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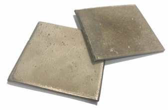

Value-in-use of nickel products in the production of ferrous alloys

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Nickel is a very important alloying metal which finds application in many cast irons and steels. The main reason for adding nickel in ferrous alloys is to promote an austenitic microstructure. Nickel generally increases ductility, toughness and corrosion resistance. There are two main categories of nickel products available for foundries, nickel metal, which is available in a variety of shapes and sizes, and ferronickel. This study investigates and compares effects of using these two groups of products on total cost and quality of produced ferrous alloys. It will help ferrous alloy producers to take more informed decisions when selecting the appropriate nickel raw material based on the individual requirements.

1. Introduction

In general, foundrymen favor pure metals over ferroalloys because of their ease of use. However, producing ferroalloys rather than pure metals has some advantages over refining them to highly purified metals. In fact, the refining and concentration process is costly and it is not logical to remove iron while it is the main element in ferrous melting [7].

The main purpose of this article is to present the advantages and disadvantages of nickel metal and ferronickel for the production of ferrous alloys. The value-in-use of these two product options are compared in technical and financial terms. The study was conducted by reviewing the available scientific research as well as considering the authors' own experiments during more than 10 years of working in ferrous alloys melting departments.

1.1. Nickel definition and application in cast iron and steel

Nickel is a silver-white transition metal with a melting point of 1458°C and a density of 8.908 g/cm^3. It belongs to group VIII on the periodic table together with iron and cobalt which are commonly referred to as the "iron triad." In fact they have similarities in properties and the source of mineral ores. Nickel has a face-centered-cubic crystal structure and also facilitates formation of this structure in ferrous alloys [1, 2].

Nickel is an essential and widely used alloying element in high-temperature-resistant superalloys and heat-, oxidation-, and corrosion-resistant irons and steels. Nickel is well-known for its solid solution strengthening and promoting of high toughness, mainly at low temperatures. Besides its main application in stainless steelmaking nickel is also widely used in low-alloys steels and irons [3].

The addition of higher amounts of nickel promotes austenite stabilization at room temperature together with loss of ferromagnetism

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and increasing resistance to corrosion. Because of its little or no affinity to react with carbon, nickel has graphitization effects in ferrous alloys which are needed for the characteristic graphite microstructure of cast iron. For steels this phenomenon needs to be stopped by keeping carbon in low percentage amounts or adding carbide forming elements like chromium. Furthermore nickel inhibits the grain growth and increases the hardenability in ferrous alloys [4-6].

1.2. Nickel products for foundries

According to the International Nickel Study Group (INSG) there are two classes of primary nickel products which are applicable for foundries. Class I, which contains products with nickel content of more than 99 wt% and Class II, which contains products with a nickel content of less than 99 wt% as shown in Table 1.

Table 1
Classification of primary nickel products

Class 1	Class 2
Products with a nickel content of 99 wt% or more	Products with a nickel content of less than 99 wt%
- Cathodes - Pellets - Briquettes - Rondelles	- Ferronickel - Nickel pig iron (NPI)

Ferronickel and Nickel Pig Iron (NPI) are two alternatives to nickel metal. NPI typically contains around 4 to 10 wt% nickel. Its high amount of carbon (>3 wt%), silicon (>3 wt%) and manganese (>1 wt%) mean that its application in foundries is highly restricted. In fact, the main consumers of this product are stainless steel mills in China, because of their capacity to reduce carbon and other undesired elements [5]. Ferronickel is a ferroalloy containing mainly iron and nickel. It is supplied in the shape of flowable granules with a typical particle size between 2 and 50 mm. Part of the production process is a refining step which reduces the amount of carbon, silicon, manganese, sulfur, and phosphorus to an acceptable level for foundries [6].

2. Comparison between using nickel metal and ferronickel

The following section compares the usage of ferronickel and nickel metal from both a financial and technical point of view.

2.1. Technical analysis

Because of its common use the authors selected a mainstream Brazilian ferronickel with nominally 28 wt% of nickel. Table 2 shows the guaranteed chemical specification of this ferronickel product and the guaranteed chemical specification of 4”x4” LME grade cut nickel cathodes.

