DIFFERENCE IN MAIN IRON RUNNER DESIGN

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ABSTRACT

The subject is dealing about a deep investigation on the design of blast furnace main runners. The main items which characterize the global performance of blast furnace main runner are its reliability, lifetime, and low cost of use. To improve these items, TRB has used its skills and expertise to create and propose the best design for the different layers composing a main runner. Thermal, thermomechanical, and fluid numerical simulations were used by our engineers to improve the usual design towards new concepts. In addition, this theoretical approach has been corrected or reinforced through a worldwide benchmarking.

INTRODUCTION

The blast furnace castfloor design is usually based on experience related to the geographic location. The place where you are when you have to build blast furnace runners will then influence you while choosing the materials or the design. Of course, in a globalize world such as today, good practices are more shared, but some trends are still remaining. Today, most of the BF main iron runners (MIR) are divided into 3 or 4 elements:

- Working lining
- Safety lining
- Insulating layer (optional)
- Structural support

This paper will try to compare different technical solutions to make these layers in term of design and explain the TRB company choice.

The working lining was considered before as a short life layer but progressively became a long duration material. The castable formulation has been continuously improved and lower wear rate of the working lining is bringing now longer campaign length and lower refractory consumption.

There are two big families for the design of this layer: single lining and zone lining. This choice of design is strongly linked to its location: in 2021 100% of the 250 MIR in Europe + CIS + Africa are made with single linings. On the contrary zone lining is still often used in America.

The idea of single lining is to cast the same material for the whole working lining. So, this material must resist to slag as well as iron. The philosophy of zone lining is different: two materials are casted, first one at the bottom and lower part of walls which has a good resistance against iron and the other one on the higher part of walls which as a good slag resistance.

Today, safety lining appears as a key point, as it can provide more safety and reliability on the casthouse. This is the last defense against a possible infiltration. For this layer, suppliers can use either precast- shaped blocks (in single or multiple rows) or also bricks.

In term of structural support different systems are used. Back in the days, the whole runner was embedded in a thick concrete floor. This system is still existing in China for example. In western countries runners are now usually supported by metallic shells with a metallic beam structure. The cooling of this shell can be natural or forced, mostly by air.

MATERIALS AND METHODS

Working lining

Single lining and zone lining will be compared in this paper. Especially we will have a particular look on the effect on the wear of the runner depending on the selected lining. First, on-site data will be analyzed to understand what is the impact of having single or zone lining in term of wear. SSAB Finland (Raahe) is a site where casting system have been changed from zone lining to single lining. This allow us to make an easy comparison of the wear along the main iron runner.

To better understand this data, a simulation by finite elements was performed. This is a multiphasic CFD calculation taking into account iron, slag and the air above.

Safety lining

Thermal and thermomechanical calculation were computed in 2D (section) and 3D (on a 2m model) to compare the stresses into the castable depending on the design.

Structural support

Thermal and thermomechanical calculation were computed in 2D (section) to better understand the influence of choosing a metallic shell casing or a civil engineering one. The influence of casing cooling (natural or forced) was also investigated.

RESULTS

Working lining

Fig. 1 represents the wear measurement taken on site and model as a CAD geometry. Comparison is made from period when working lining was made with zone lining (in orange) to when they switch to single lining (blue).

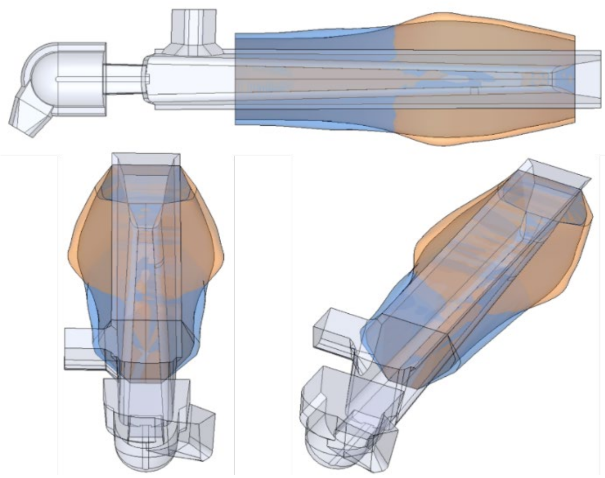

Fig 1 : SSAB Raahe 3D wear profile : zone lining in orange, single lining in blue

Same measurements are shown on a 2D graph in Fig. 2 to better understand the differences on the wear between the two casting system.

