Analysis of Casting Defects in Foundry by Computerised Simulations (CAE) - A New Approach along with Some Industrial Case Studies

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ABSTRACT

This study reports an in house experience of the occurrence of different types of casting defects and its scientific analysis by computerised simulation techniques supported by industrial case studies.

The main two categories of defects viz. Solidification related defects like Hot Tear, Shrinkage and porosity defects etc. and Flow-related defects like sand burn in and rough surface/ metal penetration, air entrapment, cold shut etc. are discussed here along with simulation results and practical case studies.

Keywords: Hot tears, Solidification range, Chromite sands, Tie rods, Anti-cracker ribs/ Cooling brackets, Alpha set core making system, Sulphur segregation, Simulations, Computer-Aided Engineering (CAE), Feedability, Refractoriness.

INTRODUCTION

The Computerised simulation technique is used here to analyse the defects found in castings.

HOT TEAR DEFECTS

Hot tear is a defect that occurs during solidification of a casting. Though steel is poured at high temperature, this temperature is low relative to high freezing temperature range for steel. The result of this is that steel starts freezing soon after being poured, often before the moulds and cores have been heated to the point where they have lost their bond strengths. These facts coupled with the relative large contraction of steel alloys make steel castings susceptible to Hot Tears (Figs. 2 and 3).

Steel Castings During Solidification undergoes Three Types of Contraction – Refer Fig. 1

In Solidification contraction occur from liquidus to solidus i.e. in the feeding range of the alloy where the liquid metal trapped between solidifying grains or dendrites. Hot Tear occurs at this solidification range.

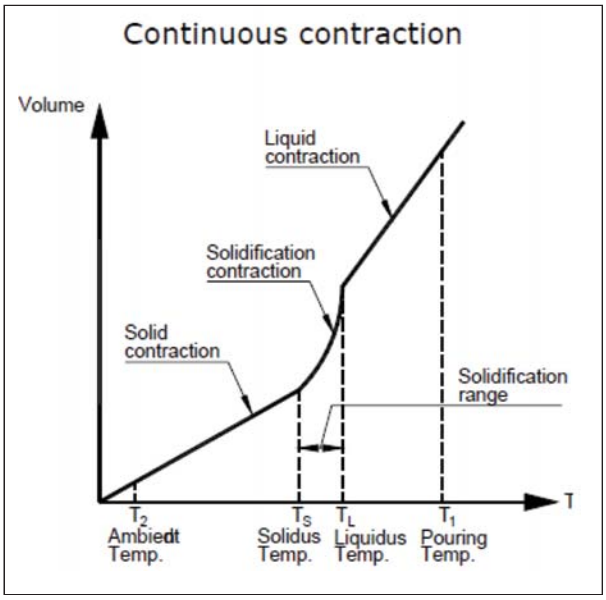

Fig.1: Continuous Contraction Curve

A) MECHANISM OF HOT TEARS

Hot tear is initiated at a temperature within the solidification range of the alloys that is before the solidus temperature is reached. Further opening and extension of tear can however occur at lower temperatures due to continuing lower contraction.

Generally two conditions are necessary for hot tearing.

a) There must be resistance to contractions.

b) There must be variable temperature gradients within the casting section.

Fig.2: Hot tear defects.

Fig.3: Hot tear defects at junctions.

B) PREVENTION OF HOT TEAR

There is usually no easy or single cure for consistent elimination of hot tears, because many factors can contribute for the formation of hot tears.

The most common precautionary measures are as follows :

a) **Moulding Materials -** Strong, hard moulds and cores that collapse slowly under heat is more likely to cause hot tears than weak, easily collapsible moulds and cores. Resin bonded sand mixes (especially alpha set – ester cured system) offer lower resistance to tearing than sodium silicate bonded sand system.

Whenever possible mould and core section should be hollowed out or notch should be provided at the corners of the hollow block as per Fig.5 for better collapsibility or a collapsible insert such as polystyrene (thermocol) incorporated into the section as close as possible to the casting surface. Alternately Paper tubes may be inserted at the corners for better collapsibility Fig.6. Binder level and rammed density should be kept to a minimum level.

b) **Steel Quality-** Sulphur and Phosphorous level should be kept below 0.02% and the Mn:S ratio at least 25:1. Deoxidation at a level avoid deleterious Type II grain boundary inclusions.

c) **Hydrogen in Steel –** The solubility of Hydrogen in molten steel is 27 ppm. While in solid condition hydrogen has very poor solubility. The dissolved hydrogen in molten steel during solidification comes out and causes hydrogen embrittlement. The stress developed during solidification causes hot tear and has led to a numbers of catastrophic failure e.g. in Bogie items of Indian Railways.

