INVESTIGATION OF DEFORMATION BEHAVIOUR OF THE NICKEL ALLOYS IN 713 LC AND MAR M-247

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Abstract

The paper is focused on investigation of the deformation behaviour of two nickel alloys - IN 713 LC and MAR M-247, delivered in the as-cast state. The aim was to determine physically the nil-strength temperatures and on the basis of tests by uniaxial tension to create 3D maps of plastic and strength characteristics of both these alloys. The determined nil-strength temperatures of the examined materials make 1295 °C for the alloy IN 713 LC and 1310 °C for the alloy MAR M-247. These values are almost by 100 °C lower than those of conventional steels, which indicates an increased susceptibility of these alloys to burning at heating prior to forming. Results of high temperature tensile tests of those alloys correspond to the low nil-strength temperatures. The investigated alloys could be processed by forming in a relatively narrow temperature range of approx. 1000 - 1100 °C (IN 713 LC), or approx. 1000 - 1200 °C (MAR M-247). The experiments were performed on a hot deformation simulator HDS-20, which is operated at the Regional Materials Science and Technology Centre at the VSB - Technical University of Ostrava (VSB-TU Ostrava).

Keywords: Nil-strength temperature, tension test, HDS-20, nickel alloy

1. INTRODUCTION

Majority of nickel-based alloys is alloyed with Al or Ti, which reinforce the matrix. Other elements include Cr, which prevents oxidation and is present in order to increase the corrosion resistance in sulphide environments and also to reinforce the steel. Nb, Mo, W, and Ta are other alloying elements, which in different combinations cause strengthening of solid solution of the basic matrix. The main strengthening effect at high temperatures is, however, caused by precipitation called γ' phase, which is essentially contained as $Ni_3(Al, Ti)$. Dome alloys contain also Co, which improves machinability and stability at high temperatures. Many alloys contain also present B or Zr as additional elements increasing the high-temperature creep properties [1]. A nickel-base superalloy Inconel 713LC (LC = low carbon) was investigated. This is a modification of the alloy Inconel 713C, which was developed primarily for application in integral wheels and blades of rotor turbines. In order to prevent creation of a large amount of carbides the carbon content in this alloy was reduced to the lowest possible level [2 - 4]. The next investigated alloy was the alloy MAR-M-247, which is classified as a Ni-based superalloy; it is cast classically or by precision casting and it is primarily used for components of gas turbines, such as turbine blades, wheels, covers and other devices [5, 6] . In principle, approx. 90 % of all superalloys, which are produced, are used for gas turbines and practically half of the weight of produced drives is assembled from parts made of Ni alloyed superalloys. The superalloys are very suitable for those drives, which operate typically from 540 °C up to 80% of the melting point of the material used. This naturally causes certain deformation at such temperatures, but the super-alloys still provide very good creep and corrosion resistance [7 - 9].

