ASSESSING THE EFFECT A REFRACTORY INSULATION LINING HAS ON EAF ENERGY CONSUMPTION

BY

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SYNOPSIS:

Electric Arc Furnaces (EAF) are the single highest consumer of electricity within a mini mill steel plant. Their magnesia based refractory linings offer optimum performance at the expense of increased heat loss. The heat loss can be addressed by incorporating an insulating refractory board, without compromising vessel capacity. However it is important to select an insulating material that has the necessary thermal structural integrity to provide optimum performance an lining security in this environment.

This paper determined the effect of incorporating Structural Insulation board (Isomag®70) in the refractory lining of the Electric Arc Furnace at an Australian Mini Steel Mill. This material was selected since it has excellent mechanical properties at elevated temperatures.
The outcomes of the comparative testing from the use of insulation are as follows:

- Average 70°C shell temperature reduction;
- Average energy consumption reduced by 1.4%;
- Less energy losses for higher Tapping Temperatures and Tap to Tap Times
- Theoretical return on investment (ROI) calculation with the use of insulation;
- Theoretical calculation in green house gas emission reduction;

Key Words: EAF ï Electric Arc Furnace; Isomag®70 ï Backup Refractory Structural Insulation Board; Working Lining, Insulation Lining, Shell Temperature Measurement, GHG ï Green House Gas, Energy Consumption, Tap to Tap.

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1. INTRODUCTION:

As part of the strategy to increase productivity, an Australian Steel Mill reduced the refractory lining thickness of their Electric Arc Furnace (EAF) to increase its carrying capacity. This was achieved but the increased heat loss resulting in high shell temperatures and contributed to permanent shell deformation. Steelmakers have several options to reduce heat loss through the refractory lining including:

- Increase the refractory lining thickness ï vessel capacity is not an issue,
- Use less conductive refractories - could adversely affect campaign life and lining integrity/ performance, or
- Use a structural Insulating layer that maintains or increases the vessel capacity - the expense must be offset with increased refractory campaign life.

To evaluate which method is suitable will be based on cost and productivity. In this situation, the customer selected to insulate the refractory lining with a 12.7mm layer of Isomag®70 Structural insulation board.

This paper assessed the effect of insulating the EAF by carrying out the following comparative tests:

- Shell Temperature;
    - Theoretical v/s Acutal
- Electricity Consumption;
    - Electricity Consumption versus Heat Number
    - Electricity Consumption versus Tap to Tap Time
    - Electricity Consumption versus Steel grade
- Calculated Saving;
    - ROI based on Electricity Savings
    - Green House Gas

The above information is presented in the results section of this paper.

2. ISOMAG®70 – THE PRODUCT

Isomag®70 is a dense $MgO\text{-}SiO_2$ structural insulating board specifically designed for back up structural refractory lining applications. Hence, the demanding application of an EAF requires an insulation material to have the following properties at elevated temperatures:

- Minimal Shrinkage,
- High strength, and
- Low thermal conductivity [1].

Figure 1 shows that ISOMAG®70 has the properties to ensure that thermal insulation is maintained throughout the refractory campaign.

Product	Continuous Service Temp. Limit	Permanent Shrinkage at 900°C	Hot Crushing Strength at 5% Strain at 500°C	Thermal Conductivity at 500°C
ISOMAG 70	1000°C	1.64%	17 MPa	0.29 W/(mK)

Figure 1: Physical properties of Isomag 70. [1]

The insulation lining is the foundation of the whole refractory and must be designed to be as secure as possible. Offering superior hot crushing strength over an extended campaign reduces lining movement, excessive metal penetration or premature lining failure. This board also has partial elasticity to accommodate radial cyclic loads and explains it proven track record in many steelmaking vessel applications. As a result this material was selected for the insulation trials [2].

3. EAF CONFIGURATION & PROCESS.

The customersô EAF (where the material evaluation trials were conducted) is a Danielli designed AC Eccentric Bottom Tapping (EBT) Electric Arc Furnace. The original charge capacity of 60 tonnes has been upgraded to 90 tonnes. The annual capacity is rated to 605,000 tonnes pa, up from 250,000 tonnes pa when the plant was commissioned in 1992. [3]

The increase in capacity has been partly achieved through the reduction in refractory lining thickness that resulted in increased heat loss and high shell temperatures.

