EFFECT OF CR IN CARBIDES PRECIPITATION IN NODULAR IRON CLASS 100-70-03

GARCIA H. Jose, MAYOGA V. Alvaro., RUIZ T. Agustín

Department of Metallurgical Engineering, Faculty of Chemistry, National Autonomous University of Mexico
Tel 0052 55 5622 5239, jagarcia@unam.mx

Abstract

This paper presents the results of the effect of Cr in the precipitation of carbides in nodular iron class 100-70-03. In this study was considered the average nominal chemical composition suggested by the ASTM standard and added with content between 0.5 to 3 %Cr. Nodular iron was manufactured in induction furnace using conventional raw materials. "Y" casting blocks were obtained in silicate sand moulds. Thermocouples were placed in Y blocks to obtain the corresponding cooling curves. "Y" castings were cut to evaluate the fraction and distribution of carbides through the casting as a function of the amount of Cr in the alloy. The cooling curves were analyzed so that on the basis of experimental eutectic temperature with the fraction of carbides precipitated by the presence of Cr. This nodular iron could be applied to CADI manufacturing components with high hardness and wear resistance.

Keywords: Nodular iron, carbides, thermal analysis, whitening elements

1. INTRODUCTION

Nodular irons are increasingly used in different industrial areas due to their mechanical properties and the manufacturing cost. In the last years new developments have been done as: high nodule density (greater than 400 nod / mm^2), thin wall casting, austempered ductile irons (ADI), thin wall ADI, carbidic austempered ductile iron (CADI) [1, 2, 3]. Carbides are forbidden in conventional nodular irons, especially in the automotive components, due to the fragility caused by this microconstituent and the difficulties during the machining process. However there are applications that request high hardness in casting conditions, therefore it is necessary the presence of certain fractions of carbides.

Carbides precipitation can be promoted by different ways: with low Carbon and Silicon contents, with high cooling rates or by the addition of whitening elements (carbidic promoting elements). Last method [4] is most practical, since during the iron melting whitening alloys are added to promote the controlled formation of carbides, especially in thick section. Elements that promote the formation of carbides have different power, the weak as manganese and molybdenum, to the most powerful as chrome and vanadium. **Figure 1** shows the whitening power for some alloying elements, its power is based on the depth of chill test.

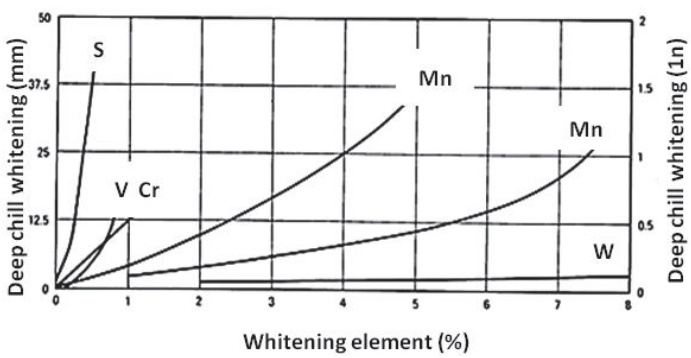

Figure 1 Whitening power for alloying elements

In this work the effect of the amount of Cr on the carbides fraction precipitated is studied, considering as reference the chemical composition of nodular iron class 100-70-03. Also the effect on the position of the eutectic temperature using thermal analysis technique, and to use this parameter in order to predict the carbides fraction precipitated.

2. EXPERIMENTAL DEVELOPMENT

For the manufacturing of the experimental irons the chemical composition of the iron class 100-70-03 was used as reference, **Table 1** shows its chemical composition.

Experimental irons were manufactured in an induction furnace of 100 kg of capacity, the materials charged were steel and nodular iron scraps. Chemical composition adjustments were made by additions of FeMn75, FeSi75 and carbon raiser. Addition of chromium was performed using FeCr65. The spheroidization treatment was carried out by applying the sandwich method with FeSi45.5Mg6.42. Inoculation treatment was done in two stages, in stream inoculation with 0.20 % Si and post inoculation with 0.10 % Si, using FeSi70 ferroalloy.