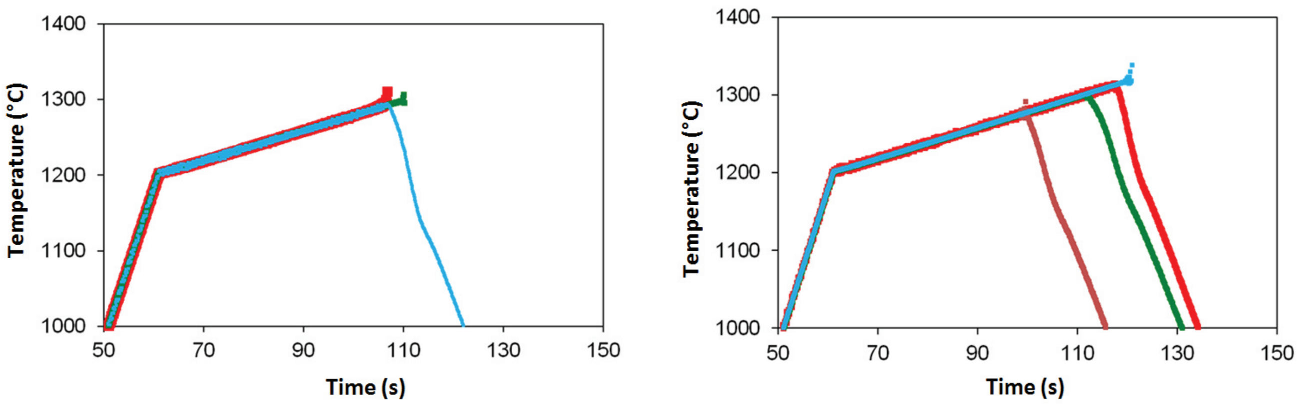
2. OBJECTIVES OF THE WORK

The aim of experiment was to determine the nil-strength temperatures of two nickel alloys - IN 713 LC and MAR M-247, and to create on the basis of tests by uniaxial tension 3D maps of plastic and strength characteristics of both alloys. Chemical composition of these alloys in mass % was for the alloy IN 713 LC: 12.0 Cr - 6.0 Al - 4.1 Mo - 2.0 Nb+Ta - 0.7 Ti - 0.09 Zr - 0.06 C - 0.011 B - (balance Ni) and for the alloy MAR M-247: 9.9 W - 9.9 Co - 8.4 Cr - 5.5 Al - 3.0 Nb+Ta - 1.3 Hf - 1.0 Ti - 0.7 Mo - 0.04 Zr - 0.14 C - 0.015 B - (balance Ni).

3. NIL-STRENGTH TEMPERATURES

Nil-strength temperature corresponds to the temperature of burning of the material during heating and it represents an important information from the viewpoint of choice of the upper forming temperatures, etc. This value was determined using a special method of high-temperature testing in the deformation simulator HDS-20 (or on its basic component - plastometer GLEEBLE 3800) [10 - 12], consisting in application of the controlled heating with interaction of constant, very small tensile force (max. 250 N) to the cylindrical sample with a diameter of 6 mm heated by resistance heating. Heating to the temperature of 1200 °C was conducted at the heating rate of 20 °C / s, next heating in the assumed critical area was performed at the heating rate of 2 °C/s. The nil-strength temperature corresponds to the highest value of the registered temperature (i.e. at the moment of loss of the material cohesion). It is calculated as an average of the values obtained from at least three tests, when anomalous result (affected by internal defects in the material, etc.) are excluded from the calculation.

It is apparent that from the graph in **Fig. 1a**, that for the alloy IN 713 LC the nil-strength temperatures of 1294 °C, 1298 °C and 1292 °C were measured successively, which gives an average value of 1295 °C with a low standard deviation of ± 3 °C. In case of the alloy MAR-M 247 the following values of nil-strength temperatures were successively: 1277 °C, 1313 °C, 1300 °C and 1318 °C (see **Fig. 1b**) - after exclusion of the value of 1277 °C, which gives an average temperature of 1310 °C ± standard deviation of 8 °C. It should be emphasized that in comparison with ordinary commercial steels the investigated alloys show the nil-strength temperature lower almost by 100 °C.



a) alloy IN 713 LC b) alloy MAR M-247

Fig. 1 Record of evolution of temperature during individual tests of nil-strength temperature (the curves for individual tests are distinguished by different colour)

4. METALLURGY OF HOT TENSILE TESTING

Testing of formability by hot uniaxial tension on the plastometer Gleeble 3800 used cylindrical bars with a diameter of 10 mm and a total length of 116.5 mm. Due to the used jaws the length of the part of the sample heated by resistance heating and then deformed was 20 mm. The samples were heated directly to the temperature of testing with dwell at this temperature for 240 s. According to the assumptions the experiment should have cover the deformation temperature in the range from 1250 to 600 °C, which, however, proved to be unrealistic. The speed of motion of the crosspiece was chosen at the levels of from 0.01 - 0.1 - 1 mm/sec. The load force was always registered in dependence on the extension. Where possible, the results were used for calculation of the contractual strength (at the given temperature) and ductility (relative elongation related to the initial length of 20 mm).

