Linear thermal expansion coefficient of porous stainless steel

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Abstract. The experimental results of the thermal expansion study of porous steel 12KH18N9TL in the temperature range 293–1173 K are presented. An anomalous change in the linear thermal expansion coefficient is found in the vicinity of 550 K. The temperature dependences of the thermal properties before and after heat treatment are obtained and reference tables of recommended values are calculated.

1. Introduction
The linear thermal expansion coefficient (α, LTEC) of structural materials is the most important characteristic, since its value affects the design of equipment parts operating at high or low temperatures. The studied porous steel 12KH18N9TL belongs to the class of heat-resistant alloys of the austenitic type with a carbon content of up to 0.12% [1]. Analogs in other countries are alloys J92630, J92701 (USA); SCS13, SCS13A (Japan); 302C25, ANC3A (England); ZG12Cr18Ni9Ti, ZG1Cr18Ni9, ZG1Cr18Ni9Ti (China). Steel is used for casting various engineering parts operating at a temperature not exceeding 973 K [2]. A wide temperature range of operation suggests knowledge of changes in the thermal properties of the material. One of the most sensitive methods for phase analysis of solid materials is dilatometric. The purpose of this work was an experimental study of the LTEC of porous steel 12KH18N9TL in the range 293–1173 K.

2. Method and experimental equipment
The measurements were carried out by the dilatometric method according to the method described in detail in [3] on a DIL-402C installation (NETZSCH, Germany) in a helium atmosphere with a purity of 99.995 vol. %. The holder and pushrod of sintered corundum and the thermocouple of S type were used. The expansion was recorded by an inductive displacement transducer (LVDT) with a resolution of up to 0.125 nm, when heating–cooling rate of the furnace was 2 K/min and at 30-minute isothermal exposure at the maximum temperature. The zero stroke of the dilatometer was determined by the standard corundum sample under identical conditions of the main experiments. The systematic error was determined experimentally on samples of aluminium (99.99 wt. %) and platinum (99.93 wt. %). The analysis has shown that the difference between our and reference data [4, 5] does not exceed 3%.

3. Results and Discussion
For measurements, a parallelepiped sample (25×1.44×5.85 mm) obtained by machining the initial material was prepared. The plane parallelism of the end surfaces relative to each other was ensured by sample processing on the SGM-402/15 (NETZSCH) setup. Density at the room temperature was determined by geometric dimensions and mass. Steel had a porous structure (figure 1). From a
comparison of its density and the density of rolled steel 12KH18N10T steel [6], the porosity was calculated, which amounted to 4.5%.

![Image](image.png)

**Figure 1.** The initial structure of steel samples 12KH18N9TL.

Two series of measurements were carried out, each including three heating–cooling cycles, in the temperature ranges of 293–773 K (4490 points) and 293–1173 K (4530 points, figure 2). The experiments demonstrated good reproducibility of the results in each series of measurements. In the temperature range of 500–675 K, a deviation from the linear dependence was observed (figure 3), which is typical for nonporous stainless steels of similar grades [7, 8]. Fitting curves were obtained by processing the raw data using the least squares method by polynomials:

$$\alpha(T) \times 10^6 = \sum_{i=0}^{k} A_i T^i,$$

where $\alpha(T) = \frac{1}{L_{293}} \left( \frac{\partial L}{\partial T} \right)_p = \left( \frac{\partial \varepsilon}{\partial T} \right)_p$; $\varepsilon(T) = \left( L(T) - L_{293} \right)/L_{293} \times L_{293}$ and $L(T)$ is the sample length at 293.15 K and $T$, respectively; $\varepsilon$ is relative expansion of the sample; and $p$ is pressure. The coefficients of equations (1) are given in table 1. The random approximation error was 0.1–0.25% for a confidence level of 95%. The smoothed values of linear and volume ($\beta$) thermal expansion coefficients, relative expansion ($\varepsilon$) and density ($\rho$) are presented in table 2.
Figure 2. Initial data of the porous steel LTEC obtained in the first series of measurements, and smoothed by the Savitsky-Golay method (a second-degree polynomial in 75 points).

Figure 3. Data comparison of steels LTEC.

1, 2 — results of the first and second series of measurements;
3, 4 — data [7, 8] for non-porous steels 12KH18N9TL and 12KH18N10T, respectively.
Table 1. Coefficients of the equation (1).

| No of reg. | $T$, K | $A_0$ (K$^{-1}$) | $A_1$ (K$^{-2}$) | $A_2$ (K$^{-3}$) | $A_3$ (K$^{-4}$) |
|------------|--------|-----------------|-----------------|-----------------|-----------------|
| 1          | 293.15–511 | 14.974          | 2.606×10$^{-3}$ | 9.007×10$^{-6}$ | –               |
| 2          | 511–598    | −88.013         | 55.8273×10$^{-2}$ | −9.7415×10$^{-4}$ | 5.6779×10$^{-7}$ |
| 3          | 598–773    | 24.7385         | −2.2386×10$^{-2}$ | 2.1094×10$^{-5}$ | –               |

