



Investigation of the effect of the metallographic properties of vertical and horizontal cylinders made of ferrochrome with different contents on heat transfer by natural convection

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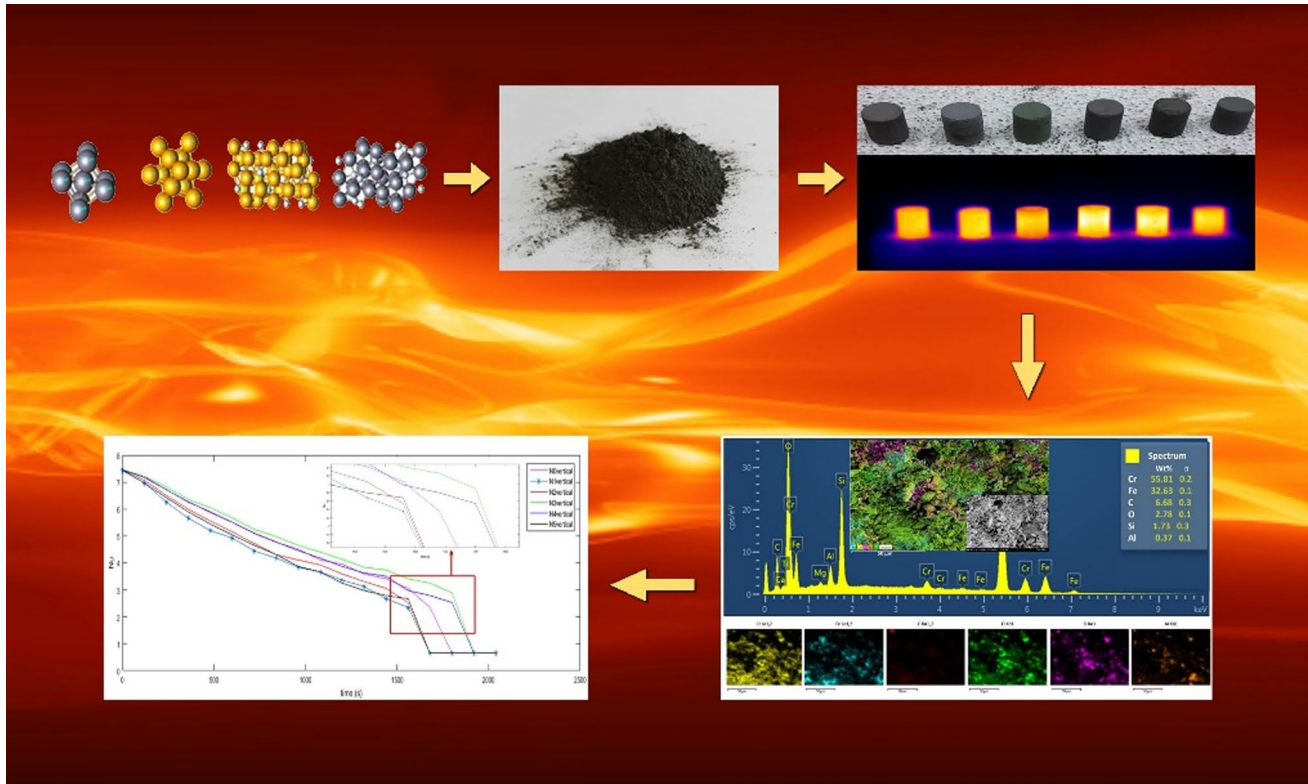
Abstract

In this study, ferrochrome materials containing elements with different content ratios were manufactured into six-cylinder specimens, 13 mm in diameter and 16 mm in length, and heated in a furnace up to 500 °C. The heated cylinders were removed and left to cool in vertical and horizontal positions in a 16 °C environment. The temperatures were recorded using thermal cameras at certain intervals while the materials cooled down. The six specimens, whose metallographic differences were identified using SEM and XRD analysis devices, were placed vertically and horizontally, and their heat transfer by natural convection was noted. In the calculations, each specimen's Nusselt and Rayleigh numbers were identified based on time and then compared. The fastest cooling among the specimens occurred in the ferrochromium material with 55.93% Cr, 31.11% Fe, 11.56% C, 0.48% Si, 0.83% O, and 0.09% Al compound ratios, both in vertical and horizontal positions. Additionally, since the Nusselt number of the horizontal cylinders remained below one based on their position, their natural convection flows were not initiated. The cooling in the horizontal cylinders occurred via conduction.

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Graphical abstract



Keywords Energy · Natural convection · Chromium material · Metallography

List of symbols

t	Time (s)
T_s	Plate surface temperature (°C)
T_∞	Ambient air temperature (°C)
D	Cylinder diameter (m)
k	Coefficient of thermal conductivity ($\text{Wm}^{-1} \text{K}^{-1}$)
ρ	Density (kgm^{-3})
c	Specific heat ($\text{Jkg}^{-1} \text{K}^{-1}$)
β	Coefficient of volume expansion (K^{-1})
L	Characteristic length (m)
h	Heat transfer coefficient ($\text{Wm}^{-2} \text{K}^{-1}$)
A_s	Heat transfer surface area (m^2)
$Q_{\text{convection}}$	Heat transfer amount (W)
Nu	Nusselt number
Gr	Grashof number
Ra	Rayleigh number
Pr	Prandtl number
ν	Kinematic viscosity ($\text{m}^2 \text{s}^{-1}$)

Introduction

Heat transfer by natural convection in vertical and horizontal cylinders is commonly encountered in many engineering fields, such as nuclear reactor cooling systems and electronic circuits [1–4]. Natural convection passing through a single horizontal cylinder has been under detailed observation for more than 50 years, and recently, the research has focused on cylinder arrays and pairs. Research in this field is applied in various applications, including heat exchangers and passive solar energy systems [5, 6].

While both Lieberman and Gebhart [7] and Marsters [8] studied heat transfer by natural convection through an array of heated cylinders, Yousefi and Ashjaee [9] examined natural convection through a vertically aligned cylinder array. In these studies, the authors calculated the Rayleigh numbers and analyzed the effect of the distance between cylinders on the Rayleigh number. Heo and Chung conducted experimental research on heat transfer by natural convection in inclined cylinders. In that research, the researchers used a copper electroplating

system to simulate the heat transfer in a mass transfer system based on the analogy between heat and mass transfer. The results showed similar tendencies to the current heat transfer correlations for inclined cylinders; the researchers also reported that the results complied with results linked to horizontal cylinders [10]. Popiel et al. conducted an experimental study of laminar-free convective average heat transfer in the air from an isothermal vertical thin cylinder with a circular cross-section. In the conclusion of that study, the researchers calculated the Nusselt and Grashof numbers according to the height-to-diameter ratio of the cylinder and compared their results to those of previous studies [11]. Reymond et al. examined heat transfer by natural convection on a single horizontal cylinder and a pair of vertically positioned cylinders. The authors revealed that when both cylinders were heated, the smoke rising from the heated lower cylinder interacted with the upper cylinder and drastically affected the surface heat transfer distribution [12]. Kiwan et al. experimentally examined the thermal effect of using circular porous fins fixed to the outer surface of a heated vertical cylinder exposed to constant heat flux. That study found an obvious increase in heat transfer when porous fins were used. The minimum enhancement of the heat transfer coefficient was 7.9% when using one fin with a 10-mm thickness, and the maximum enhancement reached 131% when using a porous layer [13]. Sebastian and Shine numerically examined the confined and unconfined laminar natural convection flow around a vertically heated cylinder. The authors concluded that confinement below the cylinder caused a decrease in the Nusselt number in the lower half of the cylinder compared to the upper half [14]. Alsuhaibani et al. conducted an experimental study on heat transfer natural convection from the outer surface of a horizontal array consisting of vertical square pipes. As a result, they obtained Nusselt number correlations based on the hydraulic diameter rate of the lengths between the centers of the square pipes. The authors reported that the Nusselt numbers determined from the experiments were applicable even at high Rayleigh numbers [15]. Azzouz and Hamida conducted a two-dimensional numerical study of the magnetohydrodynamic unsteady natural convective heat transfer on a circular plate with four horizontal and vertical cylinders.

