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THERMO-PHYSICAL PROPERTIES OF SELECTED INCONEL ALLOYS

WŁAŚCIWOŚCI TERMOFIZYCZNE WYBRANYCH STOPÓW TYPU INCONEL

The paper brings results of examinations of main thermo-physical properties of selected Inconel alloys, i.e. their heat diffusivity, thermal conductivity and heat capacity, measured in wide temperature range of 25-900°C. The mathematical relationships of the above properties vs. temperature were obtained for the IN 100 and IN 713C alloys. These data can be used when modelling the IN alloys solidification processes aimed at obtaining required structure and properties as well as when designing optimal work temperature parameters.

Keywords: Inconel alloys, LFA method, thermo-physical properties

Praca dotyczy badań głównych właściwości termofizycznych wybranych stopów typu Inconel, to jest współczynników dyfuzji ciepła, przewodności cieplnej i ciepła właściwego, mierzonych w szerokim zakresie temperatury 25-900°C. Matematyczne zależności ww. właściwości w funkcji temperatury dotyczą stopów IN 100 oraz IN 713C. Uzyskane w badaniach dane mogą być wykorzystane podczas numerycznego modelowania krzepnięcia i projektowania stopów typu IN o pożądanej strukturze i właściwościach a także projektowania optymalnych temperaturowych parametrów pracy.

1. Introduction

The nonferrous-based foundry alloys have been developed for many decades and their properties have been continuously improved by applying, for instance, grain refinement, heat treatment or protective coatings. The Ni-based cast superalloys are widely used in aircraft turbines as well as other constructions working in high temperatures and chemically aggressive environments. These alloys, e.g. the ones designated Inconel, show good strength properties in temperatures as high as 1000°C and high corrosion resistance at the same time [1-2]. The properties of these alloys can be further improved by employing heat treatment [3], optimization of chemical composition [4] and/or by coating with aluminide layer made on their surfaces by CVD process [5]. As mentioned above, the other processes aimed at improving properties of nonferrous-based cast alloys, e.g. the ZnAl-based ones or Al-Si, are grain-refinement by heterogeneous nucleation or electromagnetic stirring [6-11]. Currently designing of the cast alloys foundry technology commonly uses numerical simulations of solidification processes and processes of shaping structure and properties of castings. The basis of simulations are processes of heat exchange in mould – casting – ambient systems [12-13]. The simulations require the knowledge of many process parameters as the input-data, for instance melt overheating, thermo-physical properties of moulds and auxiliary materials (e.g. risers insulating sleeves), thermo-physical properties of casting material in liquid and solid state [14-17]. The present paper is devoted to evaluating thermo-physical properties of the Inconel alloys IN 100 and IN 713C in temperature range of 25-900°C.

2. Materials and Experimental

The main aim of these examinations was evaluating temperature relationships of the following thermo-physical properties: heat diffusivity, thermal conductivity and heat capacity. These parameters are the key coefficients of the Fourier-Kirchhoff equation used in built algorithms of numerical simulation [12-13], [19].

The chemical nominal compositions of the examined alloys IN100, IN713C and low carbon IN713LC whose thermo-physical properties were examined in [17], are collected in Table 1.

The experiments were performed on NETZSCH LFA 427 (Laser Flash Analysis) instrument [18], for temperatures 25, 200, 500 and 900°C. The samples examined were discs ø 12.5 × 7 mm, which were carefully rinsed in ethanol and dried before mounting in the instrument. During the experiment the argon-protective atmosphere was used.

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TABLE 1

Chemical composition of the examined IN100 and IN713C alloy and its low-carbon alternative IN713LC [1]

Alloy designation	Nominal chemical composition									
	C	Ni	Cr	Co	Mo	Al	B	Ti	Ta	Zr	Other
IN100	0.18	60.5	10	15	3	5.5	0.01	5	–	0.06	1 V
IN 713C	0.12	74	12.5	–	4.2	6	0.012	0.8	1.75	0.1	0.9 Nb
IN713LC	0.05	75	12	–	4.5	6	0.01	0.6	4	0.1	–

