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HOT WORKING BEHAVIOUR OF INCONEL 718 SUPERALLOY

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Present paper has the aim of establishing the plastic forming behavior of the INCONEL 718 superalloy used for turbine engines. The experiments were realized in laboratory conditions, on a free-falling dawn hammer, with high of free falling about H = 0.2 m, and the falling dawn mass about 71 kg. The determinations were made in the range of temperatures about 1100 – 1250°C, at every 50°C. Finally, the graphics of plastic forming versus temperature and mechanical working versus temperature were drawn. The final conclusion was that the optimum range of temperature for hot working of the INCONEL 718 alloy is 1150 ÷ 1250°C, in which the plastic forming resistance and specific hot working are optimum.

Keywords: deformability, optimum range for plastic forming, INCONEL 718 superalloy

1. Introduction

The physical-mechanical properties of a metallic material, in correlation with the chemical composition and structure may condition the behavior of the material during plastic deformation. Deformability is a complex technological feature that depends on the value of plasticity index and resistance to plastic deformation of the metal material analyzed and how the two parameters change depending on the material factors or specific deformation conditions. The obtaining of the plastic forming products [1-6], with no internal or external defects and with precise mechanical properties could be realized by applying some correct establishing technologies, where the properties which characterize the formability of the metallic materials, such as plasticity or forming resistance must ne known at design. Knowing the plastic forming resistance in connection with the nature of the metallic material and the plastic conditions by pressure represents one of the main problem which must be taken into account at the selection of the forging device and the heating range of temperatures [4,7].

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In turn, the resistance to plastic deformation is determined either by tensile testing, by compression or upsetting test [8-12]. Because the external force is transmitted through the metallic material that acts in the same direction and the same sense, sometimes by plastic deformation one may understand the required load for metals and alloys to pass from the elastic to plastic state [6, 13].

This paper aims to establish the plastic deformation behavior (ie determining the optimum hot plastic deformation) of a INCONEL 718 superalloy.

2. Materials and Experimental Procedure

Since direct measurement of forming stress is difficult, requiring special equipment performance to determine the optimum of forging temperatures, resistance to deformation of the material at the test temperature was determined indirectly based on the relationship of deformation work:

$$L = \sigma_c' \left(1 + \frac{1}{3}\mu\frac{d_1}{h_1}\right).V.\varepsilon_u \quad (1)$$

where: L – forming mechnical work [J, Nm]; σ'_c – forming resistance of the materials at the test temperature [N/m²]; μ – external friction coefficient; d_1, h_1 – average diameter and sample high after forming [mm]; V – material volume which is plastis formed [m³]; ε_u – unit plastic forming degree obtained at one blow, calculated with the relation:

$$\varepsilon_u = \frac{h_o}{h_o} \quad (2)$$

Where h_0 is initial high of the sample. The average diameter of the plastic formed sample by upsetting may be established with the help of the equation from the constant volume law:

$$d_1 = d_0\sqrt{\frac{h_0}{h_1}} \quad (3)$$

Table 1

Values of the rate coefficient w and external friction coefficient μ

Type of device		**Mechanical pressure**			**Hammers**	**Hammers with free blow**
Platic forming rate $W_a = \frac{h_0 - h_1}{t^*}$		10...25	25...75	>75	4...8	5
Unit measure		cm/s			m/s	m/s
Rate Coefficient *w*		1,2...1,6	1,6...2,0	2,0...2,5	2,0...4,0	3
Friction coeficientul *μ*	**hot**	0,25...0,5			0,2...0,4	
	Cold with lubrication	0,12...0,06			0,12...0,06	

t^* - time at the deformation occurs from h_0 to h_1.

Note: If using grease, the hot friction coefficient is reduced by 15÷25%.

The work of equation (1) can be replaced with energy falling part of the hammer hitting the free fall. This energy can be expressed by the formula:

$$E = G\ x\ H\ x\ \eta \tag{4}$$

where: G – the mass of the falling part of the hammer, [N]; H – height of the hammer fall, [m]; η – hammer return.

