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Article

DESIGN AND ANALYSIS OF SCRAP BOX AND OPERATING PRACTICES OF SCRAP CHARGING FOR BETTER CONVERTER LINING LIFE

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Abstract: Adding scrap as a coolant in the basic oxygen furnace, also known as the LD (Linz Donawitz) converter, during the exothermic process of steelmaking, affects the life of the refractory lining inside the furnace. The refractory lining wears by nearly 2 to 3 mm for each scrap charge in the furnace. Scrap is charged into the LD converter by tilting the converter towards the charging side and inserting the scrap box into the mouth of the converter. The scrap slides on the wall of the scrap box and falls on the hot refractory lining of the furnace. The size, weight, and nature of scrap, and the height of fall of the scrap on the refractory lining have a great impact on the life of the lining. The paper explains the design and analysis of the scrap box to reduce the impact of the scrap charge on the lining, a means to clear mouth jam before charging the scrap and the operating practices to enhance the life of the refractory lining of the LD converter.
Keywords: Steelmaking, scrap charging, scrap box, refractory lining, converter operation

1. INTRODUCTION

In the Basic Oxygen Furnace, molten iron from the Blast Furnace is refined into steel with the desired carbon content and temperature by blowing oxygen at high velocity. Scrap is added to the converter as a coolant to balance excess heat, recycle scrap, neutralise excess carbon in the melt, and reduce CO2 emissions. When scrap is charged into the converter, it creates mechanical shock, shatters the refractory, and thermal shock from cold scrap contacting the hot lining causes spalling. The drop and slide of raw materials during charging cause wear of the exposed working lining. The refractory wear rate in this impact zone, due to scrap and hot metal charging, is 2.0 to 3.0 mm/heat. At Visakhapatnam Steel Plant, Steel Melt Shop-1, three converters with a capacity of 150 tons each were revamped after 30 years of operation.

The design, fabrication and installation of the scrap box for the newly revamped converter were carried out internally, using operational experience gained over the years, to reduce the impact of scrap charging on the converter lining and increase the campaign life of the converter lining.

[1] Carlo Mapelli has concluded that melting time increases with higher scrap bulk density; higher density leads to longer heat penetration times. Metallic loss increases with bulk density because more time is needed to melt the loaded scrap, and greater oxidation affects the charged scrap. [2] Antonio Martins discussed a patented slag-less clean-up technology in which the upper cone region is heated and blown with oxygen to prevent the growth of skulls and gradually clean the upper cone with post-combustion reactions. [3] Yuriy Lytvynyuk has discussed the influence of

the scrap amount in the charge mix on the temperature and silicon content of the hot metal. The highest rate of scrap utilisation was observed in the plant that uses only burnt lime as a slag builder and taps the hot metal directly into converter charging ladles.

[4] Fei Yuan has concluded that among the three shapes of scrap steel-rectangular, thin plate and cylindrical-the rectangular form results in the shortest molten pool mixing time, followed by the thin plate, with the cylindrical form yielding the longest time. Regarding scrap steel distribution inside the converter, they found that an inclined uniform distribution of scrap in the converter has a shorter mixing time than concentrated scrap in one place. [5] Florian Markus Penz concluded that the amount of charged material significantly affects the melting behaviour and the final carbon and phosphorus contents of the steel. In contrast, variations in scrap size have a relatively smaller effect on these parameters.[6] Lingling Cao has discussed that the scrap shape is a crucial parameter affecting melting time. The melting time for large-sized scrap with a small specific surface area is three times that of smaller scrap and requires more energy to improve mixing effect and to compensate for temperature losses. [7] Kruskopf has analysed that a solidified layer with melt composition accumulates on top of the scrap. Then the layer remelts and disappears. Initially, the scrap starts getting heated up and then begins to melt. The scrap melting rate is dependent on carbon mass transfer from the hot metal to the scrap. The melt temperature is much lower for thin scrap because of the higher surface area. [8] Xiaojun multi-bar melting experimental results show that increased porosity benefits scrap melting. When porosity reaches 0.84 and above, the time taken for multi-bar is the same as for individual bars. [9] H P Sun observed the melting process of spherical scrap in hot metal. An increase in the scrap melting rate was observed with higher carbon content in the scrap and molten bath, as well as with a rising bath temperature. [10] Wang devised a statistical analysis technique for selecting scrap mix, showing the average liquid steel in BOF and the margin between the chosen confidence level and the customer-allowed upper limit for certain impurities.

