Productivity improvement and energy conversion in steel industry heat treating furnaces

Mr. Roy W Brown
International Marketing Manager
The Carborundum Company
Refractories & Electronics Divn., Monofrax Plant
Falconer, New York 14733

There is a vital need for increasing productivity through reduced down time and lower maintenance cost as well as for conservation of energy in steel heat treating furnaces. The role of fused cast refractories and ceramic fibre in accomplishing these needs is the main subject of this summary.

Fused cast refractory skid rails have been used world wide to withstand massive abrasion and heavy slagging loads experienced in reheating furnaces. Fused cast refractories which are products of "Ceramic Foundries" are different from conventional bonded refractories, as these are shaped after fusing the required raw material batch which are then annealed and cleaned, whereas the bonded refractories are shaped first using an appropriate batch of raw materials and then fired to the required temperature. While the bonded refractory attains its strength and maturity during the firing, the fused cast product develops all its strength, maturity and density due to crystallisation of the fused mass during solidification.

The widely used alpha-beta alumina fused cast refractory skid rails are cast at almost 2150°C into graphite moulds,

To increase productivity through reduced downtime and lowered maintenance, Fused Cast Refractory Skid Rails are replacing Alloy and water-cooled metal skid rails in heavy duty steel Reheat Furnaces throughout the world. Chemical, physical and petrographic characteristics of various fused cast refractory skid rails are outlined. Petrographic reactions with molten mill scale are examined. World-wide practice with different fused cast refractories used as hearths, rails or combinations are outlined, particularly with the fused cast alpha-beta alumina skid rails which are widely used in the United States, Canada and Mexico. Usage precautions, engineering design concepts and manufacturing practice indicated.

Parallelling the need for increased productivity in steel Plants is the critical world-wide need for energy conservation in the same furnaces.

Ceramic Fiber materials have been successfully used to replace fireclay and insulating brick and castables in a wide variety of steel mill furnaces, stress relieving, coil annealing, car bottom, continuous annealing, heat treating and reducing atmosphere.

which are easy to machine and assemble. Shortly after pouring, the shapes are stripped from the graphite moulds. As we have in normal foundry practice, there is a header which drains while the fused mass starts to crystallise. Ultimately the header is lifted from the casting before it is put away in the annealing bin after it is covered with aluminium oxide annealing ore. With as much as 40 to 50% of the inside of the block in the molten state, the blocks are put away in the annealing bins and this annealing process takes about 2 weeks. The blocks are unloaded and cleaned up by various diamond grinding and finishing procedures before they are individually weighed and checked and sent to warehouse for assembly and shipping.

Ceramic Fiber has been used for Reheat Furnace doors, slow-cool cars, insulation of water cooled pipes in Billet Re-heat Furnaces, Blast Furnace Tuyere and blow pipe insulation, etc.

Manufacture chemical and physical properties, and available forms of Ceramic Fiber products are indicated Fuel conservation statistics and temperature limitations are outlined.

A new concept of Ceramic Fiber Furnace walls and roofs, well established in Europe, America and Japan, will be described in detail. Advantages are principally fuel economy; parallel benefits are higher productivity, lower initial cost and lower maintenance expense. Ceramic Fiber materials are light weight and completely resistant to thermal shock.

Emphasis will be on construction detail, usage history, fuel conservation results and other practical aspects of applying Ceramic Fiber to Steel Industry problem areas.

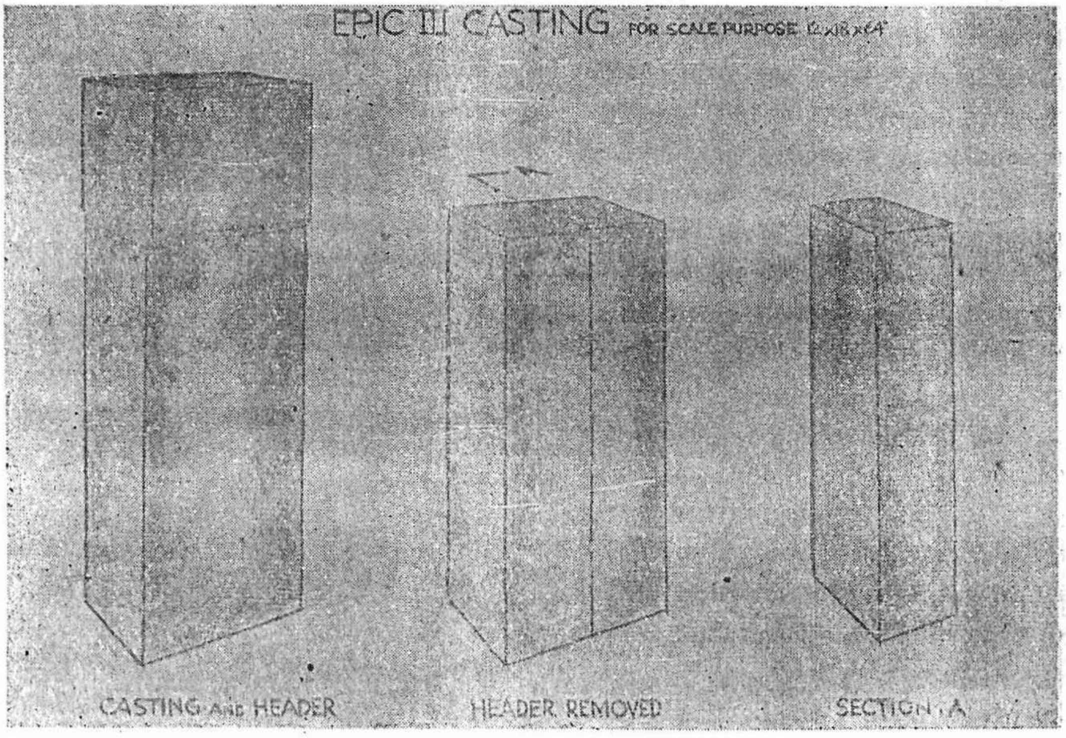


Fig. 1— Void free skid rail casting

While being stress relieved in the annealing bins, crystallisation continues inside the casting, accompanied by a small internal shrinkage which causes a void in regular cast skid rails. This shrinkage void adjacent to the casting gate is generally located on the bottom face of the block and is seldom a problem for operators. However, by end casting with large excess risers (Fig. 1), completely solid, void free skid rail can be manufactured at a slight premium. The void in the extra large header is then sawed from the block with appropriate diamond equipment, thereby eliminating the internal shrinkage void. These void free blocks are recommended for localised area of exceptional wear, where uniform high abrasion resistance is required throughout the full depth.

