Case studies - Improving EAF operations by utilizing ALX™ graphite electrodes and the ARCHITECH™ furnace evaluation system.

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This paper focuses on the benefits of differentiated products and services. In 2004, GrafTech introduced the Apollo pin-less electrode that was later renamed ALX™ after further improvements in the joint design. The article discusses the ALX™ recent performance at high productivity Electric Arc Furnaces around the world and the associated benefits. The paper also discusses the supply of value added services provided through the ArchiTech™ Arc Furnace evaluation system. Continuous monitoring of EAF parameters coupled with advanced analysis, reporting and alerting tools are discussed with practical examples of value delivery at EAF locations.

KEYWORDS: APOLLO - ALX - PIN-LESS ELECTRODE - ARCHITECH FURNACE EVALUATION SYSTEM - ADDED VALUE - ALERTS - HYDRAULIC VARIANCE - REFRACTORY INDEX - ARC VOLTAGE - PRODUCTIVITY

Part 1: The ALX pin less electrodes

BACKGROUND
In 2004, GrafTech introduced the Apollo™ graphite electrodes, a breakthrough electrode technology aimed at eliminating stub losses, reducing electrode specific consumption and improving productivity in steelmaking EAFs. The patented technology consisted of a pin-less electrode with a 2TPI joint whose female and male parts were directly machined into the graphite electrode rod. The technology also includes an Auto-Lok™ system providing superior joint strength and high resistance to joint reopening. See figure 1. Details of the technology were discussed by R.Smith et al [1].

Fig. 1 - ALX and AUTO-LOK chemical locking system

- New pin-less joint design
- Stronger than socket/pin joint
- Thermally compatible
- Lower in electrical resistance than socket/pin joint

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In 2009, further improvements were brought to the joint design and the new ALX electrode was launched to the market. ALX electrodes are available for electrode diameters 600mm, 700mm and 750mm.

**Why ALX?**
Electrode consumption in EAFs is mostly continuous due to side oxidation (carbon reacting with furnace gases, air intake, slag) and tip consumption (sublimation of the graphite by high temperature arc). These phenomena are pretty well understood and models [2] are available to anticipate the electrode consumption based on EAF parameters. Typically, continuous mode of electrode consumption represents 80 to 100% of the total graphite consumption, electrode breakages (failures at the top or middle joint of the graphite column) 0 to 10% and stub losses (graphite failure at the bottom joint) typically 0 to 10%.

Over the years, graphite makers have directed most of their efforts at improving the electrode bottom joint performance by improving the electrode and connecting pin properties and the compatibility between the two. However, in more severe applications which are mechanically more stressful to electrode columns (e.g. excess vibrations) or which use high kA or aggressive oxygen practices, stub losses remain an issue. Stub losses do not only result in excess graphite consumption per ton of steel produced but also, in some cases, they cause furnace delays when graphite stubs plug the tapping hole.

Thus, the ALX solution was introduced for these furnaces where standard electrodes with connecting pins are unable to solve the stub loss phenomenon.

By design, ALX is indeed a stub loss free solution. Besides the joint dimensions carefully designed by finite element analysis, material from both sides of the joint is made of exactly the same graphite thus alleviating material compatibility issues met with electrodes equipped with connecting pins.

Between 2004 and 2015, APOLLO and ALX electrodes were tested in more than fifty locations. On average, at these locations, the net electrode consumption (which excludes the top joint breakages but includes the stub losses) was reduced by 8% with benefits up to 15% depending on the application.

ALX electrodes also offer higher current carrying capabilities thanks to the lower joint resistance thus the possibility to boost the active power in the EAF without change in electrode diameter. See figure 2.

**ALX and top joint breakages**
After the introduction of the ALX design in 2009, besides further improvements in low column performance, the rate of top joint breakages with our pin-less electrodes also started to decrease, as will be illustrated later with our case studies.

However, for an optimum “get back” with ALX electrodes, one must consider using this product in an EAF which only breaks few electrodes a month. Typically, a breakage rate of 3% (3 electrode breaks per 100 pieces additions) and below is acceptable. The reason being that due to the unique joint design, ALX broken pieces cannot immediately be recycled/recovered for use in the steel plant.

It is worth noting that, if immediate reuse of broken pieces is not a must, GrafTech customer service and manufacturing plants offer recovery and re-machining solutions for ALX material.

**Solutions for ALX electrodes handling and jointing**
Since 2004, major improvements have been brought to the handling and jointing of APOLLO and now ALX electrodes.

New solutions now offer a single handling tool for jointing and column lifting. These tools have become standard from various manufacturers [3].

Options for “on-furnace robotic additions” are also now available from companies like FAST/EXO Technologies, NIKKO or Piccardi.
Case studies:

1-ArcelorMittal - Differdange

Differdange is located in Luxemburg. Furnace characteristics are shown in figure 4.