The objective of the present study is to design a scrap box for a newly revamped 150 T converter, develop a three-dimensional virtual model, and carry out load simulation to analyse scrap charging and its impact on converter lining. It also aims to analyse the best method for scrap charging, its implementation and results.

2. DESIGN OF SCRAP BOX

The scrap box is intended for the three revamped converters, each with a capacity of 150 tons, at Steel Melt Shop-1 of the plant. The scrap box is designed to handle 32 tons of scrap. The existing facility in the bay can handle it either by the charging crane's ladle beam hooks with a centre-to-centre distance of 4300 mm and the auxiliary hoist hook for tilting the scrap box, or by the semi-portal crane with a lifting beam of four hooks, with a centre distance of 3100 mm along the horizontal axis of the scrap box and a centre distance of 4300 mm across the axis of the scrap box. The scrap box is placed on the self-propelled car that moves from the scrap bay to the converter bay at zero-meter level. At the converter bay, the scrap box is lifted by an overhead crane and positioned on the 8.5-meter platform for charging scrap into the converter.

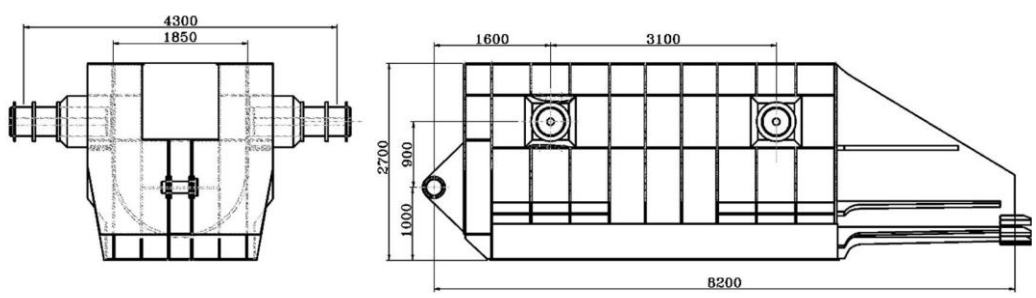


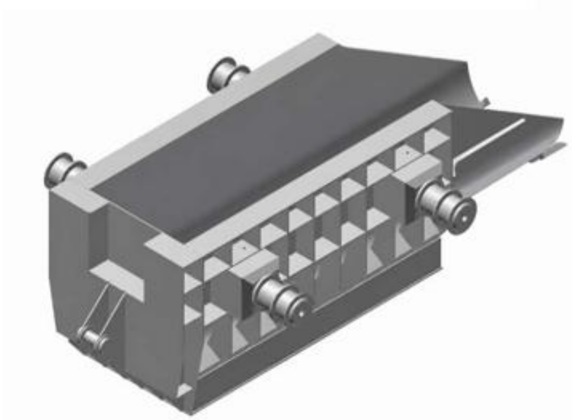
Figure 1: Sketch of scrap box

The scrap box is designed with a semicircular bottom with side walls on either side to facilitate the smooth flow of scrap from the scrap box into the converter. The front width and height of the scrap box are 1872 mm and 2386 mm, respectively. The converter has an opening diameter of 4160 mm. The front spout section is reinforced with stiffener bars welded to its outer surface to provide the required structural strength. Teeth are provided at the funnel outlet to facilitate the removal of any jams or obstructions at the converter mouth before charging the scrap. The outer surface of the scrap box is reinforced with welded plates in an open-box configuration, providing additional rigidity and structural stability, and it acts as a means for easy heat dissipation during scrap handling operations. The funnel portion of the scrap box is made of creep- and wear-resistant steel Chrome Moly plate Grade 11, Class 1 ASTM A387 /

ASME SA387, as it is subjected to thermal stress cycles and wear due to scrap sliding. The scrap box base material is E250 B IS: 2062-2011, and the pins are forged from grade 40Ni6Cr4Mo3 IS: 4367-1991. The brackets and stiffeners are made of structural steel, and the lifting pins are made of forged alloy steel. The structural fabrication is carried out using a low-hydrogen E7018 electrode.

3. GEOMETRIC MODELLING OF SCRAP BOX

The scrap box part model was created and assembled in the Autodesk Inventor assembly environment. The lifting pins are inserted into a square block with a transition fit and are welded circumferentially on both the outer and inner sides. The block is further housed between the stiffener plates. The tilting hook pin is welded to the brackets on either side, which are further welded to the back plate. After modelling the scrap box, the centre of gravity was found to be offset horizontally towards the front relative to the centre of the lifting hooks due to the scrap box's extended funnel shape. Counterweights in the form of thick plates, each weighing 2 tons, are added at the back of the scrap box near the tilting hook pin to keep the centre of gravity at the centre of the lifting pins and ensure the scrap box remains stable during tilting for scrap charging.



