NEW AGGREGATE LADLE CASTABLE AT SSAB RAAHE

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ABSTRACT
This study presents the development and industrial evaluation of a new spinel-forming ladle castable incorporating ECO-TAB, a synthetic alumina-based aggregate which has a lower bulk density than conventional Tabular Alumina. This investigation, conducted at SSAB Raahe, aimed to enhance thermal efficiency and reduce refractory material consumption in steel ladle linings. Comparative laboratory analyses demonstrated that the ECO-TAB castable exhibits mechanical properties, wear resistance, and slag infiltration behaviour equivalent to those of conventional tabular alumina-based formulations. Full-scale industrial trials confirmed the castable suitability for application in the bottom and side wall linings of steel ladles, with no adverse effects on workability, curing, or drying. Post-mortem microstructural examinations revealed similar wear and slag infiltration profiles for ECO-TAB and standard aggregates. Furthermore, a slight reduction in steel cooling rate was observed, translating into potential annual energy cost savings of approximately €260,000. These findings support the technical and economic viability of ECO-TAB as a sustainable alternative aggregate for refractory applications in the steel industry.

INTRODUCTION

The steel industry is continually seeking advancements in refractory technology to enhance the efficiency and life time of steel ladle linings. At SSAB Raahe, a significant step has been taken over the past three decades, with the implementation of monolithic steel ladle linings using spinel-forming castables and improved relining technology. This approach has demonstrated noteworthy benefits, including reduced specific material consumption, high wear resistance, and minimal slag infiltration. These advantages contribute to lower material losses during both the hot cycle and the cleaning process prior to relining.
A notable development in this field has been the introduction of the synthetic-alumina based aggregate, ECO-TAB, introduced by Almatis during the UNITECR conference in 2023 [1]. This new aggregate, with approximately 10% lower bulk density compared to regular tabular alumina, aims to further decrease material consumption and heat losses from steel to the refractory lining. The development of a new spinel-forming ladle castable based on ECO-TAB has undergone rigorous testing at SSAB Raahe. Initial repair tests indicated that the new castable maintained the same wear resistance as the regular castable. Subsequent trials, which included a complete lining of the bottom and side-wall (excluding the slag line), confirmed the comparable wear behaviour of the new castable.
This paper investigates the material differences between the regular spinel-forming castable and the newly developed castable based on ECO-TAB. It also presents industrial experiences from the application of these materials in steel ladle linings at SSAB Raahe. Additionally, the paper discusses ongoing extended trials aimed at statistically analysing the impact of the new castable on heat losses. Throughout these investigations, the study aims to provide a comprehensive understanding of the benefits and performance of the new refractory materials in enhancing steel ladle lining technology.

CASTABLE PROPERTIES

Materials and Methods

The standard spinel forming castable as applied in the ladle side wall at SSAB includes Tabular Alumina and white fused alumina ranging from 0 – 10 mm in different particle size classes. Betker developed a spinel forming castable based on ECO-TAB where majority of 0 – 10 mm were substituted directly, but the very fine fractions 0-0.3 mm and -0.045 mm remained as Tabular Alumina. As shown in Tab. 1 the water demand for the ECO-TAB based castable has increased by 1%. This is in line with previous observations [1] due to the additional aggregate porosity being infiltrated with water.

Tab. 1: Tested ladle side wall castables

	ECO-TAB Castable	Standard Castable
Al_2O_3	95%	95%
MgO	3%	3%
CaO	0.8%	0.8%
SiO_2	0.5%	0.5%
Synthetic alumina fraction 0 – 10 mm	ECO-TAB (except 0-0.3 mm and -0.045 mm)	Tabular Alumina and WFA
Water demand lab	6%	5%
Water demand in application	~5.8%	~5.3%

For calculation of the cooling rate, the temperature difference between the end of CAS-OB treatment and the second measurement in tundish during continuous casting was taken. It should be noted that the tundish is in hot stage during second measurement and it will not affect temperature losses. The data was filtered as below to minimise false data:

- Ladle empty time <120 minutes
- Only CAS-OB heats
- Interstitial free steel heats are excluded
- First heats of the sequence are excluded
- Only from CC4 and CC5

Physical parameters of castables

The flow values and wet out times for the two castables are comparable once the water demand is adjusted for the ECO-TAB containing castable (Tab. 2).