TABLE 2

Results of the thermo-physical measurements of the Inconel 100 (IN 100) and Inconel 713C (IN 713C) by the LFA method. Reference mass density of the samples 8.2 g/cm^3

Temperature [°C]	Heat Diffusivity [mm^2/s]	Standard Deviation [mm^2/s]	Thermal Conductivity [W/(m*K)]	Heat capacity [J/(g*K)]
IN 100				
25.3	3.078	0.072	10.109	0.4
199.1	3.289	0.009	12.27	0.458
500.8	3.971	0.021	16.225	0.509
900.3	4.567	0.046	22.957	0.649
IN 713C				
24.4	2.803	0.026	9.954	0.433
199.4	3.276	0.092	13.76	0.516
500.1	4.366	0.02	22.03	0.629
901.1	5.042	0.0209	31.717	0.792

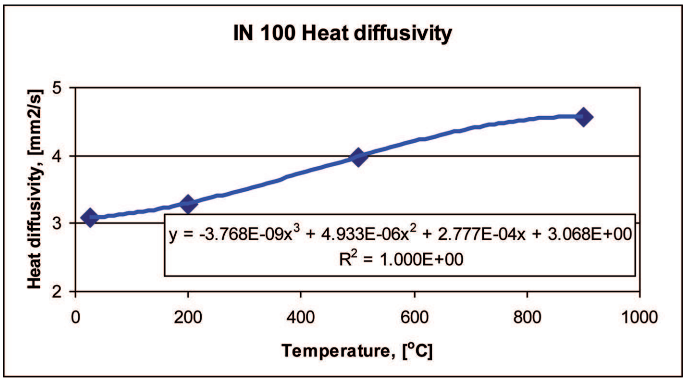

Fig. 1. Heat diffusivity of IN 100 alloy vs. temperature

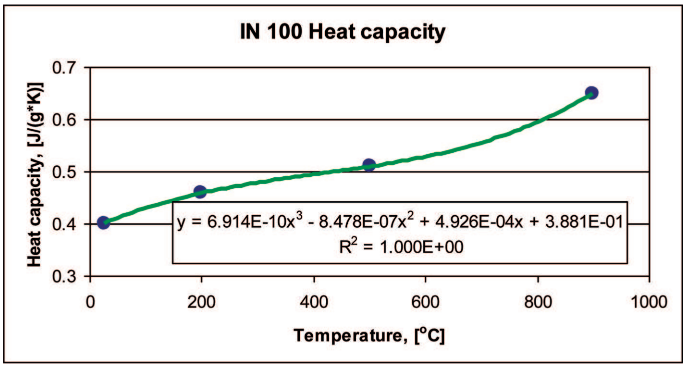

Fig. 3. Heat capacity of IN 100 alloy vs. temperature

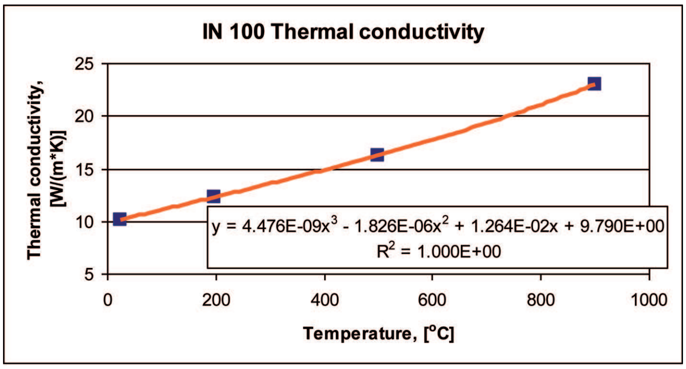

Fig. 2. Thermal conductivity of IN 100 alloy vs. temperature

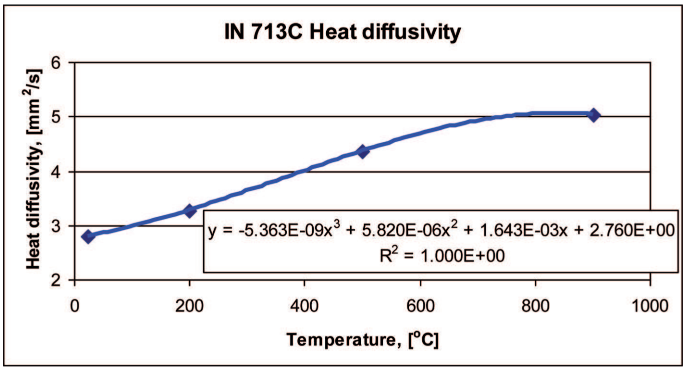

Fig. 4. Heat diffusivity of IN 713C alloy vs. temperature

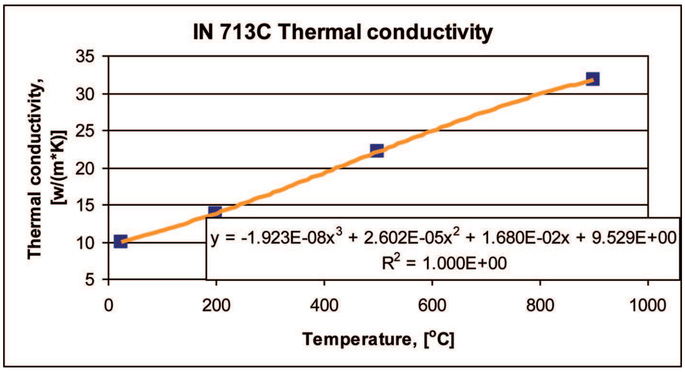

Fig. 5. Thermal conductivity of IN 713C alloy vs. temperature

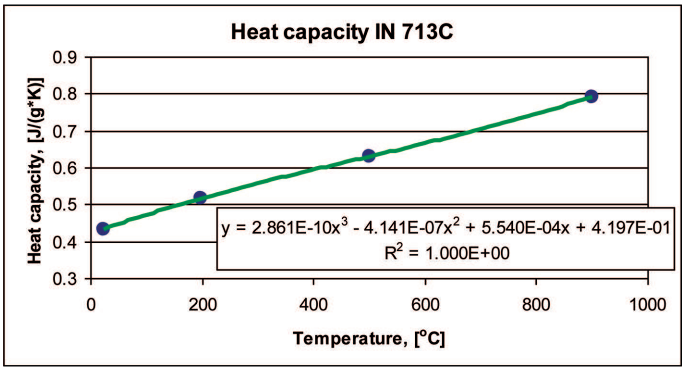

Fig. 6. Heat capacity of IN 713C alloy vs. temperature

The results presented in Figs 1-6 show that examined properties can be described by polynomial of 3^{rd} degree with very high accuracy in the measured range and these temperature relationships can be used in built calculation algorithms instead of the mean values. As it was mentioned above the thermo-physical properties of the low carbon IN713 alloy, i.e. IN713LC, were examined by LFA method in [17]. Comparing the