Y-blocks castings of 3 cm thick were obtained in silica-silicate-CO_2 sand moulds, thermocouples were attached to a data acquisition and to a computer. With the data acquired, the cooling curves of each alloy were obtained. Once solidified and cold the casting were cut and analyzed the segments shown in **Figure 2**.

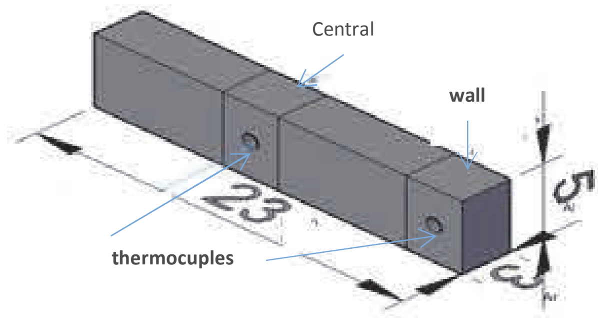

Figure 2 Y block and segments for metallographic analysis

In each segment were evaluated three zones: lower, middle and upper and also three positions from the edge to the center of the casting, in order to determine possible variations of microstructure between the different zones associated to the effect of the local solidification rate.

In all samples were evaluated the graphite characteristics: nodularity %, nodule size and nodule count (nodules / mm^2). For the evaluation of the carbide fraction the sample was etched with fresh solution of 10 mL of conc. HNO_3, 4 mL of HF conc., 87 mL of H_2O (darken reactive), which obscured all the phases except the carbides. The fraction of precipitated carbides was performed by digital image analysis (Image Pro-Plus).

3. RESULTS

3.1. Chemical composition

The chemical composition of reference iron and experimental nodular irons are presented in **Table 1**.

Table 1 Chemical composition of reference and experimental nodular irons

	%%C	%Si	%Mn	%Cr	%Cu	%Ni	%P	%S	%Mg	CE
Reference	3.62	2.45	0.60	0.13	0.34	0.042	0.013	0.012	0.045	4.44
1.35 Cr	3.76	2.48	0.60	1.35	0.34	0.041	0.015	0.020	0.08	4,59
1.95 Cr	3.82	2.31	0.63	1.95	0.34	0.040	0.016	0.020	0.062	4.59
2.49 Cr	3.78	2.34	0.60	2.49	0.31	0.041	0.016	0.025	0.085	4.57

3.2. Metallographic analysis

The microstructures non etched, etched with nital 3 % and with darken reactive are shown in **Figures 3, 4** and **5**.

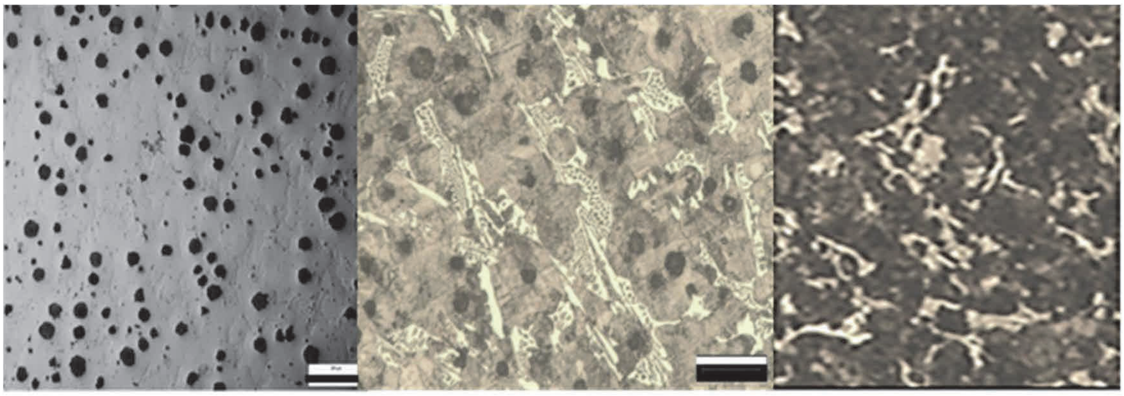

Figure 3 Nodular iron with 1.35 %Cr (scale 100 µm)

