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Ductility minimum temperature phenomenon in as cast CuNi25 alloy

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Properties

ABSTRACT

Purpose: The aim of this paper was to present DMT phenomenon in CuNi25 alloy and describe behavior of as cast alloy during high temperature tensile tests for different strain rates.
Design/methodology/approach: Numerous techniques were used to characterize properties of material: high temperature tensile tests, light microscope, scanning electron microscopy (SEM), transmission electron microscopy (TEM). Linear and point analysis of concentration executed with the help of X-ray microanalysis.
Findings: It was determine from the experimental studies the course of elongation and reduction of area curves for different strain rates. Their was analyze morphology of material in the range of 300-650°C.
Research limitations/implications: Further studies should be undertaken in order to correlate effects, processes and mechanism existing and superimpose in material in range of Ductility Minimum Temperature phenomenon and what should help us understand high temperature properties of mentioned material.
Practical implications: Knowledge about material properties during high temperature deformation leads to selection appropriate production parameters. Misapplication of parameters leads to multiplication of costs and often destruction of material during production or operating. Correct selection of technical and economical parameters of material production give us supremacy in economic and technological competition.
Originality/value: Investigations of this as cast CuNi25 alloy complete ours knowledge about mechanical properties and help us to develop correct parameters for more effective technologies for material production.
Keywords: Ductility; Minimum Temperature (DMT); Non-uniform deformation; Copper alloys

1. Introduction

Material engineering is very strongly correlated with manufacturing, ecology, economy, research and many other branches. Researchers all other the world try to optimize processes of production and achieve best material properties and economical effects. The scientific research, shows that DMT is a common attribute of many polycrystalline metals and alloys for example copper and its alloys , steel , various forms, conditions, and type of deformation causes different levels and temperature range of DMT phenomena[1-4]. Therefore the main problem of clarify of DMT existing is explanation of connections between proceeding micro mechanisms and the decreasing level of ductility, which in result, lead to described macroscopic behavior and destruction of material. We can do an assumption that DMT is a result of specific, different for each case, combination of mechanisms [5] accompanying to process of deformation at 0.3-0.7 T_m and none of them is specify mechanisms responsible for DMT phenomenon. Conditions of hot deformation in intermediate temperature in many metals and their alloys depends on many factors, selection of appropriate conditions require understanding of processes and theirs causes. Mechanism responsible for ductility trough observed during intermediate temperatures hot working processes is difficult because of many correlations between: different grain boundary/bulk diffusivity ratios, different internal oxidation course, kind and morphology of grain boundaries and grain junctions, grain boundary serrations, rate of deformation, non-uniform chemical composition, segregation, shape and size of grains, the grain boundary character distribution, Strain Induced Grain Boundary Premelting [7], character of the grain boundary connectivity [8], geometrical heterogeneity, thermal activated internal dynamic transmutation, temperature and its local changes, type of environment, differences in quantity and type of crystalline building defects, cavitations, Diffusion Induced Grain Boundary Migration, different kind, rate, and localization of stress relaxation processes.

While 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 [6,7].

The boundary misorientation angle for a specific common rotation axis, the grain boundary character distribution and the grain boundary connectivity parameters [10] help us classify relations between single grain and the properties of polycrystalline materials.

Authors in [11] claim that grain junctions (GJ) affect strongly to the thermo mechanical behavior of the material. They claim that exist differences in thermal characteristics between the grain material and the material of GJs. The thermal expansion coefficient of the amorphous material of GJ is larger than that of the bulk material .

Krishnamurthy in work [12] claims that grain boundaries and grain junctions serve both as high diffusivity paths and sites for oxide formation. Zhu and Liu [13] noticed that dynamic penetration of oxygen in Ni–Si alloys at 500- 700^{o}C- the temperature where DMT was observed, is correlated with loss of ductility and intergranular fracture.