Tab. 2: Flow values of the ladle castables measured after 10, 30 and 60 minutes.

	Unit	ECO-TAB Castable	Standard Castable
Wet out time	s	20	25
SFL-flow 10 min	mm	256	253

SFL-flow 30 min	mm	221	224
SFL-flow 60 min	mm	132	145

As shown in Fig. 1 the exothermal and ultrasound measurement shows comparable setting times for both castables.
Therefore, it can be concluded that no changes in the castable recipe are necessary while workability and setting time are maintained.

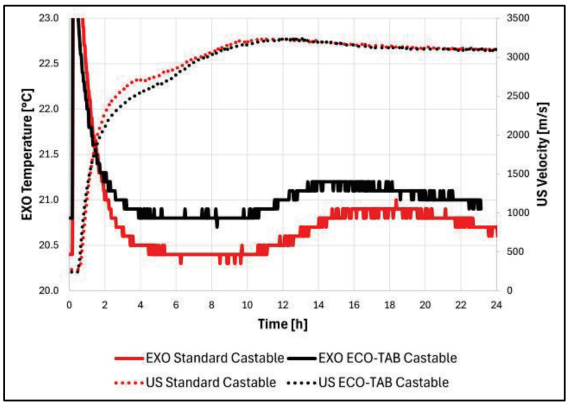

Fig. 1: Setting of Standard and ECO-TAB based castables.

As expected, the castable incorporating ECO-TAB exhibited a reduction in bulk density of approximately 3% across the entire temperature range from 20 °C to 1600 °C (Fig. 2).

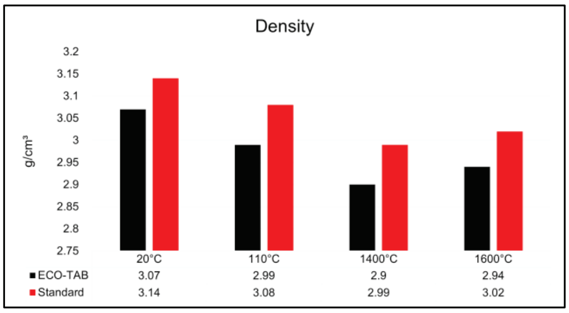

Fig. 2: Density of ladle castables dependent upon firing temperature.

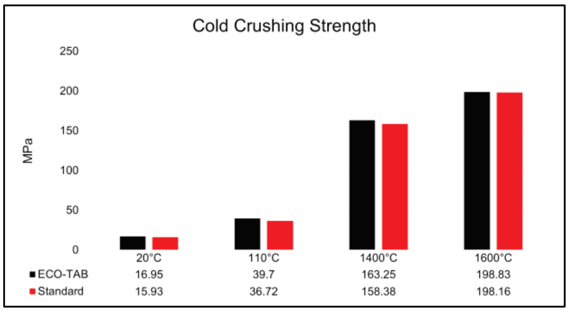

Fig. 3: Cold crushing strength of ladle castables dependent upon firing temperature.

As can be observed in Fig. 3, despite the increased water demand and lower porosity the strength of both castables remains the same. This is in line with previous observations by Almatis [1]
The permanent linear change (PLC) for the castables is shown in Fig. 4, fired at temperatures of 1400°C and 1600°C. Similar to previous results, the castables show very comparable physical parameters.

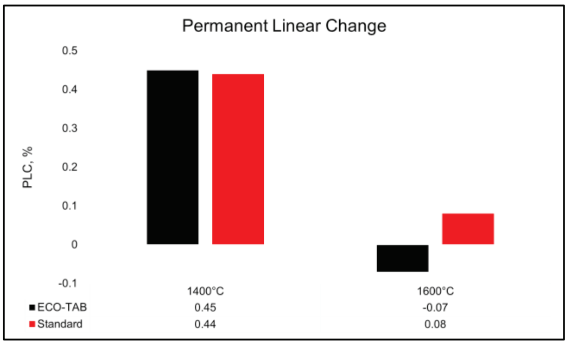

Fig. 4: Permanent linear change for the ladle castables at 1400°C and 1600°C.