In order to arrest the heat loss, Pyrotek and the Customer carried out a trial that incorporated a 12.7mm structural insulation layer of Isomag®70 and the comparison is outlined in Figure 2 below.

	Standard Lining Balcony	**<u>New Lining Balcony</u>**	**Standard Lining Main Barrel**	**<u>New Lining Main Barrel</u>**
WORKING LINING	**400mm MgO-C Brick**			
SAFETY LINING	**75mm MgO Brick**		**25mm MgO Backfill**	
INSULATION LINING	NONE	**<u>13mm Isomag70</u>**	NONE	**<u>13mm Isomag70</u>**
TOTAL THICKNESS	**475mm**	**483mm**	**425mm**	**438mm**

Figure 2: EAF Refractory Lining Standard Practice versus New Practice

Figure 3 shows the longitudinal EAF section with the floor consisting of Magnesia based dry ramming material, typically 750mm thick. The upper walls and roof (not shown) consist of water-cooled panels. [4]

In the sidewall, the Working Lining consists of a 400mm MgO-C brick throughout. The Safety Lining is zoned to optimize capacity. The Balcony, consists of a 75mm Magnesia Brick for stability. In the Main Barrel, 25mm of Magnesia backfill is used behind the Working Lining.

As outlined in Figure 2, 13mm Isomag70 board was used as the insulation lining throughout the sidewall and installed between the steel shell and safety lining. The small increase in lining thickness did not affect the vessel capacity.

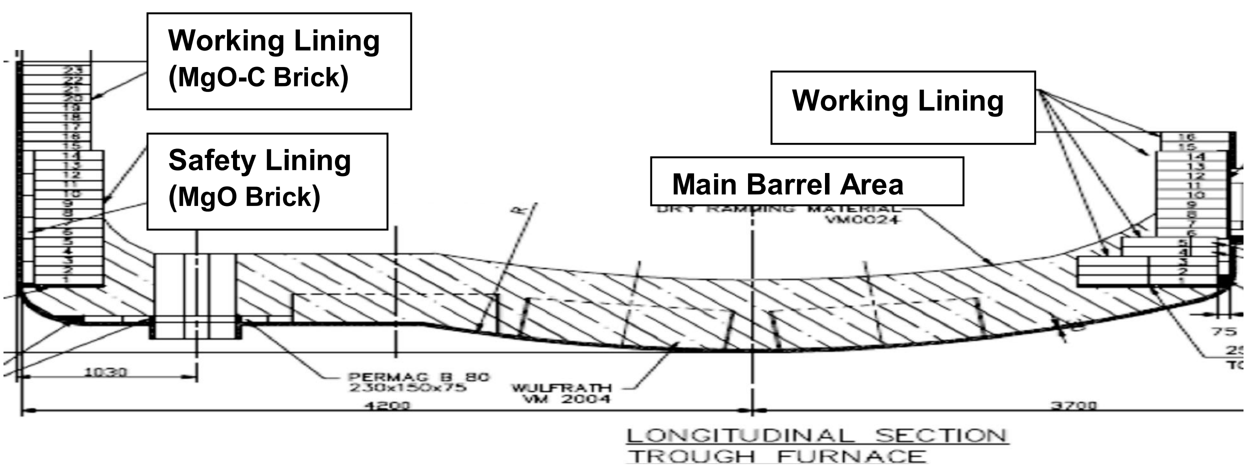


Figure 3: Longitudinal Section of EAF (Danielli S.p.A. Design) [4]

Figure 4 shows the installation of the Isomag board onto the sidewall in the main barrel area. A 25mm gap between MgO-C brick and board is for the MgO backfill safety lining. Figure 5 shows the step change in working lining in the Balcony area, due to the use of a 75mm Magnesia brick for the permanent lining.

