Archives
of Materials Science
and Engineering

Volume 104
Issue 1
July 2020
Pages 23-29

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

DOI: 10.5604/01.3001.0014.3866

The effect of thermal treatment of the melt before crystallization on the structure and properties of castings

S.Ye. Kondratyuk *, V.I. Veis, Z.V. Parkhomchuk
Physico-Technological Institute of Metals and Alloys of the National Academy
of Sciences of Ukraine, 34/1 Acad. Vernadskoho Ave., Kyiv 03680, Ukraine
* Corresponding e-mail address: mom@ptima.kiev.ua
ORCID identifier: https://orcid.org/0000-0002-4978-6740 (S.Y.K); https://orcid.org/0000-0001-8889-2303 (V.V.); https://orcid.org/0000-0002-3026-8951 (Z.V.P)

ABSTRACT

Purpose: The aim of the proposed research is to investigate the influence of temperature and duration of isothermal melt processing on structural characteristics of castings in connection with technological background of charge metal.

Design/methodology/approach: Ferrous and non-ferrous alloys were obtained by remelting a charge with a dispersion-structured structure (which was ensured by high-speed crystallization). Remelting was carried out at different temperatures of overheating of the melt over the liquidus with different isothermal exposure at these temperatures. Experimental castings were crystallized under normal conditions. It was studied a change of structure formation and mechanical characteristics depending on the temperature and duration of thermal treatment of the melt before crystallization.

Findings: It is established that isothermal treatment of the melt at the overheating of the liquid metal above a certain equilibrium temperature of the micro-inhomogeneous melt (T_e) causes a gradual loss of hereditary characteristics of the original charge metal, increase of the chemical homogeneity of the melt and the formation of crystallization and formation a corresponding change in the mechanical properties of castings.

Research limitations/implications: The results can be complemented by studies of the effect of thermal treatment in the temperature range of crystallization.

Practical implications: The results can be used to select the optimal heat treatment during remelting and, accordingly, the mechanical properties of the resulting casting.

Originality/value: The obtained results testify to the predominant influence of temperature on the dispersion of the cast structure of steels, given the duration of technological operations of preparation and casting of steels in the manufacture of castings in industrial conditions.

Keywords: Steel, Aluminium alloy, Isothermal treatment, Crystallization, Heredity of structure, Mechanical properties

Reference to this paper should be given in the following way:

S.Ye. Kondratyuk, V.I. Veis, Z.V. Parkhomchuk, The effect of thermal treatment of the melt before crystallization on the structure and properties of castings, Archives of Materials Science and Engineering 104/1 (2020) 23-29. DOI: https://doi.org/10.5604/01.3001.0014.3866

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Modern research on the hereditary connection of the structure of liquid and solid metal in the charge-melt-casting system opens the possibilities of purposeful control of crystallization processes, structure formation and formation of properties of cast products by changing the temperature-kinetic parameters of melt preparation in the pre-crystallization period, including using structural heredity.

Nowadays, the phenomenon of structural heredity is widely studied on ferrous and non-ferrous metals. Influence of the temperature of the overheated melt and its cooling rate during crystallization on the formation of the cast structure of steel castings was studied by Kondratyuk, Yang Hu et al. [1-3]. The influence of the remelting temperature on the structural heredity and technological properties of aluminium castings was studied by Sanin, Bondarev et al. [4,5]. Summarizing the research results obtained by authors, we can conclude that among the technological factors that determine the formation of the cast structure and the mechanical properties of metals, the dominant role is played by the intensity of heat removal during the solidification of castings.

Also interesting are studies in the field of the microstructure heredity conducted by Polish authors on cast irons [6,7]. Authors found that the type of carburiser affects the solidification process [6] and structure of the melted cast iron [7].

It is known that a real metal melt is characterized by short-range structures and a certain micro-heterogeneity of the structure, which naturally change depending on the liquid metal overheating relative to the liquidus and its equilibrium temperature (T_e) [8].

Summarizing the views of different researchers, we can assume that T_e – is the temperature of disordering and reducing the size of clusters, the achievement of a melt of certain equilibrium microhomogeneity and loss of hereditary properties of charge metal.