INDUSTRIAL EXPERIENCES

Experiences from steel ladle application

The ECO-TAB castable was applied in the bottom and side wall wear lining in three trial periods between 2024 and 2025. In the first period the castable was used for repairs only to observe the general performance within the application. This was later extended to a full lining of one ladle.
50 mt of ECO-TAB castable was used in a second trial phase performed in September 2024. In the third trial phase over a period of one month, 16 ladles were lined with ECO-TAB based castable. This has resulted in a total consumption of 134 mt of castable since 2025.

Fig. 5 shows the typical steel ladle cycle at SSAB Raahe. A typical ladle is used for 160 heats, which corresponds to 20-23 days of production. After ~82 heats the ladle is repaired over a period of 5-8 days followed by 80 additional heats.

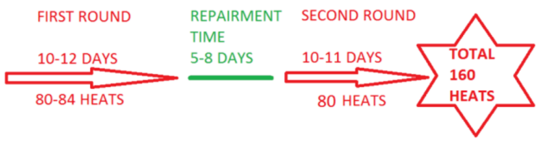

Fig. 5: Usage of steel ladles at SSAB Raahe.

The ECO-TAB castable was installed in the side wall and bottom working lining as highlighted in Tab. 3. Insulation, the backup lining and slag line was installed as usual without any changes.

Tab. 3: Ladle lining concept at SSAB Raahe.

	Insulation	Backup lining	Working lining
Slag line	Fireclay brick	Alumina spinel forming castable	MgO-C brick
Wall	Chamotte brick	Alumina brick	Alumina spinel forming castable
Bottom		Chamotte brick	Alumina spinel forming castable

Workability, curing and drying

Flow and workability are a critical factors for the application of the castable. The castable is mixed in a batch mixer connected to a double piston pump and then transferred through a piping system to the casting spot at the ladle. Clogging due to insufficient flow or early setting would lead to cumbersome cleaning and an extension of the installation time.

Similar flow and workability was achieved for the ECO-TAB castable with the necessary water adjustment. The curing and drying schedule remained the same and without any issues. The additional water content of the ECO-TAB castable showed no negative effect during drying.

Fig. 6: Ladle with applied ECO-TAB lining at the bottom and the side wall.

Fig. 6 shows a newly relined steel ladle with an ECO-TAB castable installed in the bottom and side wall wear lining. In the next step MgO-C bricks will be installed for the slag line on top of the castable.

<u>Material consumption</u>

Both castables showed similar material consumption values. The differences found in mid and full repairs and the overall material usage remained within the expected variation range (Tab. 4).

Tab. 4: Material consumption for ladle repairs.

Material	Standard Castable	ECO-TAB Castable
Average mid repairs	5.3 mt	5.0 mt
Average full repairs	10.5 mt	11.1 mt
Average Total	8.5 mt	8.1 mt

<u>Lining Performance</u>

As already shown in Tab. 1 the chemical composition of the raw materials remains unchanged. The primary distinction lies in the microstructure of ECO-TAB, which exhibits increased porosity. Although the number of pores is higher, their size is smaller, resulting in no adverse impact on performance. Laboratory tests involving slag crucibles with steel ladle slag at 1600°C confirm the performance of ECO-TAB. An examination of Fig. 7 shows no difference in infiltration depth into the refractory castables.

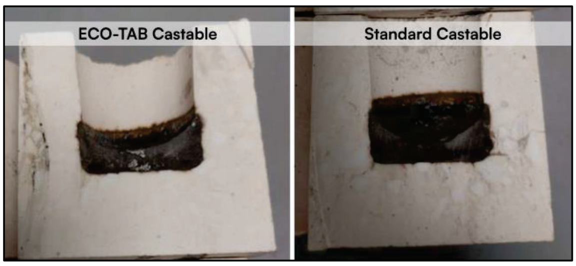

Fig. 7: Slag crucible test of ladle castables.

