Knowledge E
Engaging minds

**Conference Paper**

# Impact of Cooling Character on Structure and CTE of Cast Invar Alloy Made from Secondary Raw Materials

## A. S. Zhilin, S. V. Grachev, V. R. Ramazanova, and O. V. Maslova

Ural Federal University named after the first Russian President B.N. Yeltsin, Russia, 620002, Ekaterinburg, street Mira, 19

## Abstract

Metallography analysis of invar alloys made from secondary raw materials and crystallized with different cooling rates has been carried out. The study has demonstrated that velocity of crystallization has an impact on the dispersity of graphite. The higher velocity of cooling, the more dispersive graphite is. The volume percentage of graphite in alloy, crystallized with high cooling rate, is lower than compared with low cooling rate. Crystallization with low cooling rate leads to the reduction of the amount of carbon into $\gamma$-phase. The coefficient of thermal expansion is basically depends on the amount of carbon into $\gamma$-phase.

**Keywords:** invar, alloying, carbon, $\gamma$-phase, graphite, coefficient of thermal expansion, crystallization

**Note:** This paper was originally published on http://icie-rus.org/icie2017-eng.html [A.S. Zhilin et al., "Impact of Cooling Character on Structure and CTE of Invar Alloy with 0.6%C", Solid State Phenomena, Vol. 265, pp. 807-810, 2017] on 2nd September, 2017. It is re-published in KnE Materials Science to reach a new audience.

🔓 **OPEN ACCESS**

## 1. Introduction

Modern material science is paying special attention to the development of precision cast alloys. The first reason is their active usage in oil and gas industry [1]. Invar precision alloys allow to receive materials with low values of temperature coefficient of linear expansion (CTE) ($\alpha_{20-100} < 3 \cdot 10^{-6}\text{K}^{-1}$). Secondly, the effect of invar has a fundamental scientific interest because of its unclear origin. Constantly increasing need for large products manufacturing from the invar of alloys sets the task of creation new manufacture technologies for large products [2]. Consequently studying precision alloys on the Fe-Ni base alloyed by carbon is not only the practical interest consisting in the possibility of manufacture of large products on foundry technologies but also particular scientific interest owing to absence of complete understanding of
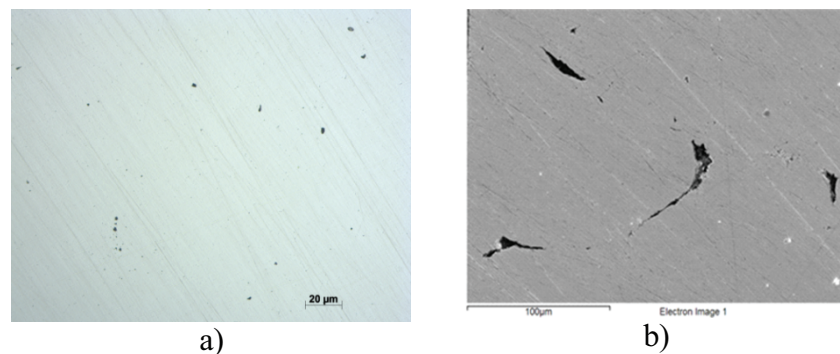
<center>a)</center>



<center>b)</center>

**Figure** 1: Microstructure of quick-(a) and slow (b) cooled alloys.

behavior the invar of properties in case of carbon in alloys. Carbon is initially entered into alloys for the purpose of temperature fall of crystallization. However along with the improvement of technological effectiveness of alloys there is a degradation in functional properties of alloys, in particular, thermophysical properties [3]. Therefore the research of structure formation processes of alloys plays an important role in case of development of new materials having precision properties [4].

## 2. Results and Discussions

This work is aimed at studying the processes of structure formation and temperature coefficient of linear expansion of industrial precision alloy depending on crystallization conditions.

The analysis of quick and slow cooled alloys microstructures has been carried out in the Common use center UrFU using microscopes of Axio Vert A1 of Carl Zeiss and "Jeol JSM-6490LV" equipped with the power dispersive Oxford Inca Energy 350 microanalyzer. Values of CTE have been measured by the dilatometer "Linseis L78".

