Whitepaper
Carbon Segregation in CA6-NM Castings

SFSA Technical & Operating Conference
December 2017
Chicago, Illinois

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Introduction

This study was focused on one significant issue facing induction melting foundries producing castings in CA6NM alloy that are mainly intended for sour gas applications.

In order to maintain a superior performance and have a limited sensitivity to sulphide stress corrosion cracking (SCC) castings made in CA6NM for oil and gas applications and exposed to corrosive environments must be relatively soft. NACE standards limit the maximum hardness of CA-6NM alloy to 23 HRc. This performance can only be achieved if a very low carbon level is maintained throughout the casting and if a proper heat treatment cycle is applied.

The occurrence of local micro and macro segregation of carbon can significantly affect the final hardness making the softening of the casting, especially in the heavily segregated areas, very difficult and occasionally impossible. It was well documented that in order to achieve NACE required maximum hardness of 23 HRc, CA6NM castings must satisfy the following:

1. Have a carbon content of 0.03% or lower.
2. Receive a heat treatment consisting of an austenitizing and double tempering cycle.
   a. Austenitizing: 1900oF followed by air cooling
   b. Intermediate tempering: 1250oF followed by air cooling
   c. Final tempering: 1150oF followed by air cooling

Weld repairs must also be taken into consideration. In order to meet NACE requirements and maintain a maximum hardness of 23 HRc in the weld, the heat affected zone and the base metal, each casting must be double tempered after the completion of the weld repair. The hardness of all welds, including heat affected zones, must be checked and qualified as being in compliance with NACE.

Castings must be allowed to cool to room temperature following each heat treatment cycle. Other residual elements responsible for the hardening of the alloy, such as vanadium and nitrogen, should also be considered when creating a melt recipe but this study will only address the maximum carbon content.

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Description

This work is intended to show the inconsistency of the carbon content at different locations of the casting and the impact of carbon inconsistency on hardness, weldability, and ultimately on the acceptance of the casting.

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The Study

The study consisted of sectioning of a casting in an area located directly under the riser, and analyzing the carbon content at multiple locations.

The results were then compared with the carbon content analysed on the final spectrometer sample removed from the ladle right before the metal was poured into the mould.

The present work was triggered by a customer material specification requesting that:

"Chemical composition shall conform to the requirements defined in ASTM A743 with the exception that carbon content is to be limited to 0.03% and shall apply to both heat and product analysis."

Furthermore, the material spec required that:

"Chemical composition for acceptance shall be based on product analysis."

The subject casting was a 1,600 lb. wicket gate. The total pour weight including the gating system and risers was 2,800 lb.

Magma simulation confirmed that the two risers, one on the blade and one on the trunnion, provided adequate feed metal to the casting.

