Nigerian Research Journal of Engineering and Environmental Sciences 2(2) 2017 pp. 408-415

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

DESIGN IN THE MANUFACTURE OF THE CRUSHER JAW USING HADFIELD STEEL PART TWO: MOULD MAKING, MELTING, CASTING AND HEAT TREATMENT

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ARTICLE INFORMATION

Article history:
Received 19 May, 2017
Revised 31 August, 2017
Accepted 07 September, 2017
Available online 29 December, 2017

Keywords:
Pattern
Mould
Melting
Casting
Heat treatment

ABSTRACT

In a previous study of the design and production of the crusher jaw, the gating and risering necessary for the proper filling and feeding of the casting to eliminate casting defects like shut-run, cold-shut and porosity were designed. This current study produced the complimentary processes including mould making, melting, casting and heat treatment that were required to mitigate some more casting defects and achieve the needed properties. Moulding was made of basic sand of Chromite from a pattern made form Sapele Walnut with 2% pattern maker's shrinkage. The melt was made of graded scraps of mild steel, charged with Ferro-alloys: Ferro-manganese and Ferro-silicon; and cast from a bottom-pour ladle. The heat treatment was to achieve retention of austenite by quenching after austenitizing at temperatures of 950°C, that is, above A_{cem} for steel of 1.25% Carbon content and soaking until full austenite transformation was achieved. All processes were successfully carried out and the casting produced worked satisfactorily for more than six months.

1. INTRODUCTION

In part 1, the gating and risering design for the casting of a crusher jaw was undertaken and these were meant to combat such defects as shut-run, cold-shut, micro-porosity and shrinkage cavity. However, all other processes in the founding of a casting generate reactions that could lead to defects (Paramenan et al. 2017). These include moulding, melting, casting and heat treatment. In this part 2, we deal with the design of the mould which could cause scabbing, metal penetration, dilation and impairment of gas evolution (Rajesh and Khan 2014); the design of the melting process, which is associated with such defects as compositional requirement, oxidation, reduction, gas absorption and generation of slag (Rod-Naro and William 2015); and heat treatment, which should be used to accomplish mechanical changes but could also lead to a variety of defects including hot tear, quenching cracks and not achieving the desired properties (Sinha 1991).

A lot of studies have been done in all these areas, moulding, melting, casting and heat treatment but this current study is different because it is specific to a particular steel quality instead of to steels in general. Just like in part 1 of the paper, general principles in foundry moulding, melting, casting and heat treatment practices were applied to the production of the crusher jaw made of Hadfield steel, a specific grade of High Carbon, High Manganese steel. This study is, thus very useful as it provides hands-on information on the casting processes of a specific quality of steel not readily available in the literature.

2. MATERIALS AND METHODS

2.1. Pattern and Mould Making

2.1.1. Materials

Materials used here were Sapele Walnut timber, wood glue, nitrocellulose lacquer, silica sand, chromite sand and bentonite. Machines include woodworking machines: band-saws, cross-cutters, thicknessers and sanding machine. There were also mould boxes and rammers. The wood, Sapele Walnut, was well seasoned to prevent it from warping, shrinkage and other shape changes as it is stored. The choice of wood glue was to ensure that when the wood is laminated to increase its thickness, it does not dismember with time. Nitrocellulose lacquer is used to paint the pattern which should make it impervious to water and moisture. High Carbon, High Manganese Steel used in this study is a ‘basic steel’ and reacts with silica hence the choice of chromite as the facing sand and silica as the backing sand.

2.1.2. Pattern making

The pattern maker’s shrinkage was 2% to take care of the post solidification contraction. Consequently, the pattern dimensions were measured with a 2% adjusted pattern maker’s rule (Delta Steel Company, 1988). The pattern also had 2% draft, that is, a 2% tapering for withdrawal from the mould. It was a one-piece pattern that will be completely moulded in the drag, the lower mould box.

