Production aspects of inhomogeneous hot deformation in as-cast CuNi25 alloy

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The attempts are being made to achieve the best economic effects and material properties by optimizing the hot working process. Production requires an accurate, specified conditions and knowledge about the influence of almost all parameters on the manufacturing process. The misapplication of materials or technological parameters lead to increase in costs and often to destruction of materials during their production or operating. The fundamental problems associated with the hot working processes of many metals and commercial alloys focus on two associated phenomena: intermediate temperature loss of ductility and hot brittleness. This paper is the result of examination of these two phenomena on industrial CuNi25 alloys, with different chemical compositions and structures. Deformation rate has also been taken into consideration. All tests have been conducted in air, within 0.3-0.7 T_H, selected ones in argon atmosphere. Numerous techniques are used to characterize material properties and to identify the inhomogeneities occurring, for example high temperature tensile tests, infrared thermography, SEM, EDS, WDS and TEM.

Keywords: Ductility minimum temperature, Hot working, Metals, Copper alloys properties, CuNi25, Hot brittleness, Hot ductility, Inhomogeneous hot deformation, ITE, ITB, ITD.

Plastic deformation is the main process of changing geometric features of metals under the influence of external forces. Each operation during metal deformation is a complex process, consisting of many diverse and often very specific interactions and organization of elementary acts of dislocation or diffusion mechanisms. Fundamental problems associated with the hot working processes of many metals and alloys are two co-dependent phenomena: intermediate temperature loss of ductility and hot brittleness. Hot working processes require less energy to deform metals due to increased material flow without cracking comparing to cold working. However, existence of intermediate temperature loss of ductility and hot brittleness phenomena impede it. There are three temperature regions of ductile deformation: low temperature, high temperature and intermediate (also called elevated) which is located within the range of 0.3-0.7 homologous temperature (T_H). Control of the elevated temperature ductility, formability and brittleness in different types of metals and commercial alloys have been an important problem and a challenge to be solved by materials scientists and engineers for a long time.

Intermediate temperature loss of ductility, also known as the phenomenon of ductility minimum temperature (DMT) or intermediate temperature ductility (ITD), and elevated temperature ductility (ETD) are the effects of transitional ductility decrease during high-temperature plastic deformation within the 0.3-0.7 T_H range. Lower ductility and formability are often associated with the presence of the intergranular fracture (Fig. 1).

Phenomenon of hot brittleness (HB) is also called elevated temperature intergranular embrittlement or intermediate temperature embrittlement (ITE) and is characterized by predominant existence of intergranular brittle fracture in intermediate temperature 5,6. Alloys deformed beyond and above the DMT range fail typically in a transcryalline ductile way.

Fig. 1—Schematic view of intermediate temperature ductility and hot brittleness phenomena occurrence
Mutual occurrence of DMT and ITE phenomena has been noted in almost all cases. However, there have been reported some cases of DMT existence without the prevalence of brittle intergranular fracture. Therefore, it can be assumed that the factors causing the ITE will also directly or indirectly cause or affect DMT.

Various forms, conditions and types of hot working (rolling, bumping, forging, stranding or pressing out) cause different levels and temperature range of ductility minimum temperature phenomenon. The ductility reduced area (DRA) is a temperature range where DMT and ITE occur (Fig. 1). This area deserves special attention because low and high temperature plastic deformation mechanisms run and overlap one another. Conventionally, recrystallization temperature was adopted as demarcation point between them. Although, recrystallization and dynamic recrystallization (DRX) do not occur simultaneously over the entire volume of the material causing extension of the material heterogeneity.

The DRA is also the range of temperature in which various combinations of mechanisms, processes and many phenomena affect one another. Their course depends on the macro-, meso-, micro-, and nanostructure and chemical composition. These all affect dynamic changes in material properties, especially in small areas. During hot deformation they run with different intensity and are located heterogeneously in different areas. The easiest way to explain the problem is to point that the strain is non-uniform across the intersection, but it is more complicated and proposed in the hypothesis of nonuniform deformation.

