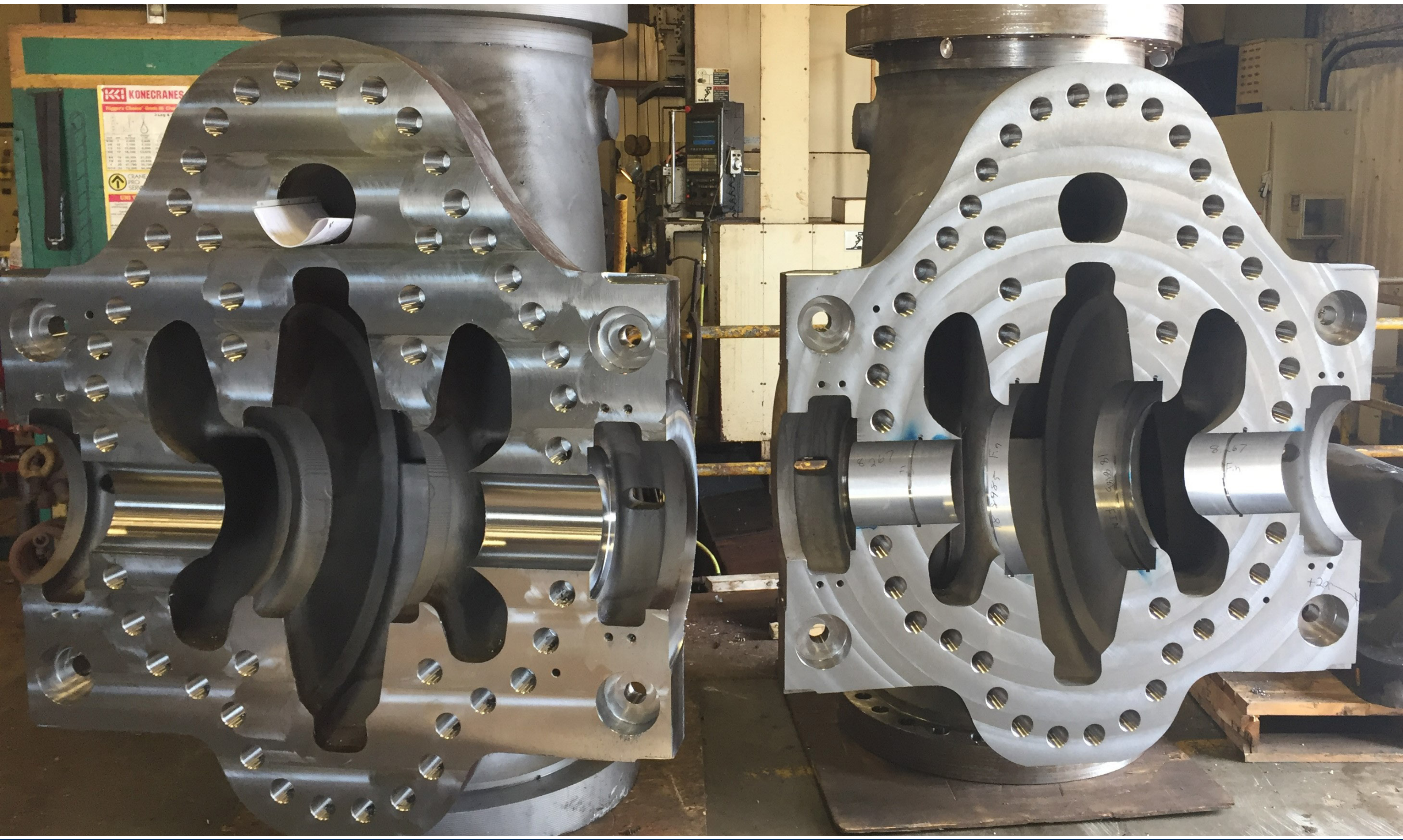
Whitepaper

Adjusting the Mechanical Properties of the Alloy to Solve Quality Issues



Unleashing an Alloy's potential to Improve Quality.

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Introduction

This work is intended to address quality constraints experienced by steel castings during the hydrostatic pressure testing. It also shows how the yield and tensile strength of WCB can be adjusted so that WCB becomes compliant with ASTM A148 grade 80/50.