results presented here with the ones published in [17] it can be seen, that obtained values of the heat diffusivity and thermal conductivity are very closed for IN100 alloy, while heat capacity shows differences by about 10%. On the other hand the obtained values of heat diffusivity are very close for IN713C (this paper) and IN713LC [17]. However, the thermal conductivity and heat capacity are higher by 20-30% for the IN713C alloy (this paper), especially in temperatures above 200°C. The above differences should be taken into account while performing numerical simulations for these alloys.

3. Conclusions

Basing on the obtained results it should be concluded that the temperature dependencies of the Inconel alloys thermo-physical properties should be used during the numerical simulations and/or designing their temperature work parameters. Using mean values can lead to high inaccuracy of the calculations because the measured coefficients significantly change their values in temperature range of 20-900°C, i.e. in relation to the values at ambient temperature by:

Inconel IN 100:	Inconel IN 713C
Heat diffusivity by 50% Thermal conductivity by 125% Heat capacity by 60%	Heat diffusivity by 80% Thermal conductivity by 220% Heat capacity by 80%

The distribution of the obtained point-values allows describing the measured thermo-physical properties with accuracy close to $R^2 \sim 1$ when using polynomial function of 3^{rd} degree. These relationships can be directly implemented as the input-data in modelling algorithms.

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