AN ASSESSMENT OF RECYCLED REFRACTORY MATERIAL PERFORMANCE AFTER TWO YEARS OF SERVICE IN A CARBON BAKE FURNACE

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Abstract

Material removed from carbon bake furnaces used to manufacture anodes for the production of aluminum metal has historically been disposed by landfill. This material is composed primarily of 50 % alumina refractory. In 1997, Alcoa completed a highly successful program to reuse the spent refractories in castables for carbon bake furnace headwalls and flooring, as roadbed aggregate, and in other internal applications. This program recycled/reused 11,000 metric tons of used refractory material (99 % of the material removed from the carbon bake furnace) and saved Alcoa over 3.8 of the 9.6 million dollar projected furnace rebuild costs. An assessment is made of the performance of the recycled refractory components after two years of service.

Introduction

Aluminum producers are interested in applications for spent refractory materials removed from carbon bake furnaces. The spent refractory material at Alcoa is a 50 pct alumina-silicate refractory, along with steel, coke and insulating castable. The carbon bake furnaces are used to bake carbon electrodes used in the manufacture of aluminum metal from bauxite. Upon removal from a furnace, the spent refractory has historically been landfilled. Interest is growing in recycling because of concerns the environment and resource conservation, "green" corporate images, landfill space and cost, potential future liability, product stewardship, and increased regulation of landfill wastes. The driving force for recycling is typically economics (does it make economic sense to recycle) or regulations. Prior to 1997, research evaluating potential applications for the alumina-silicate material removed from carbon bake furnaces by Butter (1) indicated contamination of the refractory material (high carbon and sodium levels) might limit potential reuse applications of this material as a refractory.

Individuals at Kaiser Aluminum and Chemical Corp.-Mead Works (Kaiser) and at the Alcoa Inc.-Wenatchee Works (Alcoa) researched and enacted programs to reuse the spent refractory materials in a number of in-house applications during 1997 (2). At Kaiser, the decision to recycle was based on a need to extend landfill life by reducing the volume of spent firebrick being discarded as waste. The material was crushed below a certain mesh size, combined with refractory cement, sand, water, and a retarder; then reused in headwalls, flue tops, or as flooring in the pot room. At Alcoa, the motivation to reuse spent refractory materials was part of a broader plan for the carbon bake furnace in building 62. The objective was to increase flue life, reduce rebuilding and operation costs, increase anode baking capacity and size, and reduce the quantity of materials going to landfill.

In house applications for spent refractory materials at Alcoa included direct reuse as a refractory material with no beneficiation; beneficiation and reuse as a castable material for headwalls, flue tops, and other in-house refractory applications; or reuse as a plant road grading material. Testing of materials removed from Kaiser and Alcoa for hazardous materials by Toxicity Characteristics Leaching Procedure (TCLP) (3) indicated no hazardous materials were present at either plant site. The recycled materials were successfully installed at both companies, with preliminary evaluations indicating satisfactory material performance. The purpose of this report is to:

1. Evaluate the performance of the recycled materials at Alcoa after two years of performance.

2. Make recommendations for future refractory reuse

Review of the Recycling Program at Alcoa

The carbon bake furnaces at Wenatchee are built in a cement tub, which provide the floor and outside wall support. As a starting point, a team of individuals at Alcoa investigated alternate material uses for the spent refractory materials and evaluated the recycling program at Kaiser. The following priorities were identified for materials removed from the carbon bake furnace in building No. 62 that houses the carbon bake furnace:

1. Portions of the old furnace that are still serviceable were reused without any rehabilitation

2. Used parts of the old furnace that are still serviceable were cleaned, saved, and reused in the furnace.

3. Materials (such as coke) were cleaned or screened for reuse

4. Refractory materials were recycled by crushing and grinding for use as a refractory castable raw material or for reuse in another part of the plant (road grading, landscaping material, or as future flooring in the ingot department).

Table 1. Average chemical analysis of spent 50 pct alumina firebrick.

Site	Chemical Analysis, wt pct								Total
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	
Pit	46.6	48.6	2.01	1.40	0.23	0.16	0.40	0.19	99.6

The chemistry of refractory firebrick removed from service and reused is listed in table 1. This analysis did not indicate major compositional changes in the brick or high alkali levels that would be of concern in material reuse.