By understanding the sources of hydrogen in greater detail it has been possible in optimising steelmaking processes, minimising hydrogen pickup, and more importantly, minimising Hot Tear defects.

d) **Pouring Temp.-** Pour at a minimum temperature consistent with avoiding cold metal defects and maintain high fill rate.

e) **Feeding Practice –** Adequate feeding of isolated hot spots can prevent the formation of hot tears. Excessive large feeders which may hinder contraction should be avoided.

f) **Gating Practice-** Multiple gates should be used to even out temperature gradients and locally overheated mould parts should also be avoided.

Care should be taken to ensure that the design of runners and gates is not "tying" the casting and restricting normal contraction. Over filling of the pouring basin which results in flash across the top of the moulding box can also contribute to contraction restrain.

Chromite or Zircon sand can be effective in preventing tears in thin sections particularly in fillets and junctions Fig.4, 12, 16 and Cooling bracket or anti cracker ribs can help reduce tears in fillet and their thickness should be less than 0.25 the thickness of the casting sections Fig.15.

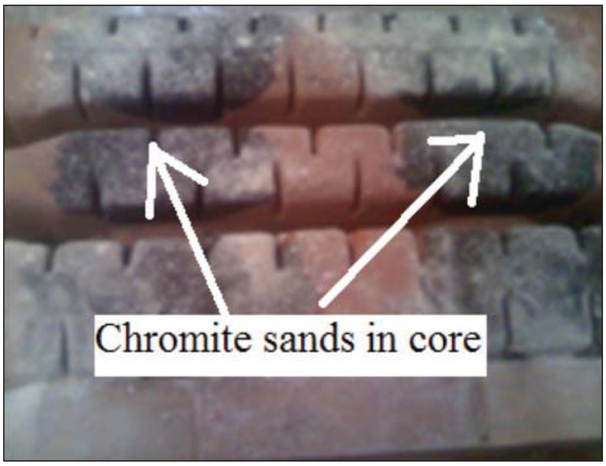

Fig.4 : Chromite sands in core for chilling.

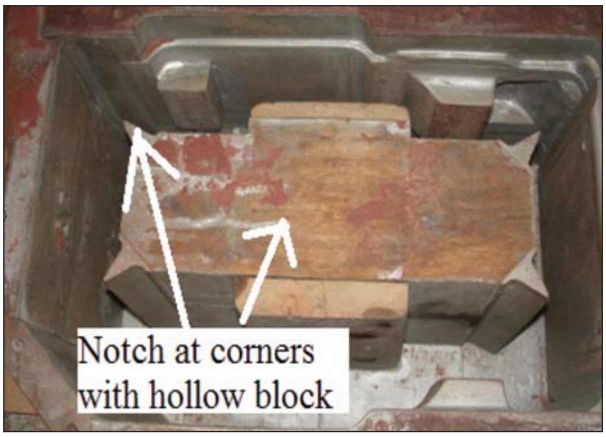

Fig.5 : Hollow block with notch effect to arrest Hot Tear.

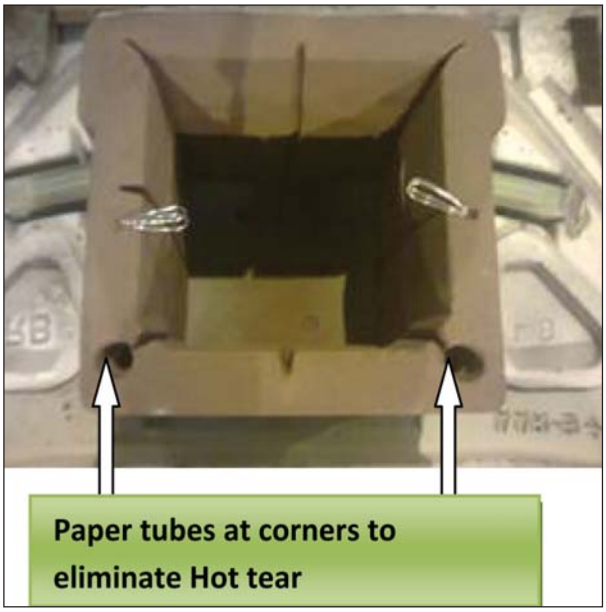

Fig.6 : Paper tubes for better collapsibility.