5. PLASTIC PROPERTIES OF THE ALLOY IN 713 LC IN HOT STATE

Diagram in **Fig. 2** documents the curves elongation-force for the alloy IN 713 LC and the slowest testing speed. Formability at high temperatures (exceeding 1200 °C) is almost negligible, it increases with the decreasing temperature. It is, however, impossible to evaluate the results at temperatures of 900 °C and lower, since rupture of the bar occurs beyond the heated (tested) zone - most often in the threaded part of the sample. Leap changes in evolution of some curves are noteworthy, as they signal evolution of fractures at various places of the tested bar. **Tables 1** and **2** present summarised results of hot tensile tests.

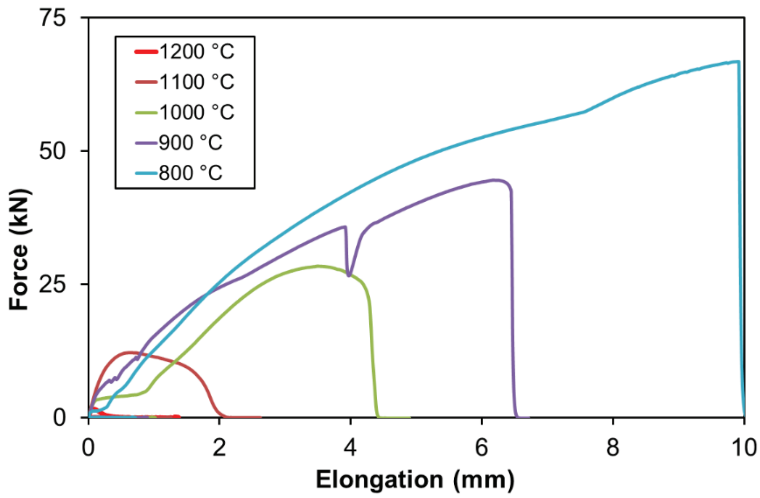


Fig. 2 Influence of temperature on results of tension tests of the alloy IN 713 LC

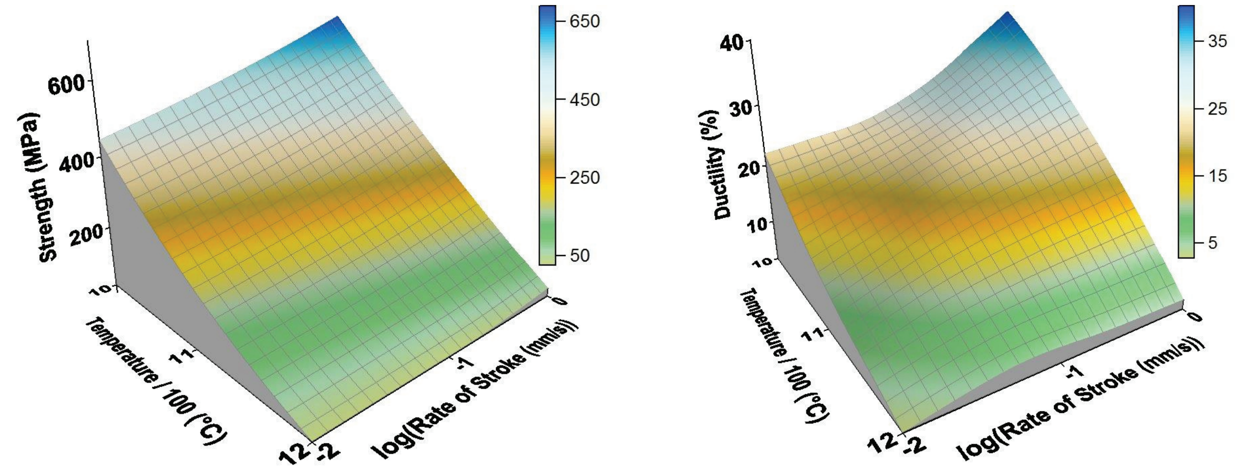
Table 1 Contractual strength (MPa) of the alloy IN 713 LC in dependence on conditions of testing