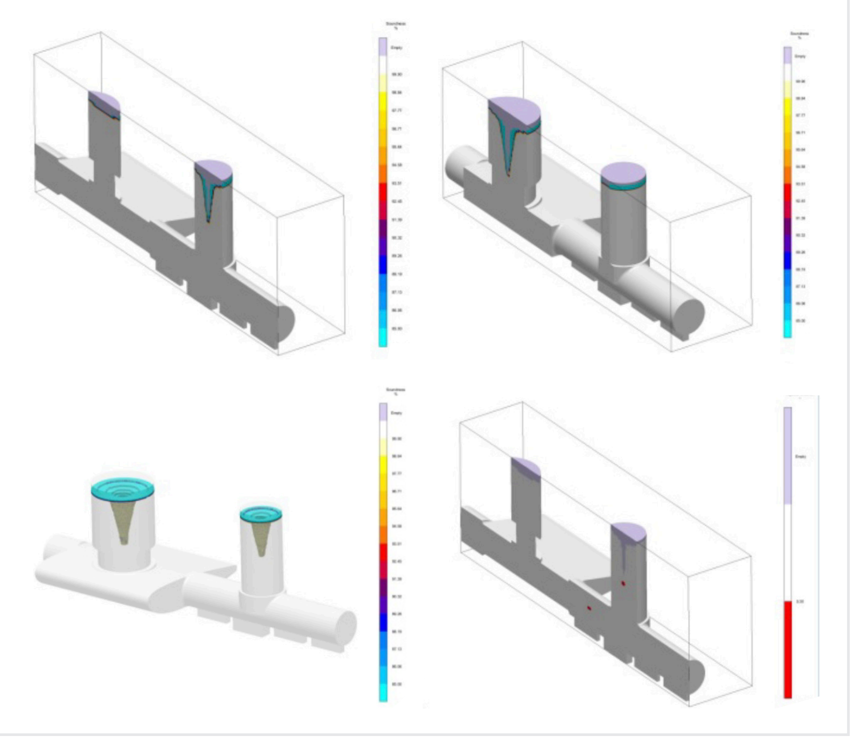
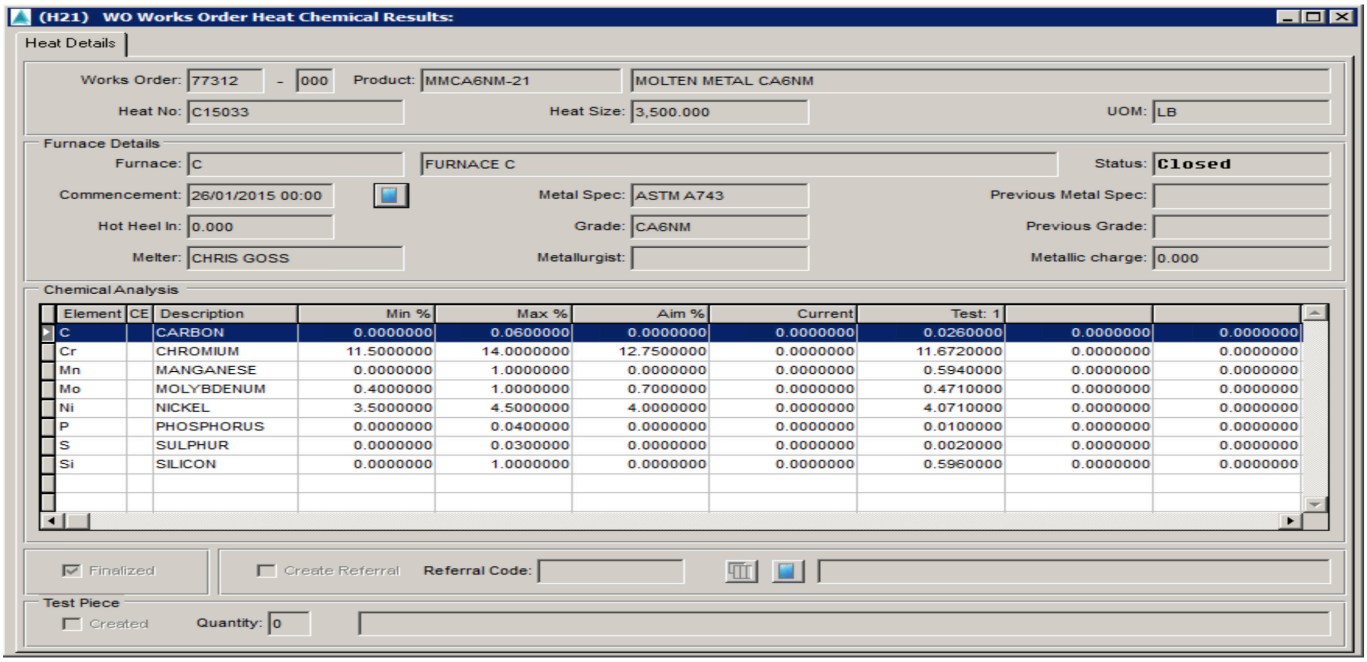


Figure 1

Melting took place in a 4,000 lb induction furnace. Metal was lip poured into a no-bake mould through a gating system provided with two 6” X 6” ceramic filters.