2.1.3. Mould making

The sand mould was made of chromite as facing and silica as backing sand. Sands used for sand mould for high manganese casting include Olivine, Chromite and Zircon (Holtzer, et al., 2013). Only zircon is available in Nigeria (Sheidi, 2012), but it needs beneficiation to meet mould making standard. The sand preparation, sand mix, (comprising sand, bentonite and water) and moulding were made to the following mould characteristics according to American Foundry Society (Dietert 1966): These characteristics are the standard properties that will enable the mould to withstand the metal pressure, erosion, gas evolution, etc. (Hoyt, 2006). The process of getting the appropriate sand mix and mould compaction to meet the recommended properties was made complicated by the quality of the bentonite used as the binder. Bentonite was sourced locally and what was obtained was of drilling mud qualities. These grades often contain additives such as barium sulfate (barite), calcium carbonate (chalk), various thickeners and deflocculants. These contrasted the bentonite grades for foundries, which are majorly bentonite, either sodium based or calcium based (Clem and Doehler 1961).

Consequently, the sand mix had to be adjusted several times to achieve the appropriate mix. The final mix for the facing sand was Chromite sand = 100%; bentonite = 8% and water = 3%. The backing sand was made principally of used sand (silica and chromite) but was upgraded with new silica sand, bentonite and water.

Table 1: Characteristics of mould materials

Parameter	Value
Screen Analysis	43 – 50 AFS
Green Compressive Strength	80 – 100 kN/m^2
Permeability	100 - 150 AFS
Moisture Content	2.5 – 3.0 %
Mould Hardness	70 – 85 No

2.2. Melting and Casting

2.2.1. Materials

Melting materials were Steel scrap, Ferromanganese, Ferrosilicon and Carbon. The melting furnace was an induction furnace; furnace lining was magnesite while the transfer and casting ladle was bottom pour. Melting was carried out in a medium frequency induction furnace in order to attain the high temperature for steel melting. The furnace was lined with magnesite, a basic refractory material to minimize melt-lining reaction. Magnesite is a basic dry ramming mass with magnesium oxide, MgO, above 80% and does not react with manganese. The furnace was lined with this material and then sintered with a charge of billet off-cuts, as graded scrap which was converted to manganese steel.

2.2.2. Methods

There were two options to generate the required manganese steel melt. These were either by using clean manganese steel scrap or by using graded scrap with known composition; the latter option was adopted. Manganese steel has a composition of 1.2% Carbon, 12-14% Manganese, 0.5% Silicon and just traces of other elements. This composition was made up from 83.63% Steel billet scrap, 16.1% Ferro-manganese and 0.27% Ferro-silicon. The compositions of all the charge material were known and the charge was determined using material balance approach (Sadjere et al., 2013). Ferro alloys were charged just before the completion of melting to avoid much loss through burn-offs and conversion to slag. The last consideration in the process of melting and casting was the ladle for the transfer of the liquid metal and casting. The ladle was a bottom pour ladle with 50mm diameter spout, which corresponded with the down sprue size of the gating system. The use of bottom pour was to prevent slag, which has formed on top of the melt, from running into the mould. The ladle was also lined with magnesite, a basic lining, for the same reason of reaction of melt with acidic lining. The ladle was, however, lined with magnesite of lower grade because the holding time in the ladle was short. Finally, the ladle had to be pre-heated enough to allow it to retained much of its superheat before casting was completed. The melt was poured at 1580 ^oC, which is about 130 ^oC superheat but cast at about 1530 ^oC or 80 ^oC superheat, where the Liquidous was taken as 1450 ^oC.

2.3. Heat Treatment

Heat treatment was carried out in a gas-fired heat treatment furnace. The main reason for the heat treatment is to have retained austenite in the steel at the ambient temperature so that it can work-harden during operation. The heating curve was determined from the Iron-Iron Carbon Diagram by Shrager (Shrager, 1961). This was obtained by tracing the line of 1.25% carbon content (Manganese

Steel has 1.25% Carbon) until it crosses A_1 and A_{cm} on the Shrager Iron Carbon Constitutional Diagram as shown in Figure 1. Manganese steel with a carbon content of 1.25% is a hypereutectoid steel and contains Cementite, Pearlite and carbides of manganese at room temperature. Phase transformation begins at Arrest point, A_1 of 725°C, (i.e. tracing along the red line) if heating was very slow and completes at approximately 900°C at A_{cm}. The austenitizing temperature ensures that the steel was completely converted to the gamma or austenite phase.