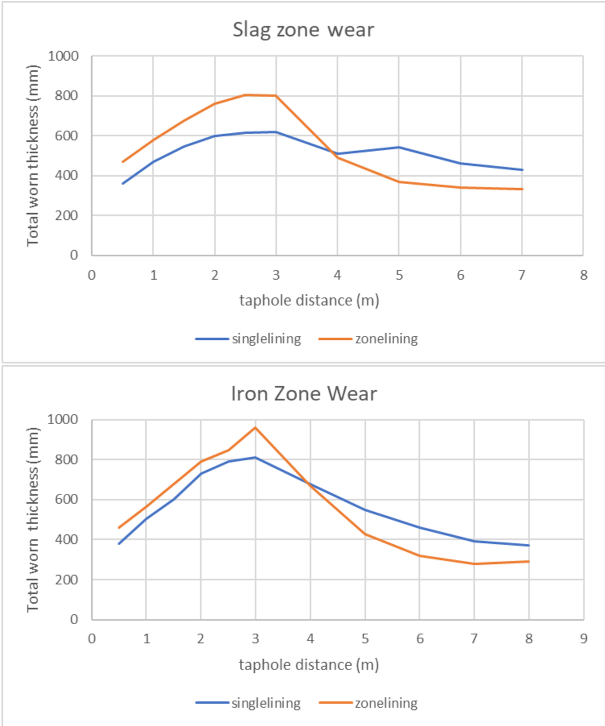

Fig. 2 : SSAB Raahe 2D graph wear profile : zone lining in orange, single lining in blue

Fig. 1 and Fig. 2 show very precisely the wear mechanism depending on the casting system. Whether it is in iron or in slag zone, zone lining seems to be more resistant than single lining on the second half of the main iron runner. On the first half, this is the opposite: single lining has a better behavior against damage and wear profile is better.

To go further in the analysis and understand the origin of this kind of measurement, a 3D multiphasic CFD calculation was carried out. Results are shown on Fig. 3 and Fig. 4.

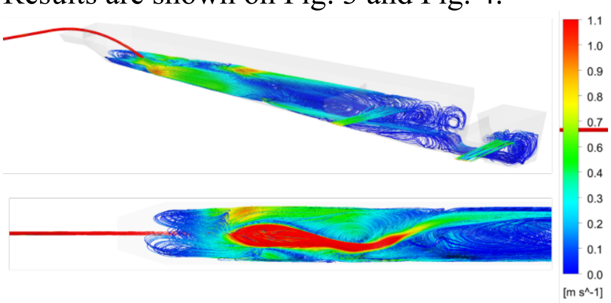

Fig. 3 : 3D multiphasic CFD calculation – velocities (m/s)

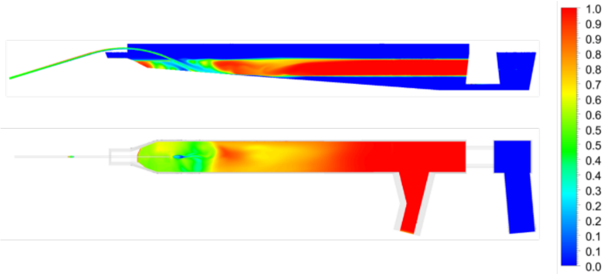

Fig. 4 : 3D multiphasic CFD calculation – slag fraction

Safety lining

First step was a 2D thermal calculation made on a classical MIR section. Results are shown on Fig. 5.

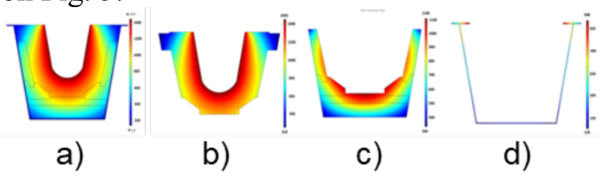

Fig. 5 : temperature distribution (°C) on a 2D section main iron runner : whole geometry (a) working lining (b), security lining (c), casing (d)

Then a fully coupled thermal and mechanical calculation was computed on a 2m section model (3D scale). For this complex study contact between the parts has been taken into consideration and accurate elastic-plastic behavior law with damage was established. This study allows us to compare two types of security lining design: single block row or double block row design (see Fig. 6 – d).

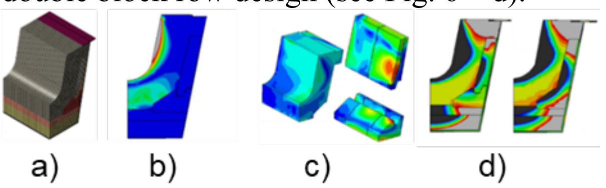

Fig. 6 : Thermomechanical calculation : 3D mesh (a), deformation analysis (b),
stress analysis (c) and design comparison on principal stress (d)

Structural support

Impact on main iron section of different types of structural support were compared on 2D thermal calculation: free, partially, or totally embedded casing.

