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The effect of ductility minimum temperature in CuNi25 alloy

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Abstract: On the basis of high temperature ductility tests in single-phase cupronickel CuNi25 sample has been found a relation between microstructure, grain size and effect of ductility minimum temperature (DMT). Metallographic tests confirmed literature studies that cracks nucleate at points of two or three grain joints and cross-cut of twined grain with border of the grains. The non-homogeneous character of chemical composition concentrating in areas of grain joints and cracks at high temperature has been investigated by linear and point Cu and Ni analysis (EDS). This analysis shows that local areas of non-equilibrium formation concentrate at this places. This fact can be accepted as one of the reasons of non-homogeneous deformation, cracking and its location at DMT.

Keywords: Hot ductility, Non-uniform deformation, Cupronickel, Ductility minimum temperature (DMT).

1. INTRODUCTION

The phenomena of ductility minimum temperature (DMT), is one of the unexplained features of metals and their alloys, observed as the effect of middle temperature ductility decrease during high-temperature plastic deformation in the range of 0.3-0.6 T_t (melting point temperature).

In literature effect of Ductility Minimum Temperature is widely described [1-7], the scientific research shows that this effect is a common attribute of many polycrystal metals and alloys [8,9] for example copper and its alloys [10-12], steel [13-15], occasionally this phenomena hasn't been noticed [16-17].

Various forms, conditions, and type of hot working (rolling, bumping, forging, stranding or pressing out) causes different levels and temperature range of ductility minimum temperature phenomena. The explanation of cause of the DMT effect is difficult because of the variety of studied materials, investigative methods, experiment conditions and also the shortage of possibilities of identical repetition of experiment each time. It is possible to identify in different metals and alloys heterogeneous mechanisms responsible for loss of ductility and crack formation, and in consequence destruction of material. The non-uniform course of plastic deformation process in middle temperature is correlated with a number of factors affecting DMT phenomena due to: rate of deformation, non-uniform of chemical composition and process of deformation, segregation of impurities on grain joints, shape and size of grains, geometrical heterogeneity, thermal activated internal dynamic transmutation, temperature of deformation and its local changes, type of environment, differences in defects of crystalline building. The critical level of non-homogeneity, caused by factors mentioned above leads to concentration of stress in material in both macro and microscopic scale causing decrease of ductility. As temperature rises, thermal activated processes take place in more areas, after reaching suitably high temperature, almost in whole volume of sample provoking stress relaxation leading to increase of material ductility [18].

The investigations conducted on copper alloys [4,5] confirm occurrence the phenomenon of ductility minimum trough out function of temperature. The single-phase cupronickel alloy seems to be an ideal material to investigations on DMT effect. Conducted on this material investigations [3,4, 19-21], they confirm occurrence this phenomena. In work [22] carried out on uniaxial grips experiment at the CuNi alloys has shown the influence of material structure on course of the plastic deformation process in wide range of raising temperatures.

An observations on other copper alloys [4, 23] has shown that the course of phenomenon DMT depends on shape and size of grain therefore the aim of undertaken investigations of this work was confirmation of similar dependences in CuNi25 alloy. The change of chemical composition in neighborhoods of migrating grain borders for example sulfur [5], oxygen [24], zinc [25], lead [4], cause the growth of stress locating in this area. One of the aims of presented work is to verify these as a potential reason of DMT phenomenon occurring in cupronickel alloy.

2. EXPERIMENTAL PROCEDURES

The samples for examination prepared from commercial CuNi25 alloy by casting of 600kg ingot preliminary rolled and cut out 250x400x600 piece. The cuboid has been cut and forged within 900-1100^{o}C on rods 17-19 mm in diameter, after these rods have been cold drawn to 15mm in diameter. The chemical composition of alloy has been shown in Table 1.

In aim to obtain diverse size of grains material has been divided into three series A, B, C, held at temperature shown in Table 2.

Table 1.
Chemical composition of the investigated cupronickel (mas. %).

The chemical composition	Cu	Ni	Mn	Fe	Co	Rest
% mas	74,1	25,5	0,247	0,089	0,003	0,006

Table 2.
Average grain size in CuNi25.