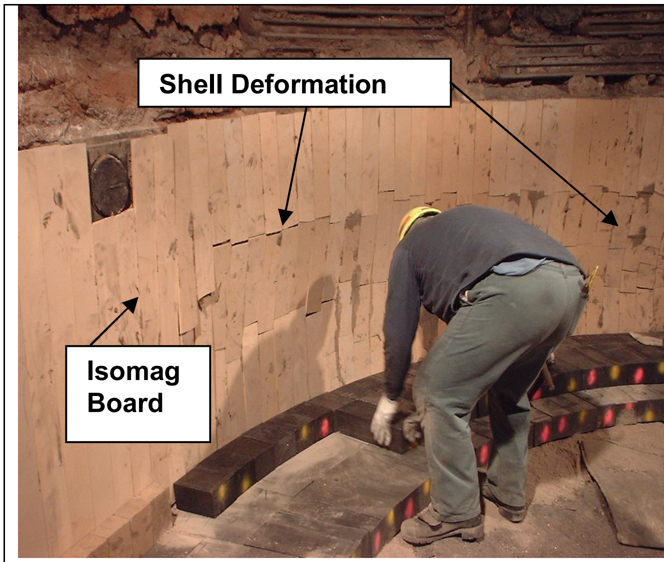


Figure 4: Installation of Isomag Board - vertical slats. Cracked board shows shell deformation

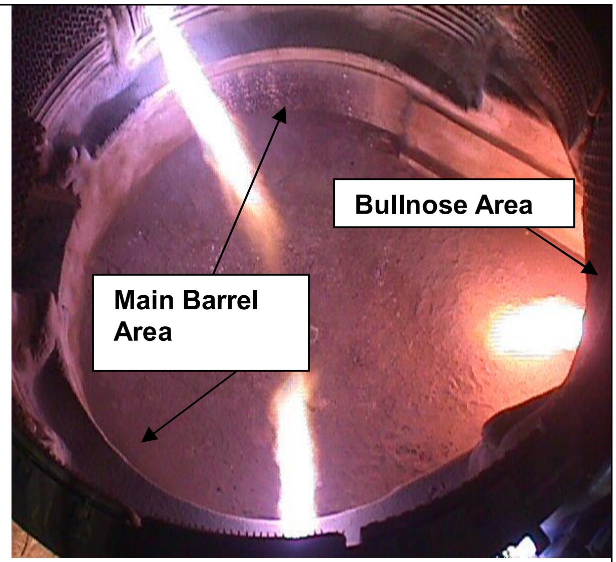


Figure 5: Lined EAF: Main Barrel (left) and Balcony (right).

4. RESULTS & DISCUSSION

The purpose of this experiment was to determine the effect of incorporating a 12.7mm thick layer of structural insulating board (Isomag®70) into the refractory lining of the Electric Arc Furnace. To quantify the benefit of using an insulation lining, representatives of the Steel plant and Pyrotek carried out comparative measurements of the following:

- Shell Temperature,
- Electricity Consumption versus Heat Number
- Electricity Consumption versus Tap to Tap Time (TTT)
- Electricity Consumption versus Steel grade
- Calculated ROI based on electricity savings only,
- Calculated Green House Gas savings based on the above ROI.

4.1: Effect of Insulation on Shell Temperature

Electric Arc Furnaces in general will have higher shell temperatures than other vessels within the Steelmaking plant. This is due to:

- Higher metal temperatures,
- Use of a higher thermal conductive brick for the Working Lining (MgO-C), and
- Hot spots near the electrodes and burner jets.

As a result, EAF shells are prone to warping and cracking due to the resulting thermo-mechanical fatigue stresses. New shell replacements are a high capital cost item, prolonging their service life results in appreciable cost savings.

4.1.1 Test Procedure

A theoretical steady state analysis showed a 50 ï 100^{o}C shell temperature reduction when using 13mm of Isomag70 insulation. [5]

Given the theoretical calculations, shell temperature measurements (using infrared thermometers), were taken at the slag line level, at the Balcony and Main Barrel areas. The readings were done 15 minutes prior to tapping (which is the highest EAF shell temperature in the process cycle) and recorded on a weekly basis for two consecutive campaigns. The results are shown in Figure 6.

