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Thermal properties of cast nickel based superalloys

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ABSTRACT

Purpose: Evaluation of specific heat and thermal conductivity of nickel based superalloys.

Design/methodology/approach: Investigation of thermal conductivity of commercial nickel based superalloys: In 713LC, In 100 and Udimet 700 was performed. Measurements were carried out from 20°C up to 1250°C using the laser flash method. The thermal conductivity was calculated as a function of density, specific heat and thermal diffusivity.

Findings: Thermal conductivity of superalloys depends on the chemical composition of alloy and the temperature. Thermal conductivity increases with the increase of the temperature from 9.8 $Wm^{-1}K^{-1}$ at 23°C to 29.5 $Wm^{-1}K^{-1}$ at 1197°C for In 713LC.

Research limitations/implications: Results can be used to describe the microstructure changes in the material during heat treatment.

Practical implications: Thermal conductivity is an important physical property of material which enable to evaluate the usefulness of metallic material to high temperature structural applications.

Originality/value: The paper presents the change in thermal diffusivity, thermal conductivity and specific heat of cast nickel based superalloy as a function of temperature.

Keywords: Superalloys; Specific heat; Thermal diffusivity; Laser flash

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MATERIALS

1. Introduction

Nickel based superalloys are used primarily in turbine of aircraft engines, marine and power industry. The operating temperature of these materials ranges from 150°C up to almost 1500°C. The high- temperature strength of superalloys is based on the principle of a stable austenitic matrix (γ phase) combined with solid solution hardening and/or precipitation strengthening. Thermal stability of γ phase, the possibility of solid solution hardening and precipitation strengthening, high elastic modulus of the matrix are main factors which define the application of superalloys. High solubility of many elements such as cobalt, iron, chromium, molybdenum and tungsten gives the possibility of strength of austenitic matrix. The addition of aluminum and titanium causes precipitation of an ordered compound based on formula $Ni_3(Al,Ti)$ which is coherent with austenitic γ matrix. This phase is required for high - temperature strength and creep resistance [1-9].

Disadvantageous property of superalloys is low thermal conductivity which is due to the high percentage of alloying elements. Thermal conductivity is an important physical property of materials which enable to evaluate the usefulness of a metallic material to high temperature structural applications. Rapid heat transfer afforded by high thermal conductivity enables efficient cooling which moderates the appearance of life limiting heat-attacked spot. High thermal conductivity assures also a uniform temperature distribution, which reduces thermally - induced stresses and thereby improves fatigue properties [9-10].

The aim of the present work was to evaluate the thermal properties of cast nickel based superalloys and the dependence of these properties on the temperature.

2. Experimental procedure

The thermal properties of nickel based superalloys: In 713LC, In 100 and Udimet 700, were investigated (see Table 1). The measurements of specific heat, thermal diffusivity and room-temperature bulk density, were performed. This data was used to compute the thermal conductivity by the following equation:

$$\lambda(T) = \rho \cdot c_p(T) \cdot a(T) \quad (1)$$

with: λ - thermal conductivity;
ρ - bulk density;
c_p - specific heat;
a - thermal diffusivity;
T - temperature.

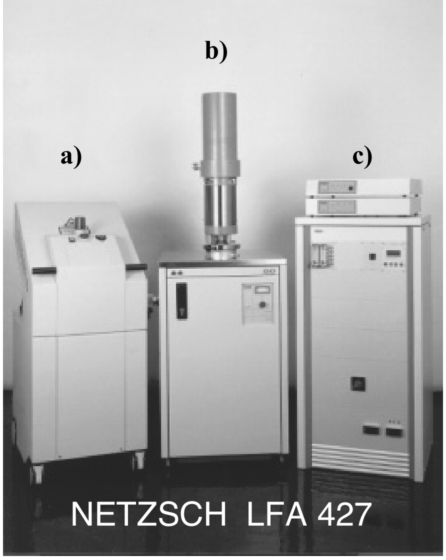

Fig. 1. General view of LFA 427 device: a) laser system connected via fiber optics, b) measuring unit with furnace, a sample carrier and In-Sb detector, c) controller for measuring unit

The thermal diffusivity was measured using a NETZSCH model 427 laser flash diffusivity apparatus presented in Fig. 1 [11,12]. The unit used in this work was equipped with a high-temperature, water-cooled furnace capable of operation from 25 to 2000°C. The sample chamber is isolated from the graphite heating element by a protective tube allowing samples to be tested under vacuum or in an oxidizing, reducing or inert atmosphere. The sample's front surface receives a pulse of energy from the laser. The absorbed heat travels through the specimen thickness causing the increase of back face temperature which is properly measured by an In-Sb detector along the time. Data acquisition and evaluation are accomplished by a comprehensive PC software package. The LFA 427 operates in accordance with national and international standards such as ASTM E-1461, DIN 30905 und DIN EN 821.

