How to Read Steel Ladle Wear – 30 Years of Experience (Good, Bad and Ugly)

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Abstract:

Steel ladle refractory wear can be boring and normal, or weird, inconsistent, and totally unpredictable. In addition to the variations of refractory material, installation, dry out, repairs, etc., there is a highly variable processing route! It can take many years to get a "keen eye" to spot ladle wear patterns and their causes (which a laser will not tell you). The author has over 30 years of experience in reading steel ladles, investigating ladle breakouts, and managing process routes, and will attempt to review key wear patterns and their potential cause(s). This paper will provide the practical tools and tips to achieve the goal of quick troubleshooting for effective wear resolution of steel ladle wear, for three (3) key examples: Vertical cracks, horizontal cracks and missing/worn bricks.

1. Vertical Cracks in Working Lining

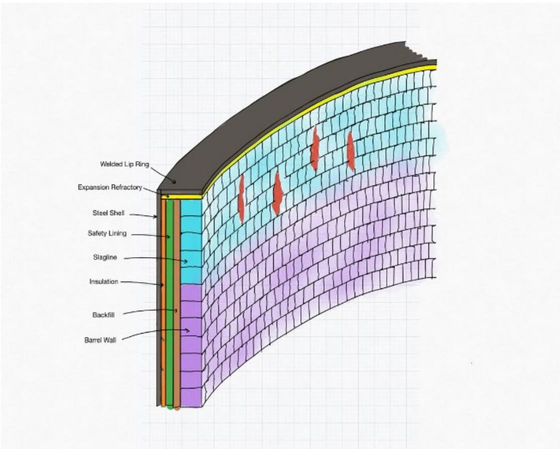

Figure 1- Vertical Cracks in ladle lining

Potential Cause #1.1:
Installation of bricks – joints lined up vertically

- **Verification method**: Check brick joints on tear out to see if they are lined up directly

Potential Cause #1.2:
Installation of bricks – Loose lining installation

- **Verification method:** Check joints and behind working lining on tear outs for steel penetration and/or excessive oxidation (>3mm) to ensure lining integrity

Potential Solution for #1.1 & #1.2:
Update and/or reinforce installation practices with masonry team to ensure minimal overlap of vertical joints and to ensure tightness of each row of brick by using "wedge" bricks for tightening lining. Visual QAQC check of brick lining when completed.

Potential Cause #1.3:
Installation of backfill (when used) – missing section of backfill

- **Verification method**: On tear out, check for missing sections, empty gaps, major steel penetration of the backfill section of the lining

Potential Cause #1.4:
Installation of backfill – Backfill not rammed properly and/or not dense enough

- **Verification method:** On tear out, check for loose backfill and/or take samples and check density versus desired specification

Potential Solution for #1.3 & #1.4:
Update and/or reinforce installation practices with masonry team to ensure proper installation practices including maximum depth of ramming (max 75mm per layer), ramming from top down (no layers that could

spall), integrity of ramming equipment to get required force

Potential Cause #1.5:
Installation of safety lining (no backfill) – missing section of safety lining

- **Verification method**: On tear out, check for missing sections, empty gaps, major steel penetration of the safety lining section of the lining

Potential Cause #1.6:
Installation of safety lining (no backfill) – Safety lining has major cracks and /or spalled sections and/or repair materials have little integrity (when safety lining used multiple times and repaired)

- **Verification method:** On tear out, check for loose safety lining brick, deteriorated / spalled sections, loose repair materials and/or take samples and check density versus desired specification

Potential Solution for #1.5 & #1.6:
Update and/or reinforce installation practices with masonry team to ensure proper installation practices including repair techniques, practices - when to repair with mortar vs plastics/rams vs cast sections vs full bricks.

Potential Cause #1.7:
Excessive thermal Cycling: Low number of heats per day for all days in service

- **Verification method**: Determine total number of heats and divide by total hours in service divided by 24 to get average heats per day.

Potential Cause #1.8:
Excessive thermal cycling – Periods of time ladle taken out of service and not used for multiple days (e.g., high heats per day while in service but then out for several days OR worst-case low heats per day and out for multiple days)

- **Verification method:** Determine number of heats/day and the total number of times ladle taken out of service / not in rotation for >8 hours. Note that the longer the duration out of service the worse the situation due to excessive lining shrinkage and oxidation of any joints/crack.

Potential Cause #1.9:
Excessive thermal cycling – No preheating when out of service

- **Verification method**: Is there any preheating of the ladle when it is out of service - either vertical and/or horizontal preheaters and what temperature is used? Is a cover used when the ladle is empty between the caster and then back in service at tapping station?