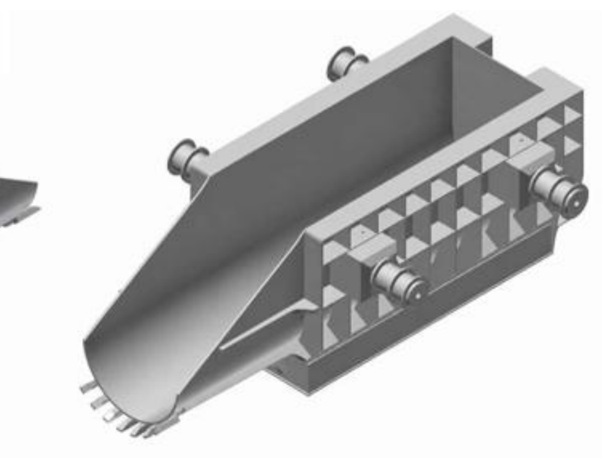


Figure 2: Scrap box model - Rear view ***Figure 3: Scrap box model – front side view***

4. FINITE ELEMENT ANALYSIS OF SCRAP BOX

The developed model was imported into Autodesk Inventor for finite element analysis. A uniformly distributed design load of 32 tons (313.92 KN) is applied to the curved area of the scrap box. Hinge support is applied to the pins. The static structural analysis is carried out on the scrap box. The model is meshed using volumetric tetrahedral elements.