M/s. Carborundum Company have their fused cast refractories 'Monofrax' plant in Falconer, New York, USA. SEPR in France and Toshiba in Japan manufacture fused cast refractories under licence from Carborundum. The latest associated fused cast refractory plant which was commissioned in February '77 is that of Carborundum Universal located at Palghat, India.

Under the trade name of 'Monofrax' there are three major compositions of fused cast skid rails :

1. Alpha-beta alumina
2. Zirconia-alumina-silica (AZS)
3. Mullite-alumina-silica

The alpha-beta alumina is 99% crystal whereas AZS and mullite corundum have 18% and 16% glass phase

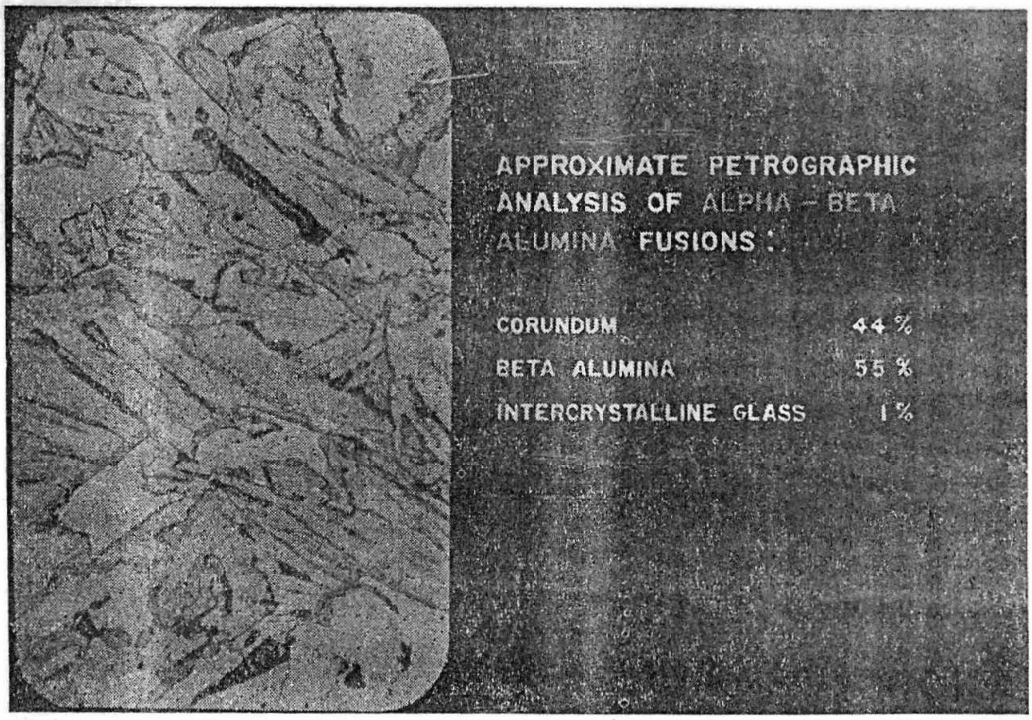


Fig. 2—Fused alpha-beta alumina bricks (Medium grey crystal-corundum and light grey crystal-Beta alumina)

respectively. For cold abrasion AZS is most effective but there are serious problem at high temperature because of glass phase softening. A study of the petrography of these three products gives an insight into the nature of their behaviour in service under different conditions. Alpha-beta alumina is essentially a crystalline highly inter locked mixture of chunky, medium grey crystals of corundum and light beta alumina (Fig 2)

AZS refractory (Fig. 3) has 18% glass phase purposely introduced to cushion the erratic expansion/contraction behaviour of monoclinic zirconia present in the body. It consists of light grey alpha alumina with white nodular zirconia inclusions together with approximately 6% white zirconia dendrites embedded in 18% of grey glass which make up the body. This refractory is widely used in glass furnaces.

The mullite-corundum fused product (Fig 4) is a random arrangement of light grey square or rhombohedral crystals, medium grey chunky corundum and some minerals, usually Titania or Zirconia embedded in a dark grey gound mass which makes up almost 6% of the body Mullite approximately 45%, Corundum 35%, Titania or Zirconia 4% and the rest glass. Incidentally mullite corundum was the first fused cast refractory ever developed in Germany in 1924 and commercialised in USA in 1926 by Corhart Refractories Company.