Plant employees were used for furnace demolition. Upon removal from the carbon bake furnace, refractory materials were segregated into future use classifications. Refractory materials that were removed from the furnace were placed into two categories, low density insulating material and dense firebrick. The refractory material was crushed at a local aggregate producer at a cost of about $5.50/metric ton. Crushed aggregate that was above 9.5 mm (3/8 inch) particle size was segregated for use as roadbed aggregate for landscaping. Material that was below 9.5 mm (3/8 inch) was used in castable mixes. Sieve analysis of the crushed aggregate is listed below in table 2. Refractory castable compositions utilizing the crushed spent refractory materials are listed in table 3 for dense castables and in table 4 for insulating castable compositions.

Table 2. Particle size distribution of crushed refractory grain used for roadbed aggregate (+9.5 Coarse) and for refractory castables (-9.5 Fine)

U.S.A. Sieve Number	+9.5 Coarse (wt pct)	-9.5 Fine (wt pct)
- 1 + 3/4	42.4	-
- 3/4 + ½	48.4	-
- ½ + 3/8	6.0	-
- 3/8 + 1/4	1.2	-
- 1/4 + 4	-	9.5
- 4 + 20	2.0	70.9
- 20 + 100	-	15.6
- 100	-	4.0

Table 3. General castable formulation using crushed dense firebrick

Material	Weight Percentage
Refractory cement	22.4
Crushed firebrick	66.2
Silica sand	2.6
Water	8.8
Retarder	28-57 grams (1-2 oz) per 1,720 kg (3800 lb) mix

Table 4. Refractory castable formulation containing used crushed insulating refractory material for use as a backup refractory insulator.

Material	Weight Percentage
High temperature refractory cement	15
Crushed insulating refractory	75
Crushed firebrick	10

A breakdown of each category of material removed from the furnace is listed in table 5 below. It is on interest to note that of the spent refractory materials removed from the furnace, over 99 pct of the material was either reused or recycled. Almost all coke and steel removed from the furnace is reused.

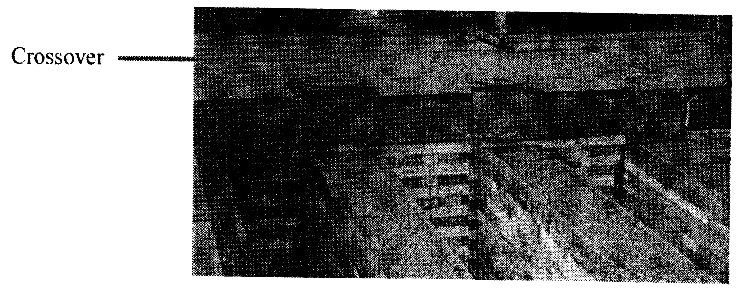
Of the total amount of waste material removed from the carbon bake furnace and listed in table 5, the materials were reused in the following percentages:

Reused - 18.1 pct
Recycled - 80.5 pct
Discarded - 1.4 pct

Table 5. Applications for spent refractory materials at Alcoa

Material	Reused (metric ton)	Recycled (metric ton)	Discarded (metric ton)
Refractory - Firebrick			
Flues and headwalls	0	6,148	0
Crossover	200	200	0
Refractory - Castable			
Baking furnace	348	715	23.9
Crossover	299	272	0
Port blocks	7.9	84	0
Headwall tops	0	0	80
Flue tops	45	477	0
Outside furnace caps	0	2,468	0
Refractory - Insulating			
Crossover	41	41	0
Port lids	5.2	1.3	0
Coke			
Packing material	1,396	0	73
Steel			
Flue tops	1.1	11.9	0
Outside furnace caps	0	2.6	0
Peephole caps	3.9	0	0

(a.)



(b.)

(c.)

Figure 1- Areas of the carbon bake furnace using refractory castable manufactured from spent firebrick. a.) flue and headwall tops, b.) crossovers, and c.) outside wall furnace cap and headwall.

Refractory applications using crushed firebrick included headwall tops, flue tops, crossovers, headwalls, and outside furnace wall caps (figure 1). Castable materials were mixed as batches in portable mixing equipment (figure 2). Refractory castables using crushed insulation was used as wall insulation, going from the furnace floor to the top (figure 3).