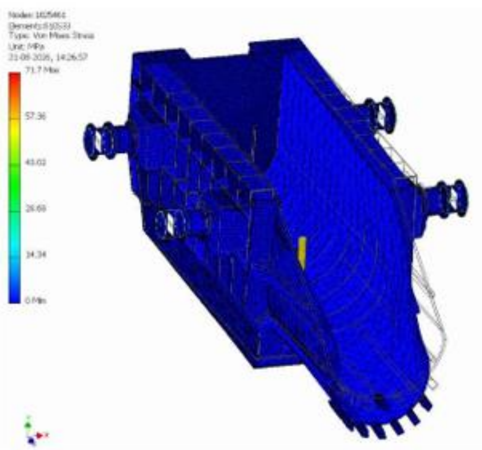


Figure 4: Von Mises Stress

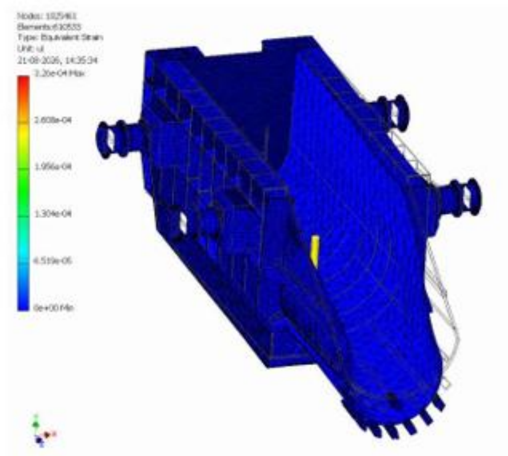


Figure 5: Equivalent Strain

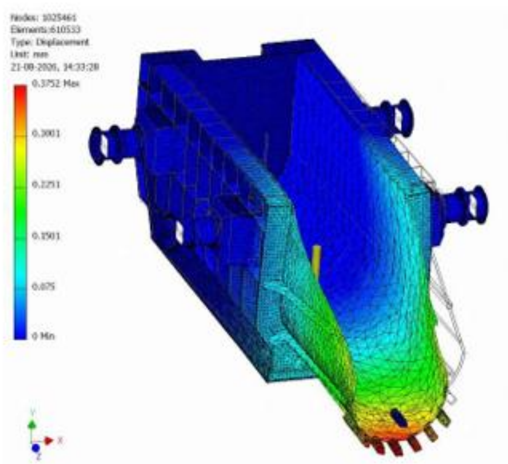


Figure 6: Displacement

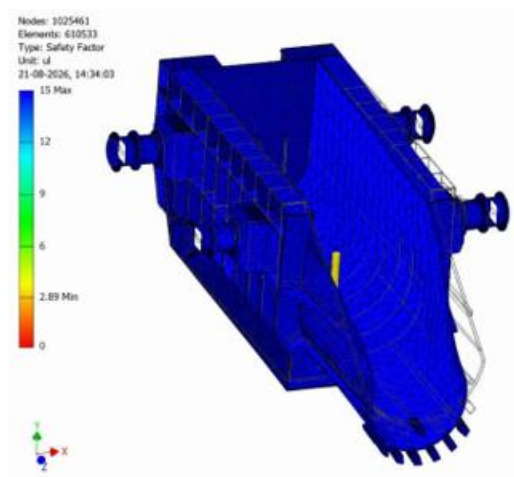


Figure 7: Safety Factor

The Von Mises Stress result indicates the maximum stress σv, max as 71.7 MPa and the maximum equivalent strain of 3.26e-04. The displacement result is δ max = 0.3752 mm. This is relatively small for a heavy fabricated steel scrap box against the required functional clearance and allowable deformation. The Safety Factor plot indicates FOS min =2.89, with the displayed maximum safety-factor scale reaching 15.

Hence, the Scrap Box is considered structurally safe for the 32 Ton design loading condition, with verification of material yield strength, pin/bearing stresses, weld integrity, and actual service boundary conditions.

5. SCRAP CHARGING AND IMPACT ON CONVERTER LINING

The scrap box containing the scrap is positioned horizontally in line with the converter to be charged by the crane operator. In case of mouth jams, the blockage is cleared using the scrap box's projected spikes. The converter is tilted 45 degrees toward the charging side, and the scrap box spout is brought close to the converter mouth. The scrap box is tilted by lifting the auxiliary hook of the charging crane or the rear hook beam. Heavy scrap begins to slide out through the scrap box chute at approximately 30 degrees. The box is then gradually tilted to 45–50 degrees until all the scrap falls into the converter. In the case of a jam during scrap movement, the operator applies a sudden movement to the scrap box to clear the obstruction. Once the scrap has been completely discharged, the empty scrap box is rotated back and safely retracted from the converter.

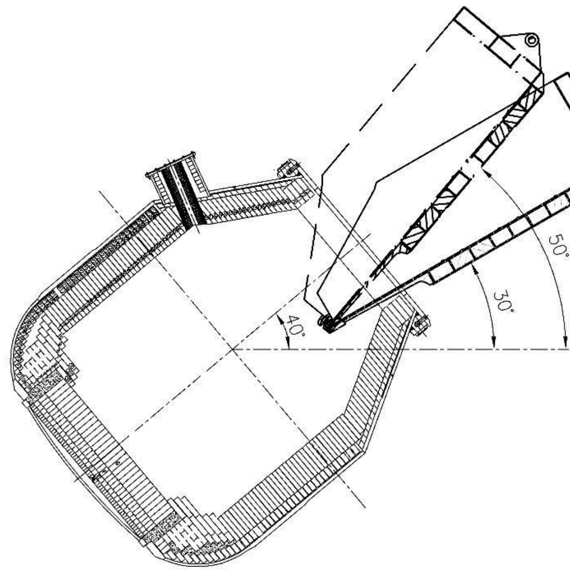


Figure 8: Scrap Charging in Converter

The scrap falls from the spout to the side walls of the barrel portion of the converter. The free fall of the scrap from the spout to the converter lining is approximately 2 meters. Dropping scrap loads causes severe mechanical shock and abrasion due to immense kinetic energy gained by the scrap. Cold scrap, on contact with the hot refractory lining, induces rapid localised thermal contraction and refractory lining deterioration due to spalling in the barrel portion. Scrap charging sometimes wears out 2 to 3 mm of the lining thickness. The scrap box is designed with a spout for smooth transfer of the scrap from the box to the barrel portion of the converter on the charging side.

6. SCRAP CHARGING PRACTICES FOR BETTER LINING LIFE

The scrap collected from different areas of the plant is heaped in the scrap bay. Balling is a process in which an iron ball is dropped on the scrap to compact it, making it thin, and it is piled in the scrap bay by a magnetic crane, eliminating all non-metallic elements from scrap. The scrap is segregated as metallic scrap of various sizes, such as less than 300 mm, 300 to 800 mm and larger scrap, and denser cast iron scrap. Once the scrap box arrives at the scrap bay in the transfer car, thin scrap is loaded at the front end, mixed scrap in the middle and heavy scrap at the back. The scrap is charged to a uniform height all along the semi-circular portion of the scrap box, leaving the spout portion empty.