The initial product developed primarily for glass furnaces was a fusion

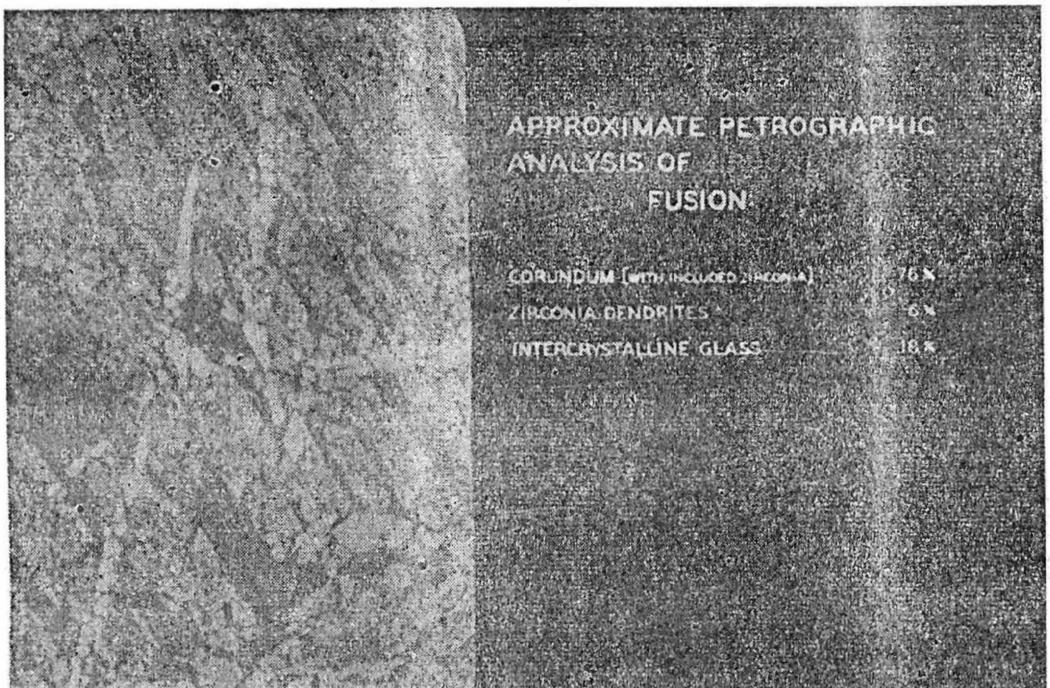


Fig. 3—Fused AZS refractory (Light grey crystals—alpha-alumina with white nodular ZrO2 inclusions with ZrO2 dendrites embeded in intercrystalline grey glassy matrix)

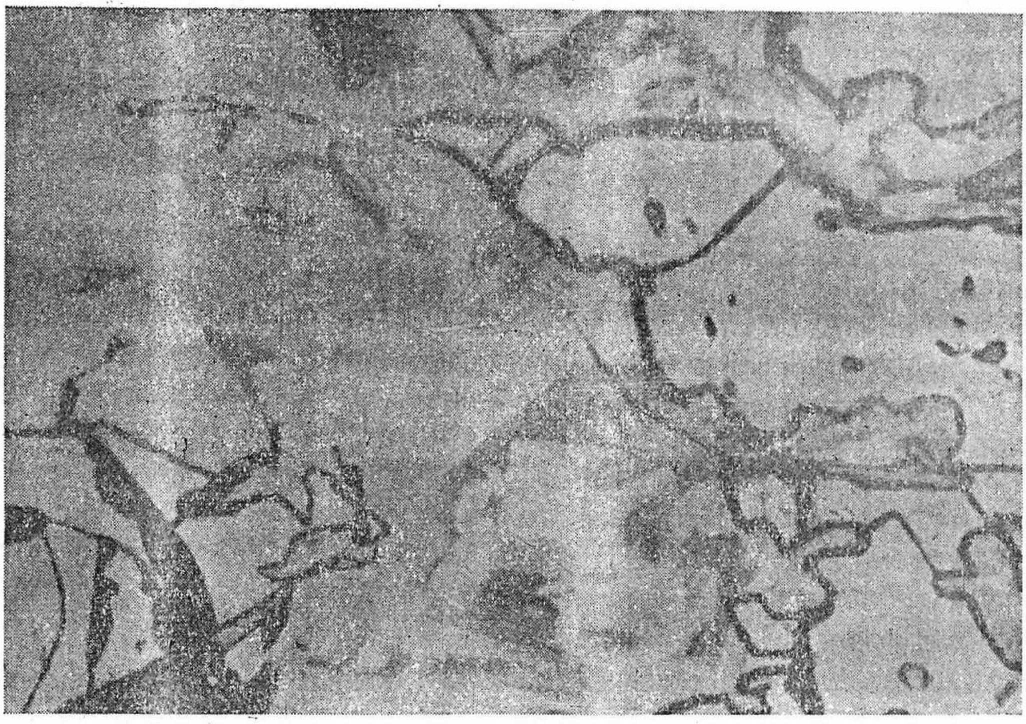


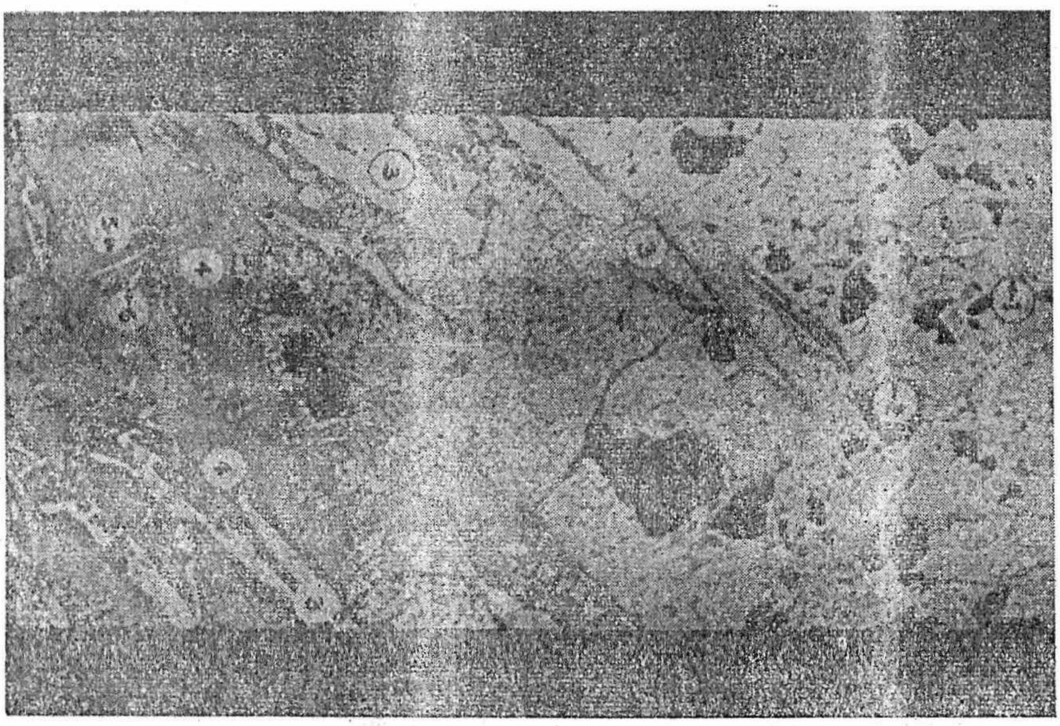
Fig. 4--Fused mullite-corundum refractory. (Light grey square or rhombohedral crystals mullite-corundum, dark grey ground mass usually TiO_2 or ZrO_2.