Table 2
Guaranteed chemical composition of a Brazilian ferronickel and 4"x4" LME grade cut nickel cathodes

Element [wt%]	Brazilian ferronickel	4”x4” LME grade cut nickel cathodes
Ni	25-35	Min. 99.8
Co	Max. 0.85	Max. 0.15
Cu	Max. 0.06	Max. 0.02
Si	Max. 0.04	< 0.005
P	Max. 0.02	< 0.005
S	Max. 0.08	Max. 0.01
C	Max. 0.04	Max. 0.03
Fe	Balance	Max. 0.02
Cr	Max. 0.04	n/a

According to the Ellingham diagram, which is a graph showing the temperature dependence of the stability for compounds in melting and casting temperature range of ferrous alloys (1300 to 1600 °C), nickel has less affinity to oxidation than other available elements in the molten path. Therefore, there is not a significant amount of nickel loss during melting and in this regard there are no differences between using ferronickel or nickel metal. However, there are three other differences that melting departments may be concerned about: the existence of iron, cobalt and other elements in ferronickel.

Iron: Ferronickel can be added to any furnace charge for making any kind of casting iron and steel with nickel equal or less than its composition. The furnace operator or melting engineer only needs to consider the amount of iron in their calculations or software tool. The iron which is included in the ferronickel is a substitute for adding steel scrap or pig iron (with less amount of carbon as in pig iron). The purchasing departments can select their required type of ferronickel based on the level of nickel in the ferrous alloy specification [8].

Cobalt: The ferronickel which was chosen for this discussion contains around 0.7 wt% cobalt. One of the reasons that ferronickel is rarely used as an alloying element in common cast iron and steels is the presence of cobalt and its negative reputation as an alloying element. To shed light on this perception, the authors have reviewed the available literature. The addition of cobalt in ferrous alloys is restricted in steels with application in nuclear reactors. Cobalt becomes highly radioactive when exposed to the intense radiation of nuclear reactors, and, as a result, any stainless steel that is in nuclear service will have a cobalt restriction of usually approximately 0.2 wt% maximum. The US Nuclear Regulatory Commission (NRC) restricts the cobalt content in steel for atomic energy applications depending on the area of use in a nuclear plant. The maximum cobalt content ranges between 0.005 wt% and 0.2 wt%. As an example, type 348 stainless steel is a very common nuclear grade with a maximum cobalt content of 0.2 wt% to limit nuclear activation of the element [9-11].

There are no known restrictions for the cobalt content in cast iron and steel for non-nuclear applications. Cobalt can even improve the properties of the alloy because it intensifies the individual effects of other elements in more complex steels. Moreover, cobalt provides some unique properties into cast iron and steels. Cobalt is not a carbide former in steels. It helps nickel and manganese in stabilizing austenite. Cobalt raises the martensitic transformation start temperature, allows for higher quenching temperatures (during the heat treatment procedure) and decreases the amount of retained austenite which increases the hardness of the alloy. Recently, several studies investigated the effects of cobalt addition in cast iron and steel and several new benefits of cobalt have been discovered. For example, Janssen (2010) reported that even small additions of cobalt (0.5 wt% to 1.0 wt %) facilitate optimal ferritic microstructure and improve the mechanical characteristics of nodular cast iron [12]. There is also a significant improvement in corrosion resistance of low alloy steel in 10 wt% sulfuric acid solution with addition of 0.05 wt% to 0.1 wt% cobalt [13].

The prominent benefit of cobalt is its abilities to improve high temperature properties of cast iron and steel. Cobalt improves strength at high temperatures and promotes higher red hot hardness. It inhibits grain growth at high temperature, improving the retention of temper and high-temperature strength, However, the high cost of cobalt, is the reason which restricted its application to high-speed steels, hot-forming tool steels, maraging steels, and creep-resistant and high-temperature materials [14, 15]. The current price of cobalt is around 58,500 $/t. This means that in a ferronickel with 28 wt% Ni and 0.7 wt% Co, the buyer receives 1,463 $ worth of free cobalt for every ton of nickel.

Other elements: There are some other minor elements in ferronickel which are listed in Table 3. The amount of these elements in ferronickel is compared with alloys that have restrictions with regards to these elements. The result shows that the maximum amount of these elements rarely exceeds their limitation and in case that it happens for carbon and sulfur it can easily be overcome through the proposed solutions.