Seria	Time	Heating temperature	Average grain size
A	0,5h	800°C	50µm
B	8 h	800°C	150µm
C	8 h	1000°C	400µm

In A and B series of samples the grain structure is homogeneous of regular A-50µm (Fig.1) and B-150µm size. However the shape of grain in C series samples is non-homogeneous of size balanced from 200µm to even 1500µm, the average size of grain carried out 400µm (Fig.2).

The tensile test temperatures was received on basis of literature analysis and contained between 300 – 800°C with graduating in 50°C, after determination of ductility curves to specify the range and level of DMT effect the graduating in 400-600°C was reduced to 25°C. The five samples have been investigated on each testing point.

The investigation has been done on tensile test machine INSTRON 1195 with electronic controlled electric furnace with measurement tolerance ±3°C. The strain rate for all series was $4.2\cdot10^{-3}s^{-1}$ and with three strain rates to A series $2.7\cdot10^{-4}s^{-1}$, $4.2\cdot10^{-3}\cdot s^{-1}$ and $2.7\cdot10^{-1}s^{-1}$. To stop structure of the deformed material after tensile test samples were immediately cooled in water.

Metallographic investigations were conducted on light and scanning microscopes in range of magnification 5-2000x. Linear and point analysis of Cu and Ni concentration executed with the help of X-ray microanalizer JCXA 733 made by JEOL.

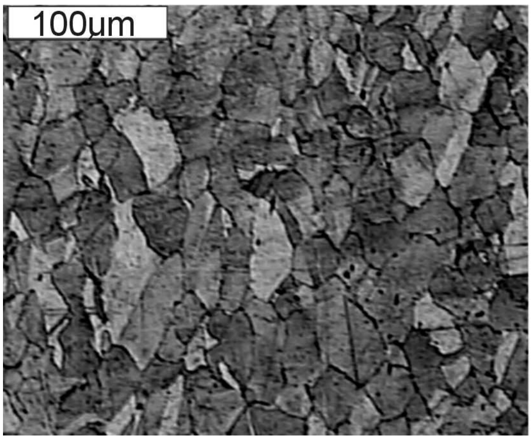

Figure 1. The structure of A series CuNi25 sample before deformation.

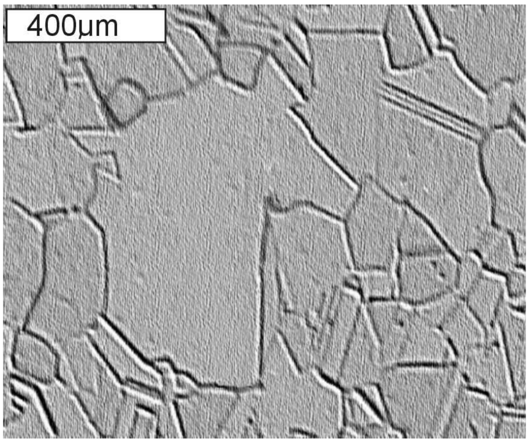

Figure 2. The structure of C series CuNi25 sample before deformation

3. RESULTS AND DISCUSSION

The results of conducted tensile tests of cupronickel CuNi25 in range of temperature 300 – 800°C confirm occurrence of the DMT phenomenon in all examined cases (Fig. 3,4). The ductility minimum contains within range of 450-600°C. The curves of elongation and reduction of the area shows that the minimum of DMT effect transfer from 475°C for A series by 500°C for B series samples to temperatures of 525°C for C. The tensile test confirms that the level of DMT effect for elongation together with grain size is decreasing, achieving 27.2% for 50µm by 23.45% for 150 µm and 15.24% for 400µm. In studied case appears that the difference in grain size affects to level and range of ductility minimum temperature effect.

The tensile test proved that escalation of strain rate both for elongation and reduction of area cause displacement of minimum of DMT to higher temperature A series samples getting for elongation minimum at 450°C for strain rate $2.7 \cdot 10^{-4} s^{-1}$, by 475°C for $4.2 \cdot 10^{-3} \cdot s^{-1}$ and within 525°C – 550°C for $2.7 \cdot 10^{-1} \cdot s^{-1}$ (Fig, 5, 6).