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Description

Casting distortion often occurs in finish machined castings during the hydrostatic pressure testing especially when testing exceeds the maximum allowable working pressure. This type of plastic deformation can be catastrophic. It can turn a perfectly sound casting into a scrap mostly because of the condition of the casting at the time the pressure testing is performed. In general, the hydrostatic pressure testing is performed on finished machined castings. Any deflection encountered at this stage can easily move the final dimensions outside of the expected tolerance band.

When anticipating this type of occurrence some machine shops try to mitigate by semi-finishing the casting first leaving machining stock on areas prone to distortion. Castings get pressure tested in this semi-finished condition and then they get machined to final dimensions. This interruptive approach can be costly, time consuming and not always successful.

In general, carbon steel castings such as the split pump casings shown in Figure 1 are prime candidates for this type of distortion. This issue triggered the concept of a modified WCB grade with improved mechanical properties capable to providing the subject casting with the extra strength needed to undergo pressure testing without any plastic deformation.

Alloy Composition and Mechanical Properties

Typically, foundries produce WCB grades using the following aimed values for carbon, silicon and manganese:

C = 0.24 – 0.26%
Si = 0.4 – 0.6%
Mn = 0.5 – 0.7%.

Mechanical properties of standard WCB in normalized (1650F) and tempered (1200F) condition are as follows:

TS = 72.5 to 77KSI
YS = 43.5 to 47KSI
E = 30 to 32.5%
RoA = 35 to 48%

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Objective

The objective here was to slightly modify the chemical composition of WCB and produce an alloy with higher yield strength.

The expectation was that the modified version would prevent deflection during the hydro pressure testing. The modified alloy had to be compliant with all requirements of ASTM A216, including the 0.50% max Carbon Equivalent per S11.1.

The goal was to create a cost-effective alloy with similar or better weldability, machinability and comparable ductility. For this to be possible the rest of the process parameters such as melting, de-oxidation practice, heat treatment had to remain unchanged.

When assessing strengthening mechanisms special consideration was given to Mn knowing that Mn is not just a deoxidizer, sulphide modifier and grain refiner but also an important alloy strengthener in carbon and low alloy steels. As a result, the WCB-Mn grade was created by simply moving the aimed range for Mn towards the upper permissible limit. The expectation was that the extra Mn would result in increased tensile and yield strength while the ductility of the alloy will not be significantly impacted.

Footnote B of ASTM A216, Table 1 states that "for each reduction of 0.01% below the specified maximum content, an increase of 0.04% Mn above the specified maximum will be permitted up to a maximum of 1.28%."

Table 1 – Chemical Requirements

Element	Composition %		
	Grade WCA UNS J02502	Grade WCB UNS J03002	Grade WCC UNS J02503
Carbon	0.25	0.30	0.25
Manganese	0.70	1.00	1.20
Phosphorous	0.035	0.035	0.035
Sulfur	0.035	0.035	0.035
Silicon	0.60	0.60	0.60
Specified Residual Elements:			
Copper	0.30	0.30	0.30
Nickel	0.50	0.50	0.50
Chromium	0.50	0.50	0.50
Molybdenum, max	0.20	0.20	0.20
Vanadium	0.03	0.03	0.03
Total of these specified residual elements[E]	**1.00**	**1.00**	**1.00**

[A] For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% manganese above the specified maximum will be permitted up to maximum of 1.0%.

[B] For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% Mn above the specified maximum will be permitted up to maximum of 1.28%.

[C] For each reduction of 0.01% below the specified maximum carbon content, an increase of 0.04% Mn above the specified maximum will be permitted up to maximum of 1.40%.

[D] For lower maximum sulfur content, see Supplementary Requrement S52.

[E] Not applicable when Supplementary Requrement S11 is specified.

Based on Table 1, footnote B, Mn content in WCB can be as high as 1.28% if C is kept below 0.23%.

The newly created version, WCB-Mn, has the following ranges for main elements: C = 0.24 – 0.26%, Si = 0.4 – 0.60% and Mn = 1.00 – 1.2%. Basically, Mn was increased by 0.50% and C was marginally reduced from 0.25% to 0.24%. The range for Si remained unchanged.