The idea of homogeneity and heterogeneity coexistence relates to the uniformity of a substance. A material that is homogeneous in chemical composition and structurally uniform in macroscale can be at the same time heterogeneous in microscale. Homogeneity considered in an appropriate scale is a property of the material, having equal properties in each area. Heterogeneity is the state of being heterogeneous and concerns the state of matter, which can be defined as non-uniformity, dissimilarity, otherness or lack of homogeneity. The concept of heterogeneity is closely related to the concept of the scale of its existence. In world science it has been adopted dividing into nano-, micro-, meso- and macroscale; it is useful for describing or classifying with large approximation the extent or size of studied or described phenomena or factors. The nature of the natural and engineering materials is inextricably linked with heterogeneity existence. Proper adoption of the scope of the analysis is essential to determine the prevalence and magnitude of their effect on material properties. The idea of homogeneity and heterogeneity coexistence relates to the uniformity in a substance. A material, which is homogeneous in chemical composition and structurally uniform in macroscale can be at the same time heterogeneous in microscale. Heterogeneity may be related to the structure of matter, as well as to the course of phenomena and processes. Heterogeneity is diverse in its nature, composed of diverse parts, or is a result of different causes. Heterogeneous factors and nonuniform processes occurring during plastic deformation have been classified in this work as heterogeneous factors (HF). For the purposes of this study, the following division of HF present during elevated temperature plastic deformation has been adopted:

(i) material heterogeneity,
   (a) chemical heterogeneity
   (b) physical heterogeneity: heterogeneity of structure, heterogeneity of physical properties, heterogeneity of the stress state
(ii) non-uniform course of: (a) processes, (b) phenomena, (c) effects and (d) mechanisms

A local chemical heterogeneity is correlated with a physical heterogeneity and determines local physical properties and non-uniform course of various processes and mechanisms. Selected examples of heterogeneous factors concerning material heterogeneity and nonuniform course of processes, phenomena, effects and mechanisms related to DMT are discussed in this paper.

Considering behavior of metals during hot forming process, we must take into account not only parameters of deformation process, but also multiple stages of heat treatment, e.g., heating, annealing, cooling, which affect the material structure, often changing it locally. Thermo-mechanical processes cause non-uniform strain across the intersection. Hot rolling, extrusion and forging are the common industrial practices to produce final metal products from ingot with desired mechanical and microstructural properties. Heat treatment process is non-uniform because of multiple stages of annealing and cooling. For example, during heating the interior
regions of the material remain shorter under elevated temperatures than the regions near the surface. Longer time under high temperature allows for more grain growth and - in addition - lowers deformation, leading to different grain structure in the interior than at the surface; recrystallized fraction can vary through the thickness of the ingot.\textsuperscript{9,10}

In various metals it is possible to identify numerous factors, processes, mechanisms and phenomena directly or indirectly correlated or responsible for inhomogeneous hot deformation. Not all of them are individually responsible for loss of ductility and material destruction, but enhancing of deformation heterogeneity is responsible for a diverse range of DMT phenomenon occurrence.

Some factors, mechanism and phenomena associated with non-uniform course of plastic deformation existing within the 0.3-0.7 $T_H$ and associated with DMT and ITE are\textsuperscript{5,31}: geometrical and structural heterogeneity in each scale, evolution of texture and microtexture, differences in quantity and type of crystalline building defects, shape and size of grains, relationship between crystal orientation and mechanical properties of deformed polycrystalline, non-uniformity of chemical composition in each scale, grain boundary premelting, intergranular segregation even of small quantities of alloying additions or impurities, diffusion processes as internal oxidation, DIR, grain boundary diffusion, oxygen-induced intergranular cracking, kind and morphology of grain boundaries and grain junctions, phase transition and change of slip system and slip directions, slip line morphology, grain boundary sliding, cavitation and nucleation, acceleration of micro-cracking, stress concentration and strain location, stress relaxation process, strain induced grain boundary premelting (SIGBP), PLC effect, GBCD, recrystallization and recovery also DRX and DRV, grain boundary serrations, protrusions, unique features and the mechanical properties of newly nucleated grains (temporary existence of ultrafine grains), kind and morphology of grain boundaries and grain junctions, GBS, unequal temperature and its local changes, thermal activated internal dynamic transmutation and many others.

