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Development of Heat & Corrosion Resistant Castings for Power Plant Applications

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Abstract: - In today's fast advancing world, the main index of progress and advancement of any country lies mainly with the power generating capacity. Power producing ways may be Thermal, Hydro, Nuclear or any other non-conventional energy resources such as solar, wind, tidal energy etc. India is also progressing very well in terms of power generation. This project work covers the development of an **Adjusting Piece Casting** which is a HEAT & CORROSION RESISTANT CASTING FOR POWER PLANT APPLICATIONS through investment casting process. It covers in detail the Mechanical, Foundry and Metallurgical aspects of the development and optimization of the critical parameters.

I. INTRODUCTION & EXPERIMENTAL PROCEDURE

A. Casting Feasibility

As per the requirement, it is a CA40 grade martensitic stainless steel. The chemistry, Mechanical properties (Tensile, Impact and Hardness) are equivalent to the standard ASTM A 743/A 743M-06). The grade, geometrical shape and dimensions can be practically melt and cast through Investment casting process.

B. Die Layout Preparation and Die Manufacturing

Die layout is one of the most important activities. After studying the drawing thoroughly, die layout had been prepared to make two cavities which included the material of die, fixing of parting line keeping in mind the positioning, shape and size of the riser, in-gate. Wax pattern ejection system, contraction allowances and wax allowances etc., dimensional tolerances to be maintained. Then the die set (1 top and 1 bottom, in this case, the parting line is exactly at the central axis of the casting) was manufactured and inspected duly.

C. Melting and Casting

Vacuum Induction Melting furnace
Make: UPPF – 4
Melting Capacity: 60 kg.
Power Capacity: 250 KW
Vacuum capacity: Ultimate vacuum 10 microns,
Leak rate 20 – 25 microns per minute
Lining: Alumina lining

As per the method, 6 kg was the required charge weight.

(a) Plant reverts of suitable size and shape of the required grade was forged to the required size. (G-X 20 Cr 14 grade as per DIN17445 (equivalent to CA40 grade as per ASTM A 743/A 743M-06). The chemistry of the rods or bars was confirmed. The good material was shot blasted before used for melting.
(b) If revert wrought rods or bars are not available, in advance the Master ingot will be produced by single vacuum induction melting practice.
(c) If foundry returns (runners, in-gates, risers, spurs and pouring cups cut from the previous melts) are available more, 60% of the foundry returns (duly cleaned and shot blasted to remove dust, oil, grease, oxide layer if any) and 40% of the charge from (a) or (b) as above will be mixed and charged into the crucible of the vacuum induction furnace.

For this casting development, it was decided to use the virgin raw materials as an input material for melting. As per the method sketch1, the input material requirement was 6kg.
The charge calculation was done as follows:-

The charge calculation was done by considering the furnace performance history and the nature of lining material used. The carbon will be slightly lost. Hence the carbon was added accordingly since carbon is the main element which imports Mechanical properties.

Table I: Charge Calculation Chart

S.No	Element	Aimed %	Addition (in kg.)
1	Carbon (C)	0.24	0.0138
2	Manganese (Mn)	0.70	0.042
3	Chromium (Cr)	13.75	0.825
4	Nickel (Ni)	0.6	0.036
5	Iron (Fe)	Remaining i.e.84.72	5.0832

The required charge as per the charge calculation were weighed and placed in the crucible. The sintered ceramic shell was placed and positioned correctly inside the mould chamber of the vacuum induction furnace. Then the mould chamber which is housed in the induction heating coil was heated to 1050^0 C and was soaked for about 30 minutes. Vacuum pumps were switched on and run for sufficient time to get required rough vacuum of about 400 microns. After getting the required vacuum, the melting was started. The melting temperature range was 1560^0C to 1580^0C. After melting the complete charge, the melting power was switched off. The crucible was tilted towards the mould chamber and was poured into the pre-heated ceramic shell. Vacuum was maintained for half an hour. The mould chamber door was opened and the molten metal poured into the ceramic shell was removed from the mould chamber. After the ceramic shell with poured casting was cooled to the room temperature and was sent for knock out.