Table 3
Max and min amounts of elements contained in ferronickel in common cast iron and steel

	Elements wt%				
	C	**Si**	**S**	**P**	**Cu**
Maximum amount in restricted cast steels	0.03	0.35	0.01	0.02	0.04
Minimum amount in restricted cast irons	2.0	1.0	0.03	0.08	n/a
Examples	Austenitic stainless steel 1.4309	Rolling steels	Austenitic stainless steel 1.4585	Austenitic stainless steel ASTM CA6N	Stainless steel ASTM A831 361
Amount in ferronickel	0.04	0.04	0.08	0.02	0.06
Possibility of reduction	Yes, by addition of lower carbon scrap	Not required	Yes, by desulfurizing agent	Not required	Yes, by addition of copper free scrap

Furnace charge calculation examples: For illustration, furnace calculations for two ferrous alloys are discussed below: one stainless steel and one high alloy cast iron. The calculations of furnace charge for two scenarios, one selecting nickel metal and one selecting ferronickel are shown in the Appendices A, B, C and D. The main difference in the calculated furnace charge is the amount of steel scrap used. By choosing ferronickel, less steel scrap or pig iron needs to be added.

Charging properties: One of the highest areas of energy consumption in a foundry is the furnace. Conventional manual charging of the furnace increases the melting time and decreases the furnace efficiency. Cut nickel cathodes can create some challenges with regards to feeding to the furnace. In contrast, ferronickel has good flowability characteristics and an automated feeding system can be utilized. This boosts the charging speed and increases safety. In addition, researchers have found out that by decreasing the particle size of the ferronickel, the melting time can be dramatically increased. This is an additional advantage of using ferronickel which has smaller particle size than 4”x4” cathodes [16].

2.2. Financial analysis

For the financial analysis, all costs that a foundry incurs, such as raw material cost and transportation cost need to be considered. Moreover, the value of other recoverable elements which are included in the products needs to be valued. To illustrate the analysis, the authors compared all of the above matters for two common nickel products in the European market, 4”x4” cut nickel cathodes with 99.8 wt% and a Brazilian ferronickel with 28 wt% of nickel. In fact, there are two main costs for supplying any raw material: the cost of the product and the cost of transporting it to the consumer’s plant. The price of purchasing ferronickel is currently lower than that of 4”x4” cut nickel cathodes. A big portion of ferronickel is iron, which increases the transportation cost of the product. However, the iron is free of charge. An analysis is required to see if the amount of iron included in the ferronickel is worth more than the extra transportation cost. Rotterdam port, in the Netherlands, was assumed as the delivery location and central Germany as the end-user location. The financial details are summarized in Table 4.

Table 4
Value-in-use comparison between nickel cathodes and ferronickel based on estimated market prices in September 2017

Value-in-use relative to LME price ($/ton of nickel)		Type of primary nickel product	
		Nickel cathode	Ferronickel
1	End-user product cost for 1 ton of nickel (Premium to LME price shown as a negative number)	-300 $/t Ni	-150 $/t Ni
2	Shipping cost for product contains 1 ton of nickel	-30 $/t Ni	-107 $/t Ni
3	Value of iron per 1 ton of nickel	0	+1,125 $/t Ni (70% iron)
4	Total value-in-use of product for 1 ton of nickel	-330 $/t Ni	868 $/t Ni

As it is shown in Table 4, using ferronickel has advantages in several areas. First, the purchase price is lower for the same amount of nickel. The in-warehouse Rotterdam price for ferronickel is currently at a premium of 150 $/t to the LME price while the price for 4”x4” cut cathodes stands at a premium of 300 $/t to the LME price. The only disadvantage of ferronickel is the higher cost of transportation which is due to the iron content. For every ton of nickel a consumer buys, in ferronickel he gets 2.5 tons of iron for free. But the consumers are in the ferrous metal melting industry and all of their molten baths contain iron. Therefore, the iron is beneficial. At the current pig iron price of 450 $/t (DDP central Germany), the value of the free iron of 1,125 $/t Ni significantly outweighs the additional transportation costs.