of enriched clays and was called Corhart standard. It is now made in Europe under the trade name of Magmalox and in Japan under the trade names of Vestal Black and Monofrax T. This product has been replaced in glass contact areas by the more corrosion resistant AZS, alpha-beta alumina and chrome-alumina fused cast refractories. However, mullite-corundum is occasionally used as a skid rail in USA in billet reheating furnaces, whereas in other steel producing nations, in Europe and Japan, it is primarily used as a solid hearth—the entire reheat furnace floor faced with mullite type fusion as compared to the American practice of fused cast skid rails and high alumina bonded ramming mass in between rails.

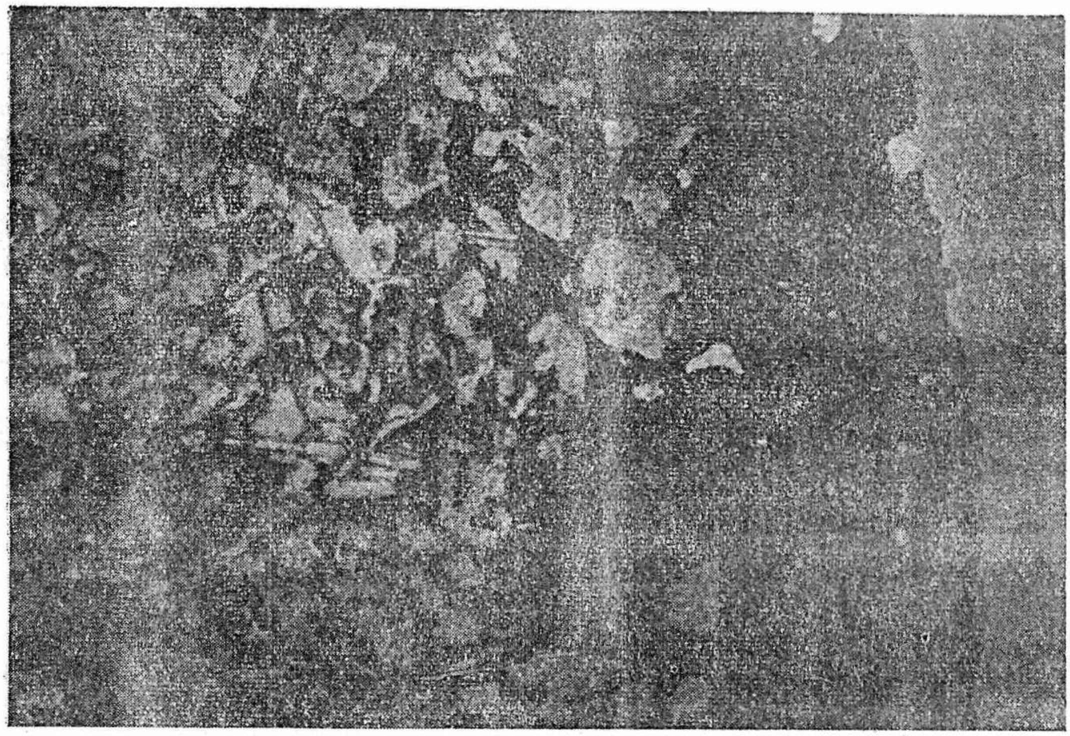
In the early sixties Carborundum Company carried out several trials at Bethleham Steel Company using AZS, alpha-beta as well as mullite corundum. Out of these, alpha-beta alumina turned out to be the best for this application in their reheating furnaces. Laboratory tests at 1400°C showed exudation of glass phase in AZS as well as mullite-corundum samples, whereas, alpha-beta was free from it. The exuding glass phase reacted with molten iron oxides, possibly forming fayalite fluxes. The resultant porous structure was penetrated and altered to a depth ranging from 1/8″ to 3/4″. Because this layer was soft at operating temperatures billets were scrapping or ploughing away the reacted surface. Reaction at the slag interface produced iron spinels, iron alumina spinels as well as iron silicates on top of the relatively unaltered AZS structure at the bottom. The high alumina spinel penetrated into the molten glass phase between crystals to surround the alumina lathes. The alumina lathes were either dissolved or pushed away by the shearing action of the billets.

Similarly in the case of mullite-corundum skid rail (Fig. 5) at the top slag zone, the iron rich alumina spinel are surrounded by a matrix of iron and silica. Although some corundum crystals penetrated into this zone almost all the mullite crystals and glass phase had dissolved. Because of these low melting iron silicates, the surface layer is subject to easy removal by subsequent ploughing action of the billets.

Compared to the above, the surface microstructures of Monofrax M (Fig. 6) alpha-beta alumina skid rails after 14 months in a billet heating furnace showed only a thin band of iron alumina spinel and only minor reaction in the area adjacent to the slag where some of the beta alumina had altered to corundum. The non-reactiveness of this surface is the main reason for the self cleaning feature of the hearth with the alumina skids. A skid in a hearth after handling over 2 million tons of steel showed practically no wear except for some slag build up on the surface as compared to a just delivered skid.