D. Chemical Analysis

After the ceramic shell with poured casting was cooled to the room temperature, a sample blank was removed from the poured tree of castings and was sent for chemical analysis. The chemistry was analyzed in Spectro analysis method. The result of the analysis is shown:

Table II: Chemical Composition of Casting

Chemical Composition (in %)								
	C	Si	Mn	P	S	Cr	Ni	Fe
Required	0.18 – 0.25	≤1.00	≤1.00	≤0.045	≤0.030	12.5 – 14.5	≤1.00	Balance
Achieved	0.22	0.05	0.69	≤0.003	≤0.003	13.7	0.58	Balance

E. Dimensional Inspection

After fettling and sand blasting, Castings were inspected for dimensions and found acceptable. The dimensional inspection report is enclosed **(Table 6)**

Table III: Casting Dimensional Inspection Report

S.No.	Dimension as per drawing (mm)	Actual dimension in Castings(mm)	Remarks
1	6^0	6^0	Accepted
2	5.5	5.5 – 5.55	Accepted
3	7.5±0.1	7.45 – 7.55	Accepted
4	5.0	5.0 – 5.05	Accepted
5	5.0 Ø	5.0Ø-5.05Ø	Accepted
6	10.5±0.1	10.45–10.55	Accepted
7	10.0±0.1	9.9 – 10.05	Accepted
8	12^0	12^0	Accepted
9	12±0.1	11.95– 12.10	Accepted
10	6.5±0.1	6.50 – 6.60	Accepted
11	R2	R2	Accepted
12	10.0±0.1	10.0 – 10.1	Accepted
13	18.0±0.3	17.95-18.2	Accepted

F. Radiography Testing of Samples

As per specification, RT is not required for castings. But the casting has to qualify in hardness testing and the mechanical samples have to be qualified for mechanical properties. Hence , even though RT qualifications not required for castings, Rising and gating system was designed in such a way to get the castings as well as the mechanical samples internally very sound as shown in sketch1 as explained earlier in this chapter.

After going through the mechanical properties requirement and with the experience of developing castings in similar grades, an internal standard was prepared for the qualification of Castings as well as mechanical samples. The governing specification for RT is ASTM E- 446 which is a standard reference radiographs for steel castings up to 2" thickness.

The internal standard for Radiography qualification:
1. Category A: Gas porosity: Severity level 2 or less.
2. Category B: Sand and slag inclusion: Severity level 2 or less.
3. Category C: Shrinkage 4 types (CA, CB, CC&CD): Severity level 2 or less.
4. Category D: Crack: not allowed.
5. Hot tear E: not allowed.

The castings were Radio graphically tested and found acceptable. The tensile (size: 16 dia. X 120mm L) and impact samples (15 sq. x 75mm L) were tested for RT (3nos each). All 6 samples were found having gas porosity more than severity level 2. So the samples were scraped.
The methoding design was revisited and found that the gases could not escape from the sample casting cavity since the samples were horizontally straight away connected to the pouring cup. Revised methoding was done in such a way to accommodate the samples in normal to the pouring cup plane so as to vent out the gases fully while the sample cavity was getting filled which is shown in the revised Methoding sketch2 (Fig.8). Then the samples were recast and RT was done. All the samples were qualified in RT.

G. Heat Treatment of Castings and Samples

Heat treatment furnace details:
Make:Therelak – II
Temperature range: Maximum temp. 1100 ˚ C
Heating system: Electrically heated
Quenching medium: Servo quench 107 (Mineral oil with low sulphur base) supplied by Indian Oil Corporation Limited
Flash point: 187˚ C, Fire point: 191˚ C
Viscosity: 32 centistokes at room temp.
Calibration: every 6 months
Heat Treatment Cycle: The hardening temperature should be within 1000˚C - 1050˚C. The quenching must be done uniformly. By means of sufficiently long soaking time and slow cooling from tempering temperature (650˚C - 720˚C) the minimum internal stresses have to be aimed for
The castings and samples were charged into the therelak II furnace. The furnace was switched on and the following cycle was followed.
Hardening Cycle: The charge was heated to 1030˚ C and soaked for 30 minutes and quenched in oil.
Tempering Cycle: Hardened charge was taken out from quenching medium and was cleaned. The charge was heated to 710˚ C and soaked for 4 hrs. After soaking for 4 hrs, the charge was air cooled.