The microstructure of the analyzed alloy is presented in the form by $\gamma$-solid solution (iron-nickel austenite). Carbon inclusions are traced in the form of untied phase of graphite. Graphitic inclusions are located in all amount of polished specimen.

According to the analysis of quick cooled alloy (Figure 1) graphite is preferentially distributed in a finely-divided state with a diameter of particles up to 3 microns.

Table 1 contains the statistical data of analysis including a scatter between minimum and maximum diameters of particles and also the calculated volume fraction of graphite. Diameter distribution of graphitic particles depending on their frequency of distribution is given in Figure 2.

In slow cooled alloy morphology and pattern of distribution of graphite inclusions are absolutely different. The volume ratio of graphite inclusions in slow cooled alloy is higher compared with quick cooled due to more developed graphitization and the

| Alloy | Absolute fraction, [%] | Min size, [$\mu$m] | Max size, [$\mu$m] | Average size, [$\mu$m] |
|---|---|---|---|---|
| Quick cooled | 0,11 | 0,7 | 3,3 | 1,8 |
| Slow cooled | 0,16 | 7,1 | 180 | 12,4 |

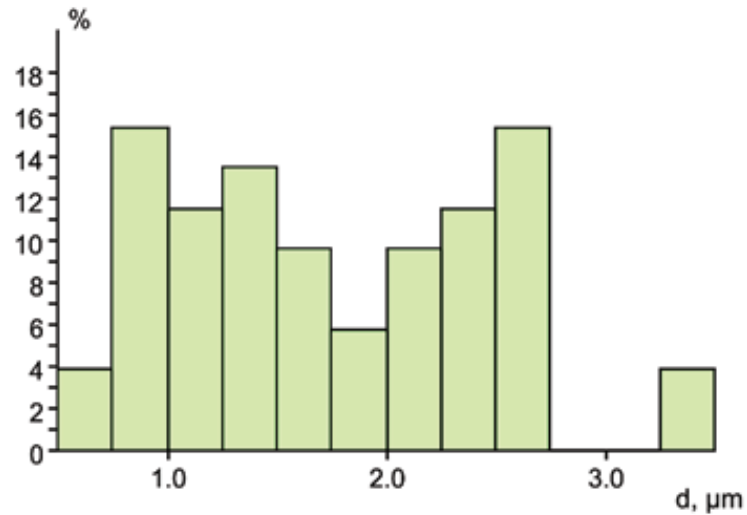TABLE 1: Results of analysis of quick cooled sample in SIAMS program.



**Figure** 2: Dependence of diameter distribution of graphite particles from their frequency of distribution in quick cooled alloy.
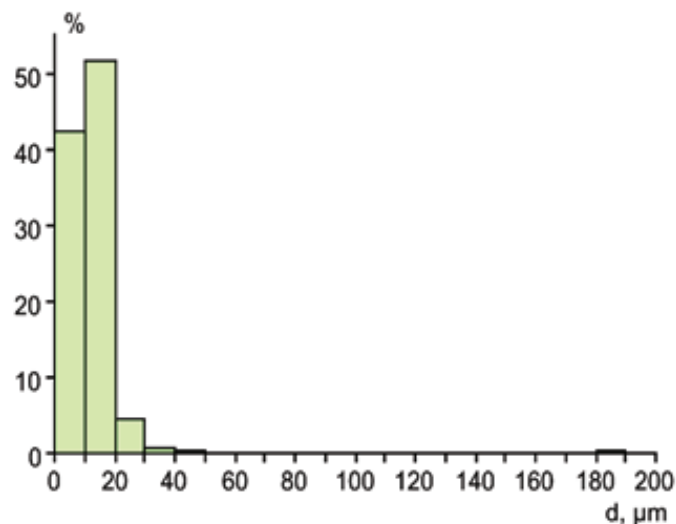


**Figure** 3: Dependence of diameter distribution of graphite particles on their frequency of distribution in slow cooled alloy.