Drying and firing of castables installed in the carbon bake furnace were accomplished during a normal furnace firing, but on a slower firing schedule. Hold times of 30 minutes per 12.7 mm (1/2 inch) of castable were made at 250°C and 500°C during initial carbon bake furnace firing to allow for moisture removal. All refractory materials appeared to have dried and experienced the first furnace run successfully.

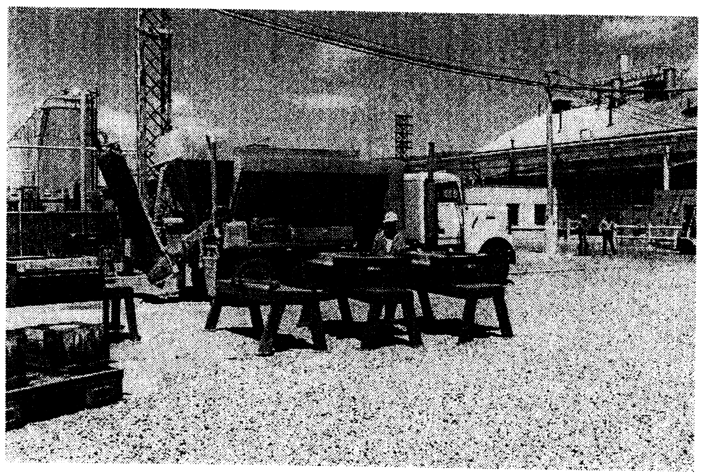


Figure 2 - Equipment used to mix and cast refractory materials.

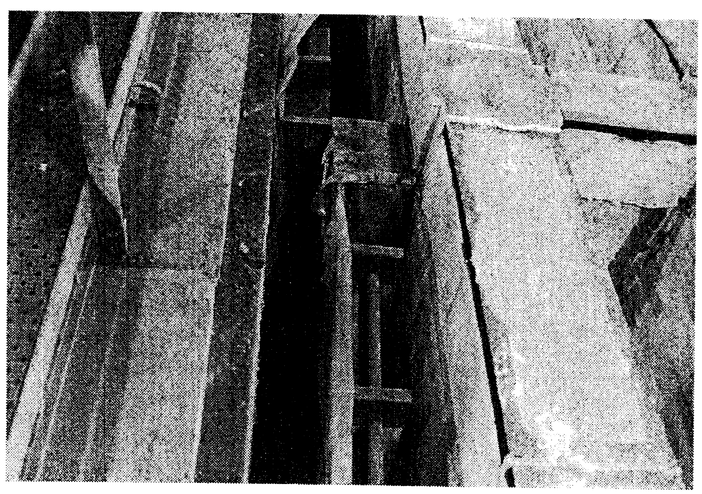


Figure 3 - Wall insulation application of refractory mixes containing reused insulating castable.

Where used materials were recycled material in the carbon bake furnace at Alcoa, the cost was about 1/4 that of materials that would normally be purchased for the furnace rebuild. If the furnace had been rebuild by prior practice, it was projected to cost about 9.6 million dollars. By recycling materials, it is estimated that 3.8 million of this cost was saved, with approximately 3 million of this savings coming from recycling materials and about 0.8 million coming from disposal savings, reduced demolition costs, etc. The carbon bake furnace contained 13,200 metric tons of refractory, coke, and steel; of which over 11,000 metric tons of refractory material was either reused or recycled. This comprised over 99 pct of the refractory material removed from the furnace. Areas of the plant to be considered for future use of spent refractory material include as ingot division flooring and in carbon bake furnace flues.

Review of The Recycled/Reused Refractory Materials Performance After Two Years of Service at Alcoa

A two year performance review of the recycled refractory materials in Alcoa's Wenatchee Works carbon bake furnace of Bld. 62 was held in June of 1999. The recycled refractory material applications have experienced no known problems different from those encountered during operation of a carbon bake furnace prior to the review, nor were there any indications of future problems. The furnace rebuild was completed in May of 1997 and had a targeted life of 100 cycles. The furnace had experienced 28 cycles at the time of the review and had been in continuous use since the rebuild was completed. During discussions with plant personnel who operated the carbon bake furnace, the following questions were asked, with emphasis placed on evaluating refractory issues:

1. *Were records kept on the causes and location of failed recycled refractory materials?*

   Records were kept of flue walls and of individual cell maintenance in the carbon bake furnace. These records indicated where spent refractory materials may have been replaced. A total of 72 rows of flue walls are in the carbon bake furnace, with 8 cells in each row. Of the cells present, only one had experienced failure (after 22 cycles), which was not traceable to refractory material failure.