H. Dye penetrant test

Heat treated castings and samples (tensile and impacts) were sand blasted. Mechanical samples and the castings were dye penetrant tested as per ASTM E165 and were cleared for further processing since there were no surface defects such as pin holes, pits , cracks etc.

I. Mechanical and Hardness testing

Mechanical samples were tested and the castings were ground on the surface to make it suitable for hardness testing. Brinell hardness was tested on castings (10 % of the total quantity). Following are the test results:-

Table IV: Test Results after Hardening & Tempering (710 ˚ C)

Heat no.	Heat treatment	0.2 %PS N/mm^2	UTS N/mm^2	% El. On d	% RA	Impact (Joules)	Hardness (BHN)
Specified	Hardened & Tempered	>540	740-880	>12	-	>12	220 – 260
Sample1	Hardened & Tempered	550	730	18	62	108	207-234
Sample2	- do -	545	726	19	59	102	
Sample3	- do -	525	727	19	55	106	

All the 3 samples had failed in Ultimate Tensile test.

I. Against the requirement of740 – 880 N/mm2, the achieved values were 730, 726 and 727 N/mm2.One sample failed in 0.2% PS. i.e. against the requirement of >540 N/mm2, the achieved value was 525 N/mm2. The range of Hardness achieved was 207 – 234 BHN as against the requirement of 220 – 260 BHN.

The structure after Hardening and tempering should be tempered martensite with small amount delta ferrite. If the hardening temperature range was higher, delta ferrite would form there by reducing the hardness and mechanical properties. So to confirm this, micro structure was studied with 100 X, 300 X and 500 X. The observed micro structure of tempered martensite with delta ferrite is shown in the fig.9The lower mechanical properties and hardness was due to the presence of delta ferrite in the micro structure with coarse carbides.

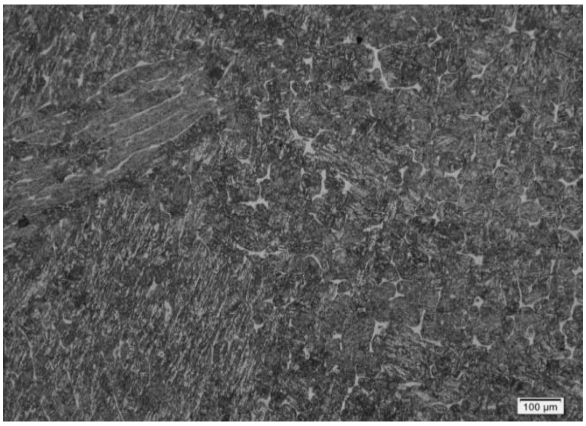

Fig. 1: A 100X

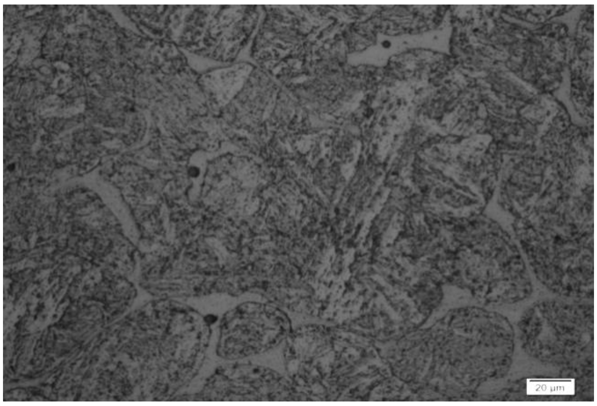

Fig. 2: A 500 X

II. FORMATION OF TEMPERED MARTENSITE (COARSER CARBIDE) WITH DELTA FERRITE

Based on the results, a lowering hardening (from 1050˚C to 1000˚ C) and tempering temperature (from 710˚ C to 680 ˚C) was adopted .Since the castings were smaller in size, due to scale formation, physical wear and tear during sand blasting and handling, some of the dimensions gone out of lower limit of the tolerances. Hence a new lot of castings with tensile and impact samples (3 each). Were hardened and tempered at 680 ˚ C. Once again the mechanical properties were tested on the mechanical test samples. The castings after suitable surface grinding subjected to Hardness testing. Following are the test results

Table V: Test Results after Hardening & Tempering (680 ˚ C)