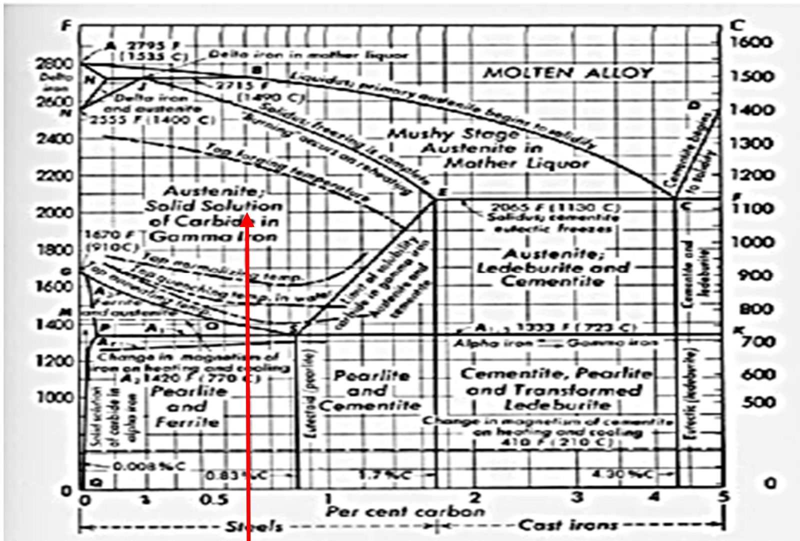

Figure 1: Iron – iron carbon diagram (Shrager 1961)

However, it is difficult to attain the slow heating required by the above condition in which case there are upwards shift in the arrest points A1 and Acm. The shifts of A1 + 50°C and Acm + 50°C are recommended, consequently, the full austenitizing temperature of 950°C was determined for this heat treatment (ASM, 2013). The heating rate of 100°C per hour was used. It should be noted that the material was not heated directly by the flame because that would have caused uneven heating; rather, the furnace atmosphere was heated until it attained the required temperature. This way, both the material and the closed atmosphere of air and combustion gases attain the same temperature. At 100°C per hour heating rate, the furnace attained the austenitizing temperature in approximately nine and half (9½) ours.

The third parameter investigated was the holding time. Due to the thickness of the material, the core of the material will not attain the austenitizing temperature at the same time with the skin. The recommended soaking time is 1 hour for the first 25mm, that is, 12.5mm outer skin; and 30 min for every other 25mm (Kuyucak et al., 2005). The largest thickness of the jaw was 110mm, which will result in about three three-quarter (3¾) hours holding time. Thus, the overall heating and holding time was twelve one-quarter (12¼) hours. The casting was therefore heat treated by austenitizing at 950°C for 13 hours including 3 hours of holding before quenching to obtain retained austenite. The plot of the heating curve of temperature against time is shown in Figure 2.

For the quenching process, the casting was transferred to the quenching bath of water large enough to have the casting fully immersed and incorporated impellers to keep the water constantly agitated during quenching. It was immersed inclined sideways in an almost vertical position to prevent warping. The whole process of transfer and quenching had to be fast, less than 30 minutes, to prevent the onset of other transformation processes.

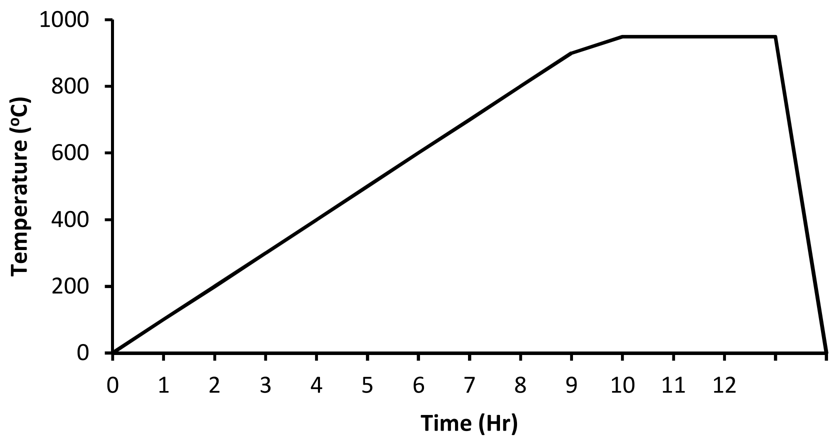

Figure 2: Heating curve of the heat treatment of hadfield steel crusher jaw

3. RESULTS AND DISCUSSION

The results of the various designs and operations are provided thus.