Despite some of the successes of researchers in determining the optimal overheating temperatures of metal melts and its duration [9,10], the influence of these parameters on the formation of cast structure and properties of cast products has not been sufficiently studied and requires further systematic studies.

The aim of the proposed research is to investigate the influence of temperature and duration of isothermal melt processing on structural characteristics of castings in connection with technological background of charge metal.

2. Experimental procedures

The study was carried out using non-ferrous and ferrous alloys. AW-2031 alloy was chosen as a non-ferrous alloy, which was obtained by remelting a charge with a dispersion-structured structure (which was ensured by high-speed crystallization (Fig. 1a) of the following chemical composition: 2.28% Cu; 0.18% Mn; 0.32% Fe; 0.50 Si; the rest is Al. Remelting was carried out in a steel crucible at different temperatures of overheating of the melt over the liquidus (T_L=650°C) – 700, 750 and 800°C with isothermal exposure at these temperatures for 10, 20, 40 and 60 minutes. Experimental castings with a diameter of 40 mm and a height of 75 mm were crystallized in a crucible in air with an average cooling rate of 40-45°C/min.

As a ferrous alloys, two structural medium-carbon steels were used, one of which (45HGSTFL) has an experimental chemical composition (developed by the authors in the course of this experiment). Complete chemical composition of the used steels is listed in Table 1.

For steels 45L and 45HGSTFL as a charge used rapidly cooled (Vc = 600°C/sec) during crystallization metal (Fig. 1b,c) obtained by inkjet technology (ospray). Steel charge metal with dispersed cast structure was melted at temperatures of normal (1530°C) and high (1600°C) overheat of the melt over liquidus with isothermal holding at these temperatures for 5, 10 and 20 minutes before crystallization in green sand moulds that provided a melt cooling rate of 5 °C/sec.

Metallographic analysis was performed on a light microscope with a 100 and 200-fold magnification. Grain size number of steels was determined according to the ISO 643:2012 [11].

Table 1.
The chemical composition of steels

Steel	Weight fraction of elements, %							
	C	Mn	Si	Cr	Ti	V	P	S
45L	0.46	0.80	0.45	-	-	-	0.035	0.025
45HGSTFL	0.46	1.12	1.30	1.50	0.18	0.43	0.035	0.025

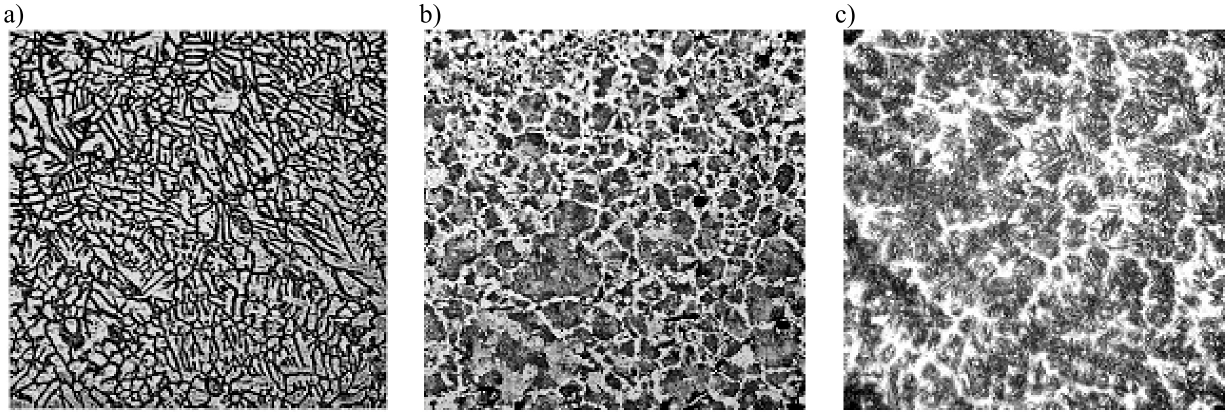

Fig. 1. The initial structure of rapidly cooled during crystallization of charge blanks AW-2031 (a), steel 45L (b) and steel 45HGSTFL (c). Mag. × 100