	0.01 mm/s	0.1 mm/s	1 mm/s
1250 °C			16
1200 °C	25		50
1100 °C	190	258	349
1000 °C	445	557	690

Table 2 Ductility (%) of the alloy IN 713 LC in dependence on conditions of testing

	0.01 mm/s	0.1 mm/s	1 mm/s
1250 °C			5
1200 °C	3		5
1100 °C	10	19	25
1000 °C	22	26	40
900 °C	>32		>49
800 °C	>50		

It is evident that the contractual strength and ductility of the investigated alloy increases with the decreasing temperature and with the increasing rate of forming, the temperature influence being much more significant. This is clearly illustrated also by 3D diagrams of these variables, constructed with use of the software Surfer 8 in experimentally limited temperature range (**Fig. 3**).



a) strength b) ductility

Fig. 3 3D diagrams of plastic properties of the alloy IN 713 LC

6. PLASTIC PROPERTIES OF THE ALLOY MAR M-247 IN HOT STATE

Diagrams in **Fig. 4** document selected curves elongation-force for the alloy MAR M-247. Formability is in comparison with the alloy IN 713 LC almost negligible only at the highest temperature of 1250 °C. At the temperatures of 900 °C and lower ones the bar is ruptured beyond the heated zone. Leap changes in evolution of some curves indicate evolution of fractures in various places of the tested bar.

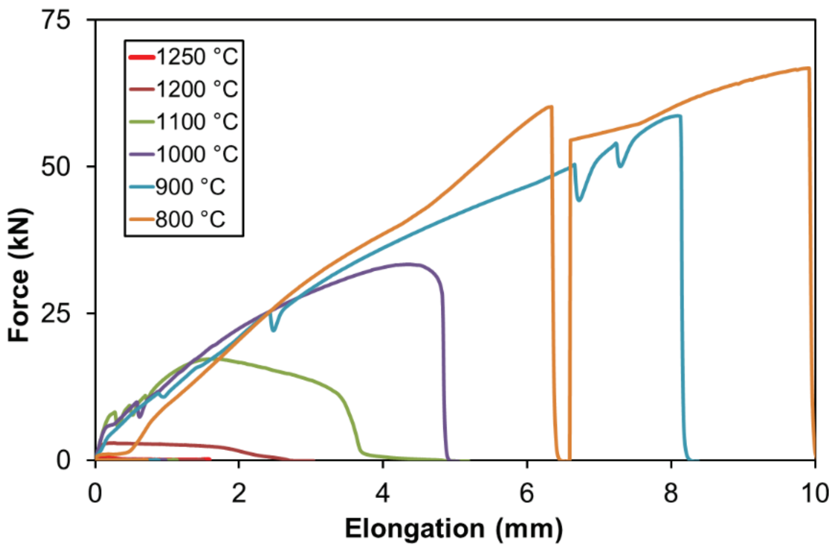


Fig. 4 Influence of temperature on results of tension testing of the alloy MAR M-247