3.1. Moulding Characteristics

The mould characteristics obtained with the mix detailed in section 2.1.3 are shown in Table 2.

Table 2: Characteristics of mould materials

Parameter	Value
Green Compressive Strength	95 kN/m^2
Permeability	150 AFS
Moisture Content	3.5 %
Mould Hardness	82 No

3.2. Melting Characteristics

The result of the melting was documented in Foundry Heat Report (Melt Card) (Figure 3). The top table of the melt card gives the charge quantities and showed the target melt to be 2,254 kg for the steel grade MNS710. The material charged were steel crap (scrap billets), 1,990 kg, Fero-Silicon (FeSi), 10kg and Ferro-Manganese (FeMn), 320 kg. The second table is the melt analysis obtained from spark spectrometer. It showed the target composition and the analysis of two samples drawn at intervals during the melt. The first sample showed a melt with both carbon and manganese contents close to the target composition but with a very low silicon content. In the attempt to balance the composition, there was increase in the Ferro-Silicon charge but this led to further increase in the carbon content because of the carbon content in Ferro-Silicon. However, because as much as ±10 % of the target melt composition is acceptable (Sadjere, et al. 2013), the melt was considered okay at 1.45 C %. Also, the Manganese content should be between 12% and 14%, consequently, 11.6% was considered close enough to 12% and hence acceptable. Other information contained in the report include the object cast and the energy consumed in the process of melting the 2,254-kg steel. The mass of the casting was 1,555 kg while 1,624 kWh of electricity was consumed. The energy

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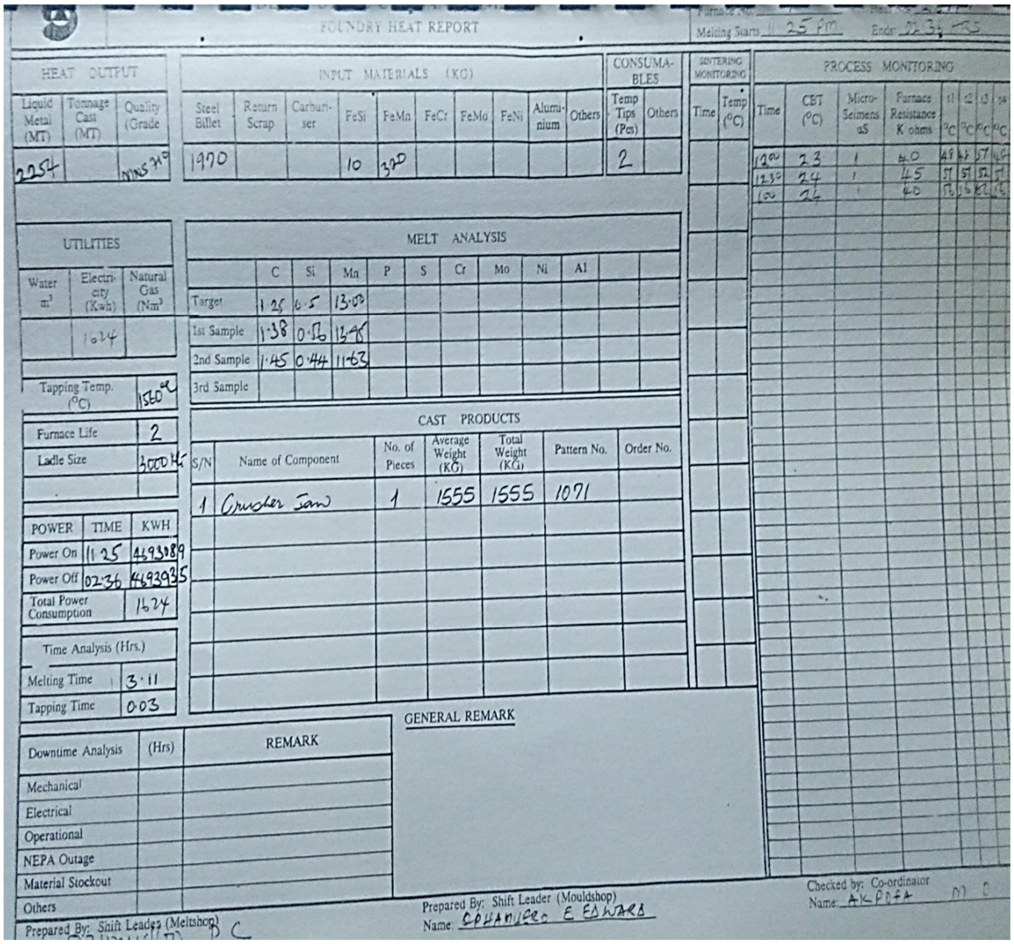
consumption is an indication of the huge energy demand for the melting of steel using a medium frequency induction furnace.



