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Bustle Pipe Repairs
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INTEROFFICE
CORRESPONDENCE

Copies to:

V. Beaucaire
J. Bitner
R. Langhoff
S. Miller
J. Seaman
R. Winters

Date: December 8, 1976

To: Mr. N. H. Keyser

From: C. Lin

Subject: Investigation of Bustle Pipe Failures in Chicago "A" Furnace

Reference: D3-002-001

Characteristics of Failure:

1. Nearby the major crack, there were lots of secondary cracks. These secondary cracks, as well as major cracks, were perpendicular to bustle pipe direction (radial direction to the blast furnace). (Figure 1).

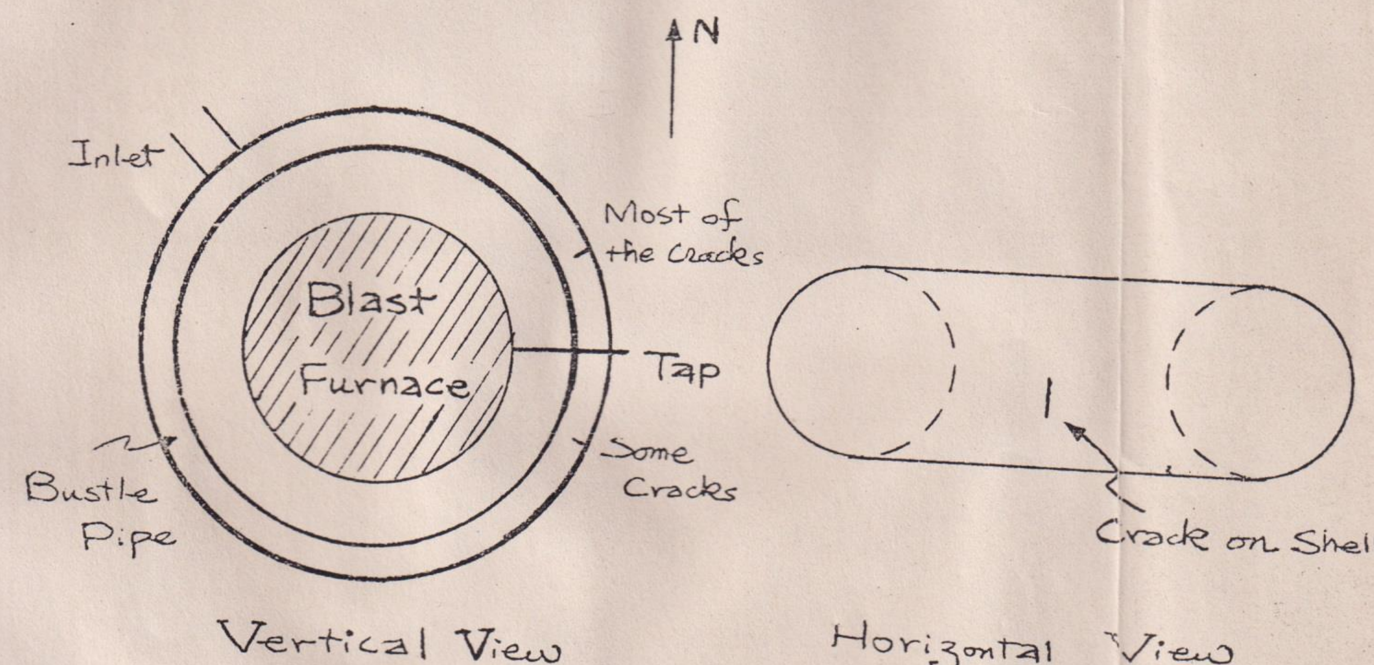


Figure 1: Location of Cracks

2. All these secondary cracks were straight and transgranular. They were perpendicular to the maximum tension stress direction, and tell us that the bustle wall had no strength at all under that service circumstance. (Figure 2)

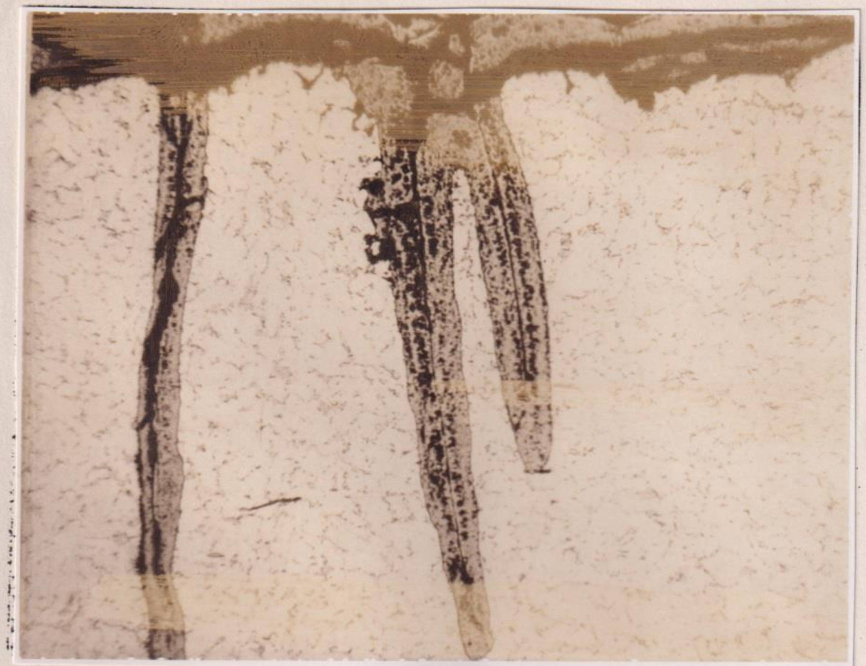


Figure 2. Secondary Cracks on Bustle Pipe (X80).

3. Thicker iron oxide at the beginning of the crack (near the surface) than the end of crack indicated that the entire cracking process was a time-consuming process. This process might take months or years just like creep test at elevated temperature (Figure 3).

Figure 3. Typical Bustle Pipe Secondary Crack (X80).

4. From AGA picture, the temperature of hot spot on bustle pipe made a big difference with its surrounding. The temperature difference between "before casting" and "after casting" nearby cracking area was only 70° - 80°F.

5. During winter time, workers there could see the bustle pipe moving when winter wind blew.

Reason for Failure: Overheated

Apparently, the overheat of bustle pipe wall is due to the crack of inside refractory lining. The reason why inside refractory lining started to crack first is not entirely known yet. However, two reasons seem possible.

1. Due to thermal expansion, and thermal contraction.

2. Due to wind force.

From engineering drawings, bustle pipe is hung there and could almost move freely if without oak block spacer. According to mathematical calculation, wind force, as well as the shrinkage due to wind chill, could move bustle pipe and cause the lining to crack considerably. Since winter wind is mostly from north direction, maybe that is why the crack on bustle pipe is on the lower side of east direction. The shrinkage, together with wind force, produces a tension force there.