g) **Casting Design -** Good casting design with uniform distribution of metal thickness can reduce the incidence of tearing. Abrupt change should be avoided, section changes should be gradually blended and internal cores should be adequately filleted.

k) **Hot Tear due to Sulphur Segregation -** The segregated sulphur forms a low melting point Fe-FeS eutectic. It is surprising that the segregation of Mn does not help as the initial sulphur is high. It is necessary to fix the sulphur by calcium silicide addition. On routine calcium silicide injection, the problem of hot tear is largely eliminated confirming that sulphur segregation is the main reason for hot tearing.

CASE STUDY NO. 1

Hot Tear Defects Supported by (CAE) Simulation Results

Figure 7, Bolster Wedge Pocket Simulation View shows that the hot spot at the junctions. Temperature at this region well within solidus range (temperature 1470°C) and the metal at this area in mushy form, causing hot tear during solidification.

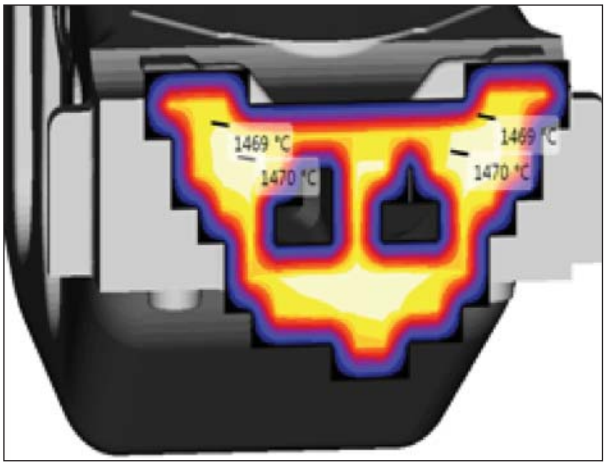

Fig. 7: Showing hot zone (temp.1470°C).

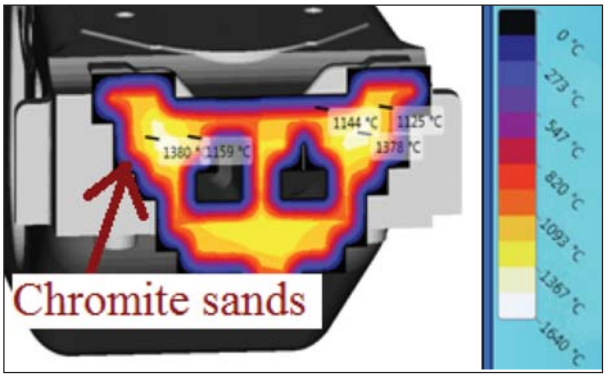

Fig. 8: No hot zone (temp.1378°C).

Figure.8, Chromite sand placed at the wedge pocket area improves the situation. Faster cooling causes the area to solidify faster (temperature 1378°C) and no hot tear found (Fig.12).

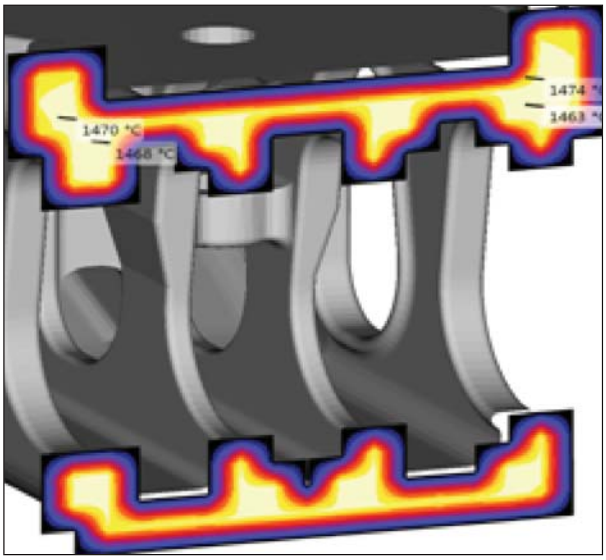

Fig.9: Showing hot zone (temp.1470°C).