FOUNDRY HEAT REPORT

Melting Starts 11 25 pm Ends 02 36 [illegible]

HEAT OUTPUT

Liquid Metal (MT)	Tonnage Cast (MT)	Quality (Grade
2254		MNS 719

INPUT MATERIALS (KG)

Steel Billet	Return Scrap	Carburi-ser	FeSi	FeMn	FeCr	FeMo	FeNi	Alumi-nium	Others
1970			10	320					

CONSUMABLES

Temp Tips (Pcs)	Others
2	

SINTERING MONITORING

Time	Temp (°C)

PROCESS MONITORING

Time	CBT (°C)	Micro-Seimens uS	Furnace Resistance K ohms	t1 °C	t2 °C	t3 °C	t4 °C
1200	23	1	40	49	[illegible]	57	[illegible]
1230	24	1	45	57	51	52	[illegible]
100	24	1	40	[illegible]	[illegible]	[illegible]	[illegible]

UTILITIES

Water m³	Electricity (Kwh)	Natural Gas (Nm³
	1624	

MELT ANALYSIS

	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Target	1.25	0.5	13.00						
1st Sample	1.38	0.56	13.45						
2nd Sample	1.45	0.44	11.63						
3rd Sample									

Tapping Temp. (°C)	1560°C
Furnace Life	2
Ladle Size	3000 Kg

CAST PRODUCTS

S/N	Name of Component	No. of Pieces	Average Weight (KG)	Total Weight (KG)	Pattern No.	Order No.
1	Crusher Jaw	1	1555	1555	1071	

POWER	TIME	KWH
Power On	11 25	4693089
Power Off	02:36	4693935
Total Power Consumption		1624

Time Analysis (Hrs.)

Melting Time	3.11
Tapping Time	0.03

Downtime Analysis	(Hrs)	REMARK
Mechanical		
Electrical		
Operational		
NEPA Outage		
Material Stockout		
Others		

GENERAL REMARK

Prepared By: Shift Leader (Meltshop)

Prepared By: Shift Leader (Mouldshop)
Name: [illegible] E EDWARD

Checked by: Co-ordinator
Name: AKPOFA

Figure 3: Foundry Melt Report for Hadfield Steel MNS710 (Source: Delta Steel Company)

3.3. Heat Treatment Result

The heat treatment was successful. There were no quenching cracks or hot tear. However, since the casting was very large, the micrograph could not be generated to verify the expected retained austenite in the microstructure. Alternatively, the casting was installed and put to work and did not fail in service for a period of at least six months. The casting is shown in Plates 1 and 2. Plate 1 shows the crusher jaw teeth while Plate 2 shows the back side with recesses, which are weight reducers.

Plate 1: Cast crusher jaw with fully formed teeth (Source: Delta Steel Company)

Plate 2: Cast crusher jaw with back recesses (Source: Delta Steel Company)

4. CONCLUSION

All foundry activities including correct pattern making, appropriate mould characteristics, correct sand type, melting and heat treatment were observed to achieve the success recorded. The casting had a very good surface finish and dimensional accuracy. The shrinkage in the riser did not extend into the casting and there were no cracks after heat treatment. The crusher jaw was successfully put in service for a good length of time.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the assistance and contributions of all who have contributed toward the success of this work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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