Figure—5 Mullite corundum skid rail



Figure—6 Monofrax M alpha-beta alumina skid rail

The general recommendation for fused cast alumina rail type construction is to space the rails for a minimum loading of 0.84 Kg. per sq c.m (12 lbs/sq. inch). Temperatures in the soaking zone of reheat furnaces generally run between 1200°C and 1350°C. At these temperatures Monofrax M skid rails give excellent performance. If the temperature exceeds 1350°C molten or sticky slag or scale builds up. This causes an iron alumina mineral (Hercynite) to form a surface skin more refractory than the iron silicates that form on mullite-corundum skids. Any excess slag build up on fused cast alumina skids will be pushed off by the work moving through the furnace, giving a self cleaning aspect to the hearth.

One of the first installation of Monofrax M was at Steel Company of Canada (STELCO) where four single rows of 225mm x 225mm x 450mm blocks were used for reheating 1.2 metre wide 2.4 to 5.5 metres long and 100 to 250mm thick slabs or billets. The furnace handled 2350 tonnes per month at a maximum temperature of 1425°C. The rails were butted up against the water cooled knuckle with 25mm of plastic ramming material or high alumina brick used as insulation between blocks and water cooled knuckle. Champfered starter rails were used to prevent hang-up of the billets or slabs as they left the water cooled skids. High alumina bricks were installed flush with the tops of the Monofrax skid rails. The methods of installation varies. While some use a bevel on each block to minimise edge pick up, others just use beveled starters. It is important to use some kind of ramming cement or an alumina brick between water cooled knuckles and fused cast refractories which are more susceptible to thermal shock than normal materials. In USA 90% alumina phosphoric acid bonded ramming material is widely used now between skid rails. Some operators prefer 70 to 80% alumina bricks between rails. Uniform temperatures of thermally conductive alpha-beta alumina skid rails eliminate cold spots experienced with water cooled rails. They also eliminate the need to pump and treat considerable quantities of cooling water. Alpha-beta skid rails have replaced many alloy skid rails which cost 3 to 5 times more. Ceramic rails do tend to warp in service as alloy rails do.

At US Steel, Fairfield, Alabama, void free castings 150 x 150 x 450mm are used with no evidence of scale build up on a double-push furnace handling billet slabs of 1.06m wide x 2.03 to 2.7 metre long and 100 to 400 mm thick. Temperatures range from 1340°C to 1400°C and total load is approximately 22,500 tonnes per month. In a Mid Western furnace seven rows of double skids with staggered joints were installed using 100 x 150 x 450 mm void free Monofrax M skid rails for handling slabs 150mm x 900mm cross section and almost 5 metres long. The rails were generally installed tight with expansion occuring over the feed end of the hearth, opposite the knuckle.

Year in and year out Carborundum supply approximately 1000 tonnes of Alumina rails (mostly regular cast 225 x 225 x 450mm) to the American Steel Industry. Major usage by far is in such plants as Bethlehem—Sparrows Point, US Steel-Gary, Bethlehem-Burns Harbor and Armco-Middleton which produce some of the thickest slabs in America—anywhere from 350 to 650 mm thick. In Gary Works, on their 210 mill, they are handling approximately 35000 tonnes per month of billet sizes that are 600mm thick, 1.9 metres wide and 3.6 metres long. At Sparrows Point, Maryland, in their No. 1 & 2 plate mills, Bethlehem Steel handles 55000 to 80000 tonnes per month on Monofrax M skid rails. This is America's largest steel plant and Caborundum's best customer.

It might be wise to point out normal precautions to take with fused cast alumina skid rails. Abrasion and molten scale resistance of Monofrax M are largely due to the glass and bond-free interlocking crystalline structure resulting from the ceramic foundry . manufacturing technique. The material, therefore, does not have the thermal shock resistance of kiln fired refractories. It is strongly recommended that slabs or billets cover Monofrax skid rails during heat-up, cooling and idling cycles to act as a buffer and prevent unnecessary thermal shock to the refractories.

Water should not be used to force cooling of Monofrax skid rails; on weekend shut-downs or inspection shut downs, the furnace should be left full of billets; the temperature should be dropped 55°C per hour down to 820°C; on weeekend shut-downs, the furnace temperature should not go below 820°C. To take the furnace to cold temperature, cool to 820°C as stated above; then cool at 30°C per hour to 650°C and then drop temperature at 45°C per hour from 650°C until cold. The same general schedule should be used in reverse to heat rails.

Sub-hearths should be flat and in same plane with the wet skid rail at either end. Valleys or depressions should be filled during shut-downs. Skid rails should be installed level. Skid rails should have joints butted with cement to retard scale penetration. Bedding level cement layer is also suggested for levelling, but no more than 6mm thick. Expansion allowance for rail length should be confined to the lead edge.

A portion of this alumina hearth is solid; if temperature were high (above 1425°C and scale was molten, mullite corundum might replace alumina. The high temperature glass does exude to create a reaction layer between hearths or skid rails and iron oxide scale formations. This micro-thin reaction layer literally acts as a parting plane or lubricant that keeps the mullite-corundum scale-free during operation. This mechanism is particularly important when the load on the rails is not sufficient to clean away scale which could normally adhere to alpha alumina.

Mr. Roy W Brown had some sad personal experience in a Canadian rod mill operated at very high temperatures (almost 1450°C) with considerable molten scale where they were pushing through rods that were 55mm x 55mm in cross-section, but over 9 metres long. Stelco first used alumina skid rails; there was considerable scale build-up on the Monofrax M that the light stick-like or spaghetti like rods were not able to clear off. It resulted in a terrible problem with rods coming out through the burner, the roof etc. In the next building, Stelco had great success with 400 x 1200 mm cross-sections. So, there is a place for mullite corundum in India following European practices wherein solid "Self-cleaning" mullite-corundum hearths are used. In furnaces using this stock, fused cast alumina must be so widely spaced to raise the load to 0.85 Kg per sc. cm. that there is a loss of support and excessive wear between the rails. With the mullite-corundum, more rails can be installed to establish a uniform wear pattern.