Their study concluded that at low Rayleigh values, heat transfer through an applied magnetic field is not affected for a given value of S (the distance between two circles) because the transport mechanism is diffusion. In contrast, for larger Rayleigh values, a complex interaction exists between the magnetic field and physical thermal properties [16].

In this study, six specimens in the form of a cylinder made of ferrochrome with different contents were manufactured. Ferrochrome is a metallic alloy consisting of iron and chrome with various properties. These properties determine ferrochrome's field of use and its significance in manufacturing alloys such as stainless steel. Ferrochrome increases the durability of steel at high temperatures. Accordingly, steel can maintain its form and durability when exposed to high temperatures. The six-cylinder specimens, manufactured based on ferrochrome's properties mentioned above, were heated vertically and then horizontally at 500 °C and left to cool down at an ambient temperature of 16 °C. Natural convection-related calculations were initiated, and the results were compared. As seen from the above-given research examples and numerous other studies, natural convection calculations of heated vertical and horizontal cylinders have been the focus of extensive research for many years. Our study differs in the percentile differences of the material content of the manufactured cylinders. We are unaware of any other study related to this topic in the literature, so we consider it a subject worthy of research.

Material and methods

In this study, carried out to analyze the thermal differences occurring when the heat transfer emerges from Ferrochrome materials with different element ratios, the alloys obtained at the micron level as powder were pressed as six cylinders, measuring 13 mm in diameter and 16 mm in height, following mechanical alloying and the use of powder metallurgy in blocks. During the pressing processes, the powder at the micron level was bound together by applying 10 tons of pressure to each specimen using a hydraulic press with a capacity of 20 tons. The manufactured specimens were

Table 1 Material content of the six specimens manufactured in cylindric form

	Cr	Fe	C	Si	O	Al	Ca	Ti	K	Mg
N0	41.45	36.09	17.01	3.59	1.73	0.13	0	0	0	0
N1	55.93	31.11	11.56	0.48	0.83	0.09	0	0	0	0
N2	36.90	1.13	7.62	11.22	37.8	2.97	0.82	0.1	0.18	1.26
N3	58.60	33.07	6.7	1.19	0.36	0.08	0	0	0	0
N4	55.72	31.36	6.52	2.07	3.93	0.4	0	0	0	0
N5	55.81	32.63	6.68	1.73	2.78	0.37	0	0	0	0

labeled N0, N1, N2, N3, N4, and N5. The material content of the specimens is given in Table 1.

The specimens in Table 1 were heated in the furnace in the same order as their code names—first vertically, then horizontally, until they reached 500 °C. The vertically positioned cylinders can be seen in Fig. 1.

The image in Fig. 1 shows the pre-heating position of the cylinders and their measured temperature. The specimens, heated up to 500 °C in the furnace, were later removed to enable them to cool down at an ambient temperature. The distance between the specimens was arranged so that the natural convection flows did not affect one another and the heat transfer through radiation could be ignored.

The microstructure of a material, the order of its components, the chemical and structural differences of its geometrical formation, its compound differences, its density, and any structural defects significantly affect its thermal properties. The significance of a microstructure is especially evident when considering that one of the fundamental factors affecting the heat conduction of a material is its structural order in its atomic arrangement and the distance between its atoms.

The samples were produced by the powder metallurgy method. The samples were subjected to a mechanical alloying device containing steel balls for 72 h in order to turn them into powder of the same size and to alloy them mechanically. Then, they were pressed at high pressure. These processes, which are carried out before the samples are produced, minimize the porosity formation within the

structure by facilitating the bonding (forming a compound) of the elements in its composition by reaching the same level in terms of dimensions (micron level). Heat treatment ensures that the elements are bonded to each other and porosity is minimized by the formation of atomic movement through diffusion of the parts depending on the determined temperature, duration, and atmospheric conditions.

The SEM, EDS, and mapping analyses obtained from specimen N0, which has the highest carbon ratio among the other ferrochrome alloys used in this study, are given in Fig. 2.

The EDS analysis shown in Fig. 2 indicates that specimen N0 has an alloy consisting of high amounts of Cr–Fe–C (Cr: 41.45, Fe: 36.09, C: 17.01). Materials with high Cr–Fe–C alloys are mainly used in many commercial applications, particularly in the aviation and space industry, by adding matrix materials at different ratios.

Considering the mapping analyses, while it can be observed that the chrome is homogeneously distributed on the entire structure of the material, it is mostly formed by Cr_7C_3 carbides in a compound with carbon. The large amounts of carbon in specimen N0 adversely affected the structure of the specimen, and regional accumulations occurred. However, the iron inside the structure—despite being present throughout it—mostly accumulated around the silicone and created a compound. SEM, EDS, and mapping analyses of specimen N1 are provided in Fig. 3.