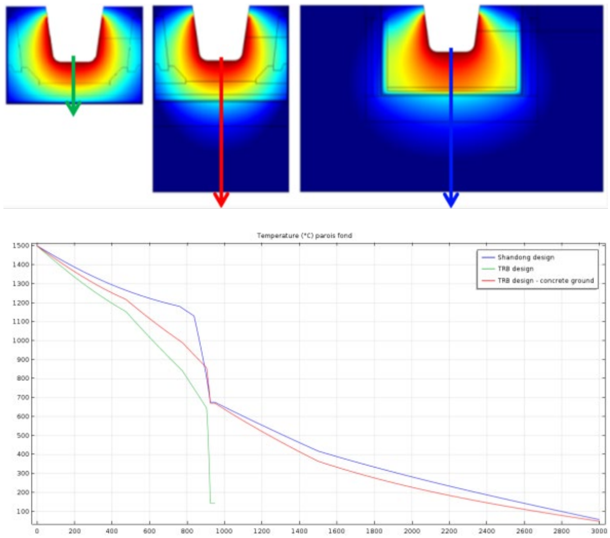

Fig. 7 : Thermal profil on the botom depending on the structural support design

On a free casing, different kinds of cooling were considered: natural convection (H5 model) or forced convection (soft : H20 and hard : H49 models). Results are shown below : thermal profile on side walls (Fig. 8) Von Mises stresses on casing (Fig. 9) and equivalent plastic strain (Fig. 10).

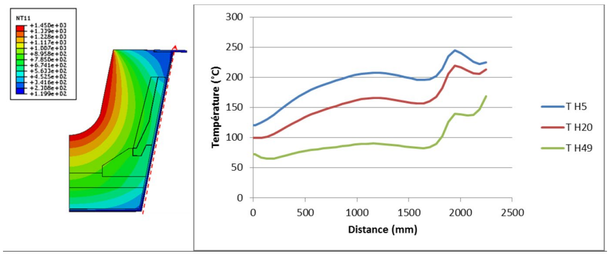

Fig. 8 : Thermal profil on the side walls depending on the casing cooling condition

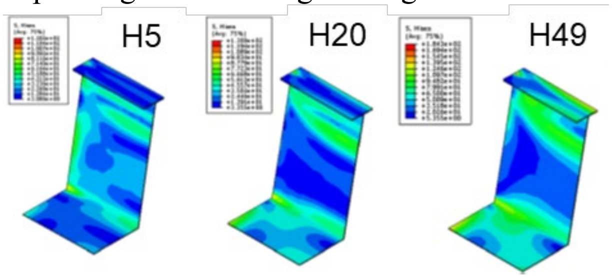

Fig. 9 : Von mises stresses on the casing depending on the casing cooling condition

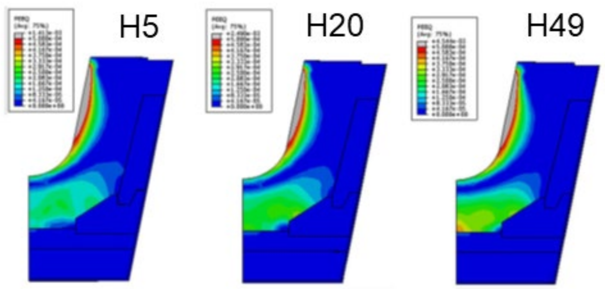

Fig. 10 : Equivalent Plastic Strain on the runner depending on the casing cooling condition

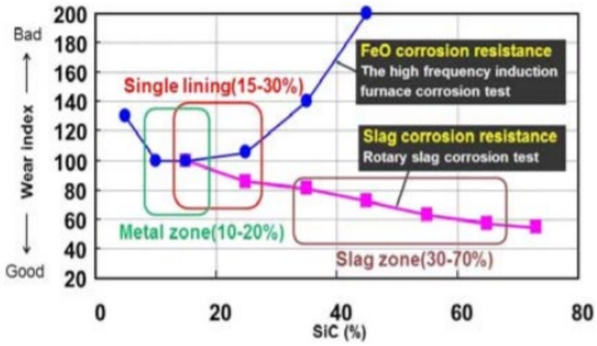

Fig. 11 : Effect of variable % of SiC on wear index of castable

DISCUSSION

Working lining

Materials used for working lining of MIR are commonly aluminous ultra-low cement castables (ULCC) containing carbon and silicon carbide (Al2O3-SiC-C system). They are brown fused alumina based with Silicon Carbide content ranging from 10 to 60%.

Silicon carbide is a well-known additive for its properties regarding slag corrosion and erosion resistance. The higher SiC content in a castable, the better the slag resistance.

On the other hand, iron corrosion resistance of silicon carbide is quite poor.

Consequently, it is better to use a material with low SiC content for iron zone, and with high SiC content for slag zone. In case of single lining SiC content should be a compromise.