The chemical composition of the alloy was analyzed on a sample removed from the pouring ladle after the slag removal. An ARL 3460 ThermoFisher spectrometer was used for the chemical analysis of the sample.

Below is the final chemistry of the alloy analyzed on the spectrometer and recorded on the certified mill test report (CMTR):



(H21) WO Works Order Heat Chemical Results:

Heat Details

Works Order: 77312 - 000 Product: MMCA6NM-21 MOLTEN METAL CA6NM

Heat No: C15033 Heat Size: 3,500.000 UOM: LB

Furnace Details

Furnace: C FURNACE C Status: Closed

Commencement: 26/01/2015 00:00 Metal Spec: ASTM A743 Previous Metal Spec:

Hot Heel In: 0.000 Grade: CA6NM Previous Grade:

Melter: CHRIS GOSS Metallurgist: Metallic charge: 0.000

Chemical Analysis

Element	CE	Description	Min %	Max %	Aim %	Current	Test: 1		
C		CARBON	0.0000000	0.0600000	0.0000000	0.0000000	0.0260000	0.0000000	0.0000000
Cr		CHROMIUM	11.5000000	14.0000000	12.7500000	0.0000000	11.6720000	0.0000000	0.0000000
Mn		MANGANESE	0.0000000	1.0000000	0.0000000	0.0000000	0.5940000	0.0000000	0.0000000
Mo		MOLYBDENUM	0.4000000	1.0000000	0.7000000	0.0000000	0.4710000	0.0000000	0.0000000
Ni		NICKEL	3.5000000	4.5000000	4.0000000	0.0000000	4.0710000	0.0000000	0.0000000
P		PHOSPHORUS	0.0000000	0.0400000	0.0000000	0.0000000	0.0100000	0.0000000	0.0000000
S		SULPHUR	0.0000000	0.0300000	0.0000000	0.0000000	0.0020000	0.0000000	0.0000000
Si		SILICON	0.0000000	1.0000000	0.0000000	0.0000000	0.5960000	0.0000000	0.0000000

Finalized Create Referral Referral Code:

Test Piece

Created Quantity: 0

Figure 2

The ladle analysis revealed a carbon content of **0.026%**. This value was recorded in the CMTR.

The trunnion of a sacrificial wicket gate casting was sectioned and a 1.5” thick slab was removed from the area located directly under the riser. Figure 3.

Sample material was then drilled out from 15 different locations as shown in Figure 4 (overpage) and analyzed on a LECO analyzer using the combustion method per ASTM E1019. The locations of sample removal were approximately 1” apart.

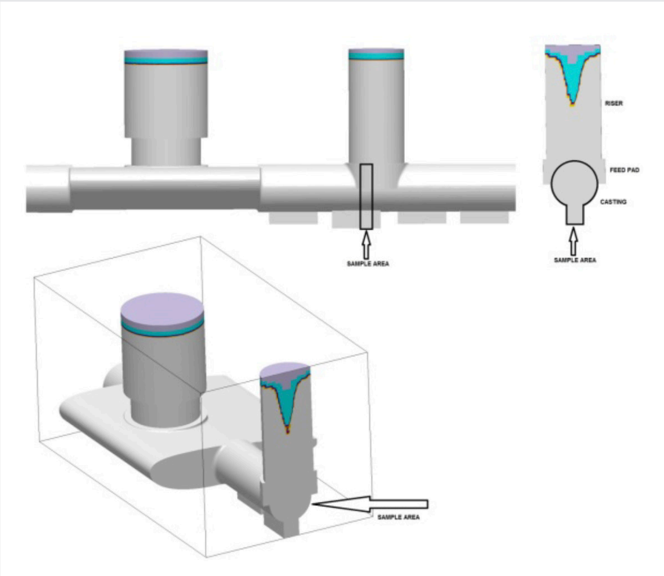


Figure 3

Table 1

Location	1	2	3	4	5
C%	0.069	0.030	0.028	0.029	0.027

Location	6	7	8	9	10
C%	0.029	0.028	0.031	0.032	0.034

Location	11	12	13	14	15
C%	0.036	0.050	0.040	0.036	0.046

The results revealed by the LECO analyser were different that the ladle analysis. Table 1 above shows that the carbon content was consistently higher than the carbon obtained on the ladle analysis and it varied significantly from one location to another.