Inoko and coworkers [14] suggested that SIGBPM noticed at 0.5-0.6T_M plays an important role in intermediate temperature embitterment. Dynamic recrystallization is extremely important in extending ductility in addition to refining grain size and lowering flow stress [15]. Above about 0.4T_M, grain boundaries sliding becomes significant and may create angular W-cracks at triple junctions, as a result of differential sliding on the arms having different orientation relative to the stress state.

The problem is relieved, to some degree, by DRV, which softens the lattice so that it can flow plastically in response to local stresses in Al this effect provides for very high ductility. In low SFE metals with limited DRV (Cu, Ni), there is a minimum in ductility with rising temperature, because GB sliding becomes significant about 0.4T_M and then DRX causes a marked rise above 0.5T_M [16]. The change of chemical composition in neighborhoods of migrating grain borders for example sulfur [17], oxygen and zinc [6], lead [1], cause the growth of stress locating in this area. Differences in quantity and type in defects of crystalline building and their thermo dynamical relationship cause the growth of stress locating in this area, leads to heterogeneous processes of plastic deformation [19] different even in neighborhood areas. Brückner and Weinacht in [9] claim that time between relaxations processes can differ by about factor of 10 at in termediate temperature range in CuNi thin films.

2. Experimental

Productions require accurate specified conditions and knowledge of influence of every parameters to process of manufacturing. In this work authors try to find relations between strain rates and material morphology in cupronickel CuNi25 as cast alloy deformed with two different strain rates

The investigations conducted on copper alloys [12] confirm occurrence the phenomenon of ductility minimum trough out function of temperature. The single-phase copper alloys seems to be an ideal material to investigations on DMT effect. The chemical composition of investigated alloy has been shown in Table 1.

The samples for examination have been prepared from commercial CuNi25 alloy by continuous casting process in plate and cut out on 500x400x20 mm piece. The plate has been cut on rods and on the lathe was prepared samples. The tensile test temperatures have been based on analysis found in literature and contained between 350 - 650°C for CuNi25 with gradating in 50°C after determination of ductility curves to specify the range and level of DMT effect, graduating has been reduced to 25^{0}C. Five samples have been investigated in each testing point with two strain rates $2{,}7\cdot 10^{-3}s^{-1}$ and $2{,}7\cdot 10^{-1}s^{-1}$.

Elongation and reduction of area were measured directly on the samples after high temperature tensile test. The investigation has been done on tensile test machine INSTRON 1195. To stop structure of the deformed material after tensile test samples were immediately cooled in water.

Metallographic investigations were conducted on light, scanning and transmition electron microscopes. Light metallographic specimens were cold-mounted and etched in $FeCl_3$ after conventional metallographic preparation, with application of diamond paste. Observations of metallographic specimens were performed on light microscopy at magnification 100 – 1000, scanning microscopes in range of magnification 5-2000x

Linear and point analysis of concentration executed with the help of X-ray microanalizer JCXA 733 made by JEOL. Diffraction and chemical composition investigations in micro-regions and of the thin foils' and carbide extraction replica microstructures were made in the JEOL 200CX transmission electron microscope with the accelerating voltage of 200 kV. Thin foils were made by mechanical thinning and elecetrolytical polishing in electrolyte with the chemical composition: 90cm^3 of methyl alcohol and 10 cm^3 of nitric acid. Temperature - 45°C, time 2-4 min, voltage 15-20 V and current density 480-570 mA/cm^2, in the Struers Tenupol-5 jet polishing machine.

3. Results and discussion

The analyzed CuNi25 alloy demonstrate classic dendrit structure. The results of tensile tests of both alloys confirm occurrence of the DMT phenomenon in all examined cases (Fig. 1 and 2).

In studied case appears that the difference in strain rates affects on scale of ductility minimum temperature effect. In CuNi25 as cast alloy the DMT effect contains within range of 400-600^{O}C.