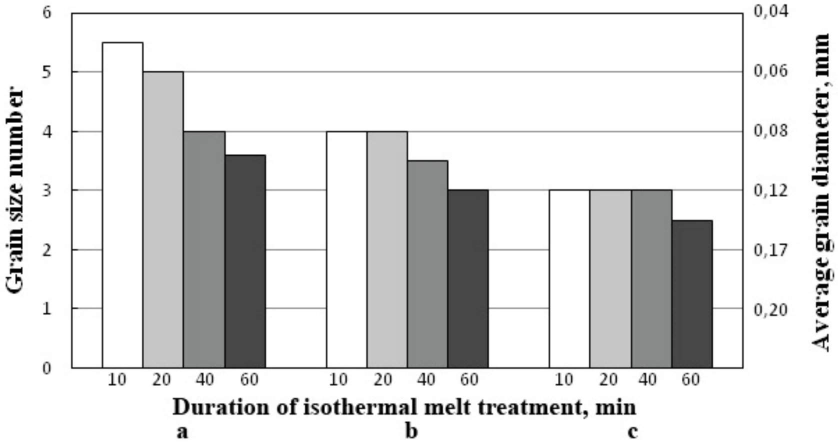

Fig. 2. Dependence of grain number and average grain diameter of AW-2031 alloy on isothermal melt processing at 700°C (a), 750°C (b) and 800°C (c)

The dispersion of the dendritic structure was determined using quantitative metallography methods [12], which guaranteed satisfactory reproducibility of the results and the possibility of estimating measurement errors. The dispersion of the dendritic structure is the number of axial and interaxial sections that fit into the unit length of the sample. It was calculated by the formula:

$$D = \frac{n}{\sum L} \tag{1}$$

where n – the number of axial and interaxial sections on the secant line drawn perpendicular to the direction of the axis of the dendrites; $\sum L$ – secant line length, mm.

Tensile strength and yield strength were determined by the methods described in ISO 6892:2016. The average hardness was obtained by using a Vickers hardness tester (ISO 6507:2018). Toughness of steels was determined on samples with U-shaped incision according to the ISO 83:1976.

3. Results and discussion

It was metallographically established that after remelting in the AW-2031 cast structure, a regular change in grain size is observed (Fig. 2) depending on the temperature-time parameters of melt processing. Thus, with an increase in the temperature of isothermal processing of the melt in the indicated temperature range, the grain size of the cast alloy structure increases by an average of 45% (with a minimum exposure) and 25% (with a maximum exposure).

It is shown that an increase in the duration of isothermal treatment causes a noticeable increase in grain size (by 2 numbers) only at a treatment temperature of 700°C. Further increase of the melt processing temperature to 750°C and 800°C becomes the determining factor for grain growth and practically negates the effect on the duration of isothermal melt processing at these temperatures.

Depending on the temperature and time parameters of the melt processing, a regular transformation of the dendritic structure of the alloy occurs (Fig. 3). The structure of the alloy is characterized by a minimum linear size of the dendrites (0.35 mm) when processing the melt at a temperature of 700°C for 10 minutes. The maximum size of the dendrites (0.55 mm) is reached at isothermal holding of the melt for 60 minutes at a temperature of 800°C.

The dispersion of the dendritic structure of the alloy within the specified modes of isothermal melt treatment significantly reduced from 36 to 28 at the minimum treatment temperature (700°C), respectively, increasing its duration from 10 to 60 minutes. At higher temperatures of 750°C and 800°C, they are decisive for changing the index of dispersion of the dendritic structure, and the duration of isothermal treatment causes its slight decrease – an average of 35 to 33.

Based on the obtained results, we can assume that changes in the structural characteristics of the alloy under study at the minimum temperature of the melt isothermal processing are due to the preservation of the inherited features of the original dispersed-structured high-speed crystallization of the original material in the charge metal.