The thermal diffusivity measurements were conducted under argon between room temperature and 1250°C. Special sample holders with additional adapter rings were used due to different dimensions of samples. The samples were coated with graphite on the front and back surfaces in order to increase absorption of the flash light on the sample's front surface and to increase the emissivity on the sample's back surface. The presented thermal diffusivity results are the average values of five individual tests. The density of samples was measured by the buoyancy flotation method.

3. Results and discussion

The change in thermal diffusivity, thermal conductivity and specific heat of superalloy In 713LC as a function of temperature was measured (Fig. 2). Thermal conductivity of In 713LC at the room temperature is 9.8 $Wm^{-1}K^{-1}$ (Table 2). The thermophysical properties were also measured for alloys with additional aluminide NiAl coating (Fig. 2, Table 2). NiAl is a high thermal conducting compound of which thermal conductivity is approximately 92.2 $Wm^{-1}K^{-1}$ [13]. The difference in thermal conductivity at 25°C for samples with and without layer is less than 5%. A little difference in the values of thermal conductivities of superalloy In 713LC with and without aluminide coating is due to the higher substrate thickness than the coating one [12].

Similar dependencies of thermal properties were detected for sample In100 (Fig. 3, Table 3). Thermal conductivity at the room temperature of this alloy is 9.1 $Wm^{-1}K^{-1}$. Lower values of thermal conductivity are the results of higher alloying elements contamination in this superalloy (see Table 1). Slight steps were detected in thermal diffusivity, heat capacity and thermal conductivity for all samples above 500°C (Figs. 2, 3). Much the same results was obtained by Przeliorz and other authors [14] who investigated the heat capacity of superalloys by the DSC method. They observed the increase of heat capacity above the temperature of 500°C and then the drop up to the temperature of 700°C, on the DSC curve. This phenomena is probably due to the distribution of γ' phase [15]. Between temperature of 700°C and 800°C the thermal conductivities remains constant and then slightly increase (Figs. 2, 3). Lower values of thermal diffusivity and conductivity were detected for samples of Udimet 700 which has the highest alloying elements content (Fig. 4, Table 4).

Table 1.
Chemical compositions of investigated alloys

Superalloy	Elements content, %mass									
	Ni	Cr	Co	Mo	Al	Ti	C	B	Zr	Nb
Inconel 713LC	74	12.5	-	4.2	6.1	0.8	0.05	0.012	0.1	2.0
Inconel 100	60	10	15.0	3.0	5.5	4.7	0.18	0.014	0.06	-
Udimet 700	58	14.6	15.0	4.2	4.3	3.3	0.07	0.016	0.04	-

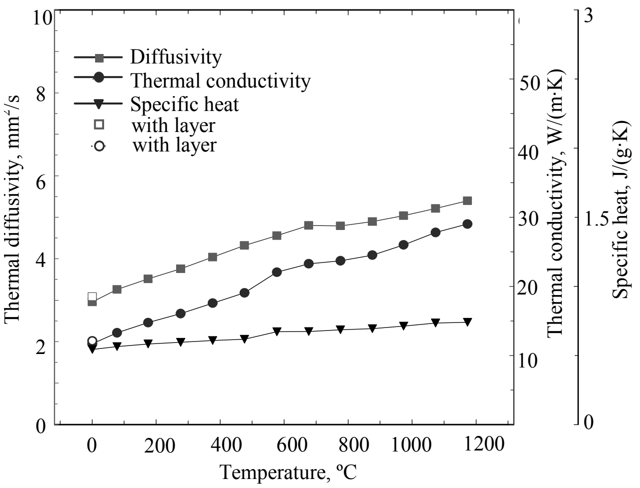

Fig. 2. Thermal diffusivity, thermal conductivity and specific heat of superalloy In 713LC as a function of temperature

Table 2.
Thermal diffusivity, thermal conductivity and specific heat of superalloy In 713LC as a function of temperature

Superalloy: In 713C - density: 7.950 g/cm^3			
Temperature, °C	Thermal diffusivity, mm^2/s	Specific heat, J/(g·K)	Thermal conductivity, W/(m·K)
24	2.783 (with layer: 2.929)	0.444	9.823 (with layer: 10.288)
101	3.129	0.467	11.617
199	3.420	0.489	13.295
300	3.695	0.503	14.776
400	4.017	0.517	16.510
500	4.337	0.528	18.205
601	4.606	0.590	21.604
701	4.887	0.592	23.000
800	4.877	0.606	23.496
900	4.995	0.615	24.422
997	5.157	0.637	26.116
1097	5.351	0.662	28.162
1197	5.564	0.668	29.548