Fig. 1 Vertical cylinders in the furnace

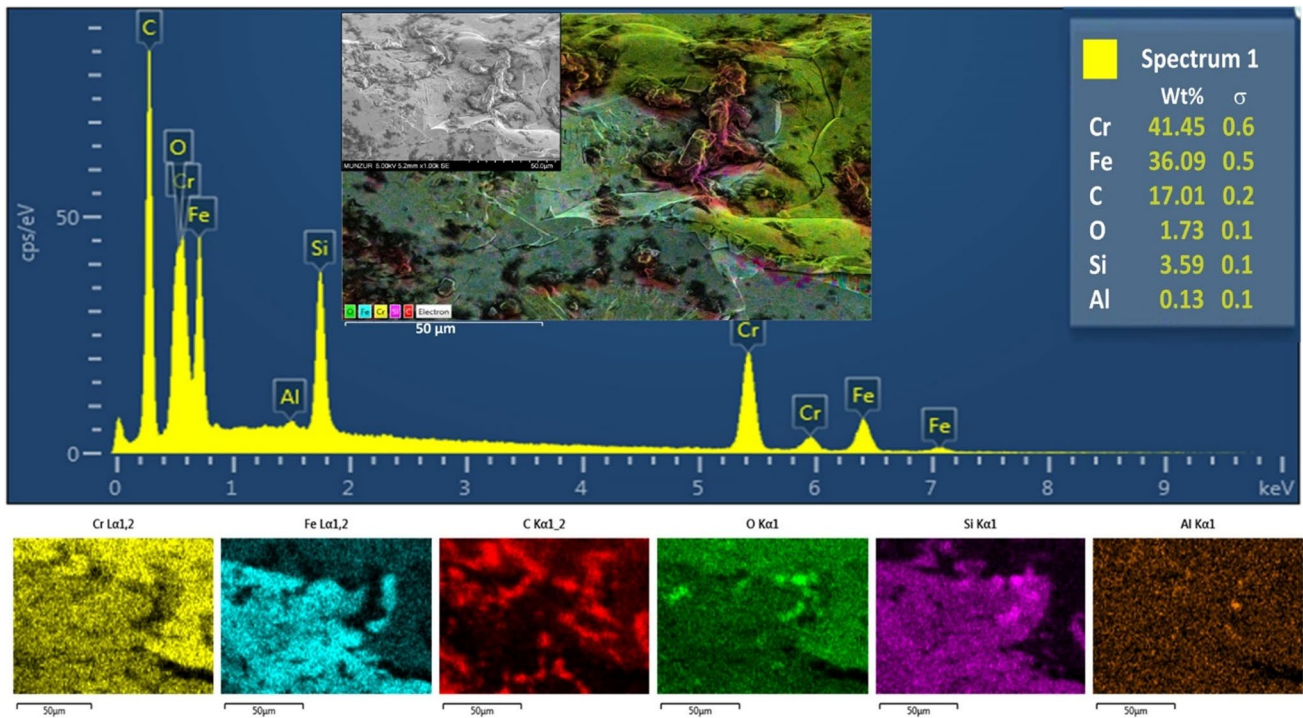


Fig. 2 SEM, EDS, and mapping analysis images for specimen N0

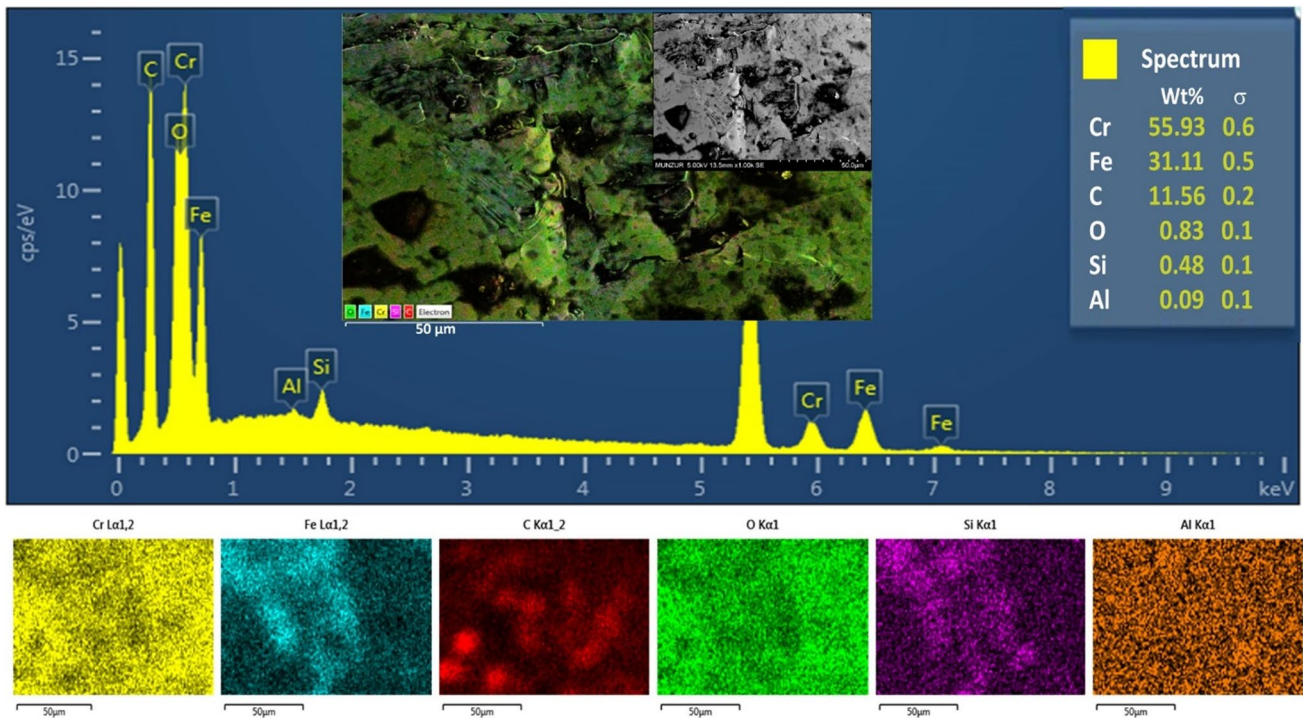


Fig. 3 SEM, EDS, and mapping analysis images for specimen N1

The Cr_{23}C_6 (M_{23}C_6) carbide at a high Cr ratio can only be seen on a single curve, as shown in Fig. 3; it was identified with XRD analysis.

Considering the mapping analysis obtained to determine the element distribution inside specimen N1, we observed that the carbon was more concentrated on the black dots

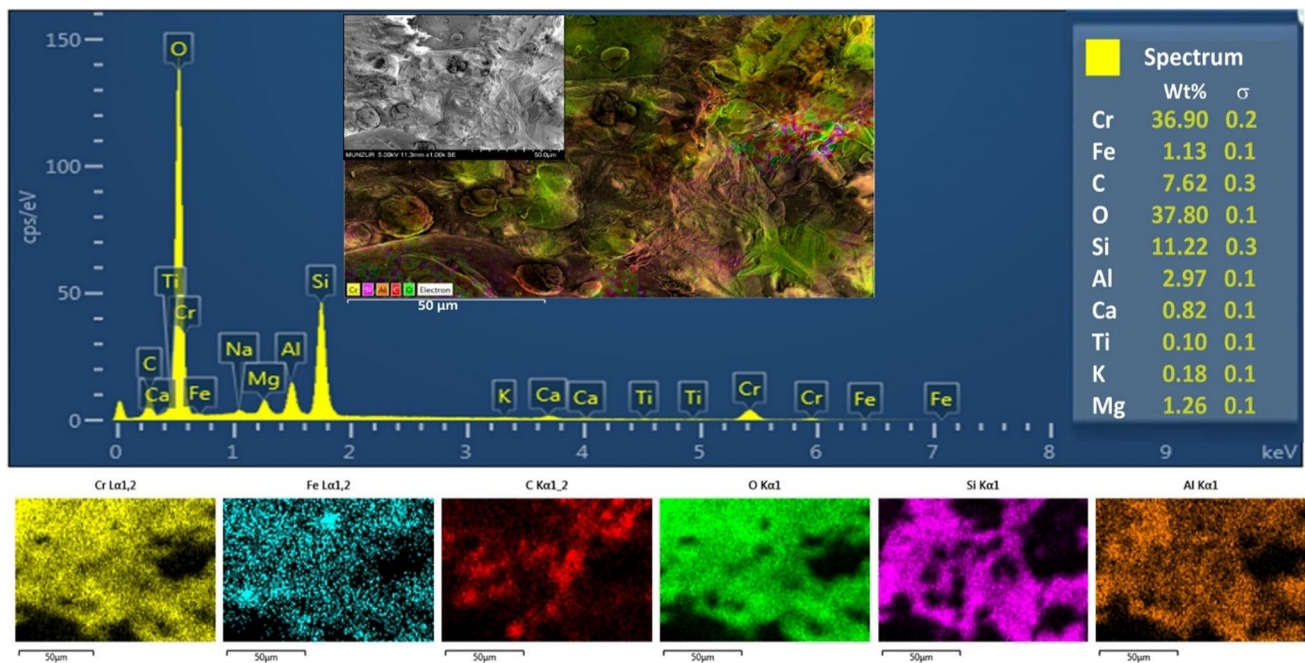


Fig. 4 SEM, EDS, and mapping analysis images for specimen N2

within the structure due to N1 being a high-carbon alloy. Other elements presented a homogeneous distribution. SEM, EDS, and mapping analyses of specimen N2 are provided in Fig. 4.

The SEM images in Fig. 4 of specimen N2, produced specifically to observe the (clinker) effects near the surface of the material, show that during the production process, N2 had a rather wavy structure instead of a layered one and that the oxide value increased to 37.80% in the EDS analysis due to the oxide compounds moving toward the surface during production. The mapping analysis of the elements in the structure shows a regional distribution and that oxide formed a compound with different elements. SEM, EDS, and mapping analyses of specimen N3 are provided in Fig. 5.