4.1.2 Shell Temperature Results

The top two lines in Figure 6 show the actual EAF shell temperatures, during a campaign without insulation, at the slag line of the Main Barrel and Balcony respectively. The data shows the shell temperature steadily increases over time, which is due to the erosion of the working lining. The Balcony region is on average 30°C cooler than the Barrel Area from a thicker safety lining and greater distance from the electrodes and burner jets.

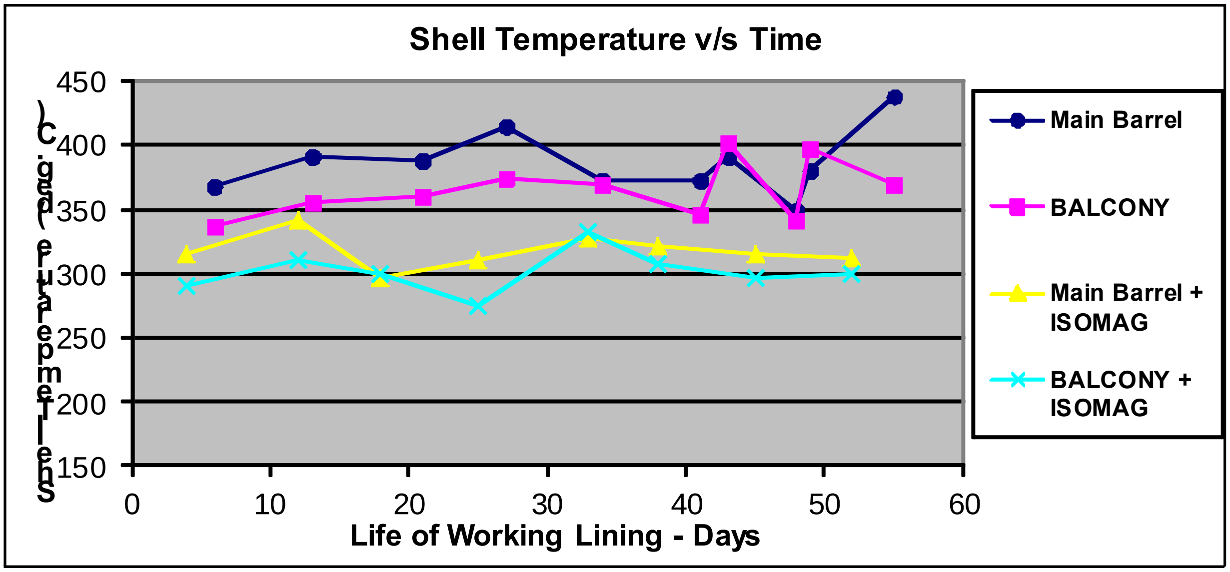
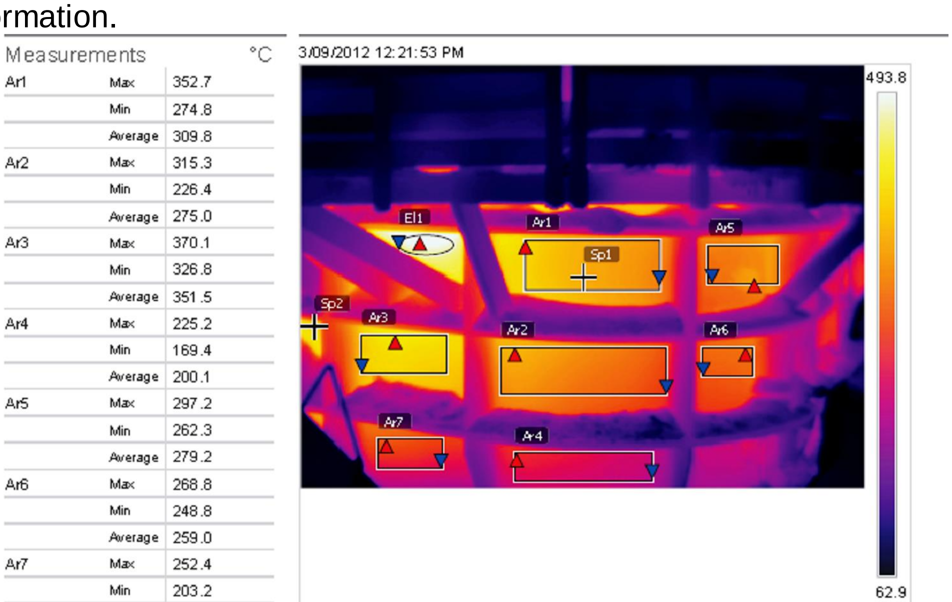