The curves of elongation shows that the minimum of DMT effect for CuNi25 alloy deformed with strain rate $2.7\cdot 10^{-3}s^{-1}$ obtain for elongation at 475°C level of 15% and for reduction of area at 500°C value 13%. Ductility minimum level for series deformed with strain rate $2{,}7\cdot 10^{-1}s^{-1}$ get for elongation at 525°C and reduction of area at 525-550 value of 13%.

In studied case appears that the difference in strain rate affects to 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 - compare to [1,6].

It has been noticed that in samples deformed in temperature of DMT effect occurred cracks placed in border of dendrite and Si inclusions. The majority of observed cracks are located at dendrite arms or grain joints with non metallic inclusions (Si), (Fig. 3,4.)

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.

The linear analysis of chemical composition in 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 copper achieve 15%. Analysis of areas, conducted in the neighborhood of dendrite boundaries cracks has shown that it is possible to observe differences of content Cu and Ni between two sides of cracks achieving even to 13% on space of a few micrometers.

Observations on transmission electron microscopy (TEM) of CuNi25 alloy samples confirmed that the microstructure of samples deformed in the temperature lower than DMT that on inclusions of Si cumulate dislocations but in samples deformed in DMT range it was shown cracks on the Si inclusions, at this places can localize process of non uniform deformation. It has been noticed during electron microscope scanning that samples deformed in range of DMT temperature indicate inter-granular fracture (Fig. 5) with deep visible grain joint cracks. Deformation of samples in lower and higher temperature shows plastic transgranular fracture.

On basis of microscope observations a conclusion was drawn that non-homogeneity in shape and chemical composition of grains cause stress concentration in adjacent areas and when its level is critical conduct to cracking in these places

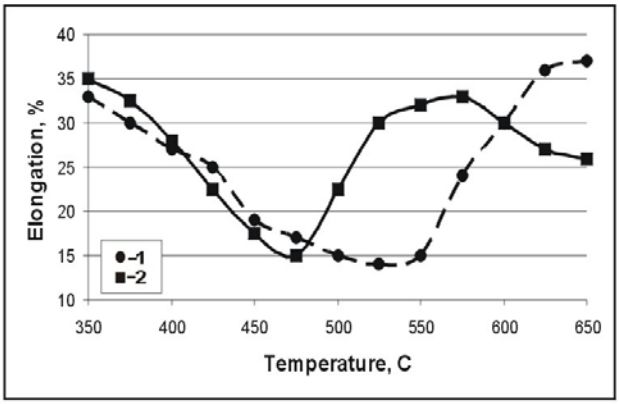

Fig. 1. Elongation vs. test temperature for CuNi25 alloy, after deformation with strain rates: 1)2.7 $\cdot 10^{-1}$ s^{-1} and 2) 2.7 10^{-3} s^{-1}

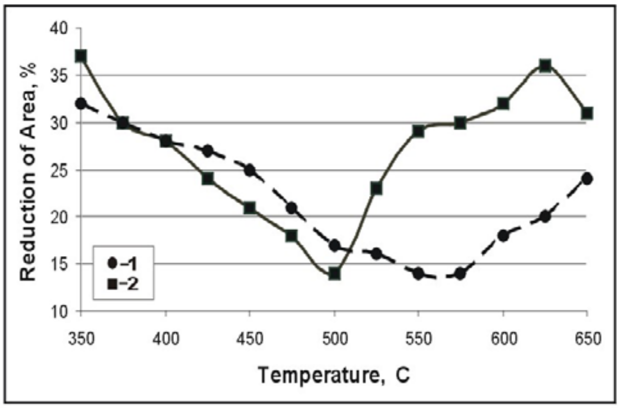

Fig. 2. Reduction of area vs. test temperature for CuNi25 alloy, after deformation with strain rates:1) 2.7$\cdot 10^{-1}$ s^{-1} and 2) 2,7 10^{-3} s^{-1}