2. *Are there areas in the carbon bake furnace where the service life of the recycled refractory material was higher or lower than expected from traditional refractory materials?*

   The performance of recycled refractory materials was thought to be comparable to or superior to the performance of traditionally used materials in the rebuilt carbon bake furnace. An area where performance increases were hoped for, port blocks, did not show significant changes from those materials typically used. The expected service life from flue tops and headwall tops were thought to be 2-3 times better than traditionally used materials.

3. *In the areas where changes were noted, are the changes felt to be caused by design changes, mixing or casting of the spent refractory material, quality control, or material issues caused by the recycled refractory material?*

   As noted earlier, the performance of the spent refractory materials was felt to be comparable to that from previously used refractory materials. The anticipated increase in service life of flue tops and headwall tops was thought to be caused by the use of a different refractory cement in the formulation mix. Many design changes were made in the carbon bake furnace to increase anode size and anode baking capacity in the furnace, to increase flue life, as well as to recycle spent refractory materials. It is difficult to determine the cause of refractory service life changes. It is important to note that the refractory mix formulations developed and used at Alcoa's Wenatchee works were robust and capable of experiencing changes in consistency or quality during batching, mixing, casting, or installation without adversely affecting furnace performance.

4. What is the general opinion of plant personnel about areas of the carbon bake furnace where recycled spent refractory material can/cannot be used? Can any changes be made in the manufacture or use of spent refractory materials that can improve their performance?

Plant personnel working in the carbon bake furnace of building 62 had no negative comments about the spent refractory performance. In all cases, personnel were pleased and very proud of the performance of spent refractory materials. It is of interest to note that the use of spent refractory material in similar repair applications throughout the plant is continuing.

Discussions centering on what could be done to ensure quality material performance in the future yielded many suggestions. These included better control of the mixing process and possible prefiring of cast materials. It was also thought that satisfactory material performance could be ensured in similar or new applications if upper and lower strength standards were established on cast mixes, if quality control testing and records were kept on where batched material was utilized (to allow the tracking of problems to a specific mixed batch), if better control of crushed particle sizes were practiced, and if better weighing and mixing of raw materials during batch processing were exercised.

5. May a tour be taken of the carbon bake furnace, with emphasis on areas where refractory materials failed or are in the process of failing?

A tour was taken of the carbon bake furnace in building 62. Photographs were taken in many parts of the carbon bake furnace which will be discussed in the "GENERAL COMMENTS" section below.

6. Were any difficulties noted with alternative applications of spent refractory materials?

The performance of spent refractory materials as a roadbed aggregate or a decorative aggregate experienced no difficulties or substandard performance.

General Comments

In two years of continuous carbon bake furnace use, no notable occurrences or trends of refractory failure occurred that might be different from those noted in a carbon bake furnace built using traditional refractory materials. The recycled refractory formulations developed and the mixing and casting practices followed at Alcoa's Wenatchee works were very robust, allowing a great deal of leeway in the manufacture and use of refractory materials without affecting its performance.

It is generally thought that use of recycled refractory materials in the port blocks did not help (or hurt) material performance with respect to cracking. Port block cracking (figure 4) typically occurs radially from the center of the port block and tends to run along lines extending to the flue walls. This cracking can cause higher natural gas usage, affecting furnace operation. However, it is thought that material performance would be improved if these pieces had metal fibers added to the castable during mixing and if the refractory castable had been prefired. The importance of prefiring is indicated by cored samples taken from a cracked port block (figure 5).

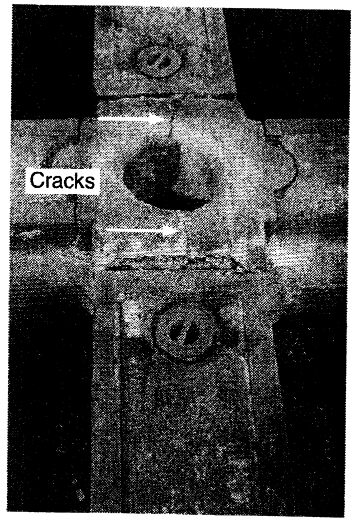


Figure 4 - Typical cracking found in port blocks.