achievement of quasi-equilibrium state of graphitization at slow velocity of crystalliza-tion. At a high velocity of cooling carbon doesn't manage to pass from $\gamma$-solid solution into free graphite. Finally it leads to the solid solution, saturated with carbon, which is the carrier low the invar of properties. Distribution on diameter of graphitic particles depending on their frequency of distribution is given in Figure 3.

| Heating temperature | 100 °C | 150 °C | 200 °C | 250 °C | 300 °C |
|---|---|---|---|---|---|
| Quick cooled alloy, 1-st heating | 2,2 | - | - | - | - |
| Slow cooled alloy, 1-st heating | 2,3 | - | - | - | - |
| Quick cooled alloy, 2-d heating | 2,8 | 2,6 | 2,3 | - | - |
| Slow cooled alloy, 2-d heating | 2,5 | 2,4 | 2,3 | - | - |
| Quick cooled alloy, 3-d heating | 2,8 | 2,6 | 2,4 | 2,9 | 3,9 |
| Slow cooled alloy, 3-d heating | 2,5 | 2,4 | 2,4 | 2,9 | 4,3 |

TABLE 2: Results of dilatometric analysis (values are set in в $\alpha \cdot 10^{-6} K^{-1}$).

Feature of both alloys is the existence of graphite in the form of very small particles (3-7 $\mu$m). The origin of fine graphite can be connected with the influence of eutectic transformation at alloy crystallization. During the growth of solid solution dendrites depleted by carbon in interdendritic space there can be portions of liquid with the increased content of carbon. This portion of liquid breaks up on the eutectic reaction to graphite and $\gamma$ - solid solution during further cooling. The influence of the eutectic transformation on processes of structure formation of carbon-containing invar alloys represents a serious fundamental problem of further studying of cast carbon-containing precision alloys.

Measurements of relative lengthening quick and slow cooled alloys are made. On the basis of the obtained data average CTE of alloys in the set temperature intervals have been calculated: 20-100°C; 20-200°C; 20-300°C. It is shown that at primary heating at 100°C, both analyzed alloys have shown low and minimum values of CTE (to $2,2 \cdot 10^{-6} K^{-1}$). It is interesting that initially low CTE shows quick cooled alloy in a cast state that, most likely, is connected with the tension in alloy structure. The subsequent heatings equalize CTE of both alloys (Table 2).

Upon transition of interval of 230-260 °C there is a sharp growth of relative lengthening and values of CTE that is connected with the magnetic transformations which are followed by transition through Curie's point. It is defined that Curie's points for quick and slow cooled alloys lie in the range of 230 - 250 °C.

## 3. Conclusion

As a result of the performed work it is established that in quick cooled alloy graphite is mainly distributed in spherical shape, in slow cooled alloy in vermiculated form. Average values of CTE in the set temperature intervals are defined. It is shown that

consecutive heatings in low-temperature area don't lead to the change of expansion parameters of both alloys that is a necessary condition of ensuring high functional properties in work of precision products.

## 4. Acknowledgments

## References

[1] M. Shiga, "Invar alloys," Current Opinion in Solid State and Materials Science, vol. 1, no. 3, pp. 340–348, 1996.

[2] G. V. Shcherbedinskii and Yu. L. Rodionov, "Multifunctional alloys with a regulated complex of hardly compatible mechanical and physicochemical properties," Russian Metallurgy (Metally), pp. 554–563, 2001.

[3] A. S. Zhilin, S. V. Grachev, N. A. Popov, S. B. Mikhailov, V. V. Tokarev, and S. M. Nikiforova, "Features of structure formation in super-invar alloys additionally doped with carbon, Higher Educational Institutions News," Oil and Gas, pp. 91–94, 2014.

[4] S. V. Grachev, M. A. Filippov, V. I. Chermenskii et al., "Thermal properties and structure of cast carbon-containing invar and superinvar alloys after two-stage annealing," Metal Science and Heat Treatment, vol. 55, no. 3-4, pp. 124–128, 2013.