Overall, when purchasing 1 ton of nickel via ferronickel rather than nickel metal the consumer saves 1,198 $/t (330+868). For the two ferrous alloys discussed in this study, Table 5 shows the total calculated material cost. The calculations assume a price of 3.26 $/kg for ferronickel, 11.8 $/kg for cut nickel cathodes, 0.293 $/kg for steel scrap and 0.03 $/kg for transportation cost. For ease of comparison, only the amounts of nickel and iron are considered in the calculation.

Table 5
Cost calculation for preparing 1,000 kg of AISI CF8 steel

	Type of consumed primary nickel	
	Nickel cathode	Ferronickel
Weight of primary nickel product	101 kg	321 kg
Cost of primary nickel product	1,192 $	1,046 $
Cost of transportation for nickel product	3 $	10 $
Weight of required steel scrap	599 kg	379 kg
Cost of required steel scrap	175 $	111$
Total cost (nickel + iron only) of making 1,000 kg of CF8 steel	1,367	1,167
Amount of saving in 1,000 kg of CF8 steel	**-**	**200 $**

As it is calculated in table 5, a consumer would save around 200 $ when ferronickel is chosen rather than nickel cathode in producing 1 ton of CF8 stainless steel. There are also other economic benefits in the consumption of ferronickel by saving time and energy through automated charging of the furnace. Table 6 shows a comparison between the use of nickel cathodes and ferronickel, this time for Ni-Resist 2 cast iron. As it is illustrated, there is a 191 $ saving for melting a ton of this alloy using ferronickel.

Table 6
Cost calculation of preparing 1,000 kg of Ni-Resist 2

	Type of consumed primary nickel	
	Nickel cathodes	Ferronickel
Weight of primary nickel product	202 kg	714 kg
Cost of primary nickel product	2,384 $	2,328 $
Cost of transportation for nickel product	6 $	21 $
Weight of required steel scrap	729 kg	217 kg
Cost of required steel scrap	214 $	64 $
Total cost (nickel + iron only) of making 1,000 kg of Ni-Resist 2	2,604 $	2,413 $
Amount of saving in 1,000 kg of Ni-Resist 2 DIN EN 13835	-	**191 $**

3. Summary and conclusion of study

In this study we compared the value-in-use of nickel metal versus ferronickel. The results help both foundry operations and purchasing departments for making more informed decisions in selecting the optimal raw material. The discussion was divided into a technical and financial analysis.

From a technical point of view, ferronickel and nickel metal both can easily be added without a major loss through oxidation. Cobalt is in the center of our consideration because it has been considered as the main reason for refusal of ferronickel. However, from a metallurgical point of view it is not a harmful element for cast iron and steel except for nuclear power applications which are sensitive to the radioactive properties of cobalt. The presence of even small amounts of cobalt, as an alloying element, has been reported to significantly improve the mechanical, metallurgical and corrosion resistance properties of cast iron and steel. Other elements like carbon, silicon, sulfur, phosphorus and copper are present in very low and acceptable amounts.

From a financial point of view, ferronickel delivers a clear cost advantage of around 1,200 $ per ton of nickel purchased. Furthermore, automated charging of the furnace saves time, which indirectly creates additional savings for the consumer depending on the specific operation. Currently, the authors are aware of foundries in Germany, Brazil and the US which are already using ferronickel. The savings potential of around 10% per ton of nickel should create a strong incentive for other foundries to use ferronickel in their process.

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Appendix A

Furnace charge details for A351 CF8M stainless steel with ferronickel

Required/ calculated weight (kg)	Material name	C	Si	Mn	Cr	Ni	Cu	Co	S	P
379	Low carbon steel scrap	0.05	0.2	0.25	---	---	--	--	0.05	0.04
321	Ferronickel	0.04	0.04	---	0.04	28	0.04	0.7	0.04	0.02
300	Low carbon ferrochrome	0.08	0.98	---	65.25	---	---	---	0.01	0.03
Total 1,000 kg charge		0.056	0.39	<0.25	19.58	9.0	<0.04	0.19	0.035	0.031
Desired alloy	1,000kg ASTM A351 CF8M (DIN 1.4408)	Max. 0.08	Max. 2.0	Max. 1.5	18-21	8-11	n/a	n/a	Max. 0.04	Max. 0.04

Appendix B

Comparison between consuming ferronickel and nickel cathode in furnace charge for A351 CF8M