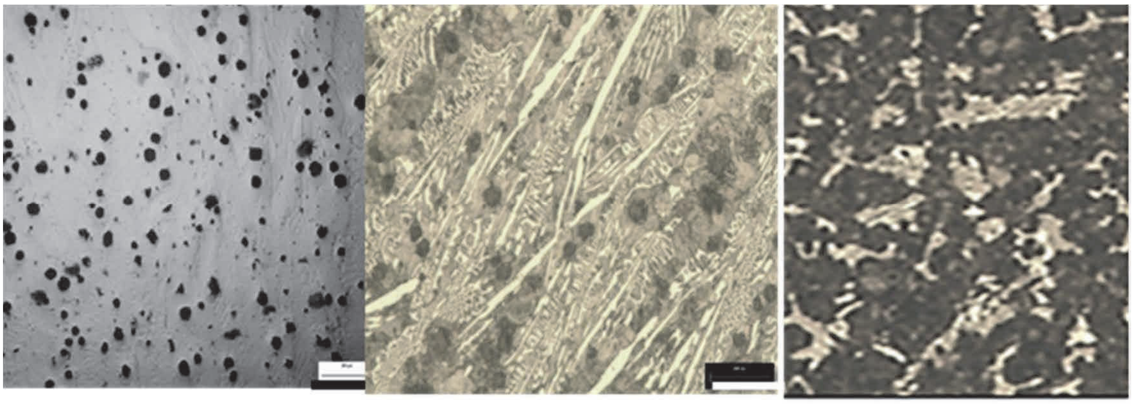

Figure 4 Nodular iron with 1.95 %Cr (scale 100 µm)

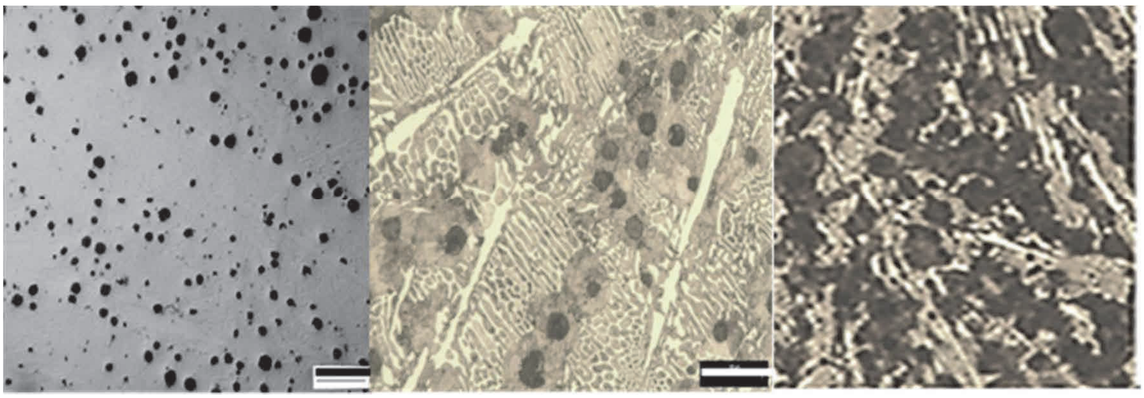

Figure 5 Nodular iron with 2.49 %Cr (scale 100 µm)

Table 2 shows the characteristics of the graphite and the average carbide fractions precipitated for each iron as a function of chromium %.

Table 2 Average carbide fraction of each experimental alloy and graphite characteristics

%Cr	% carbides wall mould	% carbides Central zone	% carbides average	% Nodularity	Nodule size	Nodules/mm^2
1.35 %Cr	9.10	7.30	8.20	> 90	5	100-150
1.95 %Cr	21.0	17.05	19.025	> 90	5-6	100-150
2.49 %Cr	27.50	23.10	25.30	> 90	6	120-150

3.3. Thermal analysis

Figures 6, 7, 8 and **9** show the cooling curves for each of the experimental irons in the eutectic transformation zone. Also eutectic stable and metastable temperatures are placed in the graph in order to compare with the experimental eutectic temperature. These temperatures were calculated according to Sheiikholeslami [5] in addition to [6, 7]. The parameter DiET is the difference between the stable and metastable temperatures, and is affect by the chemical composition. While the parameter DT is the difference between the metastable eutectic temperature and the experimental eutectic temperature.