Generally, hearth life of mullite-corundum is not satisfactory compared to an alumina skid if the load is high enough; again, the differentiation point would be 0.85 Kg. per sq. cm. or 12 lbs. per square inch load. This requires close work between furnace designer and skid rail supplier to minimize rail surface to achieve sufficient load.

Ceramic Fiber

The other great problem plaguing industry and Government worldwide is the fuel or energy crisis. This is particularly hurting industry, which is USA consumes 35 to 40% of all the available energy; one worldwide solution is fuel conservation. Ceramic fiber which is also made in electric furnaces where a mixture of alumina and silica is fused and blown (Fig 7) by steam jets into appropriate collectors and then made into ceramic bulk product, can subsequently be made into blanket. There

temperature of approximately 1260°C. The product is available in many forms, and can be made into a variety of papers.

This product line has been particularly helpful in the steel industry for a number of varied applications. Blow pipe insulation is usually either castable or ceramic paper in conjunction with the tuyers; coke oven doors usually use rope; coke oven gasketing is usually

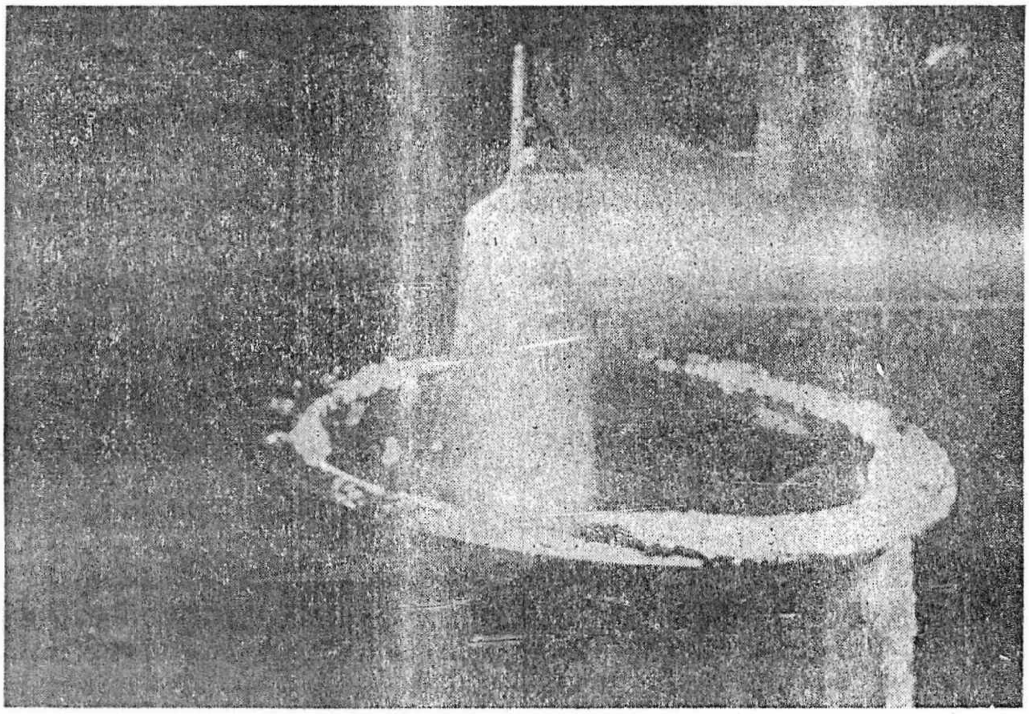


Fig. 7—Blowing ceramic fiber by steam jet

are two types of Fiberfrax manufactured by the Carborundum Co. for different temperature ranges. The 60% alumina material can take a hot face temperature of approximately 1430°C, and the standard material (approximately 50% alumina) can take a hot face

paper or cut felts; hot top linings for special alloys are usually vacuum cast parts, as are pour pads and ingot mold linings for steel forgings. Expansion joint packing is usually ceramic fiber bulk material, as it comes in bags, while recuperator tube gaskets are either vacuum formed shapes or rope.

The water-cooled riser insulation in the billet reheat furnace is usually made from stamped parts that are slit so that they can be easily slipped over tubes and then stacked on rings that are not subjected to too much drip or flame velocity. Ceramic fiber has been used in billet reheat furnaces to augment use of interlocking brick shapes or weldable castable cement/alloy wire reinforcing composites to minimize temperature loss in the water cooled pipes supporting the billets. Another general use of ceramic fiber blanket is as joint filler on soaking pit seals.

By far, most of the work with ceramic fiber has been done in some of these many furnaces, associated with the ultimate heat treating of steel in the lower temperature ranges where their insulating firebrick, fireclay and castables materials have been used in the past. Fiberwall (Fig.8) is Carborundum's tradename, world wide, for the application of ceramic fiber on new furnaces and old furnaces to replace firebrick and castables, which had very high heat storage as well as high heat losses through the walls. Similarly, on heating and reheating, there was a degradation of the brick lining due to spalling, impact, etc. The concept of using