A good example for heterogeneous deformation can occur in many metals and commercial alloys during elevated temperature deformation - the Portevin-Le Chatelier (PLC) effect. It is an evidence of non-uniform deformation. It reveals as irregularities in the form of serrations on the stress-strain curve. The reasons responsible for their appearance are not yet fully explained and views concerning physical basis of the phenomenon are diversified.\textsuperscript{34}

Based on literature studies and research on DMT phenomenon in CuNi25 alloy, a hypothesis of non-uniform deformation can be proposed. Existence of DMT phenomenon is a synergic effect of existing heterogeneities mutually overlapping and tangling, causing non-uniform intermediate temperature deformation. Non-uniform material properties and various strain across intersections of material and concentration of stress and thermal activated processes lead to localization of non-uniform deformation and cracking in a small volume of material causing reduced ductility and destruction of material.

During deformation at 0.3-0.7 $T_H$ processes take place, which generate and provoke superimposition of many "HF" causing local changes of physical, mechanical and chemical properties of material. We can assume that in macroscale we have to deal with materials with different levels of heterogeneity and with different local properties. Deformation process is located in the space prone to easier deformation in these conditions. The critical level of non-homogeneity causes concentration of stress leading to nucleation and growth of cracks. Critical level of local stress concentration causes decrease of ductility and destruction of material. At the temperature above the DRA existence, the heterogeneity level decreases and the ductility increases. With temperature increasing material homogenization progresses and uniform course of phenomena, effects, mechanisms and processes gain importance. Thermally activated processes take place in more areas increasing thus material homogeneity. After reaching suitably high temperature, almost in whole material volume, some HF disappear and other reduce importance which leads to increase of ductility.

**Experimental Procedure**

Due to the specific properties of nickel and copper alloys, they are applied in various domains of industry: mint industry, armaments industry, desalination industry, marine engineering, extensively used in the chemical, petrochemical and electrical industries and many other. Unfortunately, because of their undesired embrittlement and decrease of ductility at intermediate temperatures, these alloys
were subject of many studies\textsuperscript{2,3}. Because of absence of the phase transformation, the single-phase copper nickel alloys CuNi25 seem to be an ideal material for study on two associated phenomena: intermediate temperature loss of ductility and hot brittleness.

In order to find HFs and determine the influence of chemical composition and strain rate on HB and the scale of the DMT phenomenon, two commercial copper nickel alloys CuNi25 were taken. Chemical compositions of investigated alloys have been shown in Table 1.

Two ingots of CuNi25 (A) with dimensions 250\times400\times600\ mm were prepared. One ingot has been cut into pieces and the samples for static tensile test were prepared. The second ingot underwent industrial open-die hot forging process with a 15\% reduction in a single pass. For temperature control the thermocouple Pt-PtRh13 and infrared camera FLIR T425 were used. Thermal camera with object temperature range +200\degree C to +1200\degree C and FLIR QuickReport 1.2 software were used to analyze the images. Second commercial alloy CuNi25 B was prepared in continuous casting process. The plate of alloy has also a dendritic structure and 250 \times 500 \times 15 mm dimensions. The material was cut into bars of square section and turned into identical samples the same as alloy A were made.