Figure 6: Actual Shell Temperature v/s Time: Balcony & Main Barrel Region [5]

The following campaign incorporated 12.7mm Isomag®70 insulation into the refractory lining. The measured data shows the EAF vessel when insulated, has a shell, on average 70°C cooler throughout the campaign. Shell temperatures at the Balcony and Main Barrel appear closer, averaging 10-20°C difference.
Throughout the campaign the shell temperatures remained stable, indicating that minimal degradation of the Insulation Board during service. A cooler shell results in less deformation.



Measurements		°C
Ar1	Max	352.7
	Min	274.8
	Average	309.8
Ar2	Max	315.3
	Min	226.4
	Average	275.0
Ar3	Max	370.1
	Min	326.8
	Average	351.5
Ar4	Max	225.2
	Min	169.4
	Average	200.1
Ar5	Max	297.2
	Min	262.3
	Average	279.2
Ar6	Max	268.8
	Min	248.8
	Average	259.0
Ar7	Max	252.4
	Min	203.2

Figure 7: FLIR E60 Thermovision of Balcony Region with Wear Lining at 1300 heats

Figure 7 shows the shell temperature of the balcony using an infared camera. The picture was also taken prior to the end of a wear lining campaign at 1300 heats and represents the typical high point of shell temperature. The temperatures shown in this photograph are consistent with those in figure 7 with the working lining life now extending to 90 days.

4.2: Effect of Insulation on Electricity Consumption

The major factors that influence energy consumption in an EAF are process related including:

- Tapping setting current,
- Variations in charge blend,
- Tapping Temperatures,
- Overall Chemical / Oxygen Input, and
- Delays or power on time.

The question remains, if insulation reduces the shell temperature on average by 70°C ï as shown in Figure 6, does that translate directly to an electricity saving to produce a liquid tonne of steel?

Therefore it was proposed to investigate what effect insulating the lining has on the EAF electricity consumption as a whole.

4.2.1 Electricity Consumption vs Heat Number;

The electricity consumption for 2 consecutive campaigns is shown in Figure 8. The data is extracted from the EAF computer database and has approximately 2000 data points. Each point represents the amount of electricity (kWh) to produce a liquid tonne of steel (LTS) for each heat of steel.

The first campaign had the Isomag®70 insulation lining, lasting 11 weeks, while the following campaign (without insulation) ran for 6 weeks. Since no significant process related changes occurred during this period, both campaigns are directly comparable with the only real difference being the Isomag insulation.