Action to be taken:

Since any kind of mathematical calculation or theory needs to be proved, the best way is to be proved by observation. We will use AGA and a home-make cathetometer to find out the real cause by doing the following:

1. Check the temperature variation on bustle pipe during winter time between wind blowing.

2. Check the bustle pipe movement during windy day.

3. Determine the combined bustle pipe movement due to both wind force and thermal contraction.

If our assumption is right, we will perform one or several of the following items:

1. Close casthouse opening in the north side to stop the wind blow, especially the winter wind. Of course, some new opening on the opposite side will be open.

2. Re-install wood blocks to confine the bustle pipe.

3. Attach a circular I-beam to strengthen the bustle pipe.

4. Use heat shield to prevent wind force and wind chill.

Since there is still plenty of time and there is still lots of work to be done before any decision can be made, I will keep in touch with Messrs. James, Langhoff, and Zbos.

C. Lin

C. Lin
Senior Research Engineer

CL/mw

INTEROFFICE
CORRESPONDENCE

Date: ~~January 26, 1977~~ February 10, 1977

Copies to:
V. Beaucaire
J. Bitner
S. Jansto
R. Langhoff
S. Miller
J. Seaman
R. Winters

To: Mr. N. H. Keyser

From: C. Lin

Subject: Investigation of Bustle Pipe Failure in Chicago "A" Furnace, a Continuation of the Memo of December 8, 1976

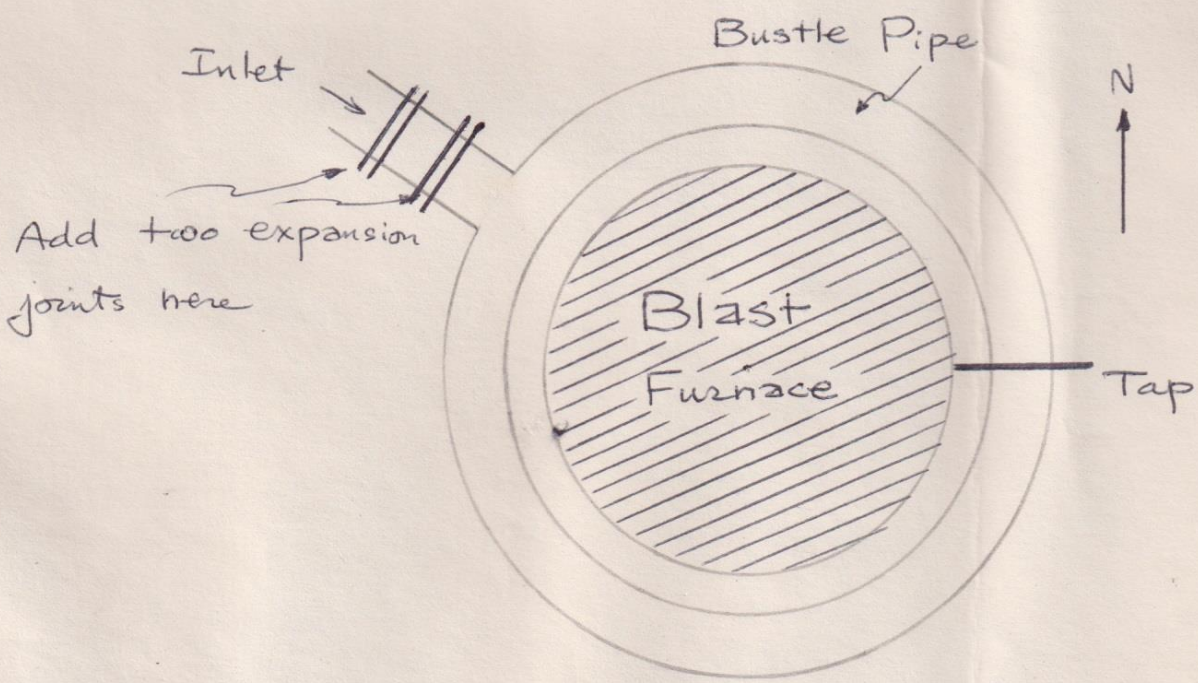
Reference: D3-002-001

After more careful studies, just like what I expected before, the bustle pipe in Chicago "A" furnace has some designing problems. Mr. Nick O'lenik, Chief Mechanical Engineer in Inland Steel, confirmed what I thought. These designing mistakes caused chain reactions, and the end of the chain reactions is what we saw -- cracks on the shell of bustle pipe in Chicago "A" furnace from time to time.

Mr. O'lenik said that the bustle pipe in Inland Steel has both expansion joints and asbestos bricks. Expansion joint is to minimize the movement of bustle pipe due to thermal expansion and contraction, or other causes. The asbestos brick is a compressible type insulation brick and can protect inside brick lining during bustle pipe movement. From various information sources, I found that there was no expansion joint and asbestos brick in our Chicago "A" furnace bustle pipe at all. The following are my suggestions:

1. Close casthouse opening in the north side to stop direct wind blow during winter time, if possible.

2. Add two expansion joints in Chicago "A" furnace bustle pipe inlet. (Fig. 1).



February 10, 1977

To: Mr. N. H. Keyser

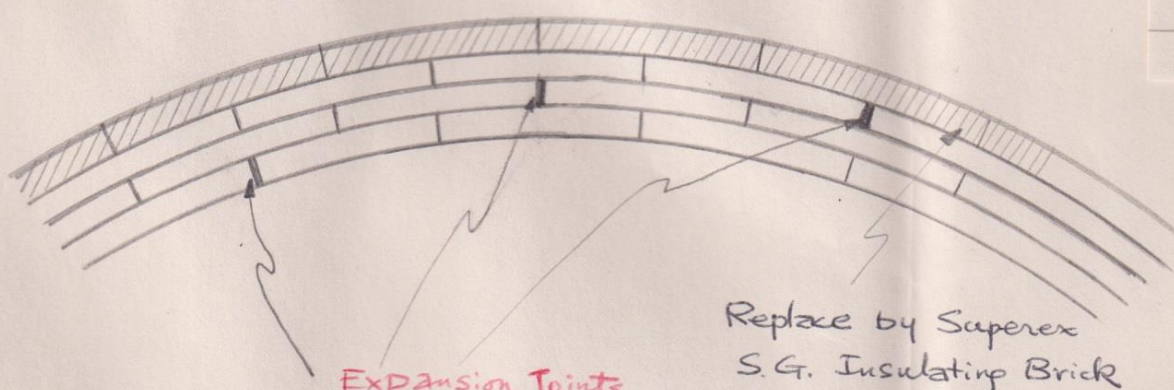
Subject: Investigation of Bustle Pipe Failure in Chicago "A" Furnace, a Continuation of the Memo of December 8, 1976.

~~January 26, 1977~~

The expansion joints should be air-tight, just like what we have in Baghouse, Selma, Alabama (DRWG. M-0894 and M-0896).

3. During next bustle pipe relinement, replace the superex block by more compressible superex S.G. Insulating Brick, Johns-Manville*. Add ~~Put~~ some ~~compressible insulating~~ [** expansion joints] bricks along other brick layers too.~~**~~ (Fig. 2) (DRWG. C-4064).

4. Re-install wood blocks to confine the bustle pipe (DRWG. AL-2308).



Add ~~Insulating Bricks~~

Figure 2

If there is any further problems, please let me know.