In the SEM images given in Fig. 5 for specimen N3, which help identify the structural image of the Cr_{23}C_6 (M_{23}C_6) carbide, all of its properties, such as the carbide being flat, cornered, and in layers, can be seen. The mapping analysis of specimen N3 clearly shows that the Cr-C-O elements are densely present, especially in layers, and seem to constitute a separate structure from the matrix. SEM, EDS, and mapping analyses of specimen N4 are provided in Fig. 6.

Considering that specimen N4 was found in layers in terms of structure, in the SEM images in Fig. 6, it can be observed that while the flat layers belong to the Cr_7C_3 (M_7C_3) carbides, the fact that the material looks complete in terms of its structure supports our belief that it has a durable and rigid structure. Specifically, the C–O–Si elements, in the form of independent globes within the

structure, are observable. SEM, EDS, and mapping analyses of specimen N5 are shown in Fig. 7.

The N5 specimen, as shown in Fig. 7 in the SEM images, has the lowest ratio of C. Compared to the other specimens, its Cr_7C_3 carbides are much denser and smaller. In the mapping analysis, the Si element was shown to have formed compounds with Cr and O at specific points and changed structure. When the specimens with a high content of Cr were examined in terms of metallography, it was observed that the structure was generally composed of Cr_{23}C_6 and Cr_7C_3 carbides.

XRD analysis of the specimens shows the compound and lattice parameters, which can be seen in Fig. 8. The compounds (Cr_7C_3 , Cr_{23}C_6 , CrFe_3 , Fe_7C_3 , and CrSi_2) formed by chrome and iron with other elements were identified using XRD analyses. Carbides (Cr_7C_3 and Cr_{23}C_6) generally found in chrome alloys were also observed in many of the specimens.

As shown in Fig. 8, the compounds (Cr_7C_3 , Cr_{23}C_6 , CrFe_3 , Fe_7C_3 , and CrSi_2) formed by chrome and Fr with other elements were identified using XRD analyses. Carbides (Cr_7C_3 and Cr_{23}C_6) generally found in chrome alloys were also observed in many of the specimens. In the XRD analysis of the specimens consisting of elements with a cubic surface-centered lattice structure, the chromium alloy peaks, which formed the largest peak, were generally located in the (111) and (110) lattice systems. In comparison, the iron alloy peaks were generally located in the (100) and (101) lattice systems.