Heat no.	Heat treatment	0.2 %PS N/mm^2	UTS N/mm^2	% El. On 5d	% RA	Impact (Joules)	Hardness (BHN)
Specified	Hardened & Tempered	>540	740-880	>12	-	>12	220 - 260
Sample1	Hardened & Tempered	577	753	19	63	88	215-229
Sample2	- do -	487	671	21	64	85	
Sample3	- do -	555	743	17	63	104	

With this reduced tempering temperature, one sample had failed in Ultimate Tensile test. i.e against the requirement of 740 – 880 N/mm2, the achieved value was 671 N/mm2. The same sample failed in 0.2% PS. i.e against the requirement of >540 N/mm2, the achieved value was 487 N/mm2. The range of Hardness achieved was 215 – 229 BHN as against the requirement of 220 – 260 BHN. When compared with the previous results, the yield strength and proof strength and even the hardness range also had improved a lot .But consistency was not there since the samples which qualified were passed marginally. So once again the micro structure was studied on the casting surface with 100 X and 300 X and 500 X. The micro structure is tempered martensite with delta ferrite with less coarsened Carbides. The micro structure is shown in the fig. 10. It was decided to still reduce the tempering temperature from 680 ˚ C to 650˚ C.

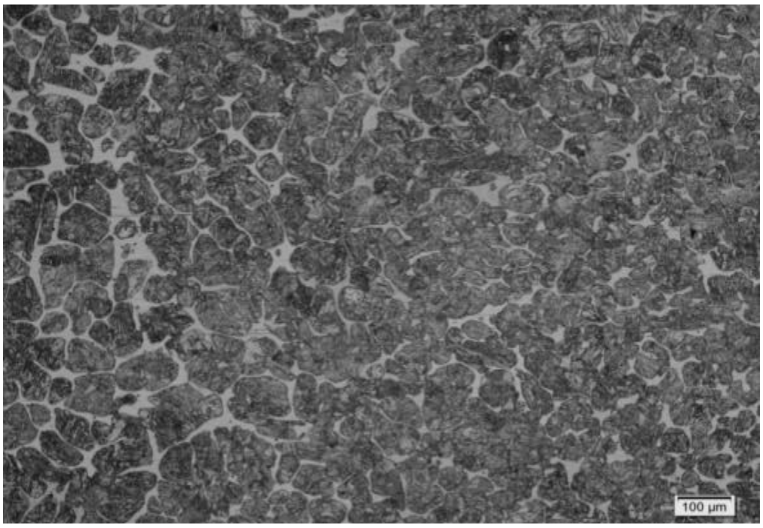

Fig. 3: A 100 X

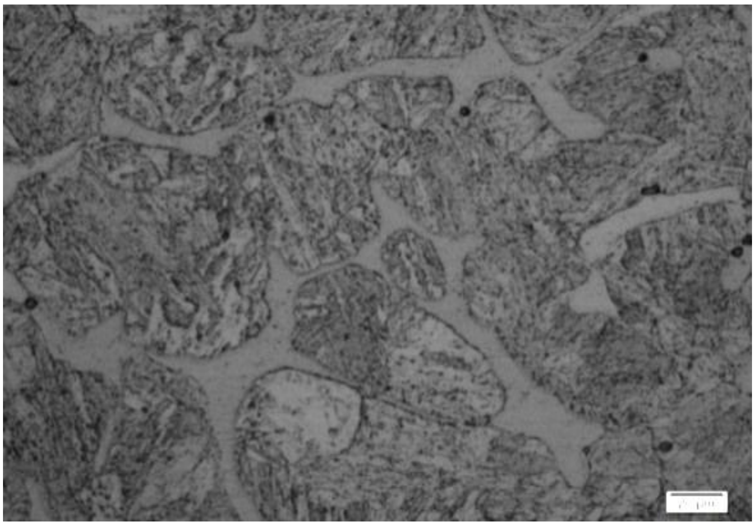

Fig. 4: A 500 X

III. FORMATIONOF TEMPERED MARTENSITE (CARBIDE) WITH DELTA FERRITE

The next lot of castings were hardened and tempered with the tempering temperature of 650˚ C. Once again the mechanical properties were tested on the mechanical test samples and the castings after suitable grinding subjected to Hardness testing. Following are the test results

Table VI: Test Results after Hardening & Tempering (650 ˚ C)