C. Lin

C. Lin
Senior Research Engineer

~~* Please consult Steve Jansto for detail.~~

~~** Please consult Robert Winters for detail.~~

* These RF Expansion Joint Boards can sustain up to 2300°F, and made by Johns-Manville. Please consult Steve Jansto for detail.

INTEROFFICE
CORRESPONDENCE

Copies to:

Date: February 23, 1977

To: Mr. N. H. Keyser

From: C. Lin

Subject: Investigation of Bustle Pipe Failure, in Chicago "A" Furnace

Reference: D3-002-001; Memo of December 8, 1976

V. Beaucaire
J. Bitner
R. Langhoff
S. Miller
J. Seaman
R. Winters

N.H.K. FEB 25 '77

The memorandum of December 8 pointed out that the bustle pipe for Chicago "A" Blast Furnace failed after being weakened from overheating. Despite the nearness of the failed region to the tap hole, surface temperature measurements showed that the heat that caused the damage did not come from external sources, it came from within the pipe. That is, the pipe failure resulted from a failure in the refractory lining. The purposes of this report are to explain why the refractory failed and to recommend measures to prevent similar failure in the future. Also presented are probable reasons for the pipe failing where it did, as compared to other points along its circumference, and why "B" bustle pipe is more durable even though it carries a hotter blast.

Facts Pertaining to the Failure

1. The failure occurred in the region of greatest refractory thickness - 22.5 inches. This includes 9 inches of Superduty Firebrick, 10.5 inches of 2300°F Insulating Brick and 3 inches of Superex 2000 Block adjacent to the steel shell. Of the three, Superex Block has the lowest crush strength and the highest insulation value. This region of thickest refractory extends for approximately 30 feet as measured along the outside radius of the pipe - from tuyere No. 13 to tuyere No. 2. Forces due to thermal expansion will be greater in this location as compared to areas of thinner refractory.

2. Temperature measurements taken along the bottom of "A" bustle pipe on December 2, 1975 showed the pipe to be hottest along the 30 foot span of thickest refractory, the area where it should have been coolest (Figure 1). This indicates that the entire 30 foot span of refractory had apparently sustained damage prior to that date.

3. Personnel who witnessed the removal and replacement of a failed section of bustle pipe last year reported that the insulation behind the steel had crumbled. This would be the Superex Block.

4. Apparently the Superduty Firebrick and 2300°F Insulating Brick sustained at least crack damage at the joints. Hot blast has been felt coming thru cracks in the shell, and the temperature measurements taken around a crack on February 4, 1976 showed evidence of hot blast channeling behind the shell[(1)].

5. As reported in the memorandum of December 8, 1976, the cracks developed on the inside of the bustle pipe and slowly propagated outward until failure occurred.

Probable Sequence of Events for Failure

1. Large thermal expansion forces of the refractory caused the Superex Block to crush in the region of thickest refractory. Cracks may also have developed in the Superduty Firebrick and 2300°F Insulating Brick networks as well. Gross thermal expansion forces would be greater here than anywhere else along the pipe, so this area would be most susceptible to failure. Since the brick cannot expand lengthwise along the pipe, forces are exerted outward against the steel shell.

2. The Superex Block is the best insulator of the three refractories present and it has the lowest crush strength. Following its damage or destruction due to forces of thermal expansion, the shell rose to some higher-than-normal temperature. It is not known what temperatures were reached on the inside surfaces of the steel; outside surface temperatures of 490°F[(1)] and 540°F[(2)] have been observed near cracks.

3. The weakened steel shell developed a series of cracks on the inside surface and gradually failed as a result of:
   (a) Internal stresses and its own weight
   (b) Vibrations
   (c) Minor thermal expansion/contraction forces as a result of wind chill and 70° to 80°F temperature rise during casting.

Compared to "B" Furnace bustle pipe, "A" furnace bustle pipe would be more susceptible to failure because:

1. The area of thickest refractory (21 inches) for "B" bustle pipe extends for only approximately 7 feet as measured along the out-

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(1) Memo from S. Jansto to Mr. N. H. Keyser, "Cracked Bustle Pipe - "A" Furnace", February 10, 1976.

(2) Memo from M. Jensen to Mr. N. H. Keyser, "Thermographic Survey Chicago "A" Bustle Pipe", September 24, 1976.

side radius of the pipe. Compared to the 30 foot span (22.5 inches thick) for "A" bustle pipe, stress concentration would be less.

2. "B" bustle pipe is smaller in diameter than "A" bustle pipe, 39 ft. 8 in. compared to 46 feet 0 in. at the center of the pipe. Total thermal expansion of the refractory in the larger pipe would be greater and would tend to produce a greater incremental increase in both the circumference and the radius of the refractory liner $[c = 2\pi r]$. Also, since the circumference is confined, proportionately more stress will release in the radial direction against the steel shell.

3. The lower temperature of "A" Furnace hot blast, c 1600°F vs c 1800°F for "B" Furnace, does not compensate adequately for the two differences cited above.

Recommendations for the Future

1. Include 1/2 inch expansion gaps in the bustle pipe refractory. The spacings of these gaps should be carefully thought out to both provide for refractory expansion and avoid weakening of the refractory structure. The expansion gaps should be filled with 1/2 inch RF Expansion Joint Board. (Johns-Manville).

2. Use Superex SG 2000 in place of Superex 2000 to provide a cushion adjacent to the shell to absorb thermal expansion forces. This cushion will provide for expansion across the width and depth of the refractory bricks. The expansion joints will take care of length-wise expansion.

Less critical but worth considering are:

3. Engineering should review the possible need for an expansion joint in the shell of the hot blast main in the area where it passes thru the cast house wall. The refractory does have expansion gaps, filled with RF Expansion Joint Board, in this region.

4. Re-install and maintain the wooden blocks at the bustle pipe hangers to help confine the pipe and minimize vibrations.

5. During the winter, close the two openings in the north cast house wall closest to the furnace to reduce the direct blasts of cold wind against the bustle pipe. These cold blasts induce small thermal expansion/contraction cycles and vibration.