Test Results

Mechanical properties shown in Table 2 were obtained from separately poured test coupons collected from a total of 20 heats: 10 heats poured in WCB and 10 in WCB. All test coupons were heat treated to the same parameters: normalized at 1650F and tempered at 1200F. In fact, all test coupons were heat treated together as a single batch.

Test results were in line with the expectations. All heats poured in WCB-Mn produced higher yield strengths. Data shows that all heats poured in WCB-Mn were 100% compliant with ASTM A216 requirements including chemical composition, mechanical properties and CE.

Table 2 – WCB and WCB-Mn. Chemical Composition and Mechanical Properties

Heat	Alloy	C	Si	Mn	P	S	C/E	TENSILE (KSI)	YIELD (KSI)	ELONG (%)	ROA (%)
D20049	**WCB**	0.26253	0.48158	0.59059	0.01646	0.01329	0.361	77.433	46.967	33	47.34
E20082	**WCB**	0.25869	0.47724	0.59907	0.02898	0.01514	0.359	73.724	47.072	31.25	30.87
C20075	**WCB**	0.26428	0.47444	0.56108	0.01992	0.01275	0.358	70.871	46.363	31.3	49
E20087	**WCB**	0.26564	0.44705	0.57038	0.01724	0.01562	0.361	70.88	45.236	32.1	35.68
E20088	**WCB**	0.25208	0.49173	0.5823	0.01597	0.01512	0.349	70.45	43.776	32.85	51.16
D20050	**WCB**	0.26652	0.50877	0.57413	0.02812	0.01883	0.362	75.404	47.57	30.7	48.01
D20051	**WCB**	0.25464	0.49873	0.59929	0.01782	0.01435	0.355	73.075	44.523	31.35	53.77
E20091	**WCB**	0.25021	0.50828	0.57272	0.01662	0.01435	0.346	72.578	43.279	23.85	48.6
E20093	**WCB**	0.25228	0.52885	0.59758	0.01412	0.01335	0.352	77.544	48.573	31.2	44.44
E20094	**WCB**	0.25988	0.49308	0.58109	0.01696	0.01632	0.357	78.986	46.94	30	34.41
AVG.		**0.25868**		**0.58282**			**0.356**	**74.1**	**46.0**	**30.8**	**44.3**
G20023	**WCB-Mn**	0.23379	0.5252	1.1012	0.02058	0.02242	0.417	86.902	60.499	27.25	47.56
G20024	**WCB-Mn**	0.22439	0.4772	1.14691	0.01832	0.01743	0.416	84.256	57.163	28.5	47.26
F20074	**WCB-Mn**	0.24459	0.47228	1.0331	0.01786	0.02015	0.417	82.424	53.424	26.5	39.29
F20076	**WCB-Mn**	0.24523	0.4506	1.07402	0.01953	0.01619	0.424	83.167	55.781	25.85	36.21
F20087	**WCB-Mn**	0.23133	0.47754	1.02879	0.02106	0.00565	0.403	84.306	57.381	29.5	46.73
F20093	**WCB-Mn**	0.24758	0.49197	1.07251	0.02213	0.02152	0.426	83.297	57.726	27.1	44.23
F20095	**WCB-Mn**	0.24491	0.45419	1.04651	0.02301	0.01375	0.419	81.575	55.497	27.9	46.45
C20142	**WCB-Mn**	0.24214	0.47946	1.06767	0.05052	0.01553	0.420	83.449	58.563	25.25	33.61
F20227	**WCB-Mn**	0.25022	0.47629	1.03731	0.01824	0.01006	0.423	83.275	53.254	27.3	34.67
F20226	**WCB-Mn**	0.25193	0.49077	1.05046	0.03376	0.0116	0.427	81.204	57.144	30.3	43
AVG.		**0.24161**		**1.06585**			**0.419**	**83.4**	**56.6**	**27.5**	**41.9**