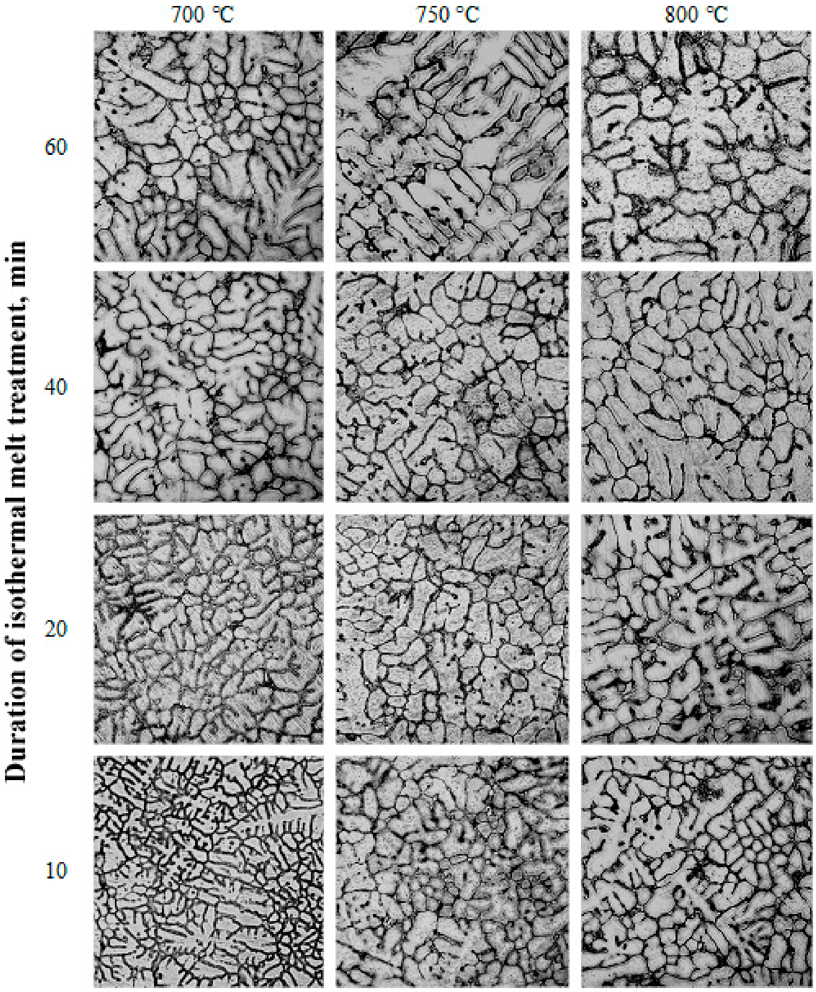

Fig. 3. Transformation of dendritic structure of AW-2031 alloy depending on temperature and duration of isothermal melt treatment. Mag. × 100

The increase in the duration of isothermal heating contributes to the reduction of the microchemical heterogeneity of the melt, resulting in a more intense growth of dendrites and a decrease in the area of the interdendritic areas.

Increasing the same processing temperature of the melt to 750°C and 800°C (above T_e) not only reduces the metallogenetic features of the rapidly cooled during crystallization charge, but also significantly increases its chemical and structural homogeneity in the liquid state before crystallization. Under these conditions, the effect of the duration of the melt isothermal treatment becomes insignificant and the structural state of the cast metal is determined by the temperature-time conditions of crystallization.

Regarding the study of the structure of steel castings (Fig. 4), at the normal temperature of the melt overheating (1530°C), the increase in the duration of its isothermal treatment from 5 to 20 minutes is accompanied by an increase in the grain size by an average of only one number for both studied steels (Fig. 5). Under conditions of significant overheating of the melt before crystallization (1600°C), a more significant increase in grain sizes is observed – by 2-3.5 numbers in the interval of studied changes in the duration of isothermal processing of the melt of steels.