Heat no.	Heat treatment	0.2 %PS N/mm^2	UTS N/mm^2	% El. On 5d	% RA	Impact (Joules)	Hardness (BHN)
Specified	Hardened & Tempered	>540	740-880	>12	-	>12	220 - 260
Sample1	Hardened & Tempered	607	785	16	64	228	224-260
Sample2	- do -	601	790	16.6	58	232	
Sample3	- do -	602	793	16	47	234	

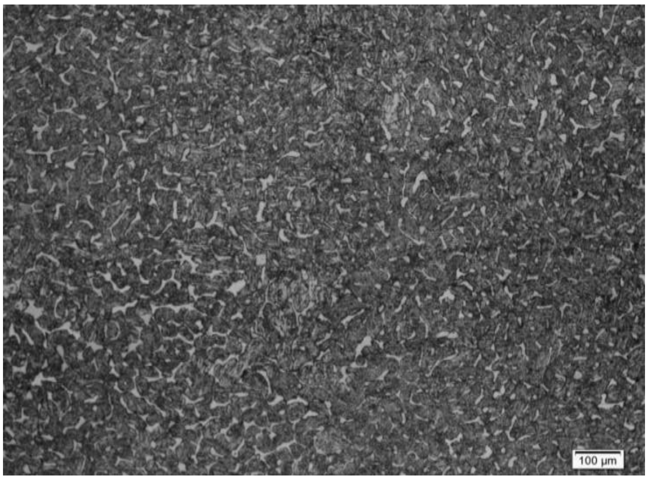

Fig. 5: A 100 X

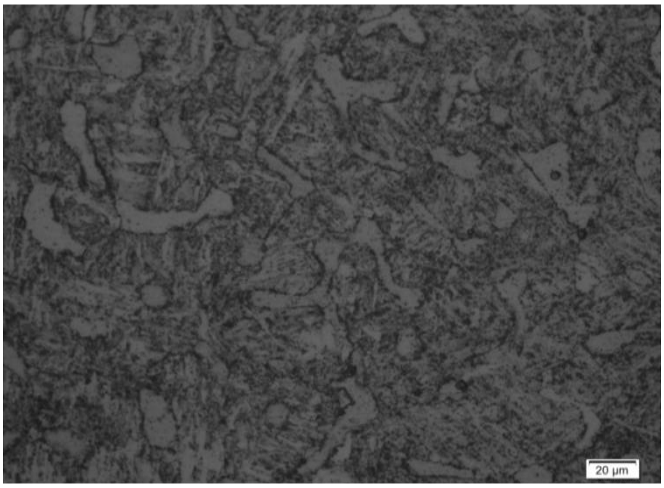

Fig. 6: A 500 X

IV. FORMATION OF TEMPERED MARTENSITE (FINER CARBIDE) WITH DELTA FERRITE

As per requirement, the chemistry, Mechanical properties (Tensile and impact), Hardness, dimensions were established. So Material Test Certificate was prepared. With the establishment of the optimum parameters, Castings were produced in bulk and supplied to the customer.

Fig. 7: Adjusting Piece Castings Ready for Dispatch

V. CONCLUSIONS

- The required grade is Martensitic steel with hardness in the higher range (up to 260 BHN).Even though; Casting requirement does not specify the Radiography quality requirements of Mechanical samples as well as Castings, The samples and the Castings were made with Radiography quality to get the required Internal soundness to achieve the Hardness and Mechanical properties.
- Even small presence of gas inclusion in the mechanical samples caused the failure in Radiography testing. So gas inclusion was eliminated by suitably modifying the gating system.
- Castings and the mechanical samples were qualified in the Radiography testing after modifying the gating system. Since the Hardening and tempering temperature were on the higher side, the formation of coarse carbides and delta ferrite in the micro structure took place, So the hardness and the mechanical properties were less.
- To improve mechanical properties, the Heat treatment procedure is modified by lowering the Hardening (from 1050˚ C to 1000 ˚ C)&Tempering temperature (from 710˚ C to 680 ˚ C), The mechanical and the hardness properties improved because of the formation of finer carbides and delta ferrite which was revealed in the micro structure.
- Further by optimizing the Hardening and tempering temperature (from 680˚ C to 650 ˚ C), The required Mechanical and Hardness properties were met with the required specifications consistently.

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