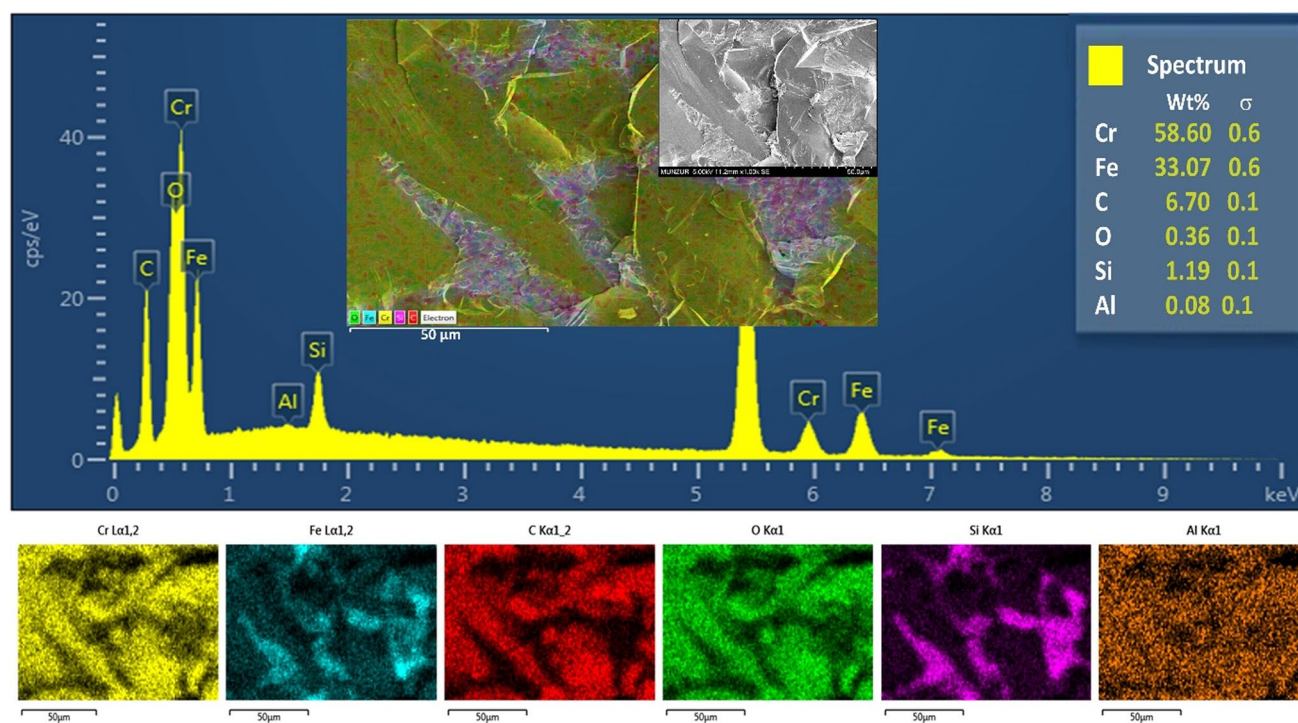


Fig. 5 SEM, EDS, and mapping analysis images for specimen N3

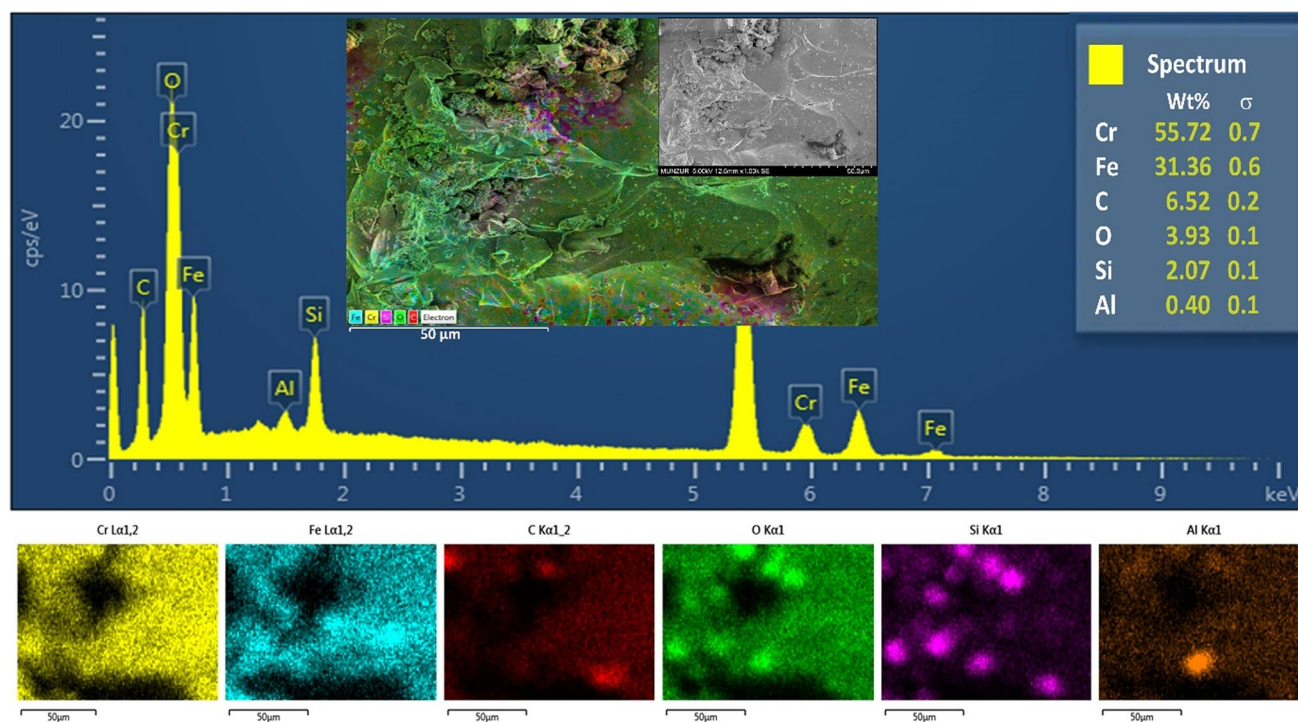


Fig. 6 SEM, EDS, and mapping analysis images for specimen N4

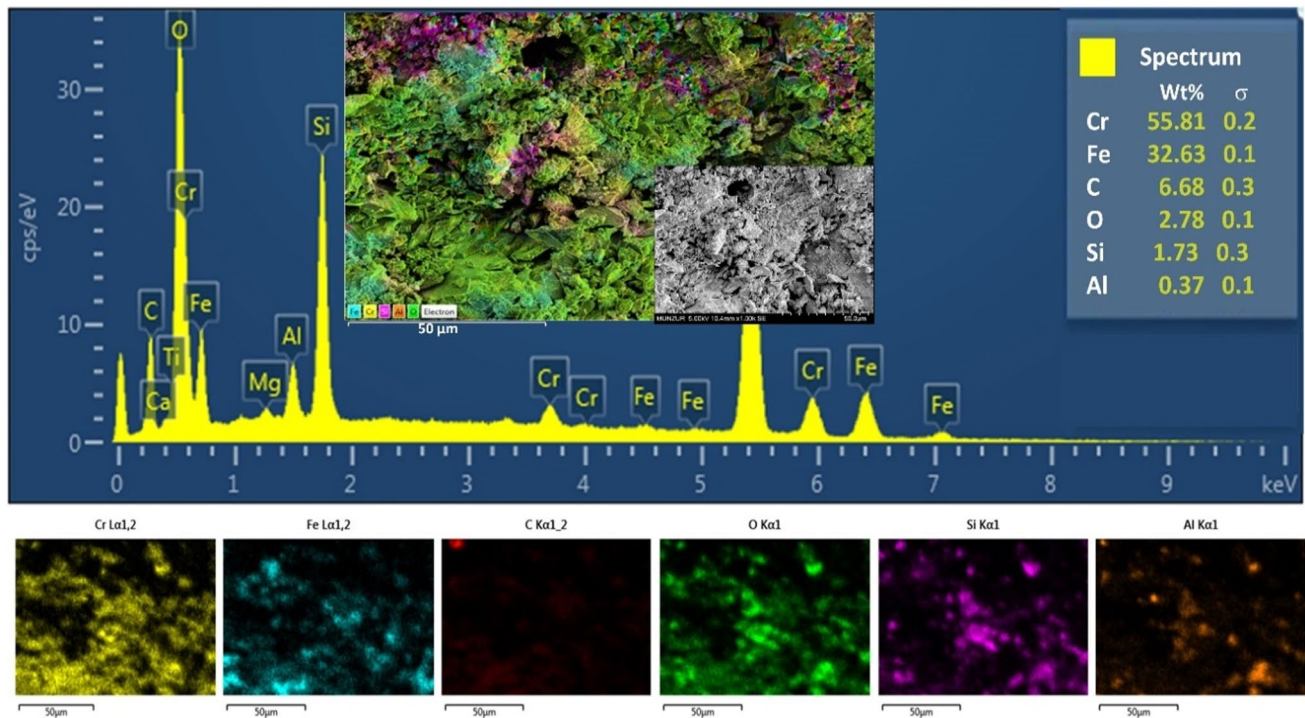


Fig. 7 SEM, EDS, and mapping analysis images for specimen N5

Figure 9 shows the temperatures of vertical and horizontal cylinders measured using a thermal camera after their removal from the furnace, respectively, at the start, in the middle of the time-based measurement, and when their temperatures approached an ambient temperature.

As shown in Fig. 9, although the temperature changes of the specimens differ, the vertical cylinders generally heated up to 500 °C in the furnace and cooled down much faster than the horizontal ones. Table 2 shows the temperature values based on time for each specimen while the cylinders cooled down.

Considering the temperature values measured for each specimen based on the times given in Table 2, it can be seen that the vertical cylinders reached an ambient temperature in a shorter time than the horizontal ones. Figure 10 shows the temperature values of the specimens in the first 120 s of the cooling down period, according to Table 2.

As seen in the graph in Fig. 10, the cooling temperature of specimen N1, common in both vertical and horizontal cylinders, swiftly decreased at the 120th s compared to the other specimens. While specimen N1 in a vertical position was measured at 75.7 °C in the 120th s, horizontal specimen N1 was measured at 107 °C.

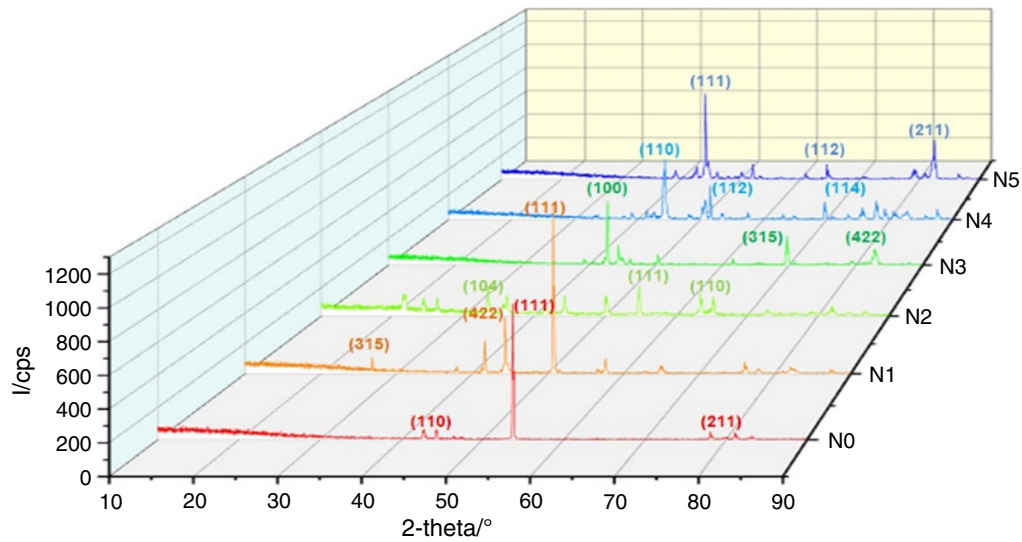
Considering natural convection flows on any surface, the flow will be laminar and the fluid Newton-type. Additionally, there must be a specific mass difference between the inside and outside of the boundary layer to create a lifting force, known as the Boussinesq approach [17].

Newton's Law of Cooling, as shown in Eq. 1, was used to calculate the amount of heat transfer by natural convection in the vertical and horizontal cylinders.

$$Q_{\text{convection}} = hA_s(T_s - T_{\infty})(W) \quad (1)$$

“h” in Eq. 1 represents the heat transfer coefficient, A_s represents the surface area of the plate, T_s is the plate's surface temperature, and T_{∞} represents an ambient temperature that is too far to be affected by the surface temperature.