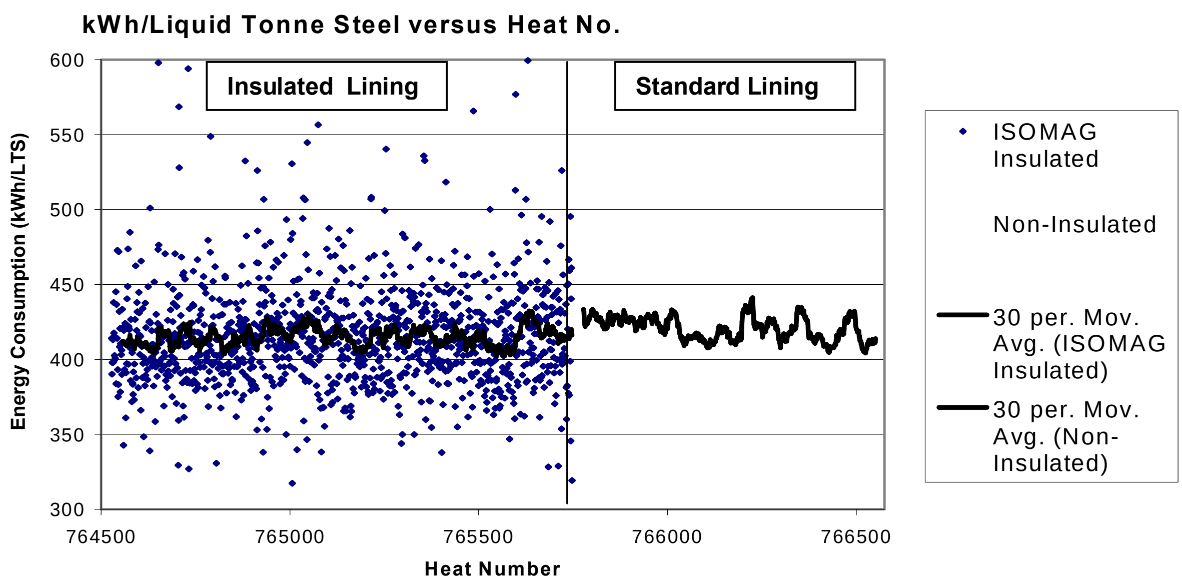


Figure 8: kW hours/ liquid tonne of steel v/s heat number – Actual Data [6]

The graph shows the variability in electricity consumption at the EAF, the bold line shows a 30 heat moving average. However with so many data points, that heats of steel produced when the lining was insulated appeared to use less electricity compared to the standard lining.

4.2.2 Electricity Consumption v/s Tap to Tap Time:

Figure 9 compares the effect Insulation has on Electricity Consumption versus Tap to Tap time (TTT) for heats of steel produced in less than 55 minutes and greater than 55 minutes.

When the EAF is operating without delays (TTT<55mins), insulation had little to no effect on saving energy.

When the EAF was operating with tap-to-tap times greater than 55 minutes (TTT>55mins), and without insulation, electrical consumption increased by 4%. However with the EAF insulated, electrical consumption increased by only 2.0% in comparison. For all heats produced, the overall saving is 1.4% with the vessel insulated with Isomag®70.

In summary, the insulation lining has little benefit in saving energy if all heats are manufactured without delays. However, with delays, the EAF without insulation through loses more heat (as shown in Figure 6) and therefore requires a corresponding increase in electricity or energy to produce the next heat of steel.