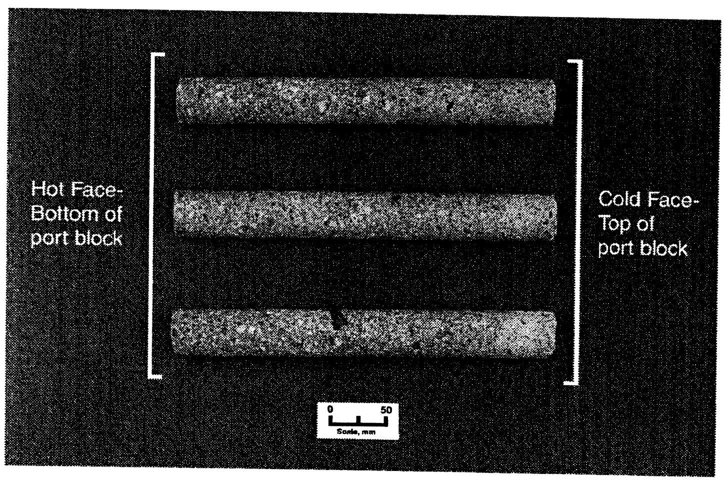


Figure 5 - Cored samples taken from a port block.

In figure 5, notice the grey gradations in the sample moving from left (hot face-bottom of port block) to right (cold face-top of port block). Also notice a shortage of coarser aggregate near the top of the casting and some brown impurities present in the casting. An evaluation of the crushing strength data taken for the top, middle, and bottom of the three cored samples is shown below:

	Crushing Strength (MPa)	Std Deviation
Top	21.1	± 3.3
Middle	29.2	± 3.7
Bottom	32.2	± 1.6

The data shows the weaker part of the casting is near the top, where the sample was not fired, and that the stronger part of the port block is on the bottom, which was the hot face of the refractory, and was fired to the highest temperature. The low values of the strength and the change in strength may help explain some of the cracking observed in the port block and in other samples such as the flue tops (figure 6).

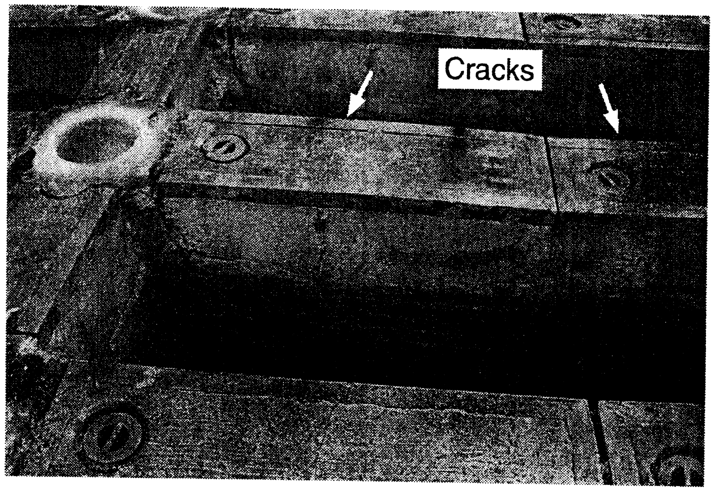
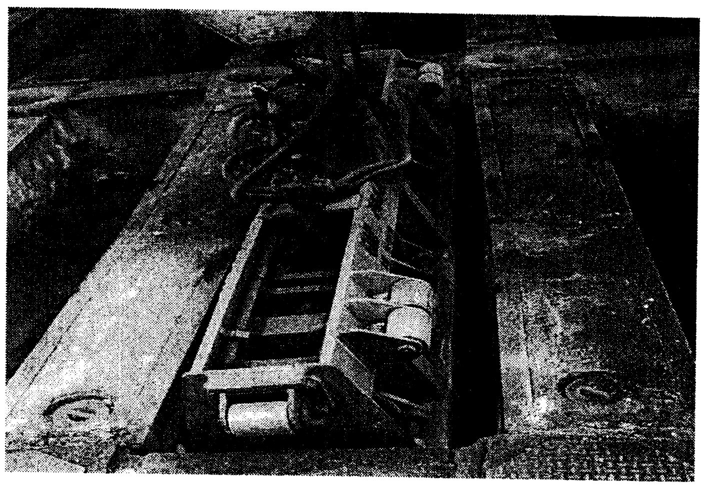
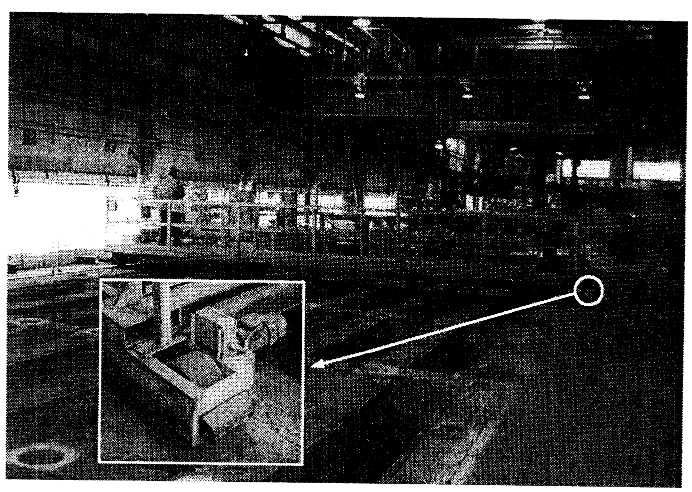