First, the Nusselt number must be calculated to measure the heat transfer coefficient. In vertical cylinders, if the condition $D \geq \frac{35L}{Gr_L}$ is met, the Nusselt number is calculated according to the formulas accepted for vertical plates. Because the outer surface of a vertical cylinder can be considered as a vertical plate if its diameter is large enough to neglect the effects of curvature, that is, if it meets the condition $D \geq \frac{35L}{Gr_L}$. When this condition is met, the connections used for vertical plates can be used for vertical cylinders [17–20]. Since the diameter of the cylinder samples produced is 13 mm and the length is 16 mm, they do not meet this condition. Therefore, the Nusselt number relations used for cylinders that do not meet this criterion in the literature are used. Le Fevre and Ede, using the “Approximate Integral Method” for laminar flows, expressed the average Nusselt number for a vertical



Alloys	Phase name (formula)	Phase data name	Molecule
N0	Fe (Iron)	111	
	Cr (Chromium)	111	
	Cr7 C3 (Chromium carbide)	022, 151	
	C Fe3 (Cohenite)	211,	
	C (Diamond)	211	
	Cr0.053 Fe0.947	110	
N1	Fe (Iron)	100, 101	
	Cr (Chromium)	111	
	Fe4 C0.63	315, 029	
	Cr23 C6	422, 511	
N2	O2 Si (Cristobalite)	111, 220	
	Cr (Chromium)	200, 110	
	A10.058 Cr1.702 Fe0.122 Mg0.042 O3 Ti0.076 (Eskolaite)	012, 104	
	Cr (Chromium)	200, 110	
N3	Fe (Iron)	100, 101	
	Cr (Chromium)	200	
	Fe4 C0.63	315, 029	
	Cr23 C6	422, 622	
N4	Fe (Iron)	211, 110	
	Cr (Chromium)	201, 100	
	Cr7 C3 (Chromium carbide)	112, 310	
	C (Diamond)	222	
	Cr Si2 (Chromium silicide)	114, 301	
	C Fe3 (Cohenite)	313, 332	
N5	Fe (Iron)	111	
	Cr (Chromium)	110	
	Cr7 C3 (Chromium carbide)	112, 311	
	Fe7 C3 (Iron carbide)	031, 211	

Fig. 8 XRD analyses of the specimens

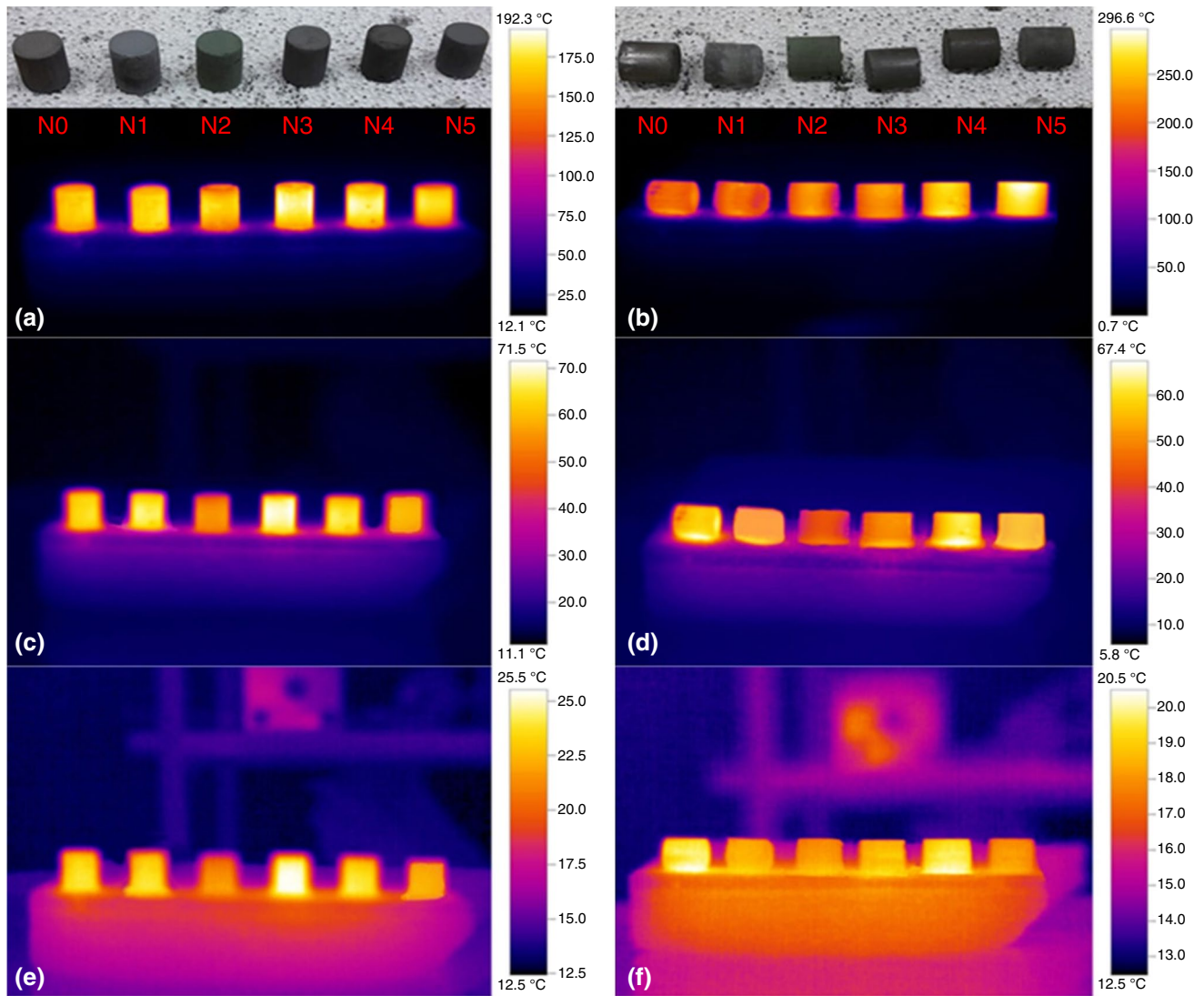


Fig. 9 Thermal images of the ferrochrome materials with different contents: **a** vertical cylinders 120 s after being taken out of the furnace; **b** horizontal cylinders 120 s after removal from the furnace; **c** vertical cylinders 360 s after being removed from the furnace; **d** hori-

zontal cylinders 360 s after removal from the furnace; **e** vertical cylinders 840 s after being removed from the furnace; and **f** horizontal cylinders 840 s following their removal from the furnace

cylinder as shown in Eq. 2, by utilizing the known velocity and temperature parabolic profiles from the analysis of the laminar boundary layer on a vertical flat plate in natural convection heat transfer [21, 22].

$$Nu = \frac{hL}{k} = \frac{4}{3} \left[\frac{7GrPr^2}{5(20 + 21Pr)} \right]^{\frac{1}{4}} + \frac{4(272 + 315Pr)L}{35(64 + 63Pr)D} \quad (2)$$

The formula in Eq. 3 was used to calculate the Nusselt number in the horizontal cylinders.