The lab test confirms the results that were obtained during application at SSAB Raahe. The ladle lifetime was unchanged, whether the standard castable or the ECO-TAB based castable was used. This also applies for the wear of the ramp or the purging plugs.

Fig. 8 shows a steel ladle lined with ECO-TAB after 82 heats. The wear of the impact area, around the purging plugs and at side wall is very typical and comparable for the wear of the standard castable.

Fig. 8: Used steel ladle with ECO-TAB lining after 82 heats.

<u>Cooling rate of steel</u>

Considering the temperature difference between CAS-OB and the continuous casting machine, the cooling rate was marginally lower with ECO-TAB. Specifically, the mean difference was 0.01 °C/min, and the median difference was 0.02 °C/min, as shown in Fig. 9. These values compare well with the calculations provided by Almatis. For example, with a ladle filled time of 100 minutes, a temperature loss reduction of 1°C can be achieved.

However, it is important to note that the current number of data points remains limited. While the observed trends are promising, additional data and a broader historical dataset would be necessary to draw statistically significant conclusions.

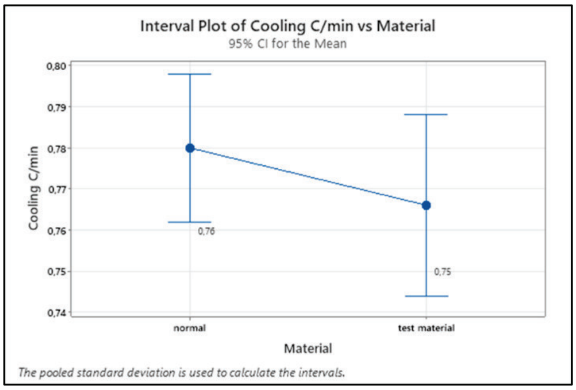

Fig. 9: Cooling rate in °C/min for fully relined ladles (test material = ECO-TAB castable)

The costs for the loss of 1°C steel temperature is considered to be in the range of 0.05 – 0.1 € per ton of steel [2]. In times of energy crisis these costs can easily be doubled.

As reported by van Beurden [3] the cost of 1°C loss per ton of steel has been €0.05/mt steel. However, the current costs are expected to be in the range of €0.14/mt steel, considering the increased energy and CO_2 prices.

At first glance, a reduction in cooling rate of 0.01 °C/min may appear to be negligible. However, this figure is put into

perspective when the large volume a steel plant such as SSAB Raahe is producing is taken into account.
Assuming an intermediate energy cost of €0.10 per metric tonne per °C, a slower cooling rate of 0.01 °C per minute, a treatment time of 100 minutes, and an annual production of 2.6 million tonnes, SSAB Raahe can achieve yearly savings of approximately €260,000 through reduced heat losses alone.

MINERALOGICAL INVESTIGATIONS OF CASTABLES AFTER USE

Post-mortem analysis of steel ladle side wall

Samples of the standard and the ECO-TAB side wall castable were taken after the ladle went for repair. The samples were prepared and investigated with an electron microscope at the DIFK (Deutsches Institut für Feuerfest und Keramik GmbH).
Fig. 10 shows the polished sections of the specimens. Both show the remaining layer of slag and infiltration into the refractory material.

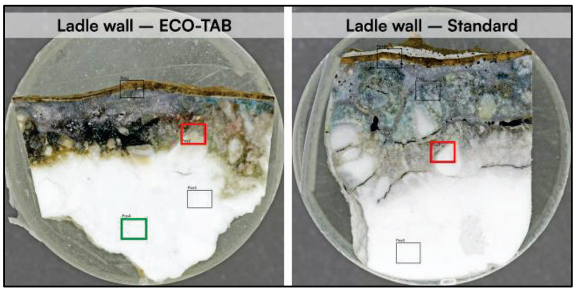

Fig. 10: Polished sections of post-mortem ladle side wall castables based on ECO-TAB and Standard recipe.