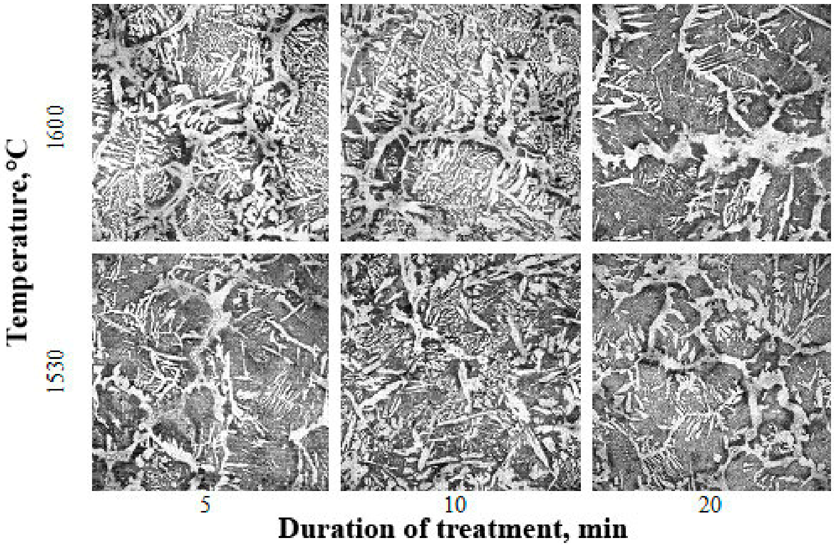

Fig. 4. Transformation of the structure of 45L steel depending on the parameters of the melt heat treatment. Mag × 200

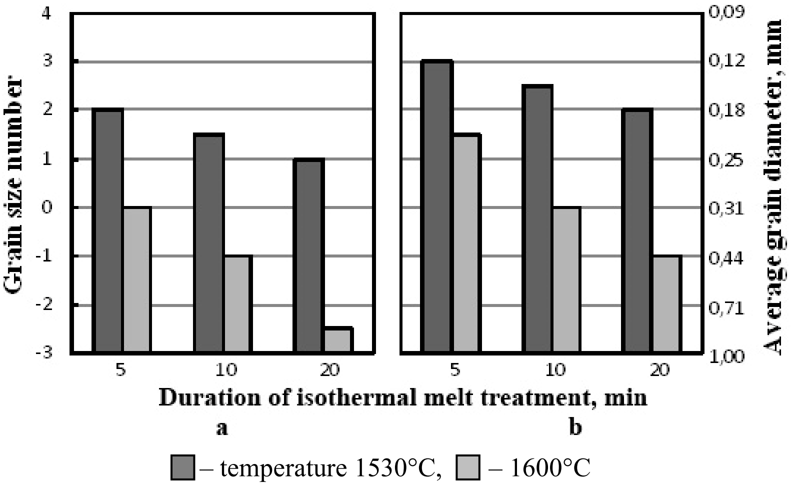

Fig. 5. Characteristics of the dispersion of the cast structure of steels 45L (a) and 45HGSTFL (b) depending on the temperature and duration of the isothermal melt treatment before crystallization

Table 3.
Influence of melt isothermal processing parameters on the mechanical properties of steels

t, min	TS, MPa	YS, MPa	δ, %	ψ, %	Hardness, HV	Toughness, J/cm^2
Steel 45L						
5	490	286	16.2	16.0	240	15.0
	448	275	11.3	12.0	226	14.0
10	485	276	15.6	14.5	235	15.6
	440	270	10.6	10.8	220	13.2
20	480	272	15.0	14.0	233	15.3
	430	266	9.0	10.0	218	12.0
Steel 45HGSTFL						
5	910	780	10.2	15.8	564	17.5
	896	765	8.4	14.3	480	15.0
10	900	772	10.0	15.6	560	17.3
	890	752	8.0	14.0	474	14.5
20	895	768	9.8	15.4	552	16.5
	882	740	7.8	13.8	470	13.0

Note: above the dash – isothermal treatment temperature 1530°C, below the dash – 1600°C

The results indicate the dominant influence of temperature on the dispersion of cast steel structure in view of the duration of technological preparation operations and casting of steel in the manufacture of castings in industrial environments.

Determination of the level of mechanical properties of the studied steels in connection with the influence of the indicated temperature and time conditions of isothermal treatment of the melt before crystallization showed that under conditions of normal melt overheating (1530°C), the duration of isothermal holding within 5-20 minutes practically does not affect the change in the level of strength indicators ductility and toughness (1-2%). An increase in the temperature of isothermal melt treatment causes a significant decrease in the mechanical properties of steels by an average of 6-10%, including the increase in the duration of isothermal melt heating (Tab. 3).

