of the critical deformation ε_{kr} shows a minimum at the temperature of stretching of about 350°C.
5. The temperature of deformation influences essentially of the character of "teething" on the curves σ-ε of the investigated alloy and the kind of fractures as well as the mechanism of fracture.

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