It has been noticed that in samples of all series, together with growth of temperature to DMT effect, the cracks placed in grain joints. The majority of observed cracks are located at triple grain joints and places of the twinned grains with grain borders' point of contact. (Fig.7). The fallowing conclusion was drown on basis of microscope observations and course of ductility curves that non-homogeneity of structure impact to DMT, testify about it cracks in C samples series placed in areas of coarse-grained contact to fine-grained areas (Fig.8).

It was supposed, that one of causes of DMT effect is the non-uniform chemical composition which can be precisely examine using modern investigative methods. In paper was examined the segregation of copper and nickel near borders of grains proceed during thermal activated dynamic internal transmutation. The point analysis of chemical composition on samples deformed in range of ductility minimum trough, made with the help of X-ray microanalizer proved difference in concentration of nickel and copper. Differences in fluctuation for coppers achieve 72.5 % to 77% and for nickel 23% to 27.5 %. Statistical analysis of areas conducted in grain boundaries cracks neighborhood shows that it is possible to observe in 30% of the cases differences of content Cu and Ni between two sides of cracks achieving even to 3% on space of a few micrometers (Fig 9.).

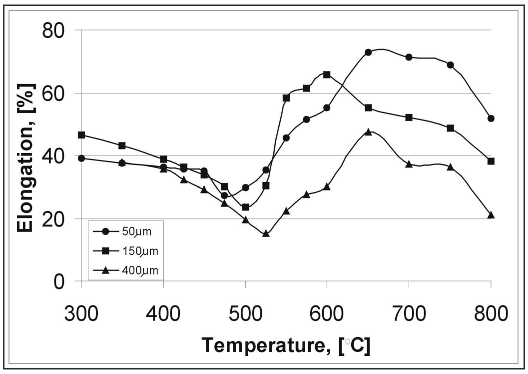

Figure 3. Elongation versus test temperature for CuNi25 alloy, with grain size 50 µm, 150µm and 400µm after deformation with strain rate: $4.2 \cdot 10^{-3} \cdot s^{-1}$

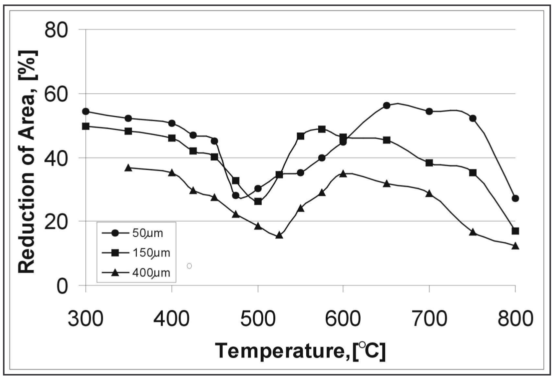

Figure 4. Reduction of area versus test temperature for CuNi25 alloy, with grain size 50 µm, 150µm and 400µm after deformation with strain rate: $4.2 \cdot 10^{-3} \cdot s^{-1}$

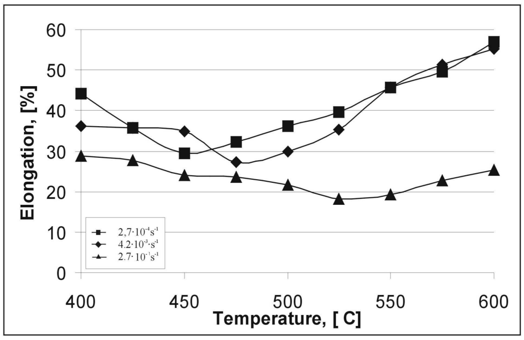

Figure 5. Elongation versus test temperature for CuNi25 alloy, with grain size 50 µm, after deformation with strain rates: $2.7 \cdot 10^{-4} s^{-1}$, $4.2 \cdot 10^{-3} \cdot s^{-1}$ and $2.7 \cdot 10^{-1} \cdot s^{-1}$