The area directly below the heavily infiltrated section as highlighted in red shows the section of the SEM image in Fig. 11. Both grains, ECO-TAB or standard Tabular Alumina, show a comparable width of the reaction rim. The infiltration within the reaction rim is comparable as indicated by the similar level of impurities shown in Tab. 5. The core of the grain consists of mainly Corundum as is expected for the raw materials that have been used. The slight increase in Calcia is likely to come from a small amount of slag which has infiltrated into the grains.
Therefore, it can be concluded that even on the hot side of a castable and in an area of high slag attack, the grain infiltration in ECO-TAB was found to be comparable to that observed in standard tabular alumina, based on reaction rim width and impurity levels.

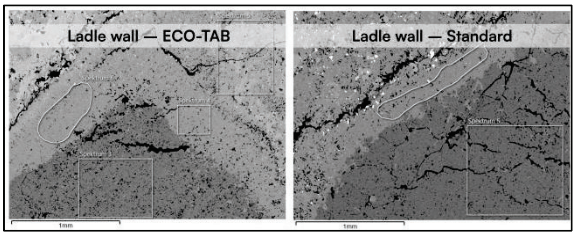

Fig. 11: Synthetic alumina grains on hot side showing a reaction rim with infiltrated slag.

Tab. 5: EDX chemistry measurements of sintered alumina grains and their reaction rim.

Oxide	ECO-TAB (Reaction rim)	ECO-TAB (Grain)	Standard (Reaction rim)	Standard (Grain)
Al_2O_3	88.7	99.7	88.1	99.7
CaO	8.9	0.3	8.8	0.4
SiO_2	1.4	-	2.0	-
FeO	1.0	-	0.5	-

Fig. 12 shows the SEM picture of an area with very little slag infiltration (green rectangle in Fig. 10). The image clearly illustrates the microstructural differences between the new ECO-TAB aggregate and conventional tabular alumina grains. The coarser ECO-TAB grains have a homogeneously distributed porosity of very small pore size, whereas the smaller light grey Tabular Alumina particles (0-0.3 mm) show the typical dense microstructure of T60/T64.

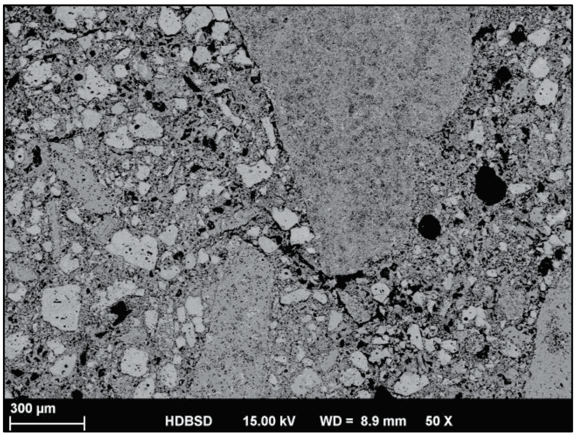

Fig. 12: SEM image of non-infiltrated castable showing coarse ECO-TAB grains surrounded by fine T60/T64 Tabular grain fraction.

SUMMARY

This paper has examined the development and application of a spinel-forming ladle castable incorporating ECO-TAB, a synthetic alumina aggregate with reduced bulk density. Laboratory characterisation and industrial trials at SSAB Raahe indicate that the ECO-TAB based castable exhibits comparable mechanical properties, wear resistance, and slag infiltration behaviour to conventional Tabular Alumina based formulations. Despite a slightly higher water demand, the castable maintained the same workability and setting characteristics. Microstructural analysis confirmed that the increased porosity of ECO-TAB does not adversely affect performance.
Although the reduction in steel cooling rate was marginal (approximately 0.01 °C/min), extrapolation to full-scale operations indicates a potential annual energy cost saving of around €260,000. This outcome emphasises the practical advantages of ECO-TAB, not only in maintaining refractory performance but also in contributing to improved thermal efficiency and operational cost reduction. These findings reinforce the technical and economic viability of ECO-TAB as a sustainable alternative aggregate for steel ladle linings.

REFERENCES

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