The first series of experiments

The second series of experiments

Table 2. Smoothed values of linear and volume thermal expansion coefficients, relative expansion and density of porous steel grade 12KH18N9TL.

| $T$ (K) | $\alpha$ (10$^{-6}$ K$^{-1}$) | $\beta$ (10$^{-5}$ K$^{-1}$) | $\epsilon$ (10$^{-6}$) | $\rho$ (kg m$^{-3}$) | $\alpha$ (10$^{-6}$ K$^{-1}$) | $\beta$ (10$^{-5}$ K$^{-1}$) | $\epsilon$ (10$^{-6}$) | $\rho$ (kg m$^{-3}$) |
|---------|-------------------------------|-----------------------------|-----------------------|------------------|-------------------------------|-----------------------------|-----------------------|------------------|
| 293.15  | 16.51                         | 4.95                        | 0                     | 7563             | 16.81                         | 5.04                        | 0                     | 7639             |
| 350     | 16.99                         | 5.09                        | 952                   | 7541             | 17.21                         | 5.16                        | 967                   | 7617             |
| 400     | 17.46                         | 5.23                        | 1813                  | 7522             | 17.65                         | 5.29                        | 1838                  | 7597             |
| 450     | 17.97                         | 5.38                        | 2698                  | 7502             | 18.18                         | 5.44                        | 2733                  | 7577             |
| 500     | 18.53                         | 5.54                        | 3611                  | 7482             | 18.79                         | 5.62                        | 3657                  | 7556             |
| 525     | 18.74                         | 5.60                        | 4077                  | 7471             | 19.12                         | 5.71                        | 4131                  | 7545             |
| 550     | 18.82                         | 5.62                        | 4547                  | 7461             | 19.32                         | 5.77                        | 4612                  | 7534             |
| 575     | 18.86                         | 5.63                        | 5018                  | 7450             | 19.33                         | 5.77                        | 5095                  | 7523             |
| 600     | 18.90                         | 5.64                        | 5490                  | 7440             | 19.28                         | 5.75                        | 5578                  | 7513             |
| 625     | 18.99                         | 5.66                        | 5963                  | 7429             | 19.22                         | 5.73                        | 6059                  | 7502             |
| 650     | 19.10                         | 5.69                        | 6439                  | 7419             | 19.20                         | 5.72                        | 6539                  | 7491             |
| 675     | 19.24                         | 5.73                        | 6919                  | 7408             | 19.21                         | 5.72                        | 7019                  | 7480             |
| 700     | 19.40                         | 5.78                        | 7402                  | 7398             | 19.22                         | 5.72                        | 7500                  | 7470             |
| 750     | 19.81                         | 5.89                        | 8382                  | 7376             | 19.27                         | 5.73                        | 8461                  | 7448             |
| 773     | 20.04                         | 5.96                        | 8840                  | 7366             | 19.30                         | 5.74                        | 8905                  | 7439             |
| 800     | –                             | –                           | –                     | –                | 19.34                         | 5.75                        | 9427                  | 7427             |
| 900     | –                             | –                           | –                     | –                | 19.59                         | 5.81                        | 11372                 | 7384             |
| 1000    | –                             | –                           | –                     | –                | 19.95                         | 5.91                        | 13349                 | 7341             |
| 1100    | –                             | –                           | –                     | –                | 20.44                         | 6.04                        | 15367                 | 7297             |
| 1173    | –                             | –                           | –                     | –                | 20.87                         | 6.16                        | 16874                 | 7265             |
Figure 3 shows a comparison of our results with published data. It can be seen that the difference between the LTEC of porous steel in the region of the local maximum and the LTEC of non-porous steel reaches 10%, which is higher than the error of our and reference data. The physical reason for the appearance of anomalies in the thermal expansion of porous steel is not clear and requires additional studies.

Conclusion
For the first time, experimental data on the thermal expansion of 12KH18N9TL porous steel have been obtained. An anomalous change on the LTEC has been found in the region of 500–675 K. It has been revealed that heat treatment affects the temperature of the anomaly and the nature of the LTEC change in this temperature range.

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References
[1] Gulyaev A P 1986 Moscow: Metallurgy 544
[2] http://www.splav-kharkov.com/en/e_mat_start.php?name_id=254
[3] Kozlovskii Yu M and Stankus S V 2014 High Temp. 52 536
[4] Kroeger F R and Swenson C A 1977 J. Appl. Phys. 48 853
[5] Kirby R K 1991 Int. J. Thermophys. 12 679
[6] http://www.splav-kharkov.com/en/e_mat_start.php?name_id=329
[7] http://metallicheckiy-portal.ru/marki_metallov/sto/12X18H9TL
[8] GSSSD 59–83 1984 Moscow: Publishing House of Standards 7