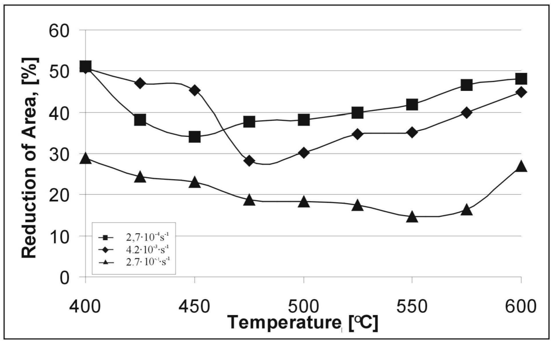

Figure 6. Reduction of area versus test temperature for CuNi25 alloy, with grain size 50 µm, after deformation with strain rates: $2.7 \cdot 10^{-4} s^{-1}$, $4.2 \cdot 10^{-3} \cdot s^{-1}$ and $2.7 \cdot 10^{-1} \cdot s^{-1}$

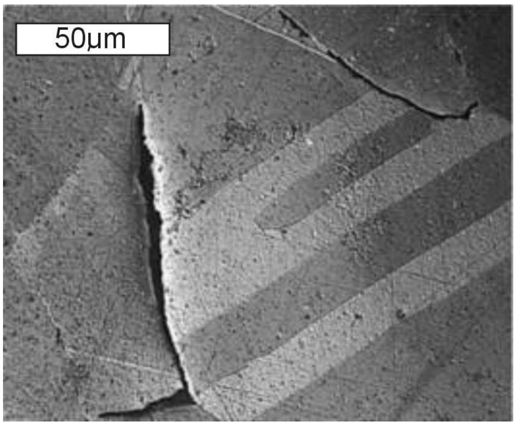

Figure 7. The structure of CuNi25 series B, deformed in temperature 500°C

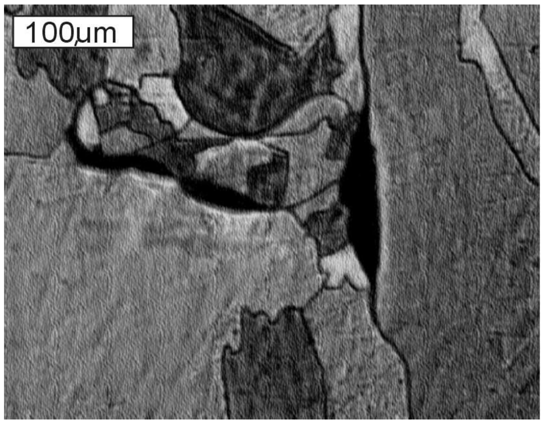

Figure 8. The structure of CuNi25 series C, deformed in temperature 500°C

Linear analysis of concentration confirms the results of points investigations, visible growth of the copper concentration from one sides of the crack and nickel on the others (Fig.10.). The chemical analysis was made on two-dimensional plane cuts through three-dimensional objects – grains, but cross-cutting plane rarely ideal cover the locations of cracks' nucleation.

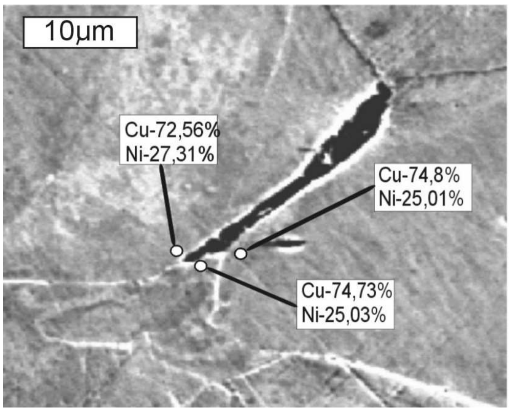

Figure 9. The structure of CuNi25 series A, deformed in temperature 500°C, with visible points of Cu and Ni analysis.