Static tensile test was carried out in air and argon atmosphere on the testing machines INSTRON 1195 and INSTRON 4505. Proper tensile temperature was ensured by the electronically controlled resistance furnace equipped with a thermocouple Pt-PtRh13 and electronic temperature controller with accuracy of \pm 2\degree C. The as-cast CuNi25 alloys were deformed with strain rate shown in Table 2. After the static tensile test, the samples were immediately cooled in water to preserve their structure. At each measured temperature 5 samples were deformed.

In order to investigate the microstructure of deformed samples, the study in transmission electron microscope on thin foils was conducted. It was performed on JEOL transmission electron microscope JEM 200. The thin foils were made from samples deformed within 300-800\degree C range. The hardness studies were carried out on microhardness tester Future-Tech FM - 700 using automatic hardness testing system FM - ARS 9000.

The fractographic investigations were made on two scanning microscopes DSM 940 OPTON and SUPRA 25 from ZEISS. For analysis of the chemical composition in micro-regions the JEXA 733 from JOEL with WDS and EDS analyzers was used.

**Results and Discussion**

High temperature tensile test results revealed, that for all cases ductility minimum temperature phenomenon was observed (Figs 2-6). The course of elongation and area reduction curves for all analyzed

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & CuNi25 (A) & CuNi25 (B) \\
\hline
Cu & rest & rest \\
Ni & 25.1 & 24.43 \\
Mn & 0.3 & 0.22 \\
Pb & 0.005 & 0.01 \\
Fe & 0.3 & 0.1 \\
Si & - & 0.033 \\
Zn & 0.3 & 0.1 \\
Sn & - & 0.011 \\
C & 0.05 & 0.016 \\
S & 0.01 & 0.006 \\
Al & - & 0.001 \\
As & - & 0.003 \\
P & - & 0.012 \\
Cd & - & 0.002 \\
\hline
\end{tabular}
\caption{Chemical composition of CuNi25 alloys (\%)}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & CuNi25 (A) & CuNi25 (B) \\
\hline
Cu & 4.2\times10^{-3}\ \ s^{-1}\text{air} & 2.7\times10^{-1}\ s^{-1}\text{air} \\
CuNi25 (B) & 2.7\times10^{-2}\ s^{-1}\text{air} & 2.7\times10^{-1}\ s^{-1}\text{air} & 2.7\times10^{-2}\ s^{-1}\text{argon} \\
\hline
\end{tabular}
\caption{The CuNi25 alloys deformation strain rate}
\end{table}
materials shows strong dependence on the test temperature. The DRA was detected in all cases and according to the different series of samples it varies within the temperature range of 400-750°C. Temperature range of minimum value of elongation and area reduction is different for as-cast CuNi25 A and B alloys. Stress-strain curves are different for both commercial alloys. We can also notice different course of elongation and reduction of area. Correctness of the adopted hypothesis is supported by the presented results of tensile tests. Even a small change in any of the parameters, for example strain rate or chemical composition, causes different course of DMT phenomenon. It states, that the heterogeneous processes of deformation depend on the structure and orientation, as well as condition of internal stress, which proves indirectly about the impact structure HF's on DMT and ITB phenomena. The strain rate of deformation affects the temperature range of ductility minimum. With faster deform, the temperature of DMT phenomenon increases. Disparities in ductility curves depending on the strain rate can be caused by many factors, e.g., metal deformed at high temperatures and low strain rate will store less energy and recrystallize less than under similar strain but at lower temperature, or at higher strain rate. This proves indirectly of deformation heterogeneity. High temperature ductility tests have proved a relation between strain rates, chemical composition and scale of ductility minimum temperature phenomenon. Results of tests performed for specimens of CuNi25 (B) alloy deformed with strain rate $2.7 \times 10^{-1}$ s$^{-1}$ in argon and air atmosphere are very similar, showing existence of DRA between 450-650°C. This may indicate, that for CuNi25 (B) alloy deformed with this strain rate the oxygen diffusion process and internal oxidation play negligible role.