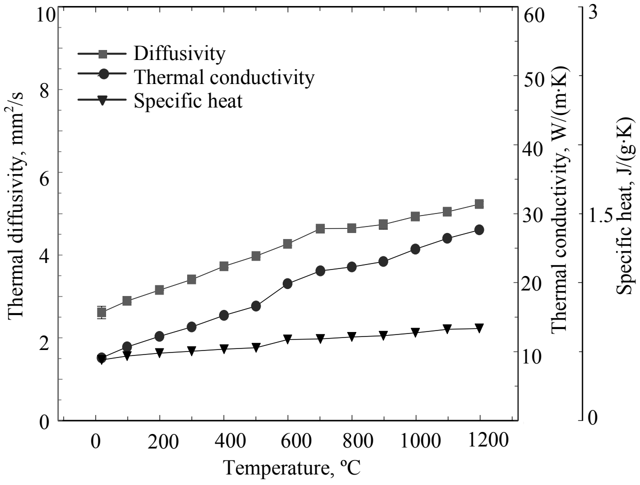

Fig. 3. Thermal diffusivity, thermal conductivity and specific heat of superalloy In 100 as a function of temperature

Table 3.
Thermal diffusivity, thermal conductivity and specific heat of superalloy In 100 as a function of temperature

Superalloy: In 100 - density: 7.910 g/cm^3			
Temperature, °C	Thermal diffusivity, mm^2/s	Specific heat J/(g·K)	Thermal conductivity, W/(m·K)
18	2.613	0.440	9.094
98	2.891	0.467	10.679
199	3.154	0.489	12.200
299	3.410	0.503	13.567
401	3.729	0.517	15.250
500	3.977	0.528	16.610
599	4.269	0.588	19.855
701	4.637	0.592	21.714
799	4.649	0.606	22.285
898	4.738	0.615	23.049
998	4.932	0.637	24.851
1097	5.045	0.662	26.418
1197	5.232	0.668	27.645

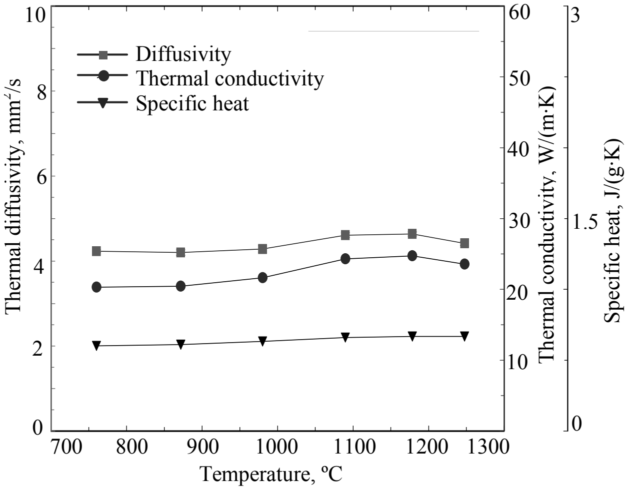

Fig. 4. Thermal diffusivity, thermal conductivity and specific heat of superalloy Udimet 700 as a function of temperature

Table 4.
Thermal diffusivity, thermal conductivity and specific heat of superalloy In 100 as a function of temperature

Superalloy Udimet 700 - density: 7.988 g/cm³			
Temperature, °C	Thermal diffusivity, mm²/s	Specific heat, J/(g·K)	Thermal conductivity, W/(m·K)
760	4.232	0.601	20.317
872	4.200	0.610	20.465
980	4.283	0.633	21.657
1090	4.610	0.660	24.304
1178	4.638	0.668	24.748
1248	4.415	0.668	23.558

4. Conclusions

Thermal conductivity of superalloys depends on the chemical composition of alloy and the temperature. It was confirmed that alloying elements decrease the thermal conductivity of superalloys. Thermal conductivity increases with the increase of the temperature from 9.8 $Wm^{-1}K^{-1}$ at 23°C to 29.5 $Wm^{-1}K^{-1}$ at 1197°C for alloy Inconel 713LC, 9.0 $Wm^{-1}K^{-1}$ at 19°C to 27.6 $Wm^{-1}K^{-1}$ at 1197°C for Inconel 100 and 20.3 $Wm^{-1}K^{-1}$ at 760°C to 23.6 $Wm^{-1}K^{-1}$ at 1248°C for Udimet 700. Slight steps were detected in thermal diffusivity and conductivity for samples above 500°C which is probably due to the distributing of γ' phase.

Acknowledgements

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