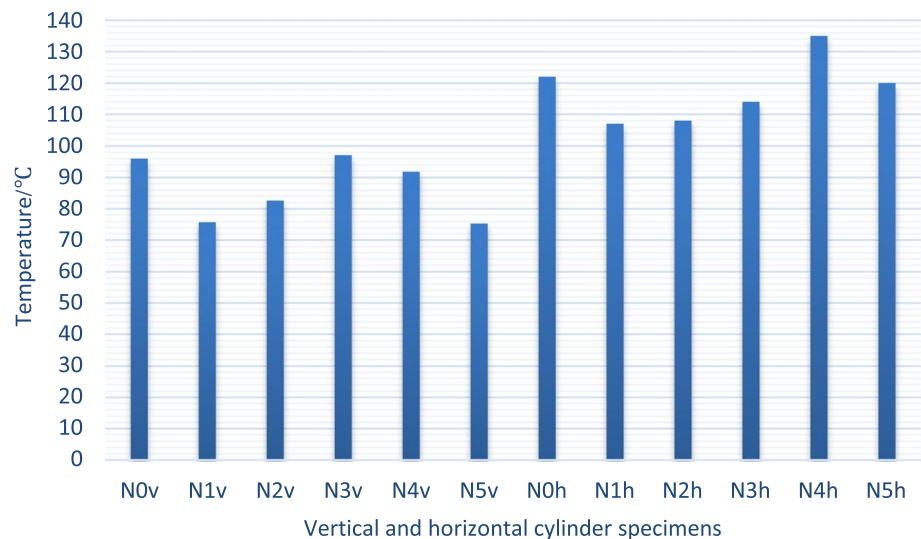
$$Nu = \left\{ 0.6 + \frac{0.387Ra_D^{\frac{1}{4}}}{\left[1 + \left(\frac{0.559}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right\}^2 \quad Ra \leq 10^{12} \quad (3)$$

The Rayleigh numbers given in Eqs. 2 and 3 are the multiplication of Grashof and Prandtl numbers. The Prandtl number is the proportion of kinematic viscosity to thermal diffusivity, representing the relative thickness of the velocity boundary layer occurring on the cylinders to

Table 2 Temperature values measured for each specimen based on time

Time (s)	N0v	N1v	N2v	N3v	N4v	N5v	N0h	N1h	N2h	N3h	N4h	N5h
	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C	Temperature/°C
120	159	139	150	158	154	141	196	200	201	194	225	220
240	96	75.7	82.6	97.1	91.8	75.3	122	107	108	114	135	120
360	61.6	45.6	53.1	66.7	62	50.4	79.8	61.8	66.5	74.3	89.9	75.3
480	46.1	33.1	39.1	48.4	45.5	37.2	55.8	41.4	39.5	52.5	63.2	50.1
600	36.7	27.1	31.5	40.4	37.3	30	43.9	27.9	30.5	35.3	40.2	31.1
720	30.8	24.35	26.6	33.3	30.8	25.5	33.2	25.3	25.6	28.2	32.7	26
840	26	21.1	22.9	27.6	26.1	22.4	28.5	22.5	21.6	24	27.7	22.6
960	23.2	19.8	20.4	24.9	23.3	20.4	24.4	21.1	20.4	22.5	24.7	21.3
1080	21.5	18.5	19.5	22.4	21.2	18.6	22.1	19.7	19.6	20.6	22.5	19.8
1200	19.5	18	18.8	20.9	19.8	18	20.5	18.8	18.9	19.7	21.1	19
1320	18.9	17.3	17.8	19.6	18.6	17.1	19.4	18.4	18	18.7	19.5	18.4
1440	17.8	16.9	17.2	18.5	17.9	16.7	18.4	17.9	17.7	18.2	18.8	17.7
1560	17.4	16.2	16.8	18.2	17.6	16.4	18.1	17.6	17.5	17.8	18.2	17.3
1680	16.8	16.1	16.3	17.4	16.7	16	17.9	17.3	17.1	17.4	17.9	17
1800	16.2	16	16	17.1	16.5	16	17.4	16.9	16.8	17.1	17.5	16.9
1920	16	16	16	16.6	16.3	16	17.1	16.4	16.5	16.7	17.2	16.5
2040	16	16	16	16	16	16	16.5	16.3	16.3	16.5	16.7	16.4
2160	16	16	16	16	16	16	16	16	16	16	16	16

Fig. 10 Temperature values of the manufactured specimens during the first 120 s of cool down



the thermal boundary layer. The formula used to calculate the Grashof number is given in Eq. 4:

$$Gr = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2} \quad (4)$$

“ g ” in Eq. 4 represents the gravity velocity, “ β ” is the volumetric expansion coefficient, “ D ” represents the cylinder’s diameter, and “ ν ” is the kinematic viscosity.

The Nusselt numbers calculated over time for the vertical and horizontal cylinders according to the thermal properties of air at average temperatures—found by averaging the cylinder surface temperatures and the ambient temperature in the formulas given in Eqs. 2, 3, and 4—are shown in Figs. 11 and 12.

Considering the data in Figs. 11 and 12, the Nusselt number at the beginning of the cool down in the vertical cylinders was approximately 7.5 and 1 in the horizontal ones. The Nusselt number shows the heat transfer improvement on the fluid layer due to the proportion of the convection to the conduction on that fluid layer [23, 24]. As shown in Fig. 8, the Nusselt number being equal to or lower than one shows that the heat transfer mechanism in the horizontal cylinder only occurs through conduction. Therefore, natural convection flows did not commence as the horizontal cylinders were cooling down, showing that the height from the ground in the horizontal cylinders is not so great as to start the natural convection flows. In addition, the graph in Fig. 10 explains why the vertical cylinders cooled down faster than the horizontal ones. The common point in the graphs in Figs. 11 and 12 is that specimen N1 (55.93% Cr, 31.11% Fe, 11.56% C, 0.48% Si, 0.83% O, and 0.09% Al) cooled down faster in the vertical and horizontal cylinders. Specimen N1 cooled down more rapidly than the others because the carbon element

inside the metallographic structure of the material is not positioned as a thin wall around the particle boundaries; instead, it is situated in certain regions in a spherical structure. A material being non-conducting in terms of heat conduction is associated with that material having a greater distance between its atoms or its atoms being irregular. Carbon, because it was present in the form of blocks within the structure, served as a barrier, especially between the M23C6 carbides identified with XRD analysis. This prevented the carbides from holding heat, thus enabling them carbides to move independently and cool down faster.

The graph of the Ra number according to the Nu number for both cases of specimen N1, which cooled down the fastest among the six specimens in vertical and horizontal positions, is shown in Fig. 13.

The graph in Fig. 13 shows a logarithmic increase between the Nu and Ru numbers in the vertical and horizontal cylinders. At the 120th s of the cool down period, the Ra number was calculated as 12,616.33 for the N1 vertical and 12,928.96 for the N1 horizontal. The difference is due to the cooling speed. Since the Nu number in the horizontal cylinder is around one at a maximum, we cannot discuss convection flows here; however, in the vertical cylinders, the Nu number is around 7.5; therefore, convection flows can be mentioned. Regarding the Ra number, we can state that the flow in the vertical cylinder is laminar.

Conclusions

In this study, ferrochrome materials made of elements with different content ratios were manufactured as six 13 mm diameter and 16 mm length cylinders, heated to 500 °C in furnaces, and left to cool down at an ambient temperature