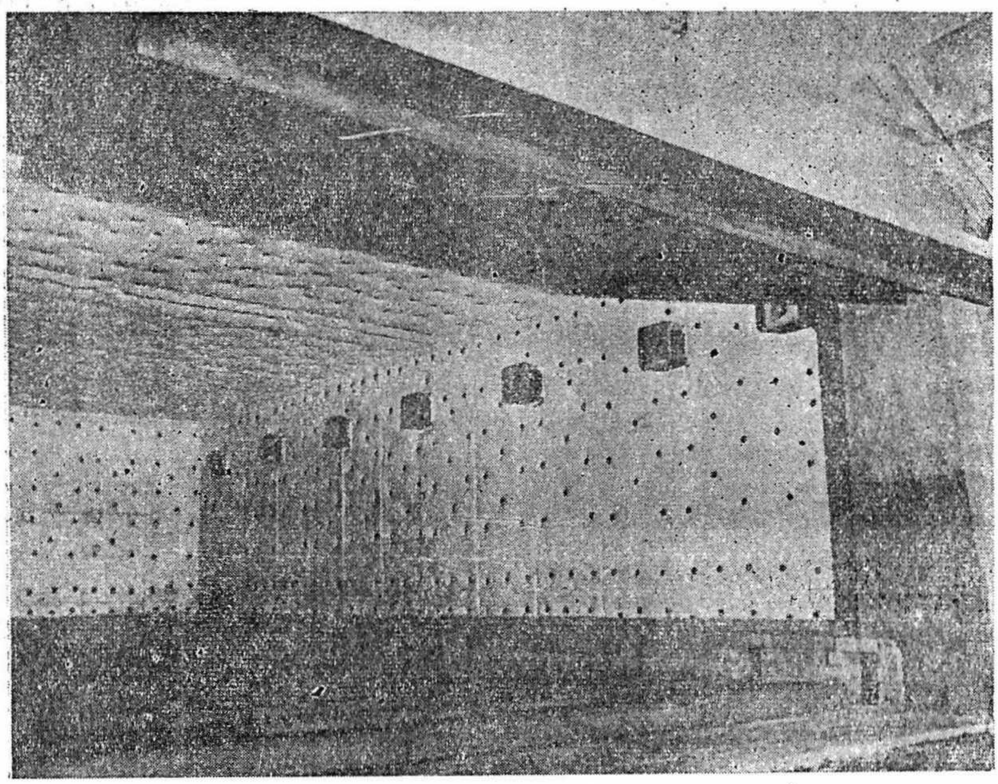


Fig. 8—Typical heat treating furnace with fiberwall lining

ceramic fiber gives us thermally more effective, more uniform linings with considerable heat reflectivity and much lower heat storage.

Essentially, fiberwall linings consist of appropriate fiberfrax blanket or felt on the hot face along with mineral wool back-up insulation and alloy steel hardware or ceramic cups to hold the assembly in place. The attachment system commonly used employs clips or anchors made of stainless steel alloys; the alloys most commonly used are 304 stainless to 700°C, 310 stainless to 950°C, and 330 stainless and inconel 601 to 1150°C.

The stud pattern is located with due consideration to the size of the mineral wool back-up and the blanket roll size; stud guns or standard welding tools attach studs to the furnace shell; mineral wool block is then impaled over studs and often held in place by speed clips to facilitate construction. Then the ceramic fiber blanket is hung over the studs (Fig. 9).

Fig. 9--Hanging ceramic fiber blanket over studs

At temperatures above 1150°C, a mullite cuplock is sometimes used in assocoiation with the ceramic flange which would be used with the standard anchor (Fig. 10), the cup is packed with ceramic fiber moldable. It is easy to wrap the blanket around flues, to pack it around burner blocks or to form it around flues. This general approach saves man hours of masonry time as well as minimizing need for many special shapes that would be very difficult to obtain and to design and secure in normal furnace refractories.

The process lends itself to small furnaces where working with a light weight, high temperature insulation that is completely resistant to thermal shock. Benefits are fuel economy, higher productivity, lower initial cost and lower maintenance. For one thing, the Fiberwall concept only weighs one-fifth that of insulating firebrick, and would obviously be considerably lighter than a fireclay castable or a fireclay lining.

Construction technique is an area where innovation by both supplier and end user have promoted wider use of ceramic fiber materials. Some new modular techniques have decreased construction time and cost and have provided a new flexibility in total

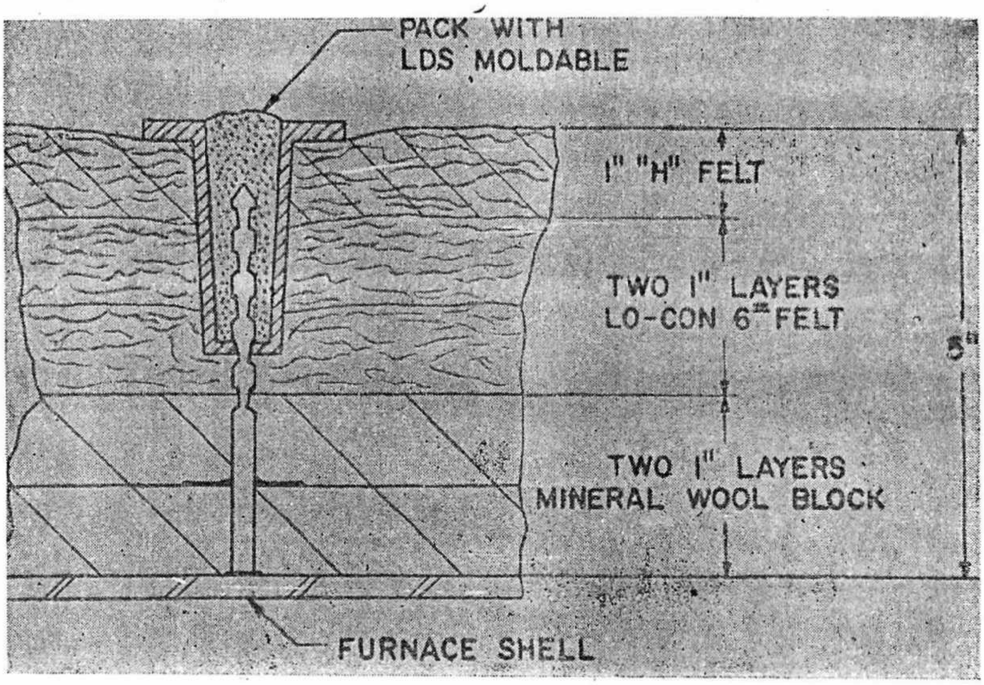


Fig. 10—Standard anchor for holding fiber blanket

design. Granges and Graver in Willebrock, Belgium, produce large steel distillation columns, tower large reactors and tanks which are heat treated in this unit, 15 metres high, 15 metres wide and 20 metres long; operating temperatures are 750°C and it normally accomodates 600 metric tonne assemblies. The furnace had to be constructed for a 980°C capability since operations in this temperature range were planned in the near future. Because of the enormity of the furnace (Fig. 11) it was an assembly of prefabricated panels that were 2 mts x 3 mts. Each steel panel was lined by 2" of Lo-Con felt on the face and 3" of low temperature rock wool on the back. The panels were stud welded in the normal manner and the insulating materials then impaled on the studs and retained with alloy washers. A hard board templet was used to avoid time consuming layout. Modules were constructed in a production line atmosphere away from the job site and weather.

