HOW MUCH AND WHAT TYPE OF REFRACTORY DO STEEL PLANTS REALLY USE?

AN ACCURATE REFRACTORY COST/USAGE MODEL FOR THE NORTH AMERICAN STEEL INDUSTRY

Thomas Vert*,
Independent Refractory Expert

ABSTRACT:

Steel plants use roughly 60% of all refractories worldwide, and yet, when trying to find accurate models of how much refractory is used it is very difficult. Currently public models available are extremely costly and based on import/export and financial data from public refractory companies and are imprecise due to their top-down approach.

A new model has been created using a "bottom-up" approach using 30 years of in plant refractory experience combined with actual operating North American AIST steel plant production data. The results are an accurate model that shows usage of refractory in steel plants by type, by region, and by spend! This paper will give an overview summary of the current state of refractory usage in steel plants in North America and a forecast for 2040 based on the author's knowledge of both the steel and refractory industry.

PREVIOUS MODELS:

Currently, to figure out how much of any type of refractory is used in the steel industry, one may purchase a model from a few different companies, however, they are all based on the same type/sources of data.

The current models base their usage rates and forecasts on a mix of:

- Import / Export data through government sources
- Refractory company reported sales / forecasts based on their quarterly and/or annual results
- Economic growth forecasts of general and/or manufacturing industries

The weakness with this approach is:

- Top down only
- Import / export codes are out of date and do not reflect accurately the current products used in the marketplace
- Company sales data are for countries and not regions
- Sales data are not broken out by product type with the best case of monolithic versus brick
- Economic forecasts are basic and never predict major swings in the market (like market crashes, changes to technology due to carbon pricing, etc.)
- There is no accounting for improvements in refractory technology or increase in wear due to more aggressive processing.

Therefore, these current models are very high level, not accurate for any real forecasting and yet can cost tens of thousands of dollars!

NEW MODEL:

The author has tried to determine what would be the outputs of a great cost / usage model for refractories in the steel industry using North America (Canada and USA) as a basis.

Key outputs that would be desired are:

- Bottom-up approach based on actual average refractory usages
- Approach that differentiates EAF versus BOF steel plants and key process vessels for example:
    - BOF
    - EAF
    - Steel Ladle
    - RHOB
    - Tundish
    - CC Flow control
    - Hot metal ladles

- Approach that has detailed product by product usage. For example, steel ladles would include:
    - Slaglines
    - Barrels
    - Bottoms
    - Safety lining
    - Argon purge systems
    - Slidegates
    - Lip Rings

- Usage rates by regions of North America for example:
    - Canada
    - USA West Coast
    - USA Northeast
    - USA Southeast
    - USA Central North
    - USA Central South

- Usage rates by end user (estimated)

In order to build the model, the following key inputs were used:

- AIST "Round-up" plant production rates for 2021
- Announcements of new steel plant builds and changes to technology (e.g., Algoma Steel move from BOF to EAF)
- Average usage rates (kg/tonne and $/tonne) for process vessels and product types based on 30+ years of experience, discussions, and benchmarking.

Note that the author has no illusions that this is perfect, however, it is believed that the accuracy of the data at this level of compilation is +/15%. Of course, any plant individually can be higher or lower based on refractory management practices and operating conditions.

This new model, however, provides data sets that have never before been compiled / published in a public forum.

Key model notes:

- Does not include project refractories like BF relines, Coke oven rebuilds, Hot mill reheat rebuilds
- Does not include any refractories from hot mill to final coil as they are <1% of steel plant refractory cost
- Focus in on steel plant consumable refractories only

MODEL OUTPUTS**:**

1. Overall market Usage / Spend

Overall Market Consumables			
	Volume (tonnes)	**Demand (US $)**	**Avg Price (US $/t)**
Coke and Iron	44,789	$ 45.0	$ 1,004.74
BOF	53,234	$ 68.5	$ 1,286.72
EAF	410,568	$ 388.6	$ 946.43
Steel Ladles	301,562	$ 468.0	$ 1,551.89
RH Degasser	28,794	$ 36.3	$ 1,261.72
Casters	146,754	$ 397.7	$ 2,710.09
Total Demand	985,701	$ 1,404.1	$ 1,424.48

Table 1 – overall usage rates

This first set of outputs shows some key learnings about the North American steel refractory market in 2021:

- Demand for refractories is highest from a volume point of view at the EAF furnace area which is a very destructive process requiring lots of repair materials.
- The BOF market is extremely small due to the long life of BOF's in North America due to slag splashing.
- Steel ladles and Tundish/Caster make up the high revenue areas of the steel plant despite lower volumes than the EAF.
- Average price of refractories used in a typical steel plant is $1,424 per ton with wide

variations depending on the complexity of individual shapes / products.