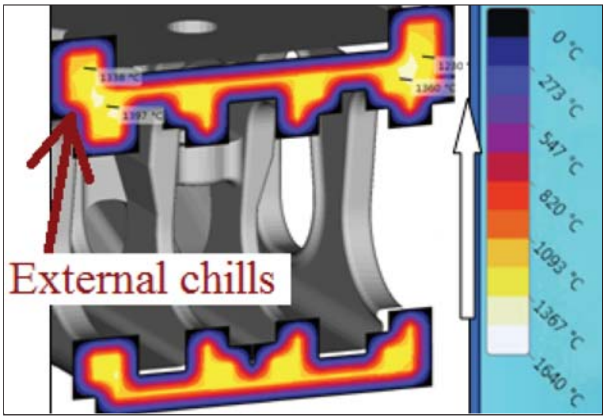

Fig.10: No hot zone (temp.1380°C).

Figure 9 shows the simulation result of Centre pivot area of Bolster castings. The view shows that the hot metal at this junction whose temperature is 1470 °C, is well within solidus range and is in mushy form and solidifies later causing hot tearing due to contraction hindrances by mould or core materials. But after positioning of external chills, Fig. 11 at this area the temperature at this area was found to be 1380 °C as per Fig.10, which indicates faster cooling of this area and no hot tear was found.

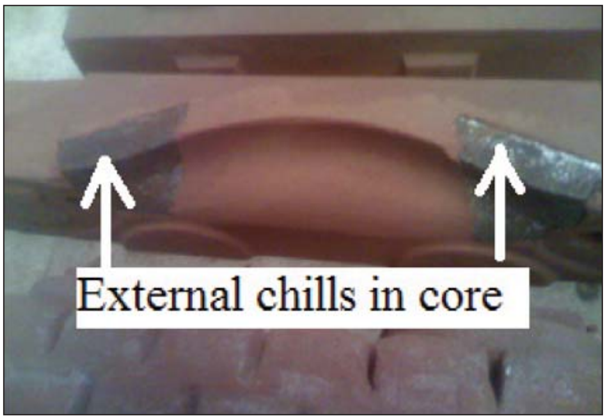

Fig. 11: External chills to arrest hot tears.

Fig. 12: Chromite sands to prevent hot tears.

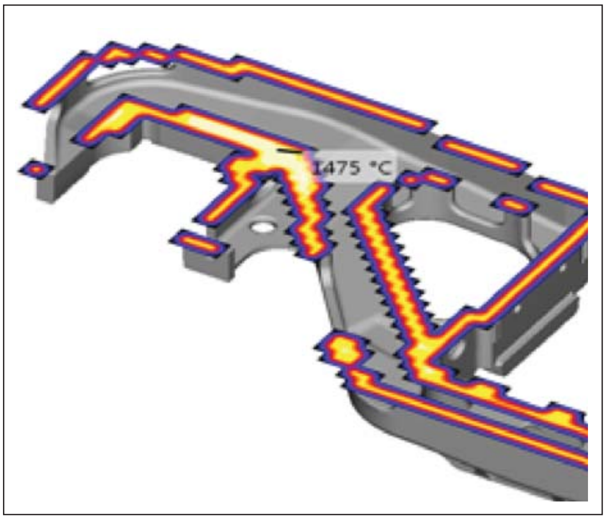

Fig.13: Showing hot zone (temp.1475°C).

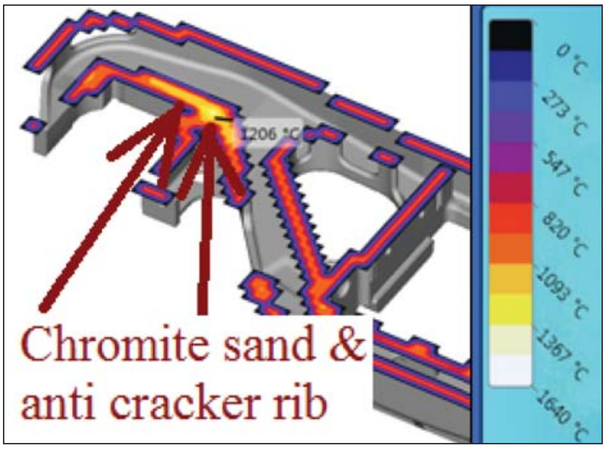

Fig.14: No hot zone (temp.1206°C).