C. Lin

C. Lin
Sr. Research Engineer

CL/ey

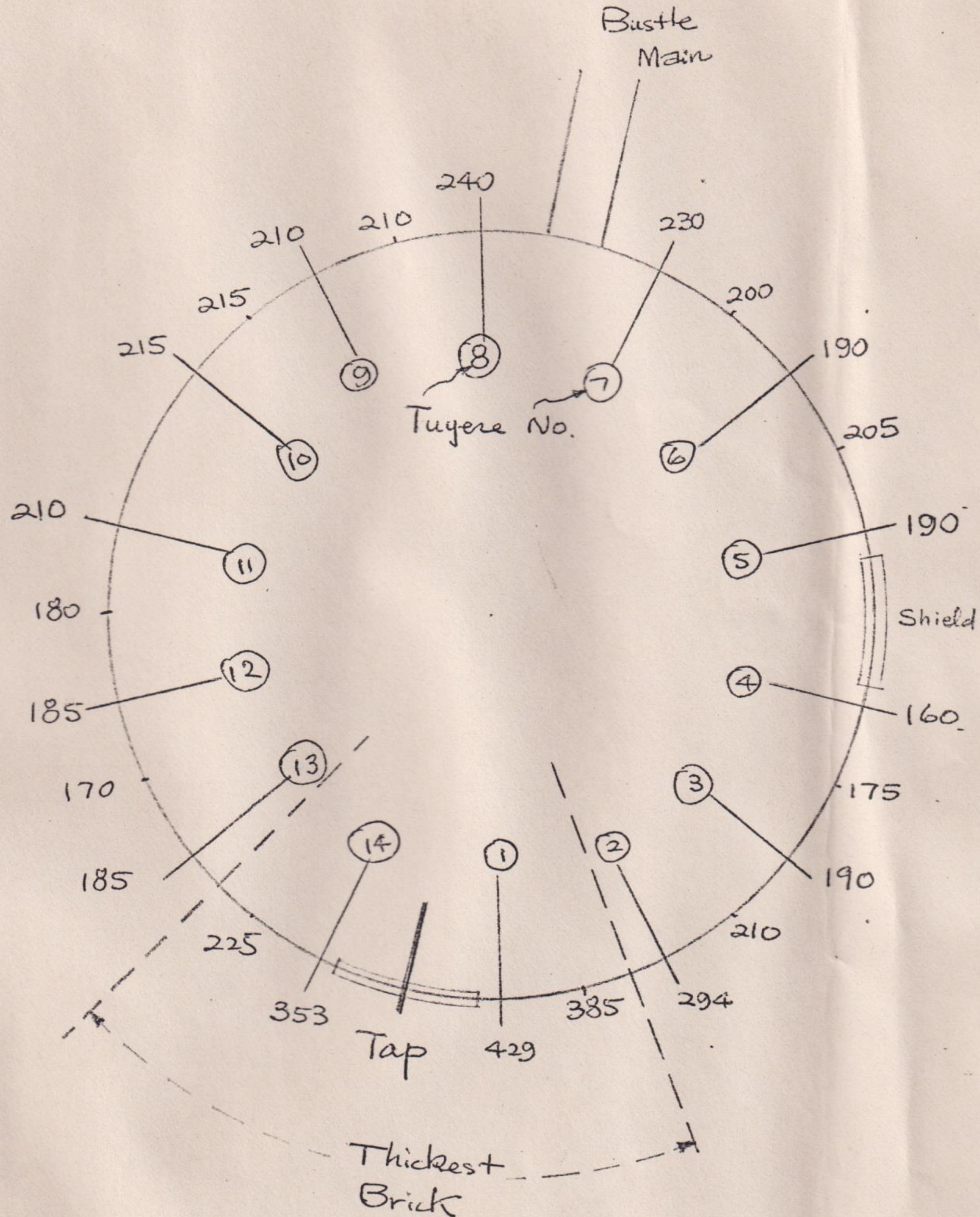


Fig. 1 Chicago "A" Furnace Bustle Pipe
Temperature, °F. 12-2-75

INTEROFFICE
CORRESPONDENCE

Date: February 10, 1976

Copies to:
J. L. Bitner
J. D. James
R. E. Langhoff
J. T. Seaman
R. P. Winters
J. A. Zbos

To: Mr. N. H. Keyser

From: S. Jansto

Subject: Cracked Bustle Pipe - "A" Furnace

Reference: D3-001-001

On the morning of February 4, the crack on the bustle pipe reopened. Since the thermovision unit was in use at Beverly, Ohio, only surface pyrometer readings could be taken. These temperatures were taken after the 10:00 a.m. cast and the furnace was at approximately 80,000 wind.

Figure 1 illustrates the orientation of the series of temperatures measured.

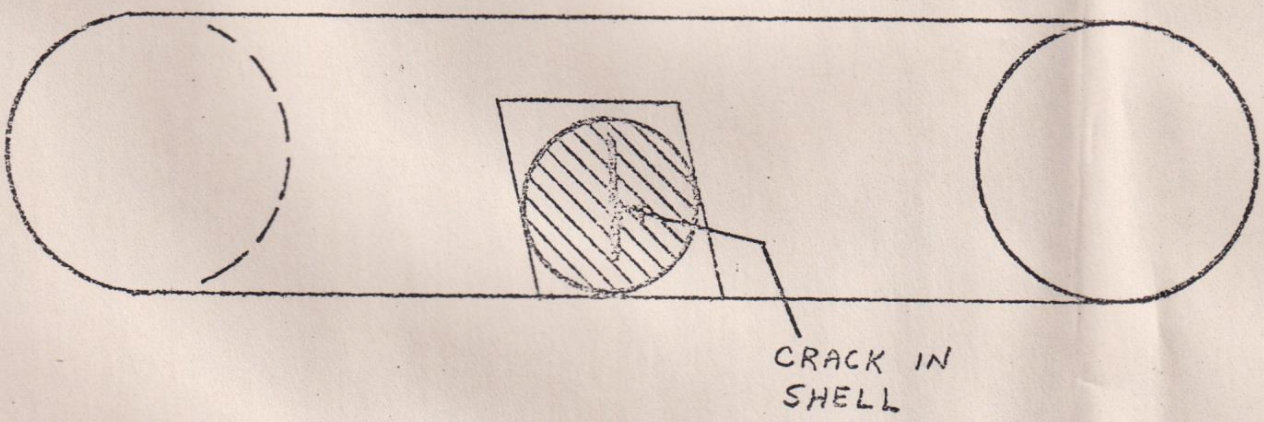


Figure 1. Orientation of Temperatures

Within the banded region in Figure 1, the following temperatures were measured.