2. Usage / Spend by Major Process Area

Coke & Iron Consumables		
	Volume (tonnes)	Demand (US $)
Casthouse	19,440	19.1
Taphole Clay	9,399	11.4
Torpedo cars	10,253	10.0
Hot metal ladles	5,696	4.6
Total	44,789	45.0

Table 2 – Coke and Iron usage rates

The statistics are interesting for the coke and iron area. Cokemaking has very few consumables (doors, jamb repairs, stovepipe repairs, etc.) with a very low volume and has therefore not been added to the model.

At the blast furnace area, the BF proper has had life extended from 2-3 years in the late 1980's to 10+ years currently due to the excellent technology of shotcreting. Materials now include alumina-silicon carbide-carbon and can last 2-3 years if installed and dried properly.

The bulk of refractory usage is casthouse materials at ~45% of the use of ceramics in this area. Current technology is high alumina castables with silicon carbide and carbon additives and include air- or water-cooled designs for the metal and slag troughs. This is followed by torpedo cars, which though they have a very long life, continue to have extensive gunning and/or shotcreting repairs to maintain this longevity. It should be noted that fully monolithic torpedo cars are no in service which have monolithic safety and monolithic working linings. This has been done to avoid the difficult task of bricking these vessels, especially the ones with tapered ends.

Taphole clay and hot metal ladles round out the usage here with hot metal ladles containing ASC as well as standard alumina brick depending on whether the ladle is used for desulphurization.

BOF Consumables		
	Volume (tonnes)	Demand (US $)
Safety lining	470	$1.0
Working brick	4,504	$7.2
Gunning	47,900	$58.4
Tapholes	360	$1.9
Total	53,234	$68.5

Table 3 – BOF usage rates

BOF refractories in North America are very interesting due to the extensive use of slag splashing and vessel life in excess of 20,000 heats. Therefore, the key refractory used is basic gunning materials to maintain the lining.

Note that safety lining usage is very low as well as tapholes, though the latter is critical for good slag carryover and one-piece tapholes continue to make inroads over the traditional segmented version.

EAF Consumables		
	Volume (tonnes)	Demand (US $)
Safety lining	815	$ 1.63
Hearth/Fettle	122,193	$ 122.19
Working Brick	81,462	$ 81.46
Gunning	203,655	$ 162.92
Tapholes	2,444	$ 20.37
Total	410,568	$ 388.57

Table 4 – overall usage rates

EAF refractories also show a low usage of safety lining, and tapholes.

Working lining brick tends to be lower as only key wear spots are replaced. Hot spots in AC furnaces and brick underneath injection systems are the high wear areas.

Fettling and gunning of the banks and bottom of furnaces is the bulk of refractory usage and is linked to the type of furnace. The highest repair rates tend to be on Consteel furnaces or shaft furnaces, then on AC designs and finally on DC furnaces.

Of course, it should be noted that an excellent foamy slag practice in all cases is critical to low wear rates and low repair rates for all furnace designs.

Steel Ladle Consumables		
	Volume (tonnes)	Demand (US $)
Safety	15,647	$ 17.07
Slagline	58,321	$ 85.35
Barrels (AMC/A)	50,619	$ 65.62
Barrels (Dolo)	26,194	$ 33.95
Bottoms	73,968	$ 99.57
Flow Control	52,631	$ 113.80
Gunning/Lips	21,337	$ 24.18
Stirring	2,845	$ 28.45
Total	301,562	$ 467.99

Table 5 – overall usage rates

Steel ladle refractories are a large consumer with many components due to their nature as the key processing vessel.

It should be noted that the type of ladle treatment will determine higher wear rates and consumption. Ladle refractory usage ranges from low to high for transfer vessel, CAS-OB, RHOB, and final LMF heating / treatment.

Flow control has the highest value per use due to the extreme nature of slidegate systems. Despite many years of research, plate life continues to average approximately 4-6 heats. It should be noted however, that carbon bonded plates (those based in reducing atmosphere at high temperatures) have much higher lives than resin bonded plates. Some carbon bonded plated on non-calcium grades can average up to 12 heats if open checked, scraped, and lubricated after each heat.

Calcium grades are notorious for low life (even one heat) especially if the steel calcium level is >30ppm and/or long cast times (>60 minutes).

Steel ladle wear is based on ladle process routes and will determine the life of the slagline and whether a second slagline can be used with a single bottom and barrel.

The use of AMC has become standard in Al-killed shops and Dolomite in Si-killed shops.

Note that other factors such as lip ring design / maintenance, brick shape (semi-u, mini-key, arch), as well as bricking configuration (spiral versus ring) all contribute to wear rates.