4. DISCUSION

4.1. Chemical composition

Chemical compositions indicate the increase of the chromium in the three experimental alloys, so it is feasible to evaluate its structural and thermal effect. Equivalent carbon in all cases is slightly hypereutectic, so the solidification pattern is similar in the three alloys.

4.2. Microstructure

Table 2 shows that the fraction of carbides is increased with the increase of chrome. There are differences between the fraction of carbides located in the wall and the center of the casting, this is an indicative of the local cooling rates effect. On the other hand, in spite of competing the solidification pattern of the stable diagram Fe-G with the metastable diagram Fe-Fe_3C, a good level of nodularity and nodule count was obtained in the three experimental alloys. Iron with the lowest content of chromium presented a smaller fraction of alloyed carbides mixed with ledeburite (carbides+perlite). The alloys with higher chromium content carbides in greater quantity with long and continuous morphology, similar to primary carbides. The elongated carbides are associated with alloyed carbides probably CrxCy type.

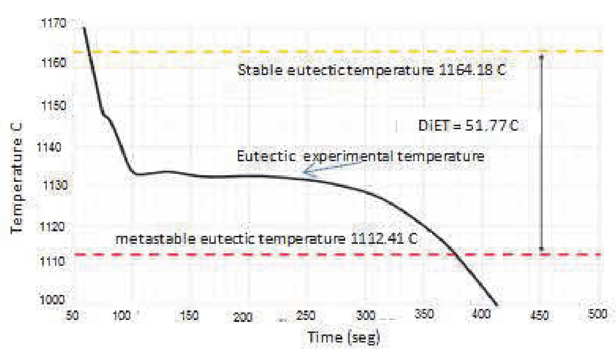

Figure 6 Cooling curve for iron without chromium

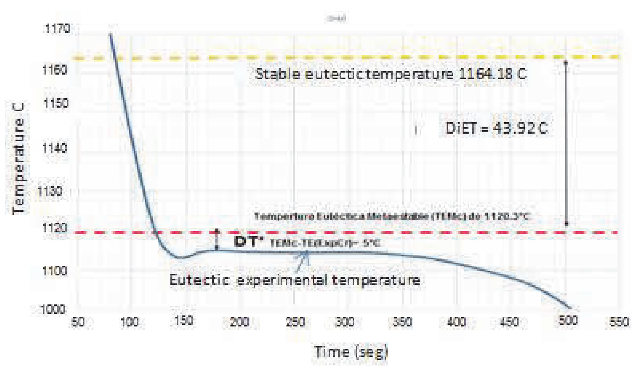

Figure 7 Cooling curve for iron with 1.35 %Cr

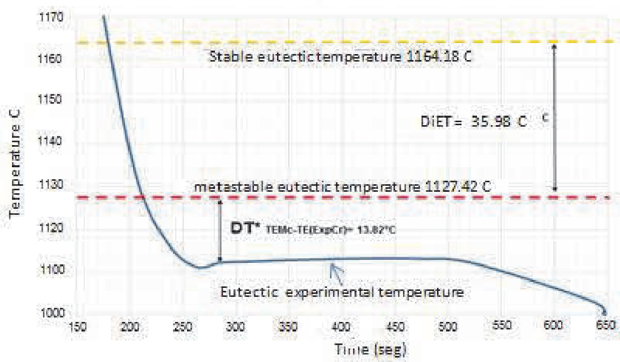

Figure 8 Cooling curve for iron with 1.95 %Cr

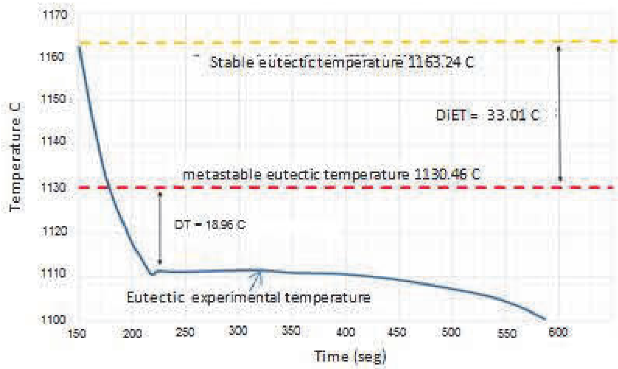

Figure 9 Cooling curve for iron with 2.49 %Cr

4.3. Cooling curves

In the cooling curve of nodular iron without chromium, the eutectic transformation is between the stable and metastable temperatures, indicating the non-precipitation of carbides during solidification, this condition agrees with the microstructure of this alloy.

Alloyed iron with 1.35 % Cr the experimental eutectic temperature is depressed to 5 °C below the stable eutectic temperature (parameter DT in **Figure 7**). This condition favors the formation of carbides during solidification by partially following the metastable diagram, a condition that is consistent with the microstructure of **Figure 3**.

In the case of iron with 1.95 % Cr the difference between the experimental and metastable eutectic temperature (DT) increases to 13.82 °C (**Figure 8**), which indicates the formation of carbides in greater quantity. This is observed in the microstructure of **Figure 4** in which the morphology of the carbides also changes. Finally the iron with 2.49 % Cr, the experimental eutectic temperature is located 18.96 °C below the metastable temperature (DT in **Figure 9**), indicating the formation of more carbides than iron with 1.95 % Cr, this is corroborated in the results of the **Table 1** and in the microstructure of **Figure 5**. The magnitude of the depression of the experimental eutectic temperature in relation to the metastable has a direct relationship with the fraction of precipitated carbides, while greater difference greater quantity of carbides. So this parameter can predict the amount of precipitated carbides when chromium is used as the alloying element.

5. CONCLUSION

1) With chromium content between 1.35 and 2.49 %, the fraction of precipitated carbides is increased from 8.2 to 25.3 %.
2) Chromium depresses the eutectic transformation temperature to below the metastable eutectic temperature.
3) When the chromium content increases the magnitude of the eutectic temperature depression also increases and is related to the fraction of precipitated carbides.
4) The magnitude of eutectic depression can be used as a parameter to predict the fraction of precipitated carbides when the whitening element is only chromium.

ACKNOWLEDGEMENTS

To the project PAPIIT IN 116514 for the financial support granted. We also thank M. in C. Victor A. Aranda V. for the support in the evaluation of carbides in the experimental alloys.

REFERENCES

[1] KEOUGH, J.R., HAYRYNEN, K.L. Carbidic Austempered Ductile Iron (CADI). Ductile Iron News, Issue 3, pp 1-9, 2000

[2] LAINO, S., DOMMARCO, R., SIKORA, J. Fundición nodular austemperizadas con carburos. El Fundidor de la Cámara de Industriales, Fundidores de la República Argentina, N° 123, pp 4-16, Mayo-Junio 2007

[3] GARCÍA, A., ATLATENCO, C., GONZÁLEZ C., AMARO A. Respuesta al tratamiento de Austemperizado (ADI) de un hierro nodular con diferentes matrices. Moldeo y Fundición, N° 175, pp 12-16, Febrero 2007

[4] BIGGE R. Tramp Elements in Grey and Ductile Iron” Iron Casting. Research Institute, Ductile Iron News, pp 1-4,Issue 2009

[5] SHEIKHOLESLAMI, M., BOUTORABI, S.M.A. A Research on the calculation of graphitization ability of gray cast irons, Iranian Journal of Materials Science and Engineering Vol. 9 Nº4, S/pp. IUST, Tehran, Iran, Diciembre de 2012.

[6] KANNO, T., KIMURA, H., HIDEO, N. The relationship between the variation of eutectic temperature and melt quality in cast iron. Kimura Foundry Co. , AFS Trans, S/pp. Japón, Septiembre del 2005.

[7] ARIAS, M., HIRSCHVOGEL, J. Influencia del silicio en la temperatura de transformación eutectoide. El fundidor de la cámara industriales Fundidores de la Republica Argentina, N°126, pp 36-50, Diciembre de 2008