To: Mr. N. H. Keyser
Subject: Cracked Bustle Pipe
"A" Furnace

February 10, 1976

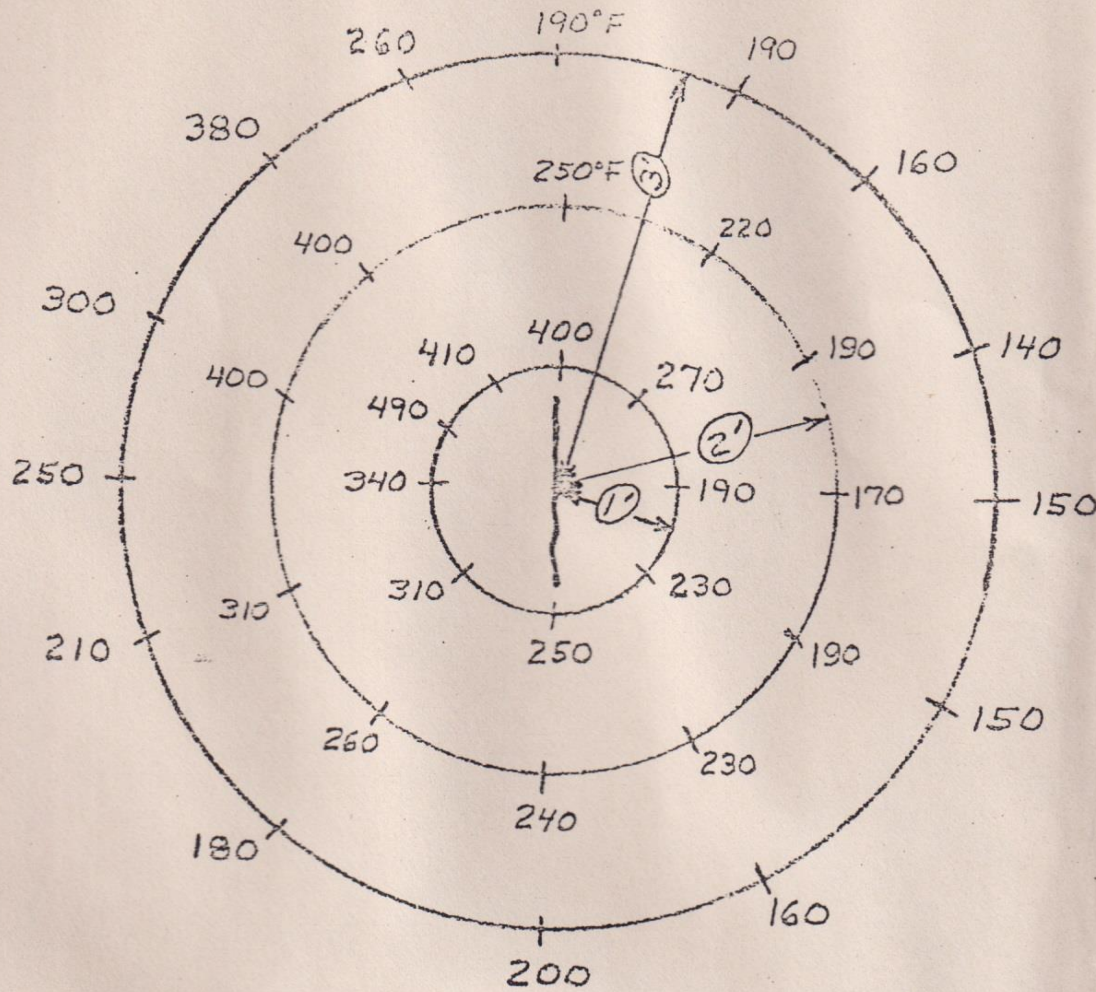


Figure 2. Measured Temperatures

The temperature gradient indicates that the hot air may be channeling behind the brickwork from the 9 to 11 o'clock position. Therefore, grouting of the main in this region may patch up any existing channels.

If the crack reopens again, the pipe will be checked with the Thermovision (if available). Possibly, a hot spot line through the brickwork will be visible. Seeing this hot spot, grout could then be pumped into the main at the locations of the hot spot. This grouting should close off any channeling of hot air from the interior of the main out to the crack in the shell.

S. Jansto

S. Jansto

SJ/mw

INTEROFFICE CORRESPONDENCE

Date: September 24, 1976

To: Mr. N. H. Keyser

From: M. D. Jensen

Subject: Thermographic Survey Chicago "A" Bustle Pipe

Reference: D3-022-009

Copies to:
V. Beaucaire
C. Lin
J. T. Seaman
R. P. Winters
J. Zbos

At the request of Mr. Beaucaire, a thermographic study was performed on the "A" furnace bustle pipe in the area where cracking has occurred recently. The survey showed a hot spot measuring 540°F. adjacent to a previous repair. This was verified as an open crack by plant personnel who welded it immediately. Another hot spot was discovered under the new extension of the radiation shield. Temperature measurement of this area is extremely difficult due to the complex shape of the spot, shield and bustle pipe. However, there is definitely a hot spot in this area.

Please note attachments.

M. D. Jensen

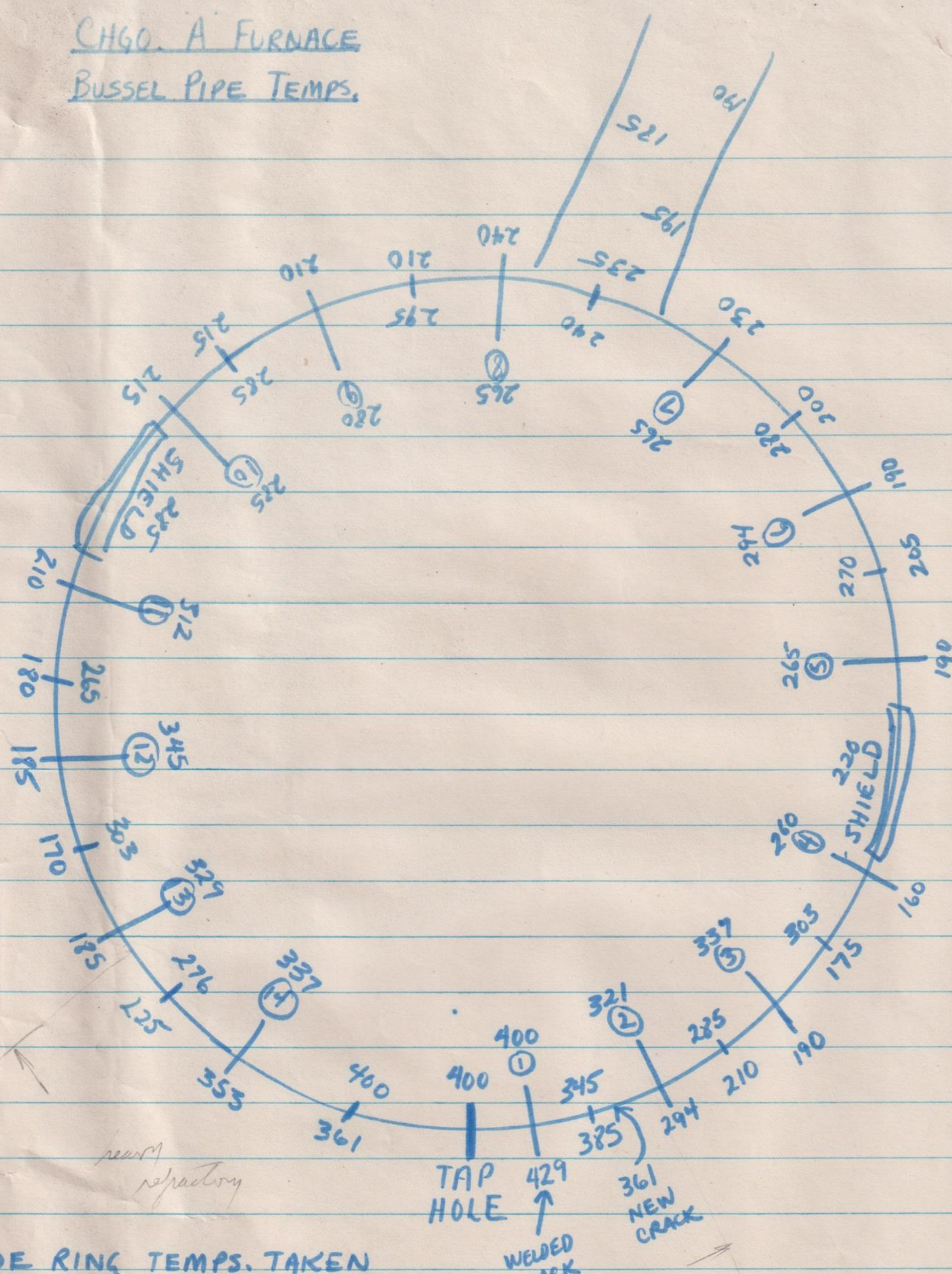
MDJ/mw

Attachment

IS-5018-1-E

CHGO. A FURNACE

BUSSEL PIPE TEMPS.