Potential Solutions for #1.7, 1.8 & #1.9:
Meet with steel shop supervisor to explain the phenomenon of low heats per day leads to higher cracking and/or oxidation and thereby cracks and lower life. Optimal is to get >=5 heats/day/ladle in service and to have no periods of time when it is taken out of rotation for >4 hours. A plan for ladle management to achieve this depends on minimum # of ladles in the steel shop as possible without creating a steel plant delay.

Also, for 1.9, is there potential for the steel plant to install ladle covers or "barn doors" to conserve the maximum amount of heat in the ladle between heats? Radiation is T^4 for heat loss and therefore the major factor is heat lost from open top when ladle is empty.

Potential Cause #1.10:
Ladle positioning – Ladle is laid on its side for argon plug and slidegate work. Potential for "sagging" of top of lining is high especially if there is any looseness in the lining

- **Verification method**: Validate when ladles are put on their sides, the position of cracking and the length of time the ladles are in this position.

Potential Solutions for #1.10:
Minimize repair times with long life argon plugs, slidegate plates/nozzles and as soon as repairs done stand the ladle up vertically (and preheat if possible).

<u>Potential Cause #1.11:</u>
Excessive ladle horizontal preheating – When the ladle is on its side AND if you have horizontal preheater AND the preheater has high temperature, long powerful flames - this may cause localized melting, oxidation of joints at the top of the ladle.

Verification method: Visually check the preheat temperature and the power/length of flame and where the flame impacts on the top of the ladle

Potential Solutions for #1.11:
Preheater temperature can be optimized (~1400 C - too hot and slag will melt) and/or flame length can be adjusted to shorter flame, so it doesn't impact directly on working lining.

2. <u>Horizontal Cracks in Working Lining</u>

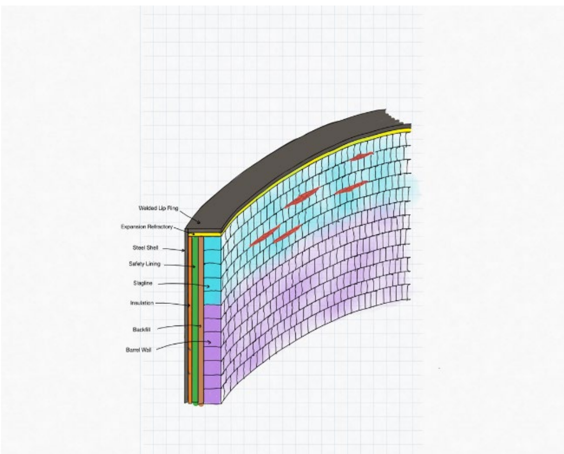

Figure 2- Horizontal Cracks in ladle lining

<u>Potential Cause #2.1:</u>
Installation of bricks – Starting surface of each course not level so gaps between bricks on top of each other

- **Verification method**: Check brick joint heights on tear out to see if they are flat or "choppy". Check for steel penetration in specific areas

<u>Potential Cause #2.2:</u>
Installation of bricks – Use of mortar in some cases leads to large joints due to creating larger mortar joints that will be quickly worn away

- **Verification method:** Check joints and behind working lining on tear outs for steel penetration and/or excessive oxidation (>3mm) to ensure lining integrity

Potential Solution for #2.1 & #2.2:
Update and/or reinforce installation practices with masonry team to ensure each course is horizontal and flat and to ensure tightness of each row of brick. Visual QAQC check of brick lining when completed.

<u>Potential Cause #2.3:</u>
Installation of Lip rings and expansion allowance – Lip rings are no longer horizontal or angled slightly downwards

- **Verification method**: Take a straight edge and measure how "lifted" the front of the lip ring is from the back. If this height lift is >25mm and <74mm then you could be losing compression. If it is >75mm then you will for sure have lost compression and be getting openings on horizontal joints.

<u>Potential Cause #2.4:</u>
Installation of Lip rings and expansion allowance – Bolted lip rings have too much "slop" in the hole they go through and/or the bolts are not tight enough

- **Verification method:** On tear out, check for how high the lip ring is sitting in the hole in which it is installed and the looseness of the bolting system

Potential Solution for #2.3 & #2.4:
Update and/or reinforce installation practices with masonry team to ensure proper installation practices including that lip ring sits horizontally, welds or bolting system is strong/tight. The rigidity of the lip ring system is the key point to keep the lining in compression and avoiding horizontal joint cracks/wear in the steel ladle. There must be clear criteria as to when to remove a deteriorated lip ring

<u>Potential Cause #2.5:</u>
Installation of monolithic material expansion allowance– Missing section of monolithic material

- **Verification method**: On tear out, check for missing sections, empty gaps, major steel penetration of the gap between the top of the working lining and the lip ring.