Figure 13 shows the simulation result of Pedestal area of Side Frame castings. The view shows that the hot metal at this junction whose temperature is 1475 °C, which is well within solidus range and is in mushy form and solidifies later causing hot tearing due to contraction hindrances by mould or core materials. . But after positioning of anti-cracker ribs inside (Fig.15) and chromite sands outside (Fig.16), the temperature at this area was found to be 1206 °C as per Fig.14, which indicates faster cooling of this area and no hot tear was found.

CASE STUDY NO. 2

Rough Surface Finish / Poor Surface Finish

Description of Causes – Sands due to high temperature of molten metal or low refractoriness of base sands, or due to poor quality of bentonite or high moisture of processed sands, or soft moulds or improper or no painting of moulds fuse at the casting surface that stick to the surface is called rough surface finish of the castings (Fig. 17).

REMEDIES

1) Moisture content/Compactibility of prepared sands

The moisture content should be in the range of 3.0 – 3.5 % for HPML, 4–4.5% for semi-mechanised moulding to get good surface.

Too high moisture makes rough surface. Too low moisture makes friable surface. Compactability should be in the range of 42-48 % for HPML.

2) High Clay Content in Process Sand

The total clay content in process should not be more than 12 % and the dead clay content should not be more than 4 % (max.).

Fig.15: Anti-cracker ribs to arrest hot tear.

Fig.16: Chromite sands at corners.

Fig.17: Castings produced in High Pressure Moulding and Semi-mechanised moulding.

3) **Temperature of the Sand** – The hot sand causes rough surface problem. The temperature of the process sand should not be more than 45 °C.

4) **Grain Fineness Nos.**- Finer sands give good surface finish & coarser sands give rough surface.

5) **Compactness of the Mould / Core** - Compactness of the mould is very important for getting good surface finish of the casting. High mould hardness gives good surface finish of the castings. On the other hand low hardness gives poor surface and swelled mould.

6) **Gating System i.e. Ingate Location and Size** – The position of the ingate plays a vital role for the surface finish of the castings. For steel castings, ingate located at the bottom of the casting gives good surface finish.

7) **Pouring Temp.** - The temperature of pouring is very vital for the surface finish of the castings. The tapping temperature of Mild steel should be 1580 – 1600 ^{0}C. High pouring temperature causes poor surface.

8) **Mould Wash and Core Wash Quality**- The base i.e. zircon or magnesite content in paint is important for getting good surface finish. At least 60% zircon carried by alcohol or water is essential for getting good surface finish. Moreover binder present in the carrier plays a vital role. In ready to use paint addition of external carrier causes poor quality as it contains no binders.

9) **Quality of Incoming Sands Used** - The Silica (SiO_2) content plays a vital role in getting good surface finish. For Low carbon steel the silica content should not be less 98%.

10) **Bentonite Quality** – The quality of bentonite is vital as in using sodium based bentonite gives good bonding and less quantity is required. But for calcium based bentonite more quantity is required and gives poor surface.

Simulation view as per Fig.18 shows that due to heavy hot spot the metal at this area remains hot at this area for a longer time causing Sand sticking and its effect in real casting as per Fig.19.

So, thick zircon-based coating or double coating at this area ensures elimination of sand sticking defects.

CASE STUDY NO. 3

Sand fusion found at the bottom part of support casting as per Fig.20.

Simulation view as per Fig.20 shows that Sand fusion found at the bottom part of the mould is due to higher temperature of moulding sands ranging from 479°C to 938°C. But at the top side there is less sand fusion due to low mould temperature ranging from 173°C to 402°C.

CASE STUDY NO. 4

Shrinkage defects found in Bogie casting (Bolster) due to potential hot spot found at junction of casting as per simulation given in Fig.21 & 22.