The largest factor for steel ladle wear remains processing route, slags, timing, temperatures and cycling.

Tundish / Caster Consumables		
	Volume (tonnes)	Demand (US $)
Stopper	23,269	$ 59.99
Nozzle	2,853	$ 27.85
SEN	14,110	$ 154.26
Backup	10,083	$ 17.72
Working Spray	72,023	$ 79.44
Ram	8,219	$ 8.69
Shroud	14,789	$ 34.76
Plates	1,409	$ 15.00
Total	146,754	$ 397.72

Table 6 – Caster usage rates

The continuous caster has become a critical area of usage for refractories due to their impact on quality control.

Working lining versus dry vibratable linings continues to be debated as to their pros and cons with differing opinions as to their impact on final product quality versus potential life of the tundish.

Flow control systems (SEN, Stopper, nozzle, and/or plates) are critical to product quality and their life is dictated also by the mold powder selected and/or tundish indexing strategy.

3. Usage / Spend by Product Type

Magnesia Carbon Brick		
	Volume (tonnes)	Demand (US $)
BOF	4,504	7.2
EAF	81,462	81.5
Ladle Slagline	58,321	85.3
Total	144,286	174.0

Table 7 – MgO-C usage rates

The model also has other potential benefits in that certain product types can be isolated for trending. For example, MgO-C brick has been shown as to the total usage as well as the process area that it is used in.

Some may find it surprising that there is more MgO-C used in EAF's than slaglines, however, when you factor in the fact that slaglines can be narrow bands as well as small diameter ladles, and that EAF's are now the "workhorse" of the North American melting strategy, it makes sense.

4. Usage / Spend by Region

Magnesia Carbon by Region	
Region	Volume (tonnes)
Canada	15,600
US West	5,306
US Middle North	28,574
US Middle South	18,141
US North east	34,756
US South east	41,909
Total	144,286

Table 8 – Regional usage rates

Further benefits of the model can be shown that the usage of any individual product (slidegate plate, taphole, brick, etc.) can be isolated and a regional breakdown can be made.

As seen in table 8, MgO-C brick are used mainly in the Southeast USA and this trend will continue with more and more mills locating to this region following their customers.

5. Current versus 2040 Usage

Another interesting way to use the model is for prediction of any of the above scenarios in the future.

A scenario has been run for the usage of refractories in steel plants in the year 2040 utilizing the following assumptions:

- *All Coke ovens, BF, BOF's shut down in North America (due to climate change and the fact that electricity and natural gas are plentiful and cheap in North America)*
- *EAF production increases to offset BOF mill shutdowns due to the competitiveness of EAF mills versus imports. Note that EAF mills use more refractories than BOF's, so this is positive for refractory manufacturers.*
- *An annual growth rate of 1% due to economic growth offset by less intense steel usage (OECD prediction)*
- *Refractory technology continues to improve but the steelmaking process continues to be more aggressive leading to a balanced increase of 1%*

Overall Market 2021 versus 2040			
	Volume (tonnes) 2021	Volume (tonnes) 2040	Delta
Coke and Iron	44,789	-	(44,789)
BOF	53,234	-	(53,234)
EAF	410,568	565,096	154,528
Steel Ladles	301,562	307,623	6,061
RH Degasser	28,794	29,373	579
Casters	146,754	149,704	2,950
Total Demand	985,701	1,051,795	66,095

Table 9 – 2021 vs 2040 usage rates

Table 9 predicts overall usage of refractories will continue to increase over the next 20 years, however, it will be mainly focused on the EAF furnace area which will continue to grow as BF/BOF plants will be shut down.

Note that this prediction may be aggressive, but with recent announcements of conversion to EAF's for Algoma Steel and ArcelorMittal Dofasco, my not be out of line with reality. This is in addition to new announcements for steel plants at Nucor and US Steel.

Potential Uses for the Model

It should be noted that the results given in this paper are still at a medium level or compiled amount. More detailed analysis is available by extremely specific area (e.g., ladle slidegate plates, nozzles, etc.) if desired.

As can be seen with the results shown, there are many potential usages for this type of model:

- For refractory companies to determine potential clients, product, or market areas and/or validate their own models
- For steel plants to benchmark their performance against an accurate standard and potential gap areas that could be improved
- For investment firms to review potential clients capital strategies for region and/or product and/or process types.
- For determination of plant or office locations near customers.
- Areas for potential R&D and product development.

SUMMARY:

A new model has been created using a "bottom-up" approach using 30 years of in plant refractory experience combined with actual operating North American AIST steel plant production data. The results are a very accurate model that shows usage of refractory in steel plants by type, by region, and by spend, including forecasts to 2040.

Many potential uses for the model are envisioned to help all stakeholders in the industry.