<u>Potential Cause #2.6:</u>
Installation of monolithic material expansion allowance– Monolithic material has major spalled sections and/or repair materials that have little integrity left and/or major steel penetration of this gap

- **Verification method:** On tear out, check for deteriorated / spalled sections, loose repair materials and/or take samples and check density versus desired specification. Also look for areas of steel penetration that may prevent proper compression of the lining

Potential Solution for #2.5 & #2.6:
Update and/or reinforce installation practices with masonry team to ensure proper installation practices (maximum depth for ramming, plastics to be <75mm for good ramming density) including repair techniques, practices, equipment (is it being rammed properly). If castable is used in the gap, ensure no excess water and/or proper dry out techniques

<u>Potential Cause #2.7:</u>
Excessive thermal cycling in service – Low number of heats per day for all days in service

- **Verification method**: Determine total number of heats and divide by total hours in service divided by 24 to get average heats per day.

<u>Potential Cause #2.8:</u>
Excessive thermal cycling in service – Periods of time ladle taken out of service and not used for multiple days (e.g., high heats per day while in service but then out for a number of days OR worst-case low heats per day and out for multiple days)

- **Verification method:** Determine number of heats/day and the total number of times ladle taken out of service / not in rotation for >8 hours. Note that the longer the duration out of service the worse the situation due to excessive lining shrinkage and oxidation of any joints/cracks

<u>Potential Cause #2.9:</u>
Excessive thermal cycling in service – No preheating when out of service

- **Verification method**: Is there any preheating of the ladle when it is out of service - either vertical and/or horizontal preheaters and what temperature is used? Is a cover used when the ladle is empty between the caster and then back in service at tapping station?

Potential Solution for #2.7, 2.8 & #2.9:
Meet with steel shop supervisor to explain the phenomenon of low heats per day leads to higher cracking and/or oxidation and thereby cracks and lower life. Optimal is to get >=5 heats/day/ladle in service and to have no

periods of time when it is taken out of rotation for >4 hours. A plan for ladle management to achieve this depends on minimum # of ladles in the steel shop as possible without creating a steel plant delay.

Also, for 2.9 is there potential for the steel plant to install ladle covers or "barn doors" to conserve the maximum amount of heat in the ladle between heats? Radiation is T^4 for heat loss and therefore the major factor is heat lost from open top when ladle is empty.

Potential Cause #2.10:
Excessive ladle cleaning: Cleaning the ladle lip between heats in the shop with picks, hooks, machines, etc. can cause major damage to the expansion monolithic and/or lift the lip ring system and/or damage to the top course of brick - this can all lead to lack of compression of the working lining and potential for horizontal cracks to open

- **Verification method**: Visual observation during the cleaning process to watch for major damage and/or lifting as well as tracking the amount of refractory gunning / shotcreting of the ladle lip area can all show if the lip system has lost its integrity to hold the lining in compression.

Potential Solutions for #2.10:
Prevention of steel "skulls" on the lip of the ladle due to excessive stirring of the ladle can stop the need for excessive cleaning. If cleaning is done, the use of tools and operators with experience to "surgically" remove this material without lifting the ring system and/or damaging the lining are the best way to prevent issues.

Potential Cause #2.11:
Overfilling the ladle with steel/slag– If the ladle heat size is not controlled, then the slag and steel can get up to the lip ring and/or monolithic expansion material and do major damage to the integrity of the area.

Verification method: Tracking the ladle heat sizes to ensure none of them reach the highest areas and visually checking for large cuts of the monolithic expansion material after a single heat

Potential Solutions for #2.11:
Prevention of overfilling the ladle is the only way to stop this mechanism from occurring.

3. Missing/Worn Individual bricks

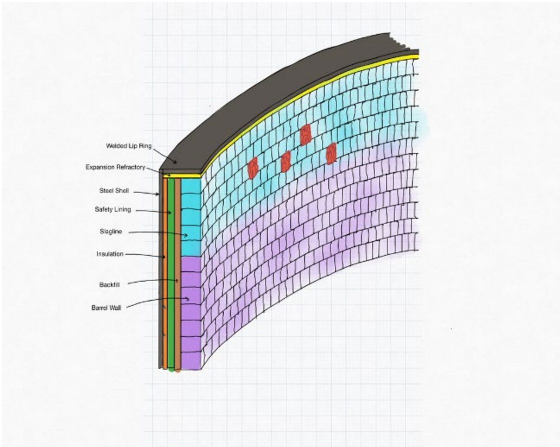

Figure 3- Missing or Worn Individual bricks

Potential Cause #3.1:
Installation of bricks – Loose installation - on a single course the bricks are not installed tightly, and this allows a brick to slip out

- **Verification method**: Check brick tightness on installation with random audits. After use, large amounts of steel penetration can show indications of this

Potential Cause #3.2:
Installation of bricks – Backward or Straight - in order to build/finish a course, a brick is installed either backward or a straight brick is used and eventually slips out

- **Verification method:** Check brick direction on installation with random audits. After use, large amounts of steel penetration can show indications of this.