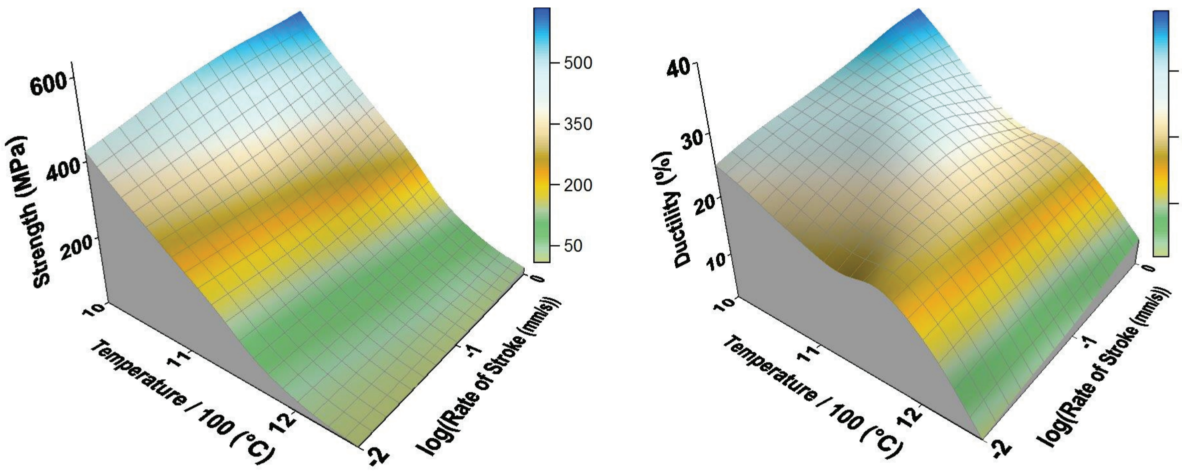
Tables 3 and 4 present summarised results of hot tensile tests. Contractual strength and ductility in this alloy also significantly increase with the decreasing room temperature and with moderately increasing rate of forming - see 3D diagrams in **Fig. 5**).

Table 3 Contractual strength (MPa) of the alloy MAR M-247 in dependence on conditions of testing

	0.01 mm/s	0.1 mm/s	1 mm/s
1250 °C	9	14	29
1200 °C	37		90
1100 °C	220	255	358
1000 °C	425	552	636

Table 4 Ductility (%) of the alloy MAR M-247 in dependence on conditions of testing

	0.01 mm/s	0.1 mm/s	1 mm/s
1250 °C	2	4	7
1200 °C	13		16
1100 °C	18	27	24
1000 °C	24	32	39
900 °C	>41		
800 °C	>32		



a) strength

b) ductility

Fig. 5 3D diagrams of plastic properties of the alloy MAR M-247

7. CONCLUSIONS

Nil-strength temperatures of the examined materials were determined by special plastometric method: 1295 °C for the alloy IN 713 LC, and 1310 °C for the alloy MAR M-247. These values are almost by 100 °C lower than those of ordinary commercial steels, which signals and increased susceptibility of these alloys to burning during heating prior to forming.

Results of high-tem tension test of those alloys correspond to low nil-strength temperatures. Ductility of the alloy IN 713 LC is at the temperatures exceeding 1200 °C (particularly at 1250 °C) almost negligible, in the case of the alloy MAR M-247 it is slightly better with prudent possibility of application of the forming temperature up to 1200 °C.

Taking into account the above exception, the strength (contractual strength) and plastic properties (relative elongation to rupture) of both alloys are very similar, which is - in respect to difference of their chemical composition - rather surprising: they increase relatively gradually with the increasing rate of forming and they increase very significantly with the decreasing temperature. This is documented by 3D diagrams in the limited temperature range (min. 1000 °C), given by atypical deformation behaviour of both alloys at lower temperatures.

Plastic deformation of both investigated materials at the temperatures of 900 °C and lower ones is accompanied by an initiation of bigger number of cracks, even beyond the heated part of the sample (probably in relation with casting defects). Although plasticity of both materials is at those temperatures better than at higher temperatures, low technological formability practically excludes use of this interesting phenomenon in practice. It would be possible to process those alloys by forming in relatively narrow temperature range of approx. 1000 - 1100 °C (IN 713 LC), or approx. 1000 - 1200 °C (MAR M-247).

ACKNOWLEDGEMENTS

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