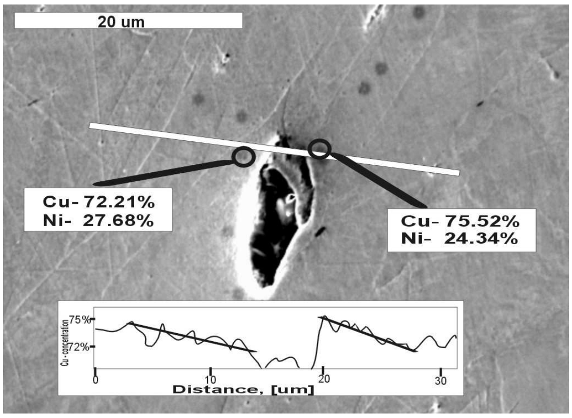

Figure 10. The structure of CuNi25 with grain size 150 µm deformed in temperature 500°C, with visible linear Cu and point Cu and Ni analysis of concentration.

It has been noticed during electron microscope scanning that samples deformed in range of DMT temperature indicate intergranular fracture with deep visible grain joint cracks (Fig.11.). Deformation of CuNi25 alloy samples in lower and higher temperature shows plastic transgranular fractures (Fig.12.).

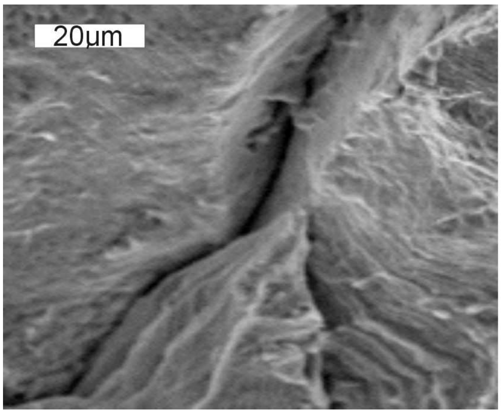

Figure 11. The fracture structure of CuNi25 series B, deformed in temperature 500°C

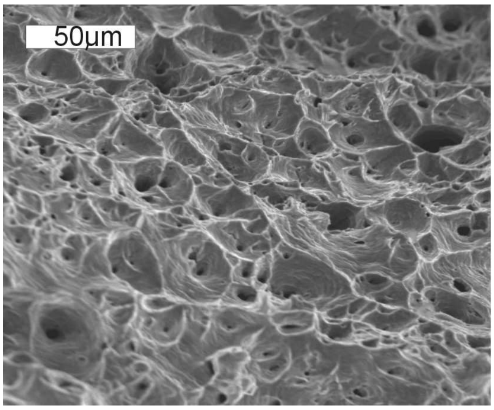

Figure 12. The structure of CuNi25 series B, deformed in temperature 650°C.

Based on observation and analysis of plastic deformation process and its influence on range and level of DMT phenomenon, in cupronickels alloy can be accepted, as in brass hypothesis of non-uniform deformation [10, 26]. Confirmation of this hypothesis can be model of "soft" and "hard" places. The location of deformation process in small volume of heterogeneous material causes the formation of stress between "soft" and "hard" areas. The critical level of non-homogeneity caused stress concentrating in whole volume of material caused nucleation and growth of cracks. In result further influence of strength, to reduced surface cause growth of stress provoking lowered ductility and destruction of material.

The measurement of deformations' of "inhomogeneities" can be relation between volumes of areas, in which the plastic deformation runs (soft areas) with definite level of stress, to total volume of sample (the hard areas). Similarly like in [4, 27] for simulation and illustrating the non-uniform plastic deformation in the range of DMT effect was used the FEM.

4. CONCLUSIONS

The deformation in temperatures approximating to beginning of thermal activated processes provoke superimpose of many “inhomogeneities” causes local changes of physical, mechanical and chemical material proprieties. It can be make an assumption that in micro scale we have to deal with two materials with different properties. The process of deformation locates in small space on theirs joints. The stress level increasing and provoke cracking between “hard” and “soft” places. The critical levels of stress concentration in whole volume of sample cause decrease of ductility and destruction of material.

In this case the differences of; nickel and copper local concentration, material geometrical structures (size and shape of grains) are responsible for dimension of DMT effect. "Inhomogeneities” leading to perturbation in physical and chemical equilibrium provoke lower ductility of material.

The “soft” and “hard” places model, bases on difficult to measuring and defining concept of heterogeneous deformation reflect in macro scale the process of plastic deformation in range of the DMT effect . Therefore, quantity description of this phenomenon in structural scope is very difficult and clarifying of DMT has a character of hypotheses.

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