OUTSIDE RING TEMPS. TAKEN FROM FLOOR UP. (BOTTOM SIDE)

INSIDE RING TEMPS TAKEN FROM CATWALK DOWN (TOP SIDE)

ALL TEMPERATURES IN °F.

TAKEN 12-2-75 @ 3:15 PM

Copies to
V. Beaucaire
J. Bitner
R. Langhoff
S. Miller
J. Seaman
R. Winters

To: Mr. N. H. Keyser

From: C. Lin

Subject: Investigation of Bustle Pipe Failure, in Chicago "A" Furnace, ~~Continuation of the~~ Memo of December 8, 1976

Reference: D3-002-001;

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Hotter Blast.

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5. As reported in the memorandum of December 8, 1976, the cracks developed on the inside of the bustle pipe and slowly propagated outward until failure occurred.

<u>Probable Sequence of Events for Failure</u>

1. Large thermal expansion forces caused the Superex Block to crush in the region of thickest refractory. Cracks

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(1) Memo from S. Jansto to Mr. W. H. Keyser, "Cracked Bustle Pipe - "A" Furnace", February 10, 1976.

may also have developed in the Superduty Firebrick and 2300°F Insulating Brick networks as well. Gross thermal expansion forces would be greater here than anywhere else along the pipe, so this area would be most susceptible to failure. Since the brick cannot expand lengthwise along the pipe, forces are exerted outward against the steel shell.

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(a) Internal stresses and its own weight
(b) Vibrations

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(2) Memo from M. Jensen to Mr. W. H. Keyser, "Thermographic Survey Chicago "A" Bustle Pipe," September 24, 1976.

(c) Minor thermal expansion / contraction forces as a result of wind ~~and ...~~ chill and 70° to 80°F temperature rise during casting.

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2. "B" bustle pipe is smaller in diameter than "A" bustle pipe, 39 ft. 8 in. compared to 46 ft 0 in. at the center of the pipe. Total thermal expansion ~~forces in the larger pipe ... have a greater tendency to increase the diameter of the refractory lining~~ of the refractory in the larger pipe would be greater and would tend to produce a greater incremental increase in both the circumference and the radius of the refractory liner [c = 2πr]. Also, since the circumference is confined, proportionately more stress will release in the radial direction against the steel shell.

3. The lower temperature of "A" Furnace hot blast, c 1600°F vs c 1800°F for "B" Furnace, does not compensate adequately for the two differences cited above.

Recommendations for the Future

(1) Include ½ inch expansion gaps in the bustle pipe refractory, using spacings either similar to those in the hot blast main or based on recommendations of the refractory supplier. The expansion gaps should be filled with ½ inch R.F. Expansion [redacted] Joint Board. (Johns-Manville, etc.). [redacted]

(2) Use Superex SG 2000 in place of Superex 2000 to [redacted] provide a cushion adjacent to the shell to absorb thermal expansion

forces. This cushion will provide for expansion across the width and depth of the refractory bricks. The expansion joints will take care of length-wise expansion.

Less critical but worth considering are:

(3) Engineering should review [redacted] the possible need for an expansion joint in the [redacted] shell of the hot blast main in the area where it passes thru the casthouse wall. The refractory does have expansion gaps, filled with R.F Expansion Joint Board, in this region.

(4) Re-install and maintain the wooden blocks at the bustle pipe hangers to help confine the pipe and minimize vibrations.

(5) During the winter, close the two openings in the north casthouse wall closest to the furnace to [redacted] reduce the direct blasts of cold wind against the bustle pipe. These cold blasts induce small thermal expansion/contraction cycles and vibration.

~~If there is any further problems, please let me know~~

C. Lin

Sr. Res. Engineer

Summary

The Causes of failures of the bustle pipe and Circle Coke oven gas line for Chicago "A" furnace have been investigated ~~through~~ ~~metallog~~ metallurgically ~~metallography~~.

The blistering and cracking of bustle pipe was found to be due to overheating.

Using AGA check-up bustle pipe constantly was recommended. Patch the overheated area and overhaul the refractory lining during furnace shutting down seems to be the only Solution.

[illegible] furnace

~~shutting down~~.

The burst of COG line was caused by corrosion. No other ~~better recommendations~~ material can be better than mild steel in our situation. ~~So~~

So, increasing wall thickness on COG line was the recommendation.

Introduction

Two distinct failures of steel piping would be investigated under this project.

First one, the bustle pipe, which provides air or oxygen to ~~the~~ Chicago "A" furnace, has been blistered & cracked several times more ~~than once~~ recently. Serious crack may lead toward shutting down the entirely blast furnace operation. The financial loss due to delay of production time would be hard to estimate.

On the other hand, the circle coke oven gas line which provides the supplimentally fuel to the blast furnace, ruptured recently. The sudden emergence of a large amount of Coke Oven gas into the vincinity of the blast furnace ared could Cause a deadly explosion.

To find out the ~~real~~ Causes of these failures ~~would~~ ~~could~~ and ~~present~~ ~~providing~~ to provide the remedies for them is essential.

Recommendation

Bustle Pipe

As long as the refractory lining could not be repaired during furnace operation, the only way to reduce the hazard of further widen of cracking is to check regular through AGA and patch with the same carbon steel plate. Spray water on overheated area in case of red hot. ~~Reline~~ Repack the refractory lining in bustle ~~Pipe~~ pipe during furnace shutting down.

Coke Oven Gas Line

Same material (mild steel 1020 or 1025) with thicker wall was the recommendation.

Check wall thickness regularly.

Conclusion

Bustle Pipe

- The blisterings and cracks were perpendicular to the bustle pipe direction.

- ~~The~~ All cracks ~~was~~ were opened up from inside wall.

- Overheat ~~was~~ is due to the inside air flow not the radiation during casting.

- Cracking was a time consuming process. It may take months or years.

- The shape of crack indicates that the wall of bustle pipe had no strength at all under that service circumstance.

- The cracks and blistering are due to overheating.

Coke Oven Gas Line

- This COG line was made of either carbon steel or low alloy steel with 0.20 – 0.30% carbon.

- The burst was parallel to the pipe direction, because this seamless pipe was made by extruding method.

- The origin of burst could be identified by the river pattern.

- The cleavage of burst was 45° to the radial direction which had the highest shearing stress.

- Most of the corrosion, how, was uniform ~~general~~ corrosion: however, there were ~~some~~ pitting corrosion.

- There was no stress corrosion crack.

- These corrosion pits could ~~can~~ cause stress concentration and thus leaded to failure

- Major cause of burst is due to corrosion.