The result of fractographic examination (Fig. 7) shows that for CuNi25 commercial alloys deformed at the 0.3-0.7 $T_H$ range the deformation temperature affects the character of the fracture. Examined copper nickel alloy showed after the tensile test in the temperature below 350°C and above 700°C transcrystalline ductile fracture. In the range of DRA the existing fracture has been changed. It can be noticed neighboring tangled areas with brittle and ductile fracture surfaces and adjoining brittle
intergranular fracture area. On the same sample fracture, in some areas ductile and other brittle places occur (Fig. 8). The temperature range of mixed fracture existence can be termed an intermediate zone. Fractures of various types occur with different intensity and different combinations, but it can indicate that temperature range of the intermediate zone is associated with the gradual fluctuation of ductility. Usually the most intercrystalline brittle fracture was noticed in samples deformed at temperature of minimum ductility existence (Fig. 9).

Even those brittle fractures show very small, local ductile areas (Figs 8 and 9), which may indirectly indicate correctness of the non-uniform deformation hypothesis$^3$.

As a proof of non-uniform deformation of CuNi25 commercial alloys at intermediate temperature we can recognize the Portevin-Le Chatelier (PLC) effect. In CuNi25 alloy it manifests itself as irregularities in the form of serrations on the stress-strain curve (Fig. 10). It proves instability of force during tension and heterogeneity of microstructure and presence of many HFs, affecting its mechanical properties.

Heterogeneous character of deformation was also confirmed by metallographic observations of samples deformed in the range of DRA. It reveals as two types of voids and cracks on grain boundaries. First type of voids is probably a result of not enough accommodation of the grain boundaries’ sliding or cavitations. Second type is represented by usually long cracks, which are located near regions of newly recrystallized grains (Fig. 11).

Macro-, meso-, micro- and nanostructural heterogeneity was seen during laboratory

Fig. 8—The SEM of fracture structure of CuNi25 (A) after tensile test at 525°C

Fig. 9—The SEM of fracture structure of CuNi25 (A) after tensile test in argon atmosphere at 475°C

Fig. 10—The load-displacement curves for CuNi25 (A) alloy deformed at 450°C with strain rate 4.2×10$^{-3}$ s$^{-1}$ in argon atmosphere with visible Portevin-Le Chatelier (PLC) effect

Fig. 11—The structure of CuNi25 (A) after tensile test at 625°C
observations. The TEM observations of all series of CuNi25 samples deformed at 400-600°C show similar regularity in the deformed samples. There are also alternative areas with partially high/partially minor defected structure and almost unspoiled structure. The places with a tendency to accumulation of point and linear defects are grain boundaries, particularly the multiple grain boundaries' junctions and inclusions. These sites generate or accumulate dislocations leading to increase in local stress. One of the mechanisms contributing to the local stress relaxation in DRA is twinning (Fig. 12). Similar mechanism was noticed in copper-nickel alloy by Bruckner. He also stated, that in the whole temperature range of 300-550°C the relaxation differs by about a factor of 10. Mechanical twinning occurring in CuNi25 alloy with accommodation especially at the grain boundaries is a fast process, but there also exists a slower one-grain boundary diffusion, especially during heat treatment.

During elevated temperature deformation the increase in material heterogeneity was observed inter alia due to the deformation mechanisms occurrence. For example diffusion, recovery and dynamic recrystallization existence cause microstructure and microtexture evolution. In the range of DRA, recrystallization and recovery are the competing processes. Both are driven by stored energy. Recrystallization is usually accompanied by reduction in the strength and hardness of a material and simultaneous increase in the alloy ductility. The defects introduced by plastic deformation, primarily dislocations, increase the yield strength of a material. Because recovery reduces the dislocation density, the process is normally accompanied by a reduction in a materials strength and it simultaneously causes local increase in the ductility. As a result recovery may be considered helpful or detrimental - depending on the circumstances.