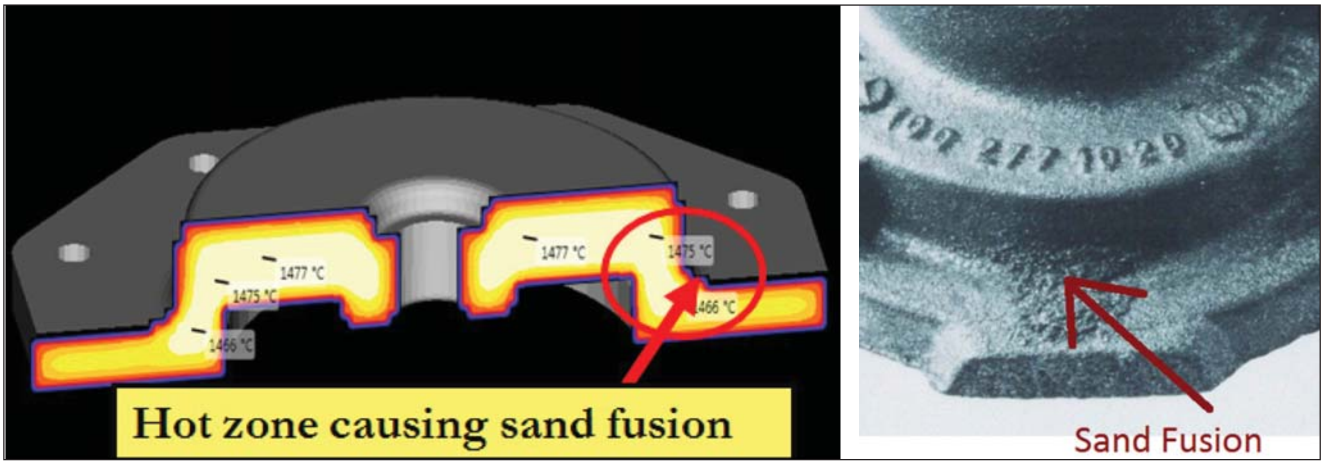

Fig.18: Simulation view of Hot Zone of Pivot casting causing sand fusion.

Fig. 19: Sand fusion in real casting

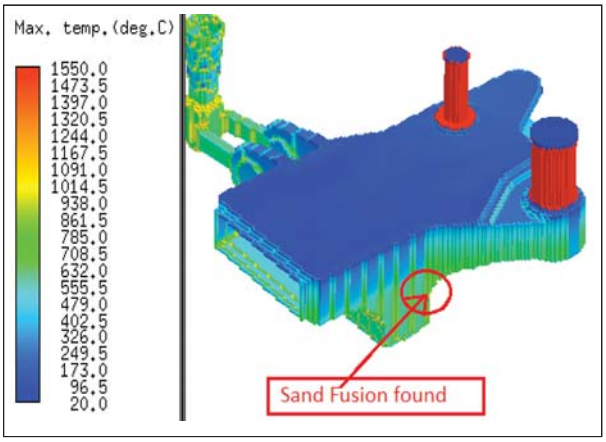

Fig.20: Sand Fusion.

The simulation view shows that there is a potential Hot spot to be fed by the risers as at that time there were only two elliptical risers.

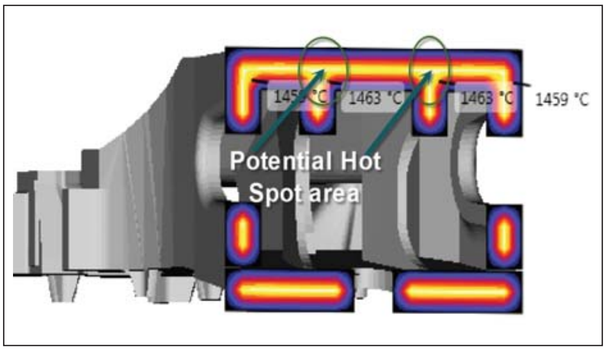

Fig.21: Hot Spot at the junction.