Observation, Discussion and Results

Bustle Pipe

Bustle pipe provided the necessary air or oxygen for blast furnace. According to ASTM specification, bustle pipe is made of A285 Grade C, which is similar to 1025 Carbon steel. The

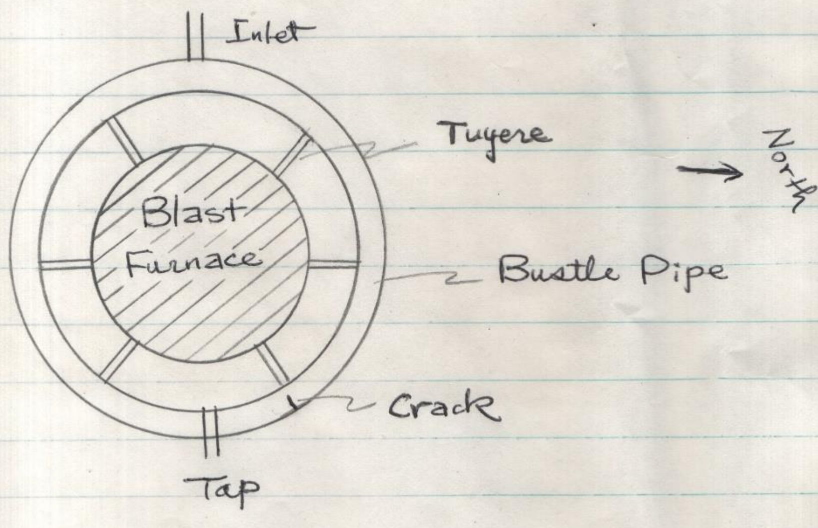


Fig. 1 Location of Bustle Pipe related to Blast Furnace

location of bustle pipe related to blast furnace is shown in Fig. 1. The cracking area was cut up and brought to the laboratory for further investigation. The shape of cracks is shown in Fig. 2

Up
↑

⊗ Outside ~~Inside~~

Fig. 2 The Cracks on Bustle Pipe

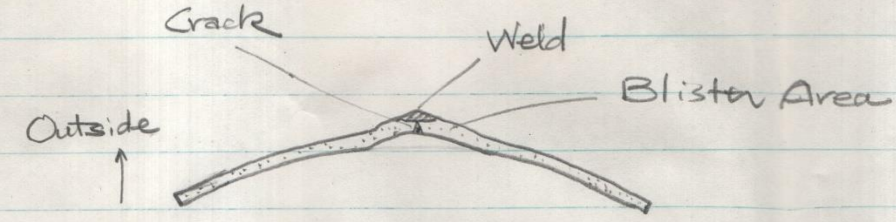


Fig. 3 Cross Section of the Crack Area.

The first appearance of the cracks on that bustle pipe was similar to the crack of mud pie due to shrinkage after drying. Samples from different locations were cut-up, mounted, and ready for metallographic study (Fig. 4).

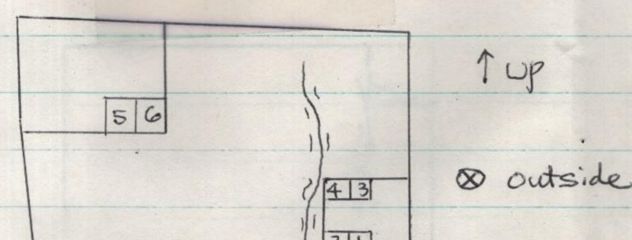
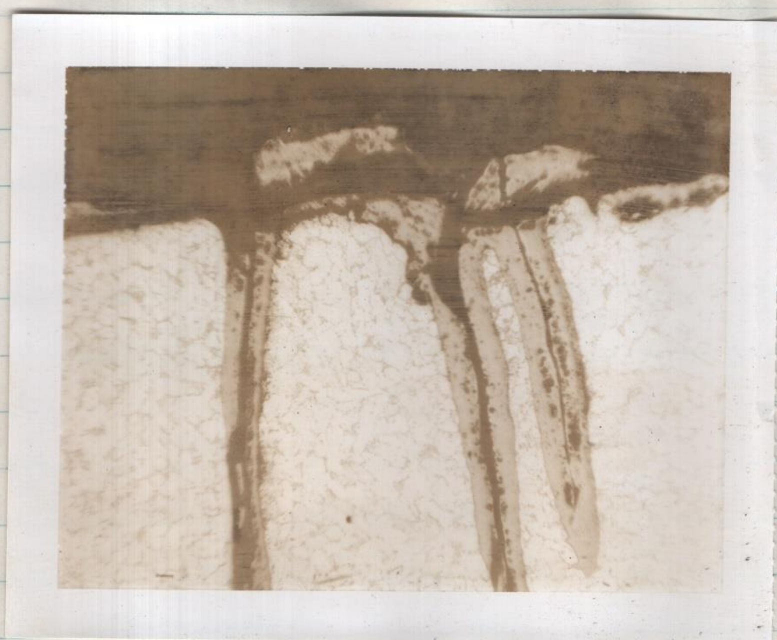


Fig. 4 Locations of ~~Cut-up~~ Samples for Bustle Pipe

Sample No. 1 through No. 4 were in the vicinity of the major crack. No. 5 and No. 6 were away from the major crack. All secondary cracks were found to be straight, ~~and~~ transgranular, perpendicular to maximum tensile direction and containing iron oxide (Fig. 5 and 6).



Inside ↑

Fig. 5 Secondary Cracks on Bustle Pipe

Inside
↑

Fig. 6 Secondary Cracks on Bustle Pipe

They looked the same as these of creep test sample at elevated temperature. In addition, more iron oxide at the beginning of the crack than in the end indicated that the entire cracking process was a time-consuming process (Fig. 7). The cracking process might take months or years.

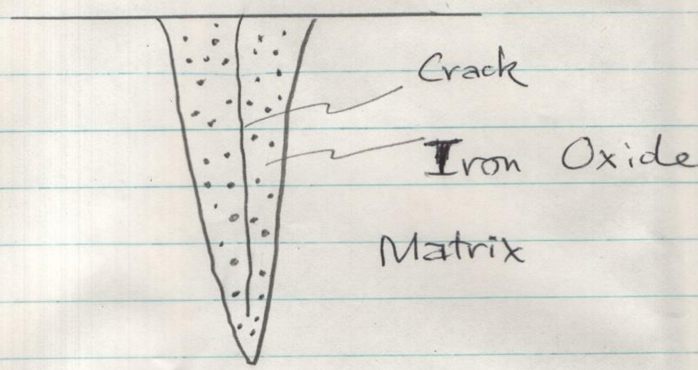


Fig. 7 Typical Secondary Crack on Bustle Pipe

All in all, they indicates that ~~the Carbon~~ the Carbon steel was almost no strength at all under that service circumstance, ~~Since the Cracks were perpendicular to the tensile direction~~, ~~it is very clear that~~ and the bustle pipe at our specified area had been overheated.

Overheated can be, and has been, suspected from two different sources:

1. Radiation during casting.
2. Leakage in the refractory lining inside bustle pipe. Air flow, inside bustle pipe, is approximately 1700° F.

In order to ~~clarify~~ find out which one is correct, AGA was used to measure the bustle pipe temperature before and during casting. See Appendix for detail. It was found that the typical bustle pipe wall temperature usually only went up ~~50°-60°~~ 70°-80° in Fahrenheit during casting. Blistering is always towards outside. The hot spots, according to AGA picture, ~~were~~ ~~was~~

always had an odd shape, not a regular shape, and ~~made~~ had a ~~sharp~~ big temperature ~~gradient~~ difference ~~different~~ with ~~it~~ ~~their~~ its surrounding. Moreover, the opening of the crack was always from the inside wall. Based on these reasons, overheat should be due to the leakage of inside refractory lining in bustle pipe.