Figure 6 - Flue top with vertical cracks.



(a.)



(b.)

Figure 7 - Mechanical abuse on flue tops and the outside wall furnace caps. a.) Equipment used to remove electrodes after baking, b.) Equipment used to repair carbon bake furnaces with larger wheels.

Cracks observed in the flue tops and outside wall furnace caps are in part due to the long span length, shifting of support material underneath the flue tops, from mechanical abuse of equipment used to lift electrodes from the cells (figure 7a), and from the weight of support wheels of equipment used to repair carbon bake furnaces (figure 7b). The wheels as originally designed were too small, causing excessive loads on the refractories used in the outside wall furnace caps, cracking the refractory material. Also, when the furnace was originally rebuilt, too large of a spacing was allowed between the furnace headwalls and the fluewalls, leading to some wall movement over time.

Recommendations

In general, the type of castable refractory materials being made at Alcoa appear to be forgiving as to inconsistencies in the process. The cast refractory materials have had an excellent performance record, equaling those of traditionally used materials during the two year time period. The recommendation suggested below in the reuse of the spent refractory materials is not meant to criticize the effort done previously, but may help ensure continued success in the reuse of spent refractory materials in this and other applications. The quality and personal attention given by all who partook in the refractory recycling/reuse effort at Alcoa's building 62 carbon bake furnace has led to continuous performance beyond expectations. Recommendations for future rebuilds are listed below:

1. Better control of the mixing process used to make the castables is needed. The process used does not allow for precise weight control of the different additives used to make a refractory castable. Much of the mixing of materials is left to the estimation of the operators or is done by timed additions of materials. Final mix adjustments are accomplished by an operator who conducts a ball in hand type test. This method appears to work for the types of castables being made, but better control of the operation would help produce a more consistent mix.

2. Upper and lower strength boundaries need to be established for the castable refractories in the application areas.

3. Quality control testing of cast materials on a periodic basis for the different cast batches would give an indication if substandard material was being installed in the furnace. This testing program should include records of where specific batches of material were utilized.

4. Prefiring of cast materials may help decrease firing cracks, give higher strength, and better material performance. Improvements in the performance of the port blocks may be most affected by prefiring.

5. Better control of particle sizing and chemistry of the spent refractory materials is needed to establish acceptable and unacceptable ranges.

6. Better control of casting may prevent material segregation and help to reduce firing cracks. In particular, the water content and the amount of vibration used to deair a mix is critical.

Conclusions

The performance of spent refractory materials at the Alcoa Wenatchee works during the first two years of usage has been comparable to traditionally used refractory materials. No sub-material performance issues associated with the spent refractory applications have been noted. Indications are that the targeted performance of 100 fires should be met. At the time of the review, the furnaces were on their 28th cycle. What refractory issues have arisen are associated with design factors or changes in furnace maintenance (too small wheels on the repair frame and too large spacing between the furnace headwalls and the fluewalls).

References

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