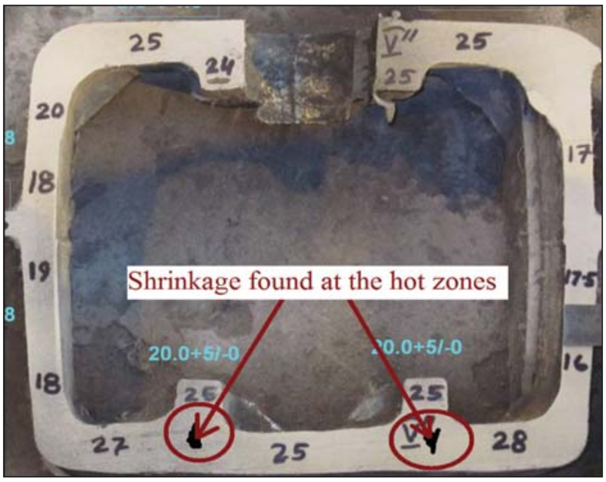

Fig.22: Shrinkage found at the junction.

But now there are 4 round risers at these hot spot areas (Fig. 23).

CASE STUDY NO. 5

Air entrapment problems in Green Sand moulds produced in High Pressure Moulding Line in support items.

3 vents at the end of support casting were provided for easy escape of entrapped gases and to eliminate air entrapment problems (Figs. 24 and 25).

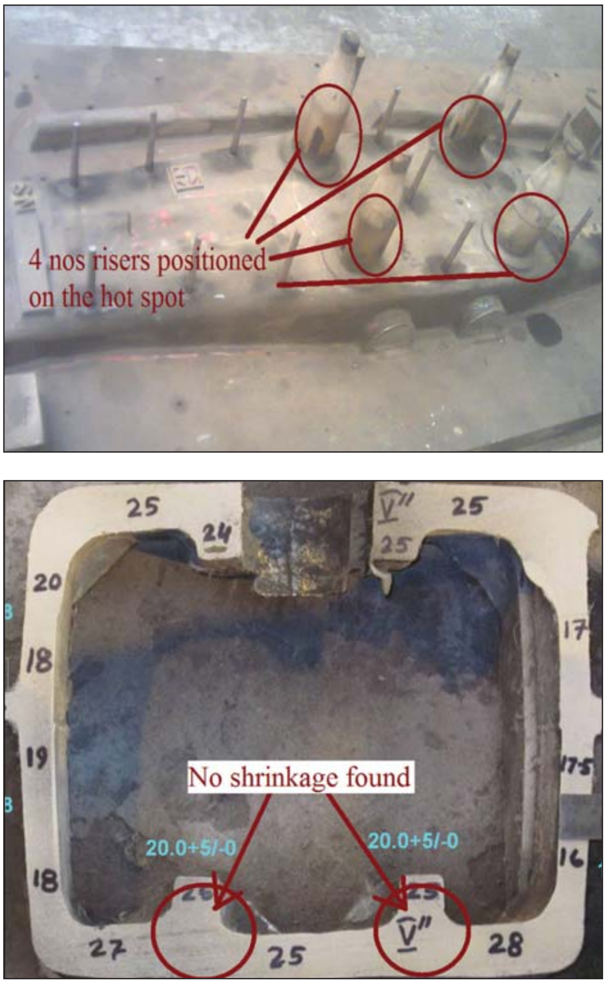

Fig.23: After modification and positioning 4 nos. round risers no shrinkage found at this area.

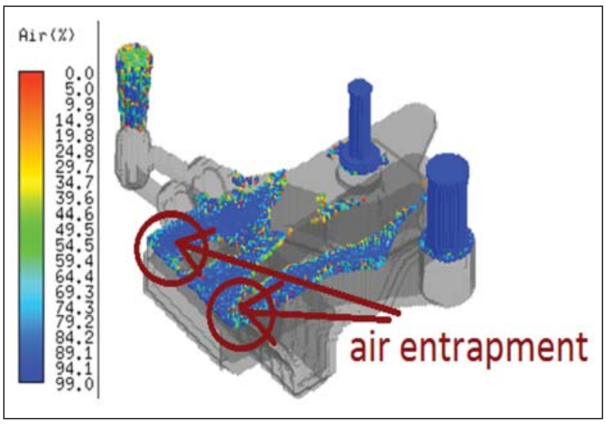

Fig.24: Simulation view of support showing air entrapment during filling of moulds.