By replacing of L with blow energy $E = G{\cdot}H{\cdot}\eta$ the forming resistance may be determined:

$$\sigma_c' = \frac{G.H.\eta}{\left(1+\frac{1}{3}.\mu\frac{d_1}{h_1}\right).V.\varepsilon_u} \tag{5}$$

Sometimes, for simplicity, the plastic forming resistance σ'c may be replaced with specific mechanical work. In turn, the specific plastic forming work is determined based on the plastic forming degree obtained with the same blow energy E at the upsetting of the cylindrical specimens heated at different temperatures. The calculation formula used is as:

$$A = \frac{E}{V_d}1000, \quad [J/mm^3, Nm/mm^3] \tag{6}$$

where: A – the specific plastic forming work ;
V_d – materials volume dislocated during upsetting (în mm3), which is determined by the relation:

$$V_d = V.\varepsilon_u, \quad [mm^3] \tag{7}$$

For the determination of the two parameters σ'_c and A versus temperature, the blow energy is mentioned constant, only test temperature being modified. The test specimens from the same charge have the same dimensions and different final plastic forming degree. Obviously, all the rest of the conditions for the upsetting, such as forming rate, external friction forces may influence the plastic forming degree, respectively forming resistance and specific mechanical work etc. Therefore, in order to obtain comparable results it was necessary, outside forming temperature change,that the remaining conditions must be are maintained to the same values for all tests.

Experimental measurements were performed at a free fall hammer (pile driver) in the endowment "Forging, die-casting, extrusion laboratory" of the Faculty of Materials Science and Engineering of the University Politehnica of Bucharest. Falling height used was H=0.2 m and the mass m=71kg shooting party; using three test pieces for each test temperature within the range 1100÷1250°C, the determinations being made from 50 to 50°C. Heating the hot plastic deformation to the drop hammer has been carried out in an oven with forced heating rods, located in the immediate vicinity of the pile. The samples were cut from the original cast specimens by electroerosion, having initial diameter d_0=10 mm and height h_0=15mm. The main data considered working in experimental determinations were: the weight of the falling hammer G = 695.8 N (m = 71 kg); hammer drop height H=0.2m; the coefficient of friction μ=0.3 (hot, without lubricant); free falling hammer yield, determined by the method of Heim was about η = 0.7 (70%).

According to Heim's method, the return hammer free fall is dependent on the size and height of the fall of the hammer. To determine this, they discharged several specimens of pure lead, with as few impurities, having the specific gravity equal to 11.3 kg/ dm^3 , the ratio of height and diameter cylindrical specimens was 1.5. In order to determine the impact energy of the hammer the following relationship was used:

where:

$$E = d_o^3[2.7\varepsilon + 4(\varepsilon^2 + \varepsilon^4)], \text{ [kgf]} \qquad (8)$$

d_o represents the initial diameter of the sample [cm]

ε- upsetting degree at one blow, expressed by the relation:

$$\varepsilon = \frac{h_0 - h_1}{h_0}$$

h_o and h_1- initial, respectively the final high of the specimen which is upsetted.

The return of the free fall hammer was calculated with the relation:

$$\eta = \frac{E}{E_n} x100 = \frac{E}{GxH} x100 \qquad [\%] \qquad (9)$$

where:

G represents the weight of the shooting, in kg,

H- Height of fall of the hammer, in m.

The return of the free-fall hammer used in our experimental measurements determined according to the method of Heim, the height of the fall used, H=0.2m, was made with a electric forced furnace bars serving free fall hammer and ensured a maximum temperature of 1600°C warming.