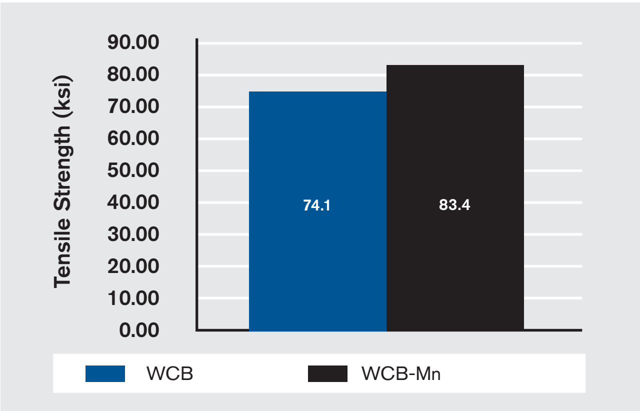
Table 2 also revealed that the yield strength of all heats poured with a Mn content above 1.0% exceeded 53 ksi in normalized and tempered condition.

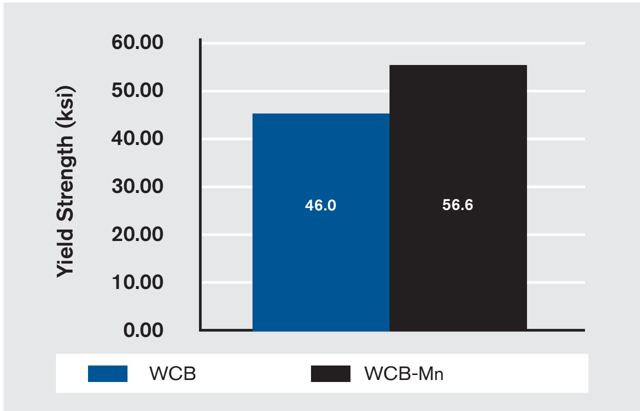
Table 3 below represents just the average values collected from Table 2 for C, Mn and CE as well as the average mechanical properties of the two alloys. It clearly indicates that a 0.50% increase in Mn content improved both the tensile and the yield strength of WCB by 10,000 psi.

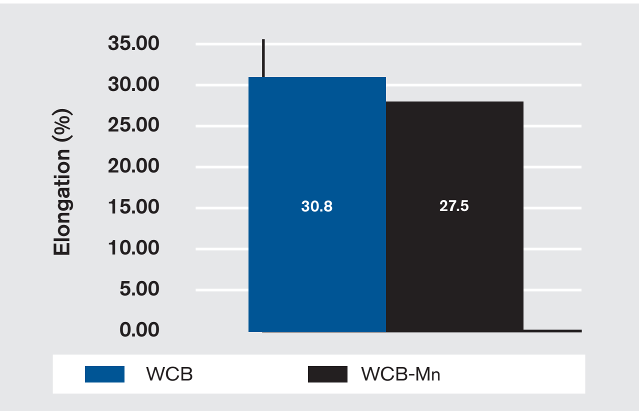
Table 3 – WCB/WCB-Mn. Composition and Mechanical Properties, Average Values

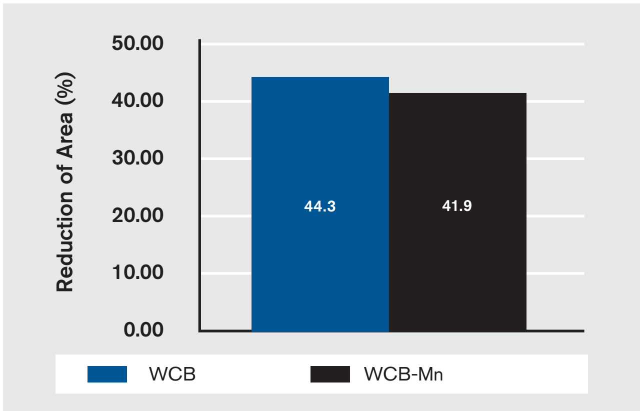
Alloy	C	Mn	C/E	TENSILE (KSI)	YIELD (KSI)	ELONG (%)	ROA (%)
WCB	0.26	0.58	0.356	74.1	46.0	30.8	44.3
WCB-Mn	0.24	1.07	0.419	83.4	56.6	27.5	41.9

As expected, a small decrease in elongation and reduction of area occurred but it was not significant enough to cause any concerns.