The changed angle of rotation pertains to the misorientation between the new grain and the parent grains, affecting also mechanical properties of deformed material GBCD and GBC and grain boundary sliding (GBS). It was proved, that there is a relationship between crystal orientation and mechanical properties of deformed polycrystalline metals. The fracture behavior depends even three times stronger on the misorientation angle and test temperature.

TEM and light microscope observations, presumptive evidence directly and indirectly revealed that in samples of both CuNi25 alloys during hot working at DRA the processes of microstructure rebuilding ran, i.e., in the same sample, at the same temperature, dynamic recovery and dynamic recrystallization were observed. With increasing temperature in the range of DRA recrystallization the recovery gain in importance. The grain boundary serrations, cellular dislocation structure of subgrains, local existence of undeformed areas, as well as small new grains were observed. During recrystallization, three process steps occurred: grain nucleation, orientation and growth, which happened simultaneously at different phases in different areas of the sample, increasing the material heterogeneity. We can make assumption that highly deformed regions with newly nucleated recrystallized grains can be treated typically as ultrafine grained metals with “non-equilibrium” grain boundaries. It was noticed by Carlton and Ferreira that materials with grain size in the nanometer range often have different properties such as increased ductility. The inverse Hall-Petch effect implies, that nanocrystalline materials get softer as grain size is reduced below critical value. Probably locally deformed CuNi25 alloy in such places has different mechanical properties, similar to ultrafine grained materials with often so called “non-equilibrium” grain boundaries.

Another example showing occurrence of HF are presented in some results of linear and point analysis of the concentration of alloying elements (Fig. 13). In the studies areas with differences in alloying elements content were repeatedly found. The most significant were Cu and Ni concentrations, especially between two sides of cracks, which confirm the stress.

Fig. 12—The TEM of structure of CuNi25 (B) after tensile test with strain rate $2.7 \times 10^{-4}$ s$^{-1}$ at 400°C
concentration and different mechanical properties of deformed material in these areas. Analysis of chemical composition of non-homogenized as-cast CuNi25 commercial alloy samples deformed at DRA proved existence of difference in concentration of Ni and Cu. Differences in fluctuation for copper achieve even ± 13% on the crack edge (Fig. 13).

Local chemical heterogeneity causes different mechanical properties and non-uniform run of various processes and mechanisms, including thermal activated dynamic internal transmutation and course of the plastic deformation in a wide range of raising temperatures. This leads to uneven distribution of stress and cracks formation. In the studies cracks with differences in Cu and Ni contents between two sides of crack border were repeatedly found. It indicates the stress concentration and different mechanical properties in these areas. Such variation in the chemical composition promotes diffusion processes during heat treatment and hot working. Even if such processes are slow, they may occur in the nano-areas, especially at the grain boundaries (e.g. DIR, grain boundary diffusion and grain boundary segregation), causing non-equilibrium state of the grain boundaries.

In commercially produced alloys, alloying elements due to technological conditions are sometimes distributed unevenly throughout the structure. Non-equilibrium concentration of the alloy components and particles segregation, particularly during casting, cause formation of regions significantly more prone to recrystallization or cavitation, increasing the material heterogeneity.

Another evidence of the occurrence of non-uniform structure and locally different mechanical properties are differences in the microhardness of deformed samples. Microhardness map made in as-cast CuNi25 (A) and (B) alloys samples revealed irregularity in mechanical properties (Fig. 14). The sample of CuNi25 (A) alloy after deformation at 650°C presents 20% differences between extreme values of micro-hardness. The classic "macro" hardness test on the same sample provided results of 80.5 HV. The microhardness test is a good way to determine the prevalence of inhomogeneities and assessing their impact on the metal properties. It is mainly carried out after surface etching. This procedure allows for the selection of areas free of porosities and cracks, allowing to make indentations to determine heterogeneity of material in microscale.