3. Results and Interpretations

After the upsetting, the average height of the outlet (h1) has been made for each temperature all the experimental measured and calculated results being shown in Table 2. The results thus obtained were carried out graphs of the variation in deformation resistance - temperature or specific mechanical work - temperature. All the data were obtained considering a return hammer a free fall η = 0.7 (70%) (Heim’s method), corresponding to the drop height about H = 0.2 m. It should be also noted that, in the present case, the friction coefficient of the material to deformation and outside working tools was considered as μ = 0.30 (if hot plastic deformation without lubrication). The weight of the falling hammer (pile) was G = 695.80 N corresponding to a mass of m = 71 kg. Fromm all the specimens after hot pile driver, there were selected only the specimens with no cracking. This selection of specimens allows a complete macro-structural analysis, which revealed the fracture behavior of these materials. Macroscopic appearance of a specimen cracked after striking suggestive pile is shown in Fig. 1, which stands that rupture propagation has a plan to 45◦, according to the Schmidt’s law.

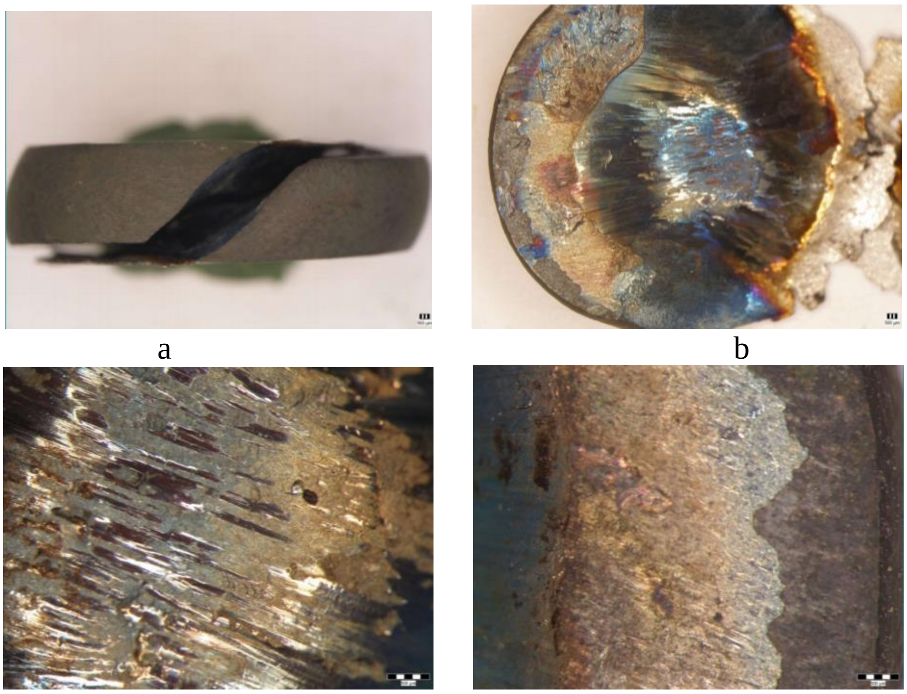

Fig. 1 -Macrostructural analysis of fracture behavior at 950°C sample after 1.55m high:
a) longitudinal appearance; (b) transversal cross section, center of sample;
c) detail of b; d) edge appearance of transversal section

At the same time fracture is a specific aspect transgranular ductile fracture, as shown in the left-right images of the fracture surfaces. It follows that this alloy, in cast state as taken directly after melting and heating for hot tapping behaves hot ductile breakage, having different color surfaces from blue to violet, due to alloying elements.

Table 2-

Experimental results concerning plastic forming resistance of the experimental INCONEL 718 superalloy

H * **[m]**	0,78	1,15	1,50	1,68	1,65	1,50	1,05	0,55
T **[°C]**	**800**	**900**	**950**	**1000**	**1050**	**1100**	**1150**	**1200**
h_0 **[mm]**	15,00							
h_1 **[mm]**	10,43	6,84	4,98	4,33	4,11	4,04	4,97	7,66
ε_a **[%]**	30,47	54,40	66,80	71,13	72,60	73,07	66,87	48,93

* - blowing high of the hammer at which the sample is not destroyed

The experimental results shown in table 2 were processed for plotting the graphs of forming resistance versus temperature (Fig. 2) and specific mechanical work versus heating temperature for the analyzed alloy (Fig. 3).