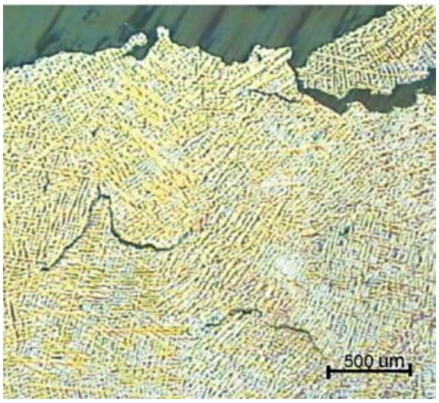

Fig. 3. The structure of CuNi25 alloy sample deformed with strain rate 2.7 $\cdot 10^{-1}$ s^{-1} in temperature 550°C, light microscope with DIC

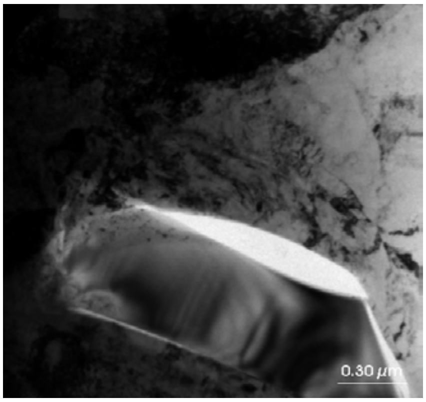

Fig. 4. The structure of CuNi25, deformed with strain rate 2.7 $\cdot 10^{-1}$ s^{-1} in temperature 550°C TEM. Visible pure Si inclusions, TEM

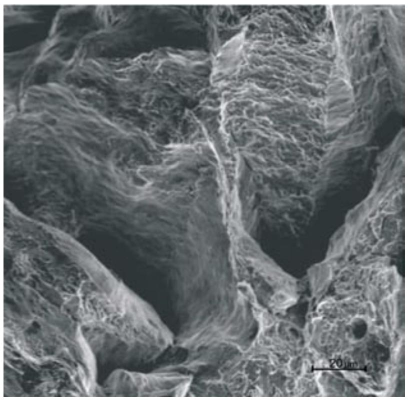

Fig. 5. The structure of CuNi25 alloy sample deformed with strain rate 2.7 $\cdot 10^{-1}$ s^{-1} in temperature 450°C

Table 1.
Chemical composition of investigated alloy

Cu	Ni	Mn	Pb	Fe	Si	Zn	Sn	C	S	Al.	As	P	Cd
75,04	24,43	0,22	0,01	0,1	0,033	0,1	0,011	0,016	0,006	0,001	0,003	0,012	0,002

After deformation in the range of DMT generally were observed microstructures with two types of voids and cracks which runs along the dendrite boundaries. First type voids are similar to those, which were observed as a result of non-enough accommodated grain boundaries sliding or cavitation. Second type is usually long cracks, which are located along the grain boundaries. After deformation at very high temperatures the cracks and voids appeared again as a result of grain grows and grain boundary premelting.

Ductility Minimum Temperature phenomenon is not uniform. There were noticed areas of very differ amount of crystalline building defect neighboring to areas without them. It was observed very often that material from the one side of grain border has appropriate structure but on the other side structure is incorrect.

4. Conclusions

In both cases DMT effect proceeds very similar, the ductility curves demonstrate the same relation between range and level of DMT effect and the strain rates. In all cases cracks nucleate at dendrite arms. Deformation in temperatures approximating to the beginning of thermal activated processes provokes superimpose of many “non-homogeneities” causing local changes of physical and chemical proprieties of material. 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 their joints. The stress level increases and provoke cracking between vary materials. The critical level of stress concentration in whole volume of sample causes decreasing of ductility and destruction of material. Based on observation and analysis of plastic deformation process and its influence on range and level of DMT phenomenon, in cupronickel alloys can be accepted a hypothesis of non-uniform deformation. “Inhomogeneities” leading to perturbation in physical and chemical equilibrium provoke lower ductility of material. The “soft” and “hard” places model [1,6], 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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