This decrease in the strength characteristics may be due to the transition of nonequilibrium, rapidly cooled during crystallization, cast structure of the high alloy of the original charge metal to a greater equilibrium with the implementation of diffusion processes and the allocation of excess phases under normal crystallization conditions. The change in plasticity and toughness is explained by the increase in grain sizes in the steel structure with a significant melt overheating over equilibrium liquidus.

4. Conclusions

Thus, through research, it is established that isothermal treatment of the melt at the overheating of the liquid metal above a certain equilibrium temperature of the micro-inhomogeneous melt (T_e) causes a gradual loss of hereditary characteristics of the original charge metal, increase of the chemical homogeneity of the melt and the formation of crystallization and formation a corresponding change in the mechanical properties of castings. In the case of isothermal treatment of the melt at normal temperatures (below the equilibrium temperature), the manifestations of the laid structural heredity of the charge remain even with the considerable duration of the thermal treatment of the liquid metal. The structural state of the castings is determined mainly by the temperature-time conditions of crystallization.

References

[1] S.E. Kondratyuk, Structure formation, heredity and properties of cast steel, Naukova Dumka, Kyiv, 2010 (in Ukrainian).

[2] S.Ye. Kondratyuk, V.I. Veis, Z.V. Parkhomchuk, Structure formation and properties of overheated steel depending on thermokinetic parameters of crystallization, Journal of Achievements in Materials and Manufacturing Engineering 97/2 (2019) 49-56. DOI: https://doi.org/10.5604/01.3001.0013.8537

[3] Y. Hu, W. Chen, H. Han, R. Bai, Effect of cooling rate after finish rolling on heredity in microstructure and mechanical properties of 60Si2MnA spring steel, Metallurgical Research and Technology 113/5 (2016) 508. DOI: https://doi.org/10.1051/metal/2016024

[4] V.V. Sanin, M.R. Filonov, V.I. Yukhvid, Yu.A. Anikin, A.M. Mikhailov, Investigation into the

influence of the remelting temperature on the structural heredity of alloys fabricated by centrifugal SHS metallurgy, Russian Journal of Non-ferrous Metals 57 (2016) 124-130.
DOI: https://doi.org/10.3103/S1067821216020097

[5] A.A. Bondarev, A.V. Lozovskaya, G.M. Shelenkov, Effect of metallurgical heredity of the AMts alloy semi-finished products on their brazing ability, Automatic Welding 3 (2005) 15-20 (in Russian).

[6] K. Janerka, D. Bartocha, J. Szajnar, J. Jezierski, The carburizer influence on the crystallization process and the microstructure of synthetic cast iron, Archives of Metallurgy and Materials 55/3 (2010) 851-859.

[7] K. Janerka, J. Jezierski, D. Bartocha, J. Szajnar, Heredity of the structure and properties of grey cast iron melted on a basis of steel scrap, Advanced Materials Research 622-623 (2013) 685-689. DOI: https://doi.org/10.4028/www.scientific.net/AMR.622-623.685

[8] H.I. Aaronson, M. Enomoto, J.K. Lee, Mechanisms of Diffusional Phase Transformations in Metals and Alloys, First Edition, CRC Press, 2016.

[9] J. Piątkowski, B. Gajdzik, T. Matuła, Crystallization and structure of A390.0 alloy with melt overheating temperature, Metalurgija 51/3 (2012) 321-324.

[10] J. Piątkowski, Effect of overheating on the mechanical and plastic properties of A390.0 cast alloy, Solid State Phenomena 211 (2014) 9-14. DOI: https://doi.org/10.4028/www.scientific.net/SSP.211.9

[11] ISO 643:2012 Steels – Micrographic determination of the apparent grain size.

[12] O.M. Bialik, S.E. Kondratyuk, M.V. Kindrachuk, V.S. Chernenko, Structural analysis of metals. Metallography. Fractography, Polytechnics, Kyiv, 2006 (in Ukrainian).