Method of selecting charge	Furnace charge details (kg)			
	Low carbon steel scrap	Nickel cathode	Ferronickel	Fe-Cr
By Nickel cathode	599	101	-------	300
By Ferronickel	379	-------	321	300

Appendix C:

Furnace charge details for Ni-Resist alloy cast iron with ferronickel

Required/ calculated weight (kg)	Material name	Chemical composition wt%								
		C	Si	Mn	Cr	Ni	Cu	Co	S	P
217	Low carbon steel scrap	0.05	0.2	0.25	---	---	--	--	0.05	0.04
714	Ferronickel	0.04	0.04	---	0.04	28	0.04	0.7	0.04	0.02
12	High carbon ferromanganese	7.02	0.01	78.1	---	---	---	---	0.002	0.1
37	High carbon ferrochrome	7.28	0.65	---	66.8	---	---	---	0.05	0.009
20	Carbon (graphite)	100	---	---	---	---	---	---	---	---
Total 1,000 kg charge		2.36	0.1	0.95	2.47	20	<0.04	0.4	0.035	0.031
Desired alloy	1000 kg Ni-Resist 2 DIN EN 13835	Max. 3.0	1.0-2.8	0.5-1.5	1.5-2.5	18-22	Max. 0.5	n/a	Max. 0.05	Max. 0.2

Appendix D

Comparison between consuming ferronickel and nickel cathode in furnace charge for Ni-Resist 2

Method of selecting charge	Furnace charge details (kg)					
	Low carbon steel scrap	Nickel	Ferro-nickel	Ferro-chrome	Ferro-manganese	Carbon
By nickel cathode	729	202	-------	37	12	20
By ferronickel	217	-------	714	37	12	20

References

[1] Pierre-Jean Cunat, Alloying Elements in Stainless Steel and Other Chromium-Containing Alloys, Euro Inox 2004

[2] RAYMOND A. HIGGINS Engineering metallurgy Part I APPLIED PHYSICAL METALLURGY Sixth Edition, pp. 547-548

[3] Frank K. Crundwell, Extractive Metallurgy of Nickel, Cobalt and Platinum-Group Metals, 2011 Elsevier, pp 7-11

[4] Metals Handbook: Properties and selection: Irons and Steels, American Society for Metals, 1978. Page 91

[5] RAYMOND A. HIGGINS, ENGINEERING METALLURGY, Parti, APPLIED PHYSICAL METALLURGY, Sixth Edition

[6] E.T. TURKDOGAN , FUNDAMENTALS OF STEELMAKING, The Institute of Ma-terials 1996, page 211

[7] Onuralp Yucel Et al, INVESTIGATION OF PYROMETALLURGICAL NICKEL PIG IRON (NPI) PRODUCTION PROCESS FROM LATERITIC NICKEL ORES, 3rd International Symposium on High-Temperature Metallurgical Processing , TMS (The Minerals, Metals & Materials Society), 2012

[8] Michael Gasik, Handbook of Ferroalloys: Theory and Technology, ELSEVIER 2013, pp 3-5

[9] Salvatore Pinizzotto, International Nickel Study Group (INSG) Changes in nickel production capacity on the horizon

[10] 2009. AMG Vanadium, http://amg-v.com/cobaltpage.html

[11] Ernest J. Henley, Advances in Nuclear Science and Technology, ACADEMIC PRESS 1964, pp 87-91

[12] Stefan Janssen, CAST IRON COMPRISING COBALT AND COMPONENT, US 2010/0178192 A1, Jul. 15, 2010

[13] Keon Ha Kim Et al, Effect of cobalt on the corrosion resistance of low alloy steel in sulfuric acid solution, Corrosion Science 53 (2011) 3576–3587

[14] G. BELLANGER, CORROSION INDUCED BY LOW-ENERGY RADIONU-CLIDES Modeling of Tritium and Its Radiolytic and Decay Products Formed in Nuclear Installations, 2004 Elsevier, 2004, pp 73-75

[15] George E. Totten, Steel Heat Treatment: Metallurgy and Technologies, CRC Press 2006, page 7

[16] O. V. Zayakin Et al, Melting Time of Nickel-Bearing Ferroalloys in Steel, Steel in Translation, 2007, Vol. 37, No. 5, pp. 416–418.