Usually SiC content of castables depending on the application is:

- Zone lining iron zone : 10 – 20%
- Zone lining slag zone : 30 – 60%
- Single lining: 15 – 30%

This is perfectly illustrated by Dr. A. K. Samanta [1] in Fig. 11 where iron and slag resistance were tested in a Rotary Corrosion test at 1600°C

Table 1 : Typical composition of castables

	Single lining material	Zone lining material	
		Iron zone	Slag zone
Main aggregates	Brown fused alumina - SiC	Brown fused alumina - SiC	Brown fused alumina - SiC
Al2O3 (%)	70	81	48
SiC + C (%)	25	15	47

As already seen in Fig. 1 and Fig. 2 there is a big difference of wear in iron or slag zone depending if you use single or zone lining and adapting material by zone appears to work only after a few meters. Our interpretation of this phenomena is that the mixing state of the fluids (iron and slag) is the key. On the first meters of the MIR, as fluids are not segregated yet, walls have to face slag or iron whatever the heights. This is perfectly shown on the CFD simulation. Fig. 3 show the high velocities and back-flow around the impact zone. Fig. 4 give us an idea of the segregation process: it takes almost half of the MIR to have a complete segregation with slag on the top (red) and iron on the bottom (dark blue). On the first half this is a mix with yellow and green colors.

So even if single lining is a compromise with lower resistance against slag in the slag zone and against iron in iron zone, its usage shows a

better behavior on a global point of view as the worst wear zone is traditionally located just after the impact. Therefore, a single lining castable should ensure a safer operation and a better lifetime.
Silicon carbide is one of the most expensive raw materials used in MIR castables and its cost represents between 20 and 70% of the final cost of the material depending on its composition. That means the material used for slag zone will be much more expensive than the one for iron zone.
Luckily in case of zone lining casting, we use more metal zone castable than slag zone castable (typically 2/3 - 1/3).
So, at the end of the day, the cost of the materials to fill the runner is usually quite similar between zone lining or single lining system. From an economic point of view the only way to save money in using zone lining instead of single lining system is if this leads to longer campaign so lower consumption.

Safety lining
Fig. 5 and Fig. 6 show the temperature distribution inside the refractory layers and how it damages the castable in term of stresses. With this type of gradient and as the materials are set inside a fix casing, expansion causes compression on the skin (iron and slag side) and tension inside the castable. Maximum stress is located on the longitudinal axis, which is shown on Fig. 6-d with compressive zone in black and tensile one in grey. On this same Fig., the difference between two designs can be seen: one precast block for the whole security lining heights or 2 rows of blocks. Results are showing lower stress with this second option. The reason is the higher flexibility of this solution because it contains more degree of freedom which release the thermomechanical stress.
Bricks that are sometimes used for security layer have the advantage to be a cheaper material but cannot withstand the level of stress present there. This study is the base of our design philosophy in term of security lining and with this design, we ensure a lifetime up to 10 years for security lining. On a long term, our solution is much cheaper rather than a less resistant material that you will have to replace very often.
We can adapt this solution whatever the MIR design is as seen on Fig. 12.

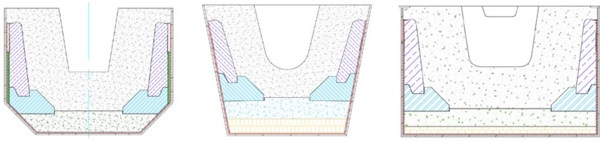

Fig. 12 : safety lining set on different casing shapes (left to right : Azovstal Russia, AM Dunkirk France, Shandong steel China)

Structural support
Fig. 7 show the very high casing temperature if this one is inside civil engineering : temperature can reach more than 500°C. At this level, depending on the grade (which is generally standard S235) and the thickness, casing could be cracked and damaged because it will become very soft. On the contrary, a free casing ensure temperature lower than 250°C and so its integrity.
Fig. 8 show the impact of a forced cooling on the outside of the casing. Consequently, temperature will be lower on the skin, but it also has side effects. This will be higher stress on the casing (Fig. 9) and also plastic strain increase (Fig. 10). The reason is the change of the gradient with a temperature still high inside which is falling down suddenly.

CONCLUSION
At TRB, our activity is worldwide and so is our market. Therefore, we come across a lot of practice and every time we try to understand which is the best. From the inside to the outside, every layer of a main iron runner has been studied in this paper, with a consideration to different kind of design used everywhere in the world. The overview of all this measurement and calculation is an accomplished design made of single working

lining, a safety lining made of two row of precast shape block on sides, a thin insulation layer and a free casing naturally cooled (see Fig. 13).

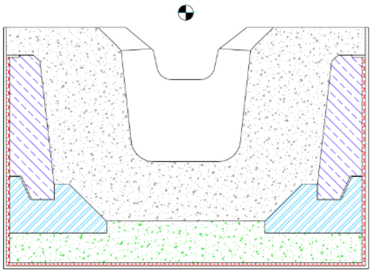

Fig. 13 : classical TRB main runner cross section design

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