While the yield strength of the alloy was quantifiable increased by Mn additions it was not 100% clear at this point if this increase would be enough for the casting to withstand the pressure testing without any permanent deformation.

Case Study

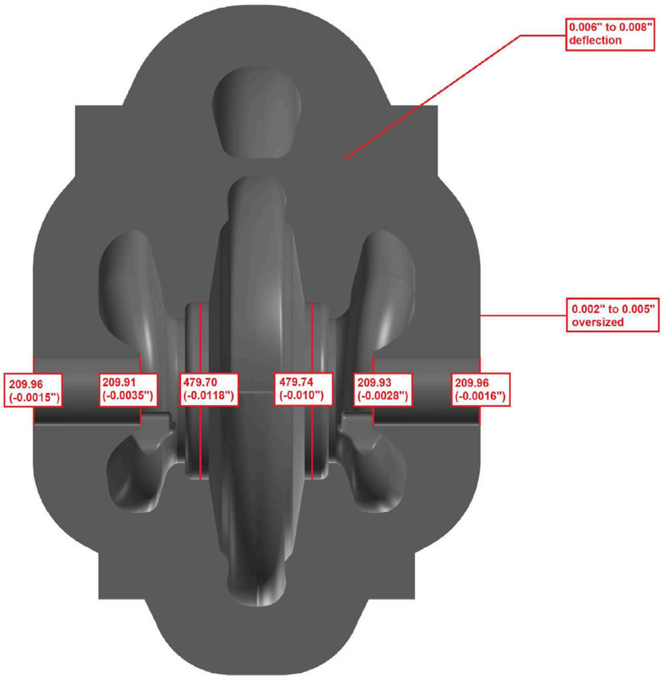
As stated at the beginning of the article, the need for a carbon steel grade with superior mechanical properties was triggered by the distortion experienced by cast pump casings during pressure testing. Figure 1 shows a typical example of a split pump casing affected by distortion during the hydro pressure testing. Distortion occurred mostly in the top half of the casing, shown below in Figure 1b.

Figure 1a – Pump Casing Bottom

Figure 1b – Pump Casing Top

The split face, internal diameters and end faces were the areas frequently affected as shown in Figure 2. Dimensional variations of up to 10 thou were recorded on these zones.

The distortion was 100% eliminated once the WCB-Mn alloy was introduced in the production of these pump casings. It seems that WCB-Mn has enough yield strength to resist the testing pressure parameters. Castings now go straight to finish machining then undergo hydrostatic pressure testing. There is no need for the semi-finishing stage or additional set-ups. Currently all castings are CMM inspected before and after the completion of the hydrostatic pressure testing and no dimensional changes are ever recorded after the introduction of the new alloy.



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Conclusions

Major quality issues such as the distortion / deflection described here can sometimes be resolved by applying simple, and in this case, inexpensive solutions.

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An increase by 0.50% of the Mn content improved the alloy tensile and yield strength by roughly 10,000 psi while the ductility of the alloy was not significantly affected. The average elongation and reduction of area decreased by only 3.0%.

Table 4 shows that the WCB-Mn alloy complies with ASTM A216 requirements for WCB and it also complies with ASTM A148 requirements for grade 80-50.

Table 4 – WCB-Mn Mechanical Properties

Alloy	ASTM A216 WCB	WCB-Mn	ASTM 148 80-50
TS (KSI)	70-95	83.4	80 min
YS (KSI)	36	56.6	50 min
E (%)	22 min	27.5	22 min
RoA (%)	35 min	41.9	35 min

The WCB-Mn alloy can be recommended to construction casting users as a cost-effective alternative to ASTM A958 grade SC 8620 class 80/50 that they usually order.

The effects of manganese in WCB-Mn discussed here addressed mainly the strength of the alloy and its advantages when used to fix certain quality issues such as distortion.

Having a slightly lower elongation and reduction of area, that may impact weldability, machinability and tendency to cracking, WCB-Mn should not be produced indiscriminately as a replacement for the standard WCB grade.

Mn alone can't fix all quality issues related to casting strength. The casting strength is greatly impacted by the quality of the steel and foundry processes. Using high quality charge materials and applying sound foundry processes such as gating and risering, melting and pouring, deoxidation, heat treatment is equally important.

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