The spheroidized Carbide seems to indicate that this portion had been overheated to 800°F or more for a certain amount of time. Unfortunately, we could not get samples from other locations (at least 3 or 4 feet away from this hot spot) or unused sample from the same heat. Since the stress release at 1100° – 1200°F, required ~~specified~~ by A285 specification, yielded some spheroidized Carbide too, this information ~~evidence~~ became not useful.

Change A285 to other high temperature alloy or low-alloy steel with 0.5 – 1.0% Mo is not ~~profitable~~ recommended here. Reasons are very simple! If all bustle pipe was made by expensive alloy steel, cost would be too high. If only the overheated spot patched by low-alloy steel with 0.5 – 1.0% Mo, the welding might not hold, since the bustle pipe was constantly subjected to severe temperature change.

Coke Oven Gas Line

Coke oven gas line provides the supplimental fuel for blast furnace in addition to Coke. The location of Coke oven gas line ~~is~~ related to blast furnace & bustle pipe is shown in Fig. 11, and Fig. 12.

Fig. 12. COG Pipe is underneath the Bustle Pipe.

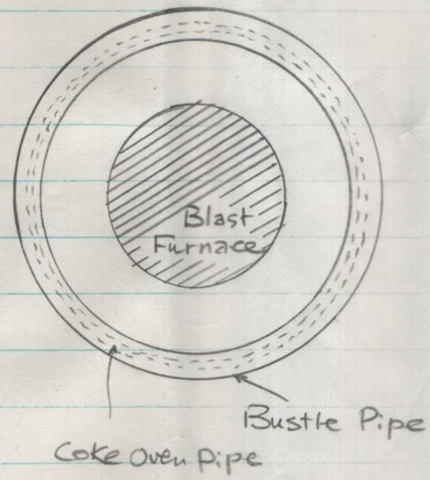


Fig. 11. Vertical View of COG Pipe, Bustle Pipe & Blast Furnace. COG Pipe is underneath the Bustle Pipe.

This gas line, originally purchased from U.S. Steel during 1964, was a type of 6" diameter seamless pipe. Material specification was not able to obtain. However, judging from metallographic study, it should be made of low-alloy steel or Carbon steel with 0.2%–0.3% Carbon. Whether it is low alloy steel or Carbon steel, it is the same from fractographical point of view. The hardness of this pipe line is pretty soft, $R_B \cong 80$.

The shape of burst and locations of samples are shown in Figure 13.

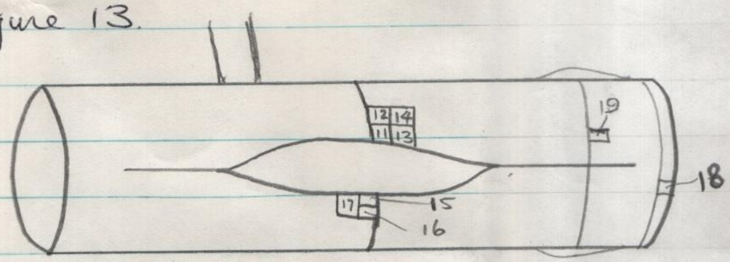


Fig. 13 Shape of Burst and Locations of Samples for COG Line

The inner wall usually was corroded by ~~General~~ Uniform Corrosion (Fig. 14)

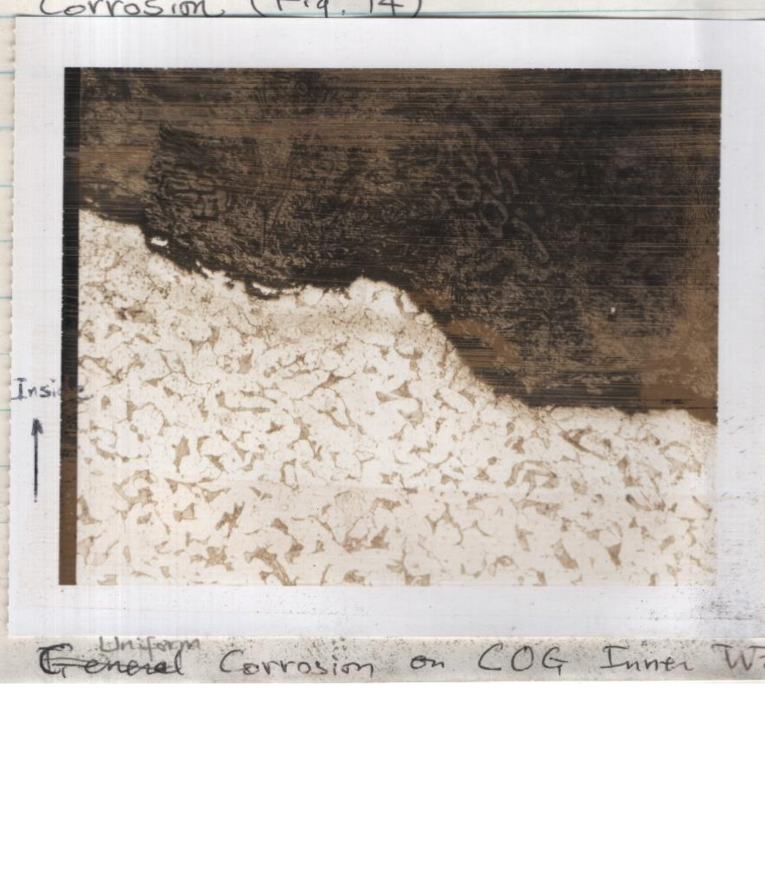


Fig. 14 ~~General~~ Uniform Corrosion on COG Inner Wall

However, there were some pitting Corrosion existed. These ~~pitting~~ pitting corrosion provided stress concentration and finally leaded to erupture (Fig. 15 &16). Some pits even ~~went~~ penetrated ~~way way~~ extreme deep into the wall (Fig. 17)

side
↑

↓
utside

Fig. 15 Pitting Corrosion on COG Inner Wall.

The fractograph of Coke oven gas line reveals that the origin of rupture was

The cleavage of burst was 45° to COG pipe radial direction which had the highest shearing stress. p. 9

Originated from the middle of burst and quickly spreaded towards two end

Fig. 16 Some ~~other~~ pitting Corrosion with Less Severe Stress Concentration.

On the Origin, two defects, one defect on each surface, and river pattern were found. These defects, I believe, ~~is~~ were originated from the pitting

Corrosion. The wall thickness along the rupture path had been greatly thin-down by ~~General~~ Uniform corrosion. Few pitting corrosions, relatively sensitiveless of pit notch on mild steel, and the lack of stress corrosion cracks is the reason why this COG line could last for 12 years.

It seems to be ~~pretty~~ very hard to make a recommendation to substitute this mild steel by some other material. As we know, all brass or Copper metal is out of question, since Coke Oven gas contains lots of ammonia. All 300 or 400 level stainless steel (except 316 or 321) are out of question too, since there is few Oxygen in the coke oven gas and naphthalene can aggregate crevice or pitting corrosion. Cast iron will not fit here ~~too~~ either, since it could not be bended.

Finally, stainless ~~321~~ 316, stainless 321 and Carpenter 20 are too expensive. That is the reason, I believe, to increase the wall thickness and use the same material (mild steel) will be the best answer.