After slag splashing and at the start of the steelmaking process, the converter is tilted to 45° toward the charging side. The scrap box is aligned to the converter axis, and the spout is inserted into the mouth of the converter. The scrap box is gradually tilted, with the spout moving further into the converter. The smaller scrap starts falling into the converter, followed by the mixed scrap. The impact exerted by smaller scrap pieces on the refractory lining is negligible. Once scrap piles up inside the converter barrel, the remaining material falls a much shorter distance. Then the scrap box is tilted further to 50°, the scrap slides along the lining rather than free-falling allowing the heavy scrap to fall onto the already discharged smaller scrap, which acts as a cushion. Once the scrap is completely discharged, the scrap box is retracted back in the tilted position and then made horizontal. The converter is brought back to the vertical position and once again tilted for hot metal charging.

7. RESULT

The refractory lining thickness is measured by a laser profile measurement scanner with a precision of ± 2 mm. The scanner analyses the vessel, and the software calculates the required maintenance and gives directions to spray patch materials onto worn-out areas.

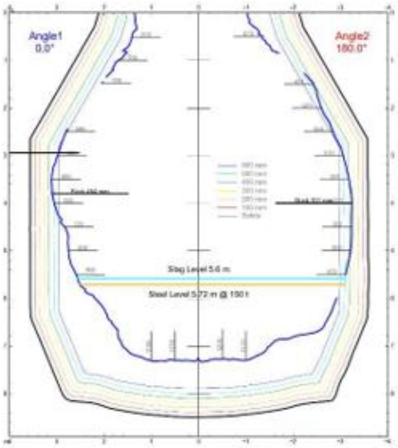


Figure 9: Lining profile cross-section (Charging and Tapping side)

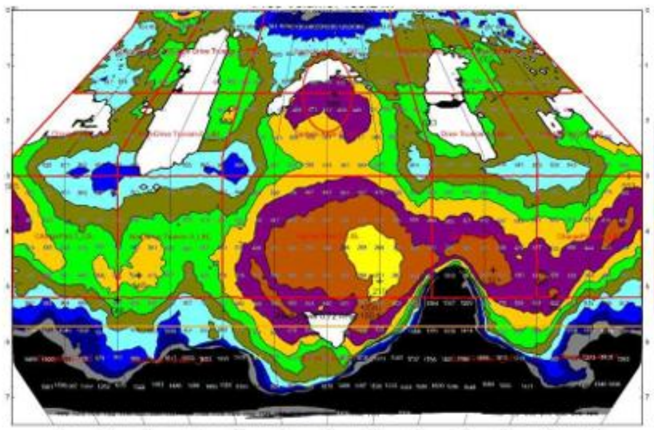


Figure 10: Converter refractory lining wear profile

The entire scan of the converter refractory lining is completed in 2 to 4 minutes, fitting into the standard tap-to-tap cycle. After implementation of the new scrap box and its usage in steelmaking operations, the lining life of converter B is examined to assess the condition of the refractory lining.

The cross-sectional profile of the converter lining along Angle 1 (0.0°), corresponding to the centre of the scrap charging axis, and Angle 2 (180.0°), corresponding to the centre of the liquid steel tapping axis, for Converter B after completion of 5,053 heats in a campaign shown in Figure 9. The minimum refractory lining thickness is 454 mm, compared with the original working lining thickness of 700 mm. The average refractory lining wear rate is calculated to be 0.0487 mm per heat.

The 2-dimensional colour plot of the refractory lining wear profile over the 360° circumference of Converter B is depicted in Figure 10. The refractory lining thickness in the scrap and hot-metal charging zones is found to be in the range of 400–500 mm. The lining condition is considered satisfactory, and MgO-based gunning material is applied to the worn areas to restore the lining thickness and enable the converter to continue for additional heats.

8. CONCLUSION

A 32-ton scrap box is designed for a 150 T revamped converter to extend the converter lining life by 500 to 1000 heats, saving an estimated Rs 50,000 each in lost production opportunity. The scrap box is designed to suit the existing facility in the converter bay. The three-dimensional model of the scrap box was developed and subjected to the virtual load conditions. The scrap box was found structurally adequate for the specified load. The drawing was made and released for structural fabrication. The impact of scrap charging on the converter lining was analysed, and best practices for charging scrap to improve converter refractory life were shared with the steel melt shop operation team. Removing the skull formed at the mouth of the converter facilitates easier entry of the spout into the scrap box and better view for the crane operator during scrap charging. Arranging the scrap in a specific sequence creates a cushioning effect before heavy scrap falls on the refractory lining. The newly implemented scrap box and the follow-up of operating practices have resulted in a decrease in converter refractory wear-out and an increase in the campaign life from an average of 5600 heats to 6524 heats.

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