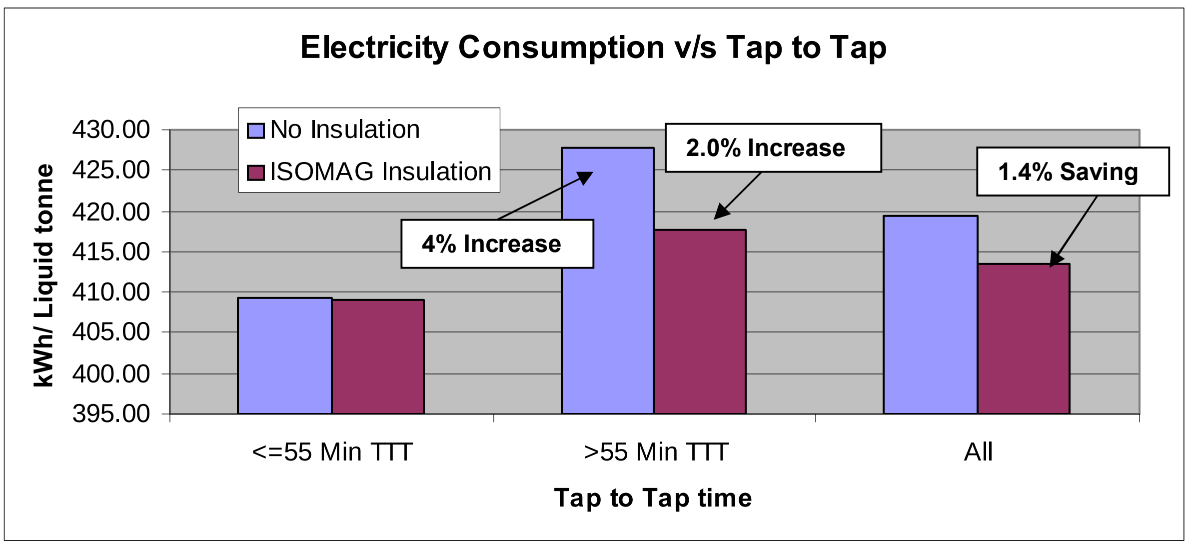


Figure 9: Energy Consumption versus Tap to Tap – Actual Data [6]

4.2.3 Electricity Consumption vs Steel Grade:

A further analysis along this theme is to assess the effect that the steel grade or tapping temperature has on energy consumption and if insulating the refractory lining has an effect. Figure 10 is the graph of energy consumption as a function of steel grade and its respective tapping temperatures.

The 1015 grade with the lowest aim tapping temperature of 1610^{o}C shows the least electrical saving using insulation at 0.6%. At 1630^{o}C tap, medium carbon steel shows a 1.3% electrical saving with furnace insulation (which at 1.4% is close to the average saving of all heats produced). The HSLA grade shows the greatest saving in energy or 2.1% with insulation but has the highest tapping temperature of 1650^{o}C. As a result steel grades produced with higher tapping temperatures consume more energy per liquid tonne of steel but also offer a greater potential electricity savings with refractory insulation.

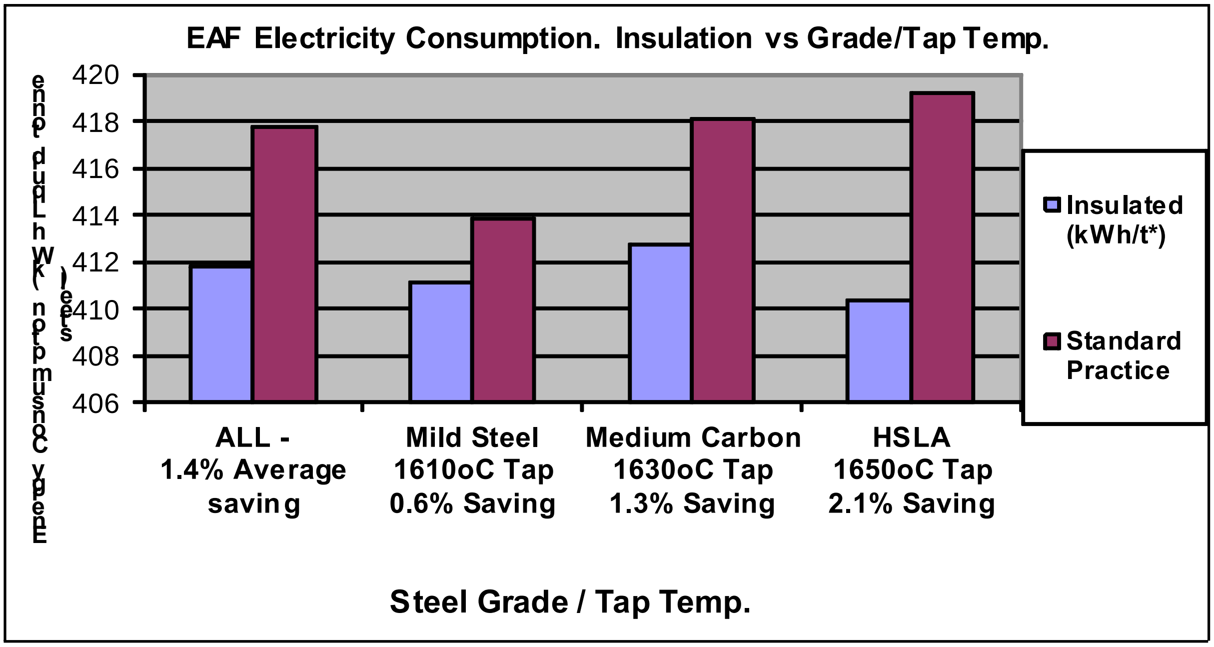


Figure 10: Energy Consumption versus Steel Grade – Actual Data [6]