To determine occurrence and as confirmation of experimental studies to verify the course of the DMT phenomenon, as well as for the occurrence of the ITE one of CuNi25 (A) ingots was open-die forged with 15% reduction. The process started at 900°C and finished at DRA after the appearance of cracks at 650°C. The created cracks are present only on the parallel walls of the ingot; it has rather transverse orientation and different length and depth (Fig. 15).

Fig. 13—The structure of as-cast CuNi25 (A) alloy after deformation at 500°C with visible linear and point Cu and Ni concentration analysis

Fig. 14—The structure of CuNi25 (A) after tensile test at 650°C with indicators of micro-hardness testing

Fig. 15—The ingot after open-die forging at 650°C
Many potential causes of DMT and ITE can be, but most likely responsible is non-uniform deformation caused by synergy effect of HF superimpose. The open-die forging is heterogeneous in its nature since multi-step process results in non-uniform stress distribution and unequal pressure. One of many illustrations can be structure of grains during the severe forging deformation leading to the development of adjacent grain clusters having lattice orientations corresponding to the variants of the deformation texture. During hot working multiple stages of annealing take place when deformed metals are heated. During forging and cooling the interior regions of the work-piece remained at high temperature longer than the regions near surface. Longer times at high temperatures allow for more visible grain growth and, in addition to lower deformation, lead to a coarser grain structure in the interior than at the surface causing structural heterogeneity. Slow cooling also leads to the heterogeneous nucleation and growth of large grains. Due to the inhomogeneous structure of hot-worked ingots, recrystallization effects can vary significantly throughout the thickness due to changes in a stored energy and chemical heterogeneity, quantity, size and spatial distribution of intermetallics, dispersoids and inclusions.

Next evidence for heterogeneity of the plastic deformation process can be shown on thermogram made during open die forging (Fig. 16). The linear analysis showed non-uniform temperature distribution on the ingot surface. Especially a decline is visible in areas adjoining with material deformed during previous passes, where additional strain and non-equiaxed stresses exist. Indicated by the infrared camera “loss” of the temperature may be unreal because of the change of emissivity coefficient, caused by locally changed surface structure, which - for example - can be less oxidized. However, this result also demonstrates the heterogeneity of the hot forging process.

In metals deformation process runs similarly, however differently. In many metals and commercial alloys it is possible to identify various mechanisms responsible directly or indirectly for the elevated temperature loss of ductility and often for the existence of mechanisms causing microcracks formation, leading to intergranular fracture and destruction of material. In all cases none of them occurs on its own and it’s always responsible for the DMT phenomenon. In result the critical degree of heterogeneity causes synergetic effect of existing heterogeneities mutually overlapping and tangling, causing non-uniform intermediate temperature deformation.

Conclusions

The results of the investigations carried out on two commercial as-cast CuNi25 alloys demonstrate the presence of hot brittleness and intermediate temperature ductility phenomena effects in all cases. Presented data prove and presumptive evidence demonstrates directly and indirectly correlation between many heterogeneous factors causing non-uniform course of deformation and the ITE and DMT existence. The results demonstrate existence of inhomogeneous deformation and its heterogeneous location within commercial CuNi25 alloys during deformation at 0.3-0.7 $T_H$. Discussion of the results and proposed hypothesis is related to
behavior of metals during elevated temperature nonuniform deformation.

Various structures, forms, conditions and types of deformation in nano-, micro-, meso- and macroscale are correlated with a number of heterogeneous factors leading to different, but always reduced level of ductility affecting ITD and ITE phenomena. Knowledge about conditions and the mechanisms of deformation allows one for appropriate programming of technological cycle of hot, warm and cold working in the industrial practice.

Selection of the parameters values for technology of hot working based only on previously obtained results excluding multiplicity of factors which may occur in various combinations often causes mistakes and errors. Optimization of hot deformation processes is necessary to connect scientific knowledge and commercial needs. However, very important is to be aware of the synergy effect of tangled and overlapping heterogeneity factors causing non-uniform courses of plastic deformations at intermediate temperature values.

References