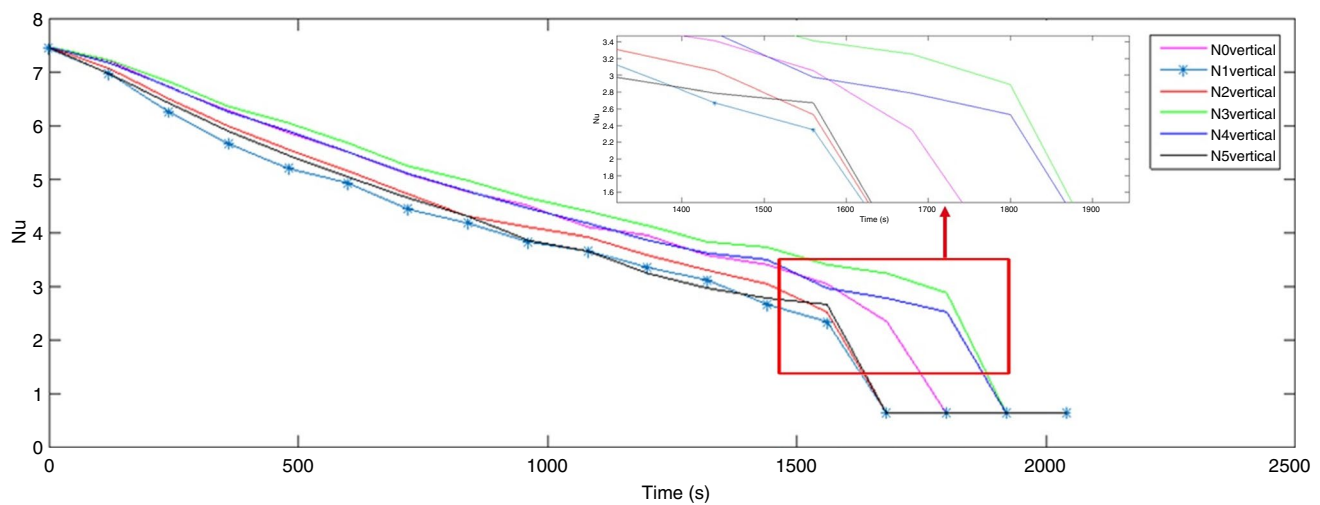


Fig. 11 Nusselt number graph of the vertical cylinders based on time

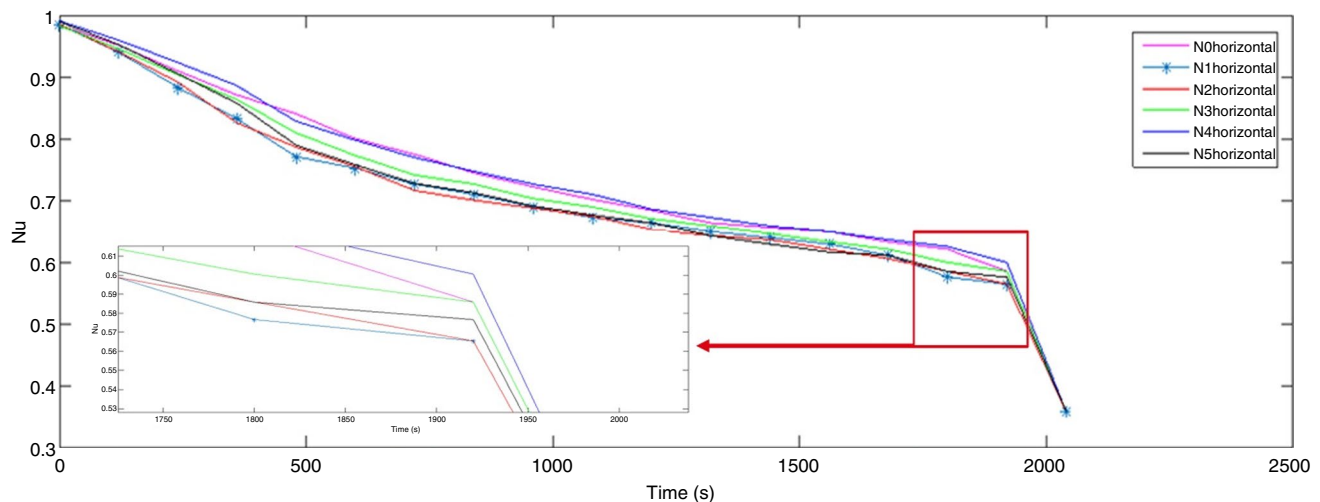
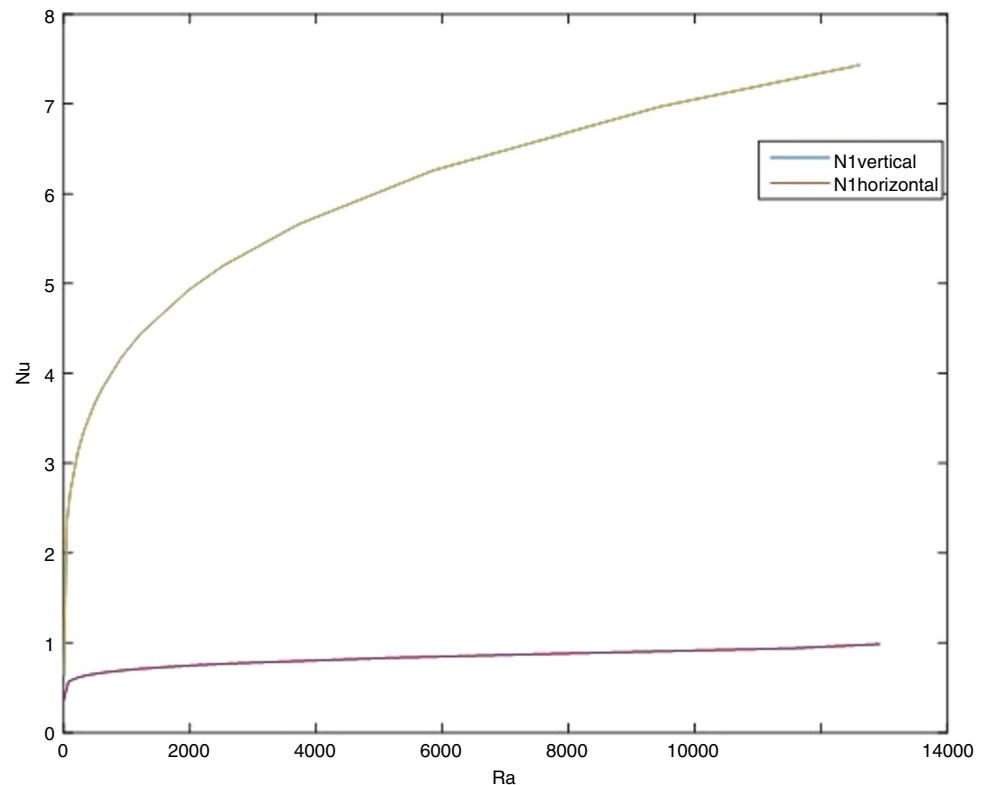


Fig. 12 Nusselt number graph of the horizontal cylinders based on time

of 16 °C. Metallographic analyses of the specimens were conducted, and the heat transfer by natural convection on their surfaces was observed. Accordingly, the vertical cylinders left to cool down at an ambient temperature cooled down faster than those in a horizontal position. When the natural convection phenomena are examined according to geometrical shape, the Nusselt number of the vertical specimens starts at 7.5 at the start of the cool down process. It decreased as the specimens drew closer to the ambient temperature. The Nusselt number of the horizontal specimens, on the other hand, began at one and decreased as they drew closer to the ambient temperature. The calculated Nusselt numbers show that the natural convection flows did not start in the horizontal specimens and that a large portion of the cool down process occurred through heat conduction,

explaining why the vertical specimens cooled down more quickly. Comparing the Nusselt numbers of the specimens according to time, specimen N1 was the fastest cooling in vertical and horizontal positions. In the metallographic examination of the specimens, carbon in the form of blocks within the structure served as a barrier between the $M_{23}C_6$ carbides, preventing them carbides from holding heat. This, in turn, enabled them to carbides move independently and cool down faster. The Nu–Ra graph arranged for specimen N1 shows that the Nu number followed a logarithmic increase compared to the Ra number. The effect of materials with different structures on natural convection is a topic worthy of future research, and we hope that this study will attract the interest of researchers working in thermal science.

Fig. 13 Nusselt Rayleigh numbers graph of specimen N1



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Declarations

Conflict of interest All authors declare that they have no conflict of interest.

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