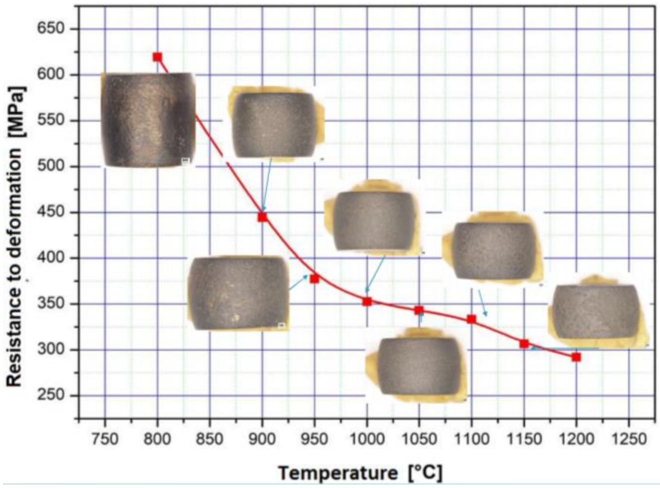

Fig. 2 – Plastic forming resistance versus heating temperature of the INCONEL 718 experimental superalloy

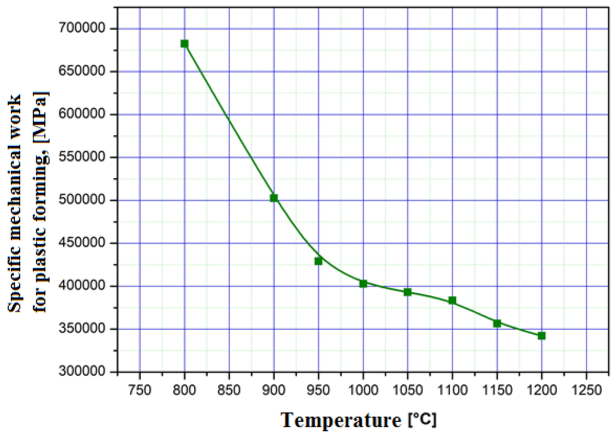

Fig. 3 – Specific mechanical work versus heating temperature of the INCONEL 718 experimental superalloy

After analyzing the graphs of variation of the two parameters σ'_c and A versus heating temperature one can observe that with increasing temperature, resistance to plastic deformation of the investigated INCONEL 718 superalloy decreases in the investigated range temperature. Similarly, specific work done considerable plastic deformation decreases with increasing temperature. In other words, the obtained data shown that both strength yield and specific mechanical work of deformation decrease with increasing temperature, as a curve whose slope varies to some of the experimental range temperature.

Both forming resistance and specific hot forming mechanical work roughly decrease up to the 950°, have a bearing appearance in the range of 950 ÷ 1050°C, then begin to decrease slowly; this behaviour is probably due to intergranular compounds which begin to melt at low temperatures. Compared to other alloys or class of superalloys, or from other systems, it can be considered that Inconel 718 superalloy has a range of deformable located quite high, having fracture behaviour with ductile character and transcystalline shiny appearance.

4. Conclusions

The optimum range of temperature for hot plastic deformation of Inconel 718 superalloy, strictly in terms of resistance to deformation, is in the range of 950 ÷ 1050°C, because the deformation resistance of the material values and the specific mechanical work of deformation are optimal;

Both forming resistance and specific hot forming mechanical work roughly decrease up to the 950°, have a palier appearance in the range of 950 ÷ 1050°C, than begin to decrease slowly; this behaviour is probably due to intergranular compounds which begin to melt at low temperatures; The admissible forming degree is very high in the range of 950 ÷ 1050°C, around 65%-75%, having a steep increase up to the temperature 950°C; Compared to other alloys or class of superalloys, or from other systems, it can be considered that Inconel 718 superalloy has a range of deformable located quite high, having fracture behaviour with ductile character and transcystalline shiny appearance.

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