Potential Solution for #3.1 & #3.2:
Update and/or reinforce installation practices with masonry team to to ensure tightness of each row of brick. Also, ensure all bricks have marking on hot face only so that a backwards brick could be seen. Visual QAQC check of brick lining when completed.

Potential Cause #3.3:
Brick quality: wrong type of brick used - for example an AMC brick installed in the slagline, or a dolomite brick installed in slagline.

- **Verification method**: Check brick type on installation with random audits (note that this assumes a proper marking system exists. If all MgO-C brick are black only than it is difficult to check). After use, samples can be taken, and microscopic checks can be done in the lab to show if the wrong brick was installed.

Potential Cause #3.4:
Brick Quality: Backward or Straight - Poor quality brick originating from supplier - low density, impurities, change in raw materials, etc.

- **Verification method:** After use, samples can be taken, and microscopic checks can be done in the lab to show if the wrong brick was installed. For fired bricks, a "ring" test can be done by hitting with a steel brick hammer to ensure a high pitched "ping" is heard which helps to ensure good quality.

Potential Solution for #3.3 & #3.4:
Update and/or reinforce installation practices with masonry team to ensure proper installation practices including a simple, effective system for marking the front faces of bricks with names, shapes, and colors to ensure bricklayers install correctly. For example, slagline bricks could be triangles of different colours and a character to distinguish. This makes it easy to audit. A system of random tests of incoming brick can also be used but is expensive.

Potential Cause #3.5:
Excessive thermal cycling in service – Low number of heats per day for all days in service

- **Verification method**: Determine total number of heats and divide by total hours in service divided by 24 to get average heats per day.

Potential Cause #3.6:
Excessive thermal cycling in service – Periods of time ladle taken out of service and not used for multiple days (e.g. high heats per day while in service but then out for a number of days OR worst case low heats per day and out for multiple days)

- **Verification method:** Determine number of heats/day and the total number of times ladle taken out of service / not in rotation for >8 hours. Note that the longer the duration out of service the worse the situation due to excessive lining shrinkage and oxidation of any joints/cracks

Potential Cause #3.7:
Excessive thermal cycling in service – No preheating when out of service

- **Verification method**: Is there any preheating of the ladle when it is out of service - either vertical and/or horizontal preheaters and what temperature is used? Is a cover used when the ladle is empty between the caster and then back in service at tapping station?

Potential Solution for #3.5, 3.6 & 3.7:
Meet with steel shop supervisor to explain the phenomenon of low heats per day leads to higher cracking and/or oxidation and thereby cracks and lower life. Optimal is to get >=5 heats/day/ladle in service and to have no periods of time when it is taken out of rotation for >4 hours. A plan for ladle management

to achieve this depends on minimum # of ladles in the steel shop as possible without creating a steel plant delay.

Also, for 3.7 is there potential for the steel plant to install ladle covers or "barn doors" to conserve the maximum amount of heat in the ladle between heats? Radiation is T^4 for heat loss and therefore the major factor is heat lost from open top when ladle is empty

Potential Cause #3.8:

Excessive ladle cleaning: Cleaning the ladle between heats in the shop with picks, hooks, machines, etc can cause major damage to the brick if it is very vigorous and a hole and/or individual brick can be removed and/or extremely damaged

- **Verification method**: Visual observation during the cleaning process to watch for major damage and digging into individual bricks that can cause the ladle to look like this. Especially if using a "Gradall" type device with a very sharp pick.

Potential Solutions for #2.10:

Prevention of steel "skulls" on the lip of the ladle due to excessive stirring of the ladle can stop the need for excessive cleaning. If cleaning is done, the use of tools and operators with experience to "surgically" remove this material without lifting the ring system and/or damaging the lining are the best way to prevent issues.

Summary:

Steel ladle refractory wear can be boring and normal, or weird, inconsistent, and totally unpredictable. In addition to the variations of refractory material, installation, dry out, repairs, etc., there is a highly variable processing route!

There can be one or multiple causes and a combination of all. This paper has shown three possible examples with ways to validate the cause and potential fixes.

There are many more wear patterns that can be seen and these will be reviewed in future papers.