The highest carbon concentration was at location 1 and was attributed to surface contamination and therefore disregarded from this study.

Figure 5 and the graph (above and to the right) show that the heaviest carbon segregation occurred at locations 8, 9, 10, 11, 12, 13, 14 and 15. The segregated zone was located within 3 to 4 inches below the riser.

The segregated under-riser casting region may have inferior mechanical properties, poor weldability and poor machinability. It can cause cracking under the riser during the riser removal and machining. It can also affect the component susceptibility to stress corrosion cracking while in service.

The results of this investigation are consistent with previous findings on macrosegregation studies. The former American Cast Iron Company (ACIPCO), Foseco and University of Iowa also studied the segregation of carbon during solidification, but on carbon and low alloy steel, not on stainless steel castings with a very low carbon level.

Figure 4

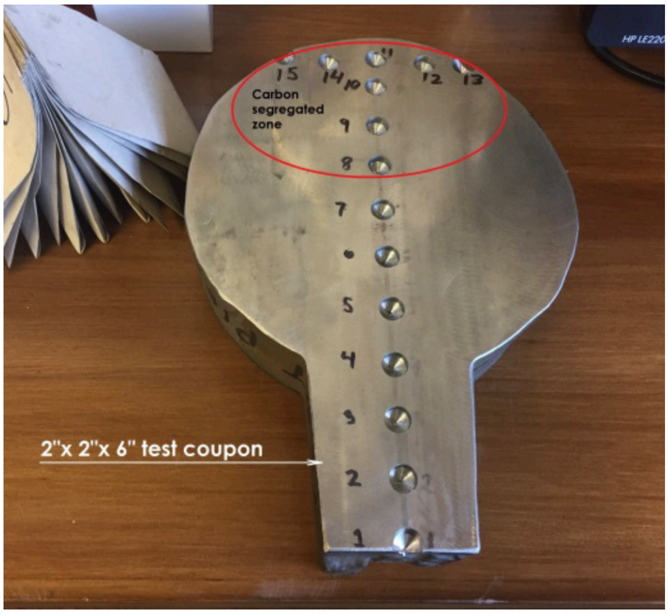


Figure 5

Figure 5 – Graph

Conclusions

- **Carbon segregation occurs in steel castings even in alloys with a very low carbon content.**
- **Segregation of carbon occurs during the last stage of solidification.**
- **Segregation occurs preferentialy under the riser, this being the last area that solidifies.**
- **Segregation can also be noticed in the heavier sections of the casting away from the riser.**

Summary

- It is important to aim for a very low carbon content when writing up an alloy recipe especially when dealing with specifications that limit the maximum carbon content to very low levels. However, it is even more important to do so when the specification has an acceptance criteria based on the product analisys and not just on ladle analysis.
- Ideally the ladle analysis should reveal a carbon content of 0.015% when melting for CA6NM with carbon 0.03% or lower.
- There are two main sources of unwanted carbon into the charge: charge materials and contamination.
- Charge materials must be carefully selected, especially when melting takes place in induction furnaces. Only charge materials with a very low carbon content must be used. Materials must be clean, free of dirt, oils and rust.
- The use of foundry returns is not recommended as they can be highly contaminated with carbon from previous oprations such as arc-wash, grinding, shotblast, etc.
- Use clean furnaces and ladles in order to prevent carbon contamination. A wash heat is highly recommended prior to melting CA6NM with a final carbon content of 0.03%.

Acknowledgements

Kenneth W. Murphy American Cast Iron Pipe Company, Birmingham, Alabama – Understanding Under Riser Cracking.

Kent D. Carlson and Christoph Beckermann, The University of Iowa, Iowa City, IA - Prediction of Riser Carbon Macrosegregation due to Flow in Steel Castings.

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