4.2.4 Net Profit Energy Saving from Using Insulation

Shown below in Figure 11 is a calculation of the direct electricity saving resulting from using insulation as compared with the current practice. It is based on various assumptions on cost of electricity, continuous operational practice etcé

It provides an estimate on the dollar saving of an EAF (70t producing 605,000 tpa) consuming an average of 1.4% less electricity. The pay back is greater than 10:1.

Isomag Insulation of Electric Arc Furnace		
Size of EAF Vessel =	70	tonnes
Tap to Tap time =	55	minutes
Tonnes produced per hour	76	tonnes / hr
Operation =	24	hours/day
Included delays, maintenance etc..	330	days/year
Total Tonnes produced/ year =	604,800	tonnes pa
Cost of Electricity =	$0.06	USD/kWh
Average Energy / liquid Tonne of Steel =	418	kWh
Total Yearly Energy Cost for EAF =	$15,168,384	pa
Use Isomag Insulation.		
1.5% Energy Saving =	$227,526	pa
Cost of Isomag to Reline	$4,000	pa
No of relines pa	4	
Total Cost of Isomag Insulation	$16,000	pa
Net Profit to Steelmaker =	$211,526	pa

Figure 11: Energy Consumption versus Tap to Tap – Calculated [6]

4.2.5 Green House Gas Emission Saving comparison

The majority of scientific opinion is that increasing emissions of greenhouse gases (GHG) like CO and CO_2, most of which are of human origin is the cause for increased global warming. [7]

Like Figure 11, Figure 12 below shows the calculated comparative savings of Greenhouse Gas (GHG) emissions, between the current refractory practice and insulated lining, based on a 1.4% electricity saving, of 3,340 tonnes CO_2 pa [8].

In the future there may also be a financial incentive to reduce green house gases. Governments throughout the world are considering various carbon taxes, credits and trading schemes in encouraging industry to further reduce their emissions.

	EAF Electricity Usage. kWh/LTS	Annual consumption (605,000 tpa)	Units	Gross energy value	Energy - Giga Joules	Emission Factor	Greenhouse Gas Emissions, tonnes CO_2
Electricity EAF Current Practice	417.8	252,769	MWh	3.6 GJ / MWh	909,968	0.92 t CO2 / MWh	232,547
Electricity EAF Current Practice	411.8	249,139	MWh	3.6 GJ / MWh	896,900	0.92 t CO2 / MWh	229,208
				Total Energy Savings, GJ	13,068	Total Greenhouse Gas Emissions, tonnes CO_2	3,340

Figure 12: Greenhouse Gas Saving Comparison - Calculated [8]

5. CONCLUSION

This paper determined the effect of incorporating a 12.7mm thick layer of structural insulating board (Isomag®70) into the refractory lining of the Electric Arc Furnace at an Australian Mini Steel Mill. So that the benefits of insulation could be quantified, measurements in two consecutive campaigns were taken of:

- Shell Temperature,
- Electricity Consumption versus Heat Number
- Electricity Consumption versus Tap to Tap Time (TTT)
- Electricity Consumption versus Steel grade
- Calculated ROI based on electricity savings only,
- Calculated Green House Gas savings based on the above ROI.

The testing was done during a stable period in which the only notable difference between these campaigns was the inclusion of an insulating lining.

In comparison, the refractory lining insulated with Isomag®70was more efficient having the following cost saving benefits:

- Average 70°C shell temperature reduction;
- Potential to reduce shell deformation, particularly in hot spot areas;
- Overall Energy consumption reduced by 1.4% and
- Insulation provides most benefit for increased delays (TTT) and higher tapping temperatures.
- Insulation has minimal effect on electrical saving where operations are continuous and tapping temperatures are less than 1610°C.

6. REFERENCES

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