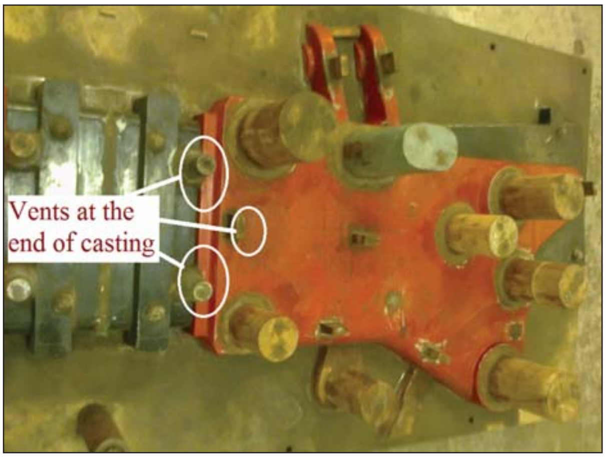

Fig. 25: 3 Nos. vents at the end of the casting.

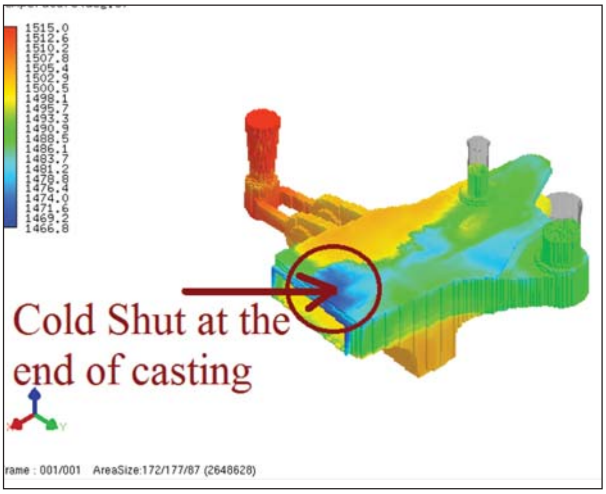

Fig.26: Cold shut at the end.

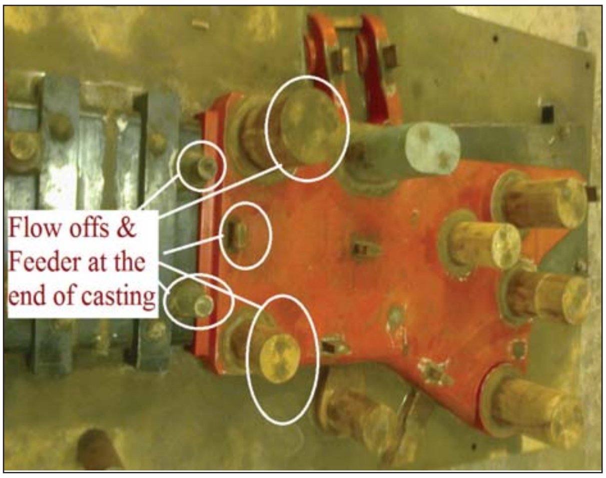

Fig. 27: Flow offs and feeder at the end.

CASE STUDY NO. 6

Cold shut problems found in support item at the end due to improper filling.

3 flow offs and 2 feeders are added at the end of support casting to eliminate cold shut problems. As the cold shut occurs due to back pressure of air on the flowing metal, provision were made for escape of gases and thus cold shut was removed (Figs. 26 and 27).

CONCLUSIONS

From the above study it can be concluded that the defect analysis done by simulation help a practical foundry man to take decision and corrective actions can be taken to eliminate these defects with lesser efforts.

REFERENCES

1. Hot Tears in Steel Castings – By J.F.Meredith, Articles published in Metal Casting Technologies of Vol. 53, No. 2, June 2007.
2. Directional Solidification of Steel Castings, R.Wlodawer.
3. Principles of Metal castings, Heine Loper and Rosenthal, Second Edition, McGraw-Hill.
4. Metal Casting, Computer-Aided Design and Analysis, Dr. B.Ravi, Published by Prentice -Hall of India, New Delhi, 2005.
5. Gas Analysis in Steel: Identifying, Quantifying, and Managing Hydrogen Pick-up in Steel, Charles R. Hurst, Product Engineer, Heraeus Electro-Nite Australia, Ir. M. Vergauwens, Product Manager, Heraeus Electro-Nite International N.V.
6. Simulation of the Components done by Auto Cast-X CAD Simulation Techniques and ADSTEFAN, Japanese Casting Simulation Software developed by HITACH, JAPAN. ■