This allowed good planning and minimized wasted material and confusion. At the job site, modules were raised into position without the need for special hoisting equipment or complicated scaffolds. When located, the modules were simply bolted into the supporting steel work. The final step was to lay small rolls of ceramic fiber over the joints.

A multiple stack annealing furnace, used at Steel Company of Wales, was fabricated off-site and easily carried

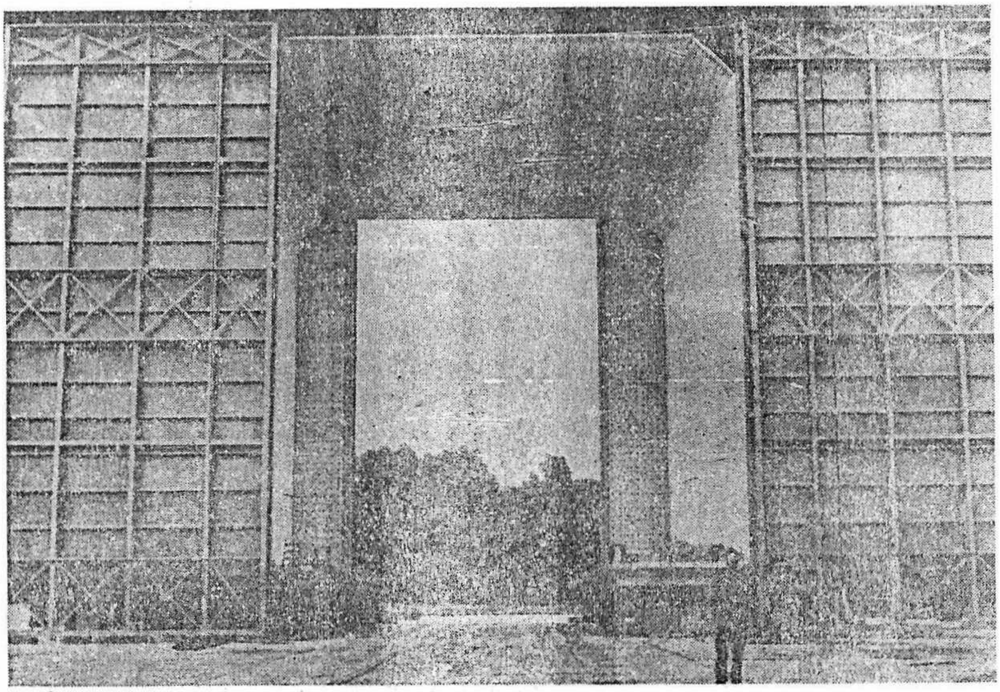


Fig. 11—Large heat treating furnace with fiberwall lining

into the plant on a truck with minimum moving difficulties. This would have been impossible with a firebrick lining where over-the-road transportation would have caused considerable cracking and mechanical pinching of the brickwork.

Fiberfrax is widely used now in coil annealing furnaces in all types of steel plants and again is very simple to install.

One interesting case history is Buckeye Steel Castings Co., Columbus, Ohio. This is an area that was faced with a great shortage of natural gas; their plant managers were told that they had to reduce their use of natural gas by 55% which at first meant that production could not be maintained on a normal level. Buckeye Steel Castings, committed to do everything possible to maintain operations, thus began a program to analyze usage and move to increase efficiency They had 11 of these large car bottom heat treating furnaces, one means by which the fuel curtailment could be circumvented. These furnaces had heavily deteriorated insulating firebrick linings and experienced severe leakage in the door and car joint areas.

After a detailed survey of alternates, Buckeye Steel chose Fiberwall as the system to upgrade their furnace. They used 50mm of the 8 lb. felt (0.129 gm/cc felt) backed by 75mm of 1040°C mineral wool block. The problems of sealing the joints and cars were solved by an innovative use of Fiberfrax blanket and bulk packed into Inconel mesh. In addition, the use of Fiberwall because of its lower heat storage, prompted a reduction in the number of burners used in their furnace.

Their rebuilding program produced some impressive results. First, they had a 50% reduction in fuel consumption. Equally important was a 50% increase in productivity. Their total cycle time for a batch in and out of the furnace was reduced to 3 hours from 4½ hours. This was because most of the heat generated by the burners could go into the material being annealed rather than into heating the firebrick and insulating firebrick lining. Finally, their casting quality improved because there was less scale and oxidation on work pieces which were in the furnace for a shorter time. After lining only 5 furnaces and shutting down 6 furnaces, Buckeye Steel Casting were able to operate at their normal production levels despite the substantial 50% cutback in fuel allocation. For this dramatic story, there are many others worldwide.

Many furnaces now lined with firebrick, castables, or insulating firebrick are not ready to be completely rebuilt, but have poor fuel economy because of cracks, general loosening, etc. For these furnaces, Carborundum has devised the LOR or Lining on Refractory approach.

A hilty (vibrating hammer) stud gun drills holes into the old refractory on a measured basis; this can be done manually as well. Then pins are installed and ceramic fiber impaled over them and retained with appropriate clips.

Again, in large furnaces or small, there is a significant message here that we hope will be of interest. We have been working worldwide on both the design materials and on-site supervision of Fiber-wall. We hope this insight into two American practices with fused cast alumina skid rails and ceramic fiber furnaces that the author had been quite familiar with since its inception will prompt some short range and long range interest in India.