<table>
<thead>
<tr>
<th>Type of EAF</th>
<th>DC, twin shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>SMS Demag - Revamped by Sarralle in 2008</td>
</tr>
<tr>
<td>Tapping weight</td>
<td>150 liquid mt</td>
</tr>
<tr>
<td>Shell diameter</td>
<td>7.7m</td>
</tr>
<tr>
<td>Electrode size</td>
<td>750x2700mm</td>
</tr>
<tr>
<td>Electrode additions</td>
<td>Off-furnace with Fast Technology automatic jointing station.</td>
</tr>
<tr>
<td>Charge/Number of baskets</td>
<td>100% scrap, two baskets</td>
</tr>
<tr>
<td>Transformer capacity</td>
<td>2x80 MVA</td>
</tr>
<tr>
<td>Current load</td>
<td>124kA average, 136kA max</td>
</tr>
<tr>
<td>Average power</td>
<td>100 MW</td>
</tr>
<tr>
<td>Productivity</td>
<td>175 mt/hr</td>
</tr>
<tr>
<td>Annual production</td>
<td>1,250,000 mt</td>
</tr>
<tr>
<td>Type of steel products</td>
<td>Low carbon, Beam blanks</td>
</tr>
<tr>
<td>Others:</td>
<td>Camera system for electrode performance monitoring (developed by Arcelor Mittal R&amp;D) GrafTech ArchiTech EAF monitoring system</td>
</tr>
</tbody>
</table>

This high productivity shop first started using APOLLO electrodes in 2007 and ALX electrodes from 2009. The shop is equipped with a camera system which was developed by Arbed Research (now ArcelorMittal R&D) [4] and which monitors the electrode tip performance. Figure 5 is a capture of an ALX joint consumed through the arc tip. It shows the uniform and predictable rate of consumption of the ALX joint. Electrode additions are made off-furnace using an automatic jointing station.

Fig. 5 - ALX joint consumed through the arc tip at Differdange on February 10th 2016. Capture by Arcelor Mittal camera system.
Electric arc furnace

Figure 6 illustrates the electrode consumption and breakage rate respectively since 2013. One can see the 10% advantage in specific consumption (kg/t) over competition providing electrodes with a standard joint equipped with connecting pins. Also worth noting is the extremely low ALX electrode breakage rate. As a matter of fact, Differdange EAF enjoyed a continuous 18 months period without a single ALX top joint break. Worth mentioning that the application is scrap based thus not necessarily friendly to electrodes.

Besides the improvement in specific consumption, meltpshop management perceives the ALX product as being stronger and more reliable than electrodes with standard joints. It provides a safer working environment for furnace operators thanks to the reduction in electrode break occurrences and related hazardous fishing operations.

**Fig. 6** - Electrode consumption and breakage rate at ArcelorMittal Differdange

### Belval

Belval is a sister company of Differdange, also located in Luxemburg. Furnace characteristics are shown in figure 7. It is another high productivity shop producing large and medium sections. An initial APOLLO trial took place in March 2007 and Belval has been using ALX electrodes regularly since April 2010. Electrode additions in this shop are on furnace and fully robotic.

**Fig. 7** - ArcelorMittal Belval furnace details

<table>
<thead>
<tr>
<th>Type of EAF</th>
<th>DC, single shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>SMS Demag - Revamped by VAI Siemens in 2013</td>
</tr>
<tr>
<td>Tapping weight</td>
<td>155 liquid mt</td>
</tr>
<tr>
<td>Shell diameter</td>
<td>6.0m</td>
</tr>
<tr>
<td>Electrode size</td>
<td>750x2700mm</td>
</tr>
<tr>
<td>Electrode additions</td>
<td>On-Furnace with Picardi robot</td>
</tr>
<tr>
<td>Charge/Number of baskets</td>
<td>100% scrap, two baskets</td>
</tr>
<tr>
<td>Transformer capacity</td>
<td>2x70 MVA</td>
</tr>
<tr>
<td>Current load</td>
<td>122kA average, 136kA max</td>
</tr>
<tr>
<td>Average power</td>
<td>105 MW</td>
</tr>
<tr>
<td>Productivity</td>
<td>162 mt/hr</td>
</tr>
<tr>
<td>Annual production</td>
<td>900,000 mt</td>
</tr>
<tr>
<td>Type of steel products</td>
<td>Low carbon, Light and medium sections</td>
</tr>
<tr>
<td>Others:</td>
<td>Camera system for electrode performance monitoring (developed by ArcelorMittal R&amp;D) GrafiTech ArciTech EAF monitoring system</td>
</tr>
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</table>

Figure 8 illustrates the electrode consumption and breakage rate respectively since 2013. Once again, the ALX product shows a clear advantage in specific consumption (kg/t) and in breakage rate over competition which supplies electrodes with connecting pins. Note that the electrode breakage rate increased both for ALX electrodes and competitive product during 2015 after a new electrode mast was installed at the EAF in December 2014.
Meltshop management sees ALX electrodes as a clear advantage to increase furnace availability. It is estimated that the lower electrode specific consumption (meaning less additions) and the reduced breakage rate (meaning less furnace stops) increased the furnace availability by more than 2,700 min during 2015.

3-Oskol ElectroMetallurgical Kombinat (OEMK)
OEMK is located in the Russian province of Belgorod. It is a longtime business partner of GrafTech and in 2015, both companies agreed to test ALX material on one of the four EAFs. OEMK is a fully integrated plant producing DRI, which typically makes 67% of the EAFs charge. Plant and furnace characteristics are shown in figure 9. Due to the type of operation (DRI charge, flat bath operation, low electrode breakage rate), it appeared to be a good location for testing ALX electrodes.

The ALX electrode trial consisted of 146MT and was on furnace for five weeks during the summer of 2015. There were no issues with the ALX electrodes utilization and a clear reduction in stub losses with improved tip appearance (see picture in figure 10). Specific consumption showed almost a 5% advantage over standard electrodes with connecting pins and a single accidental top joint break was experienced (0.86% breakage rate). Meltshop management was adamant that the use of the ALX electrodes provided a clear improvement in bottom joint performance and a larger trial is planned in 2016 to assess more accurately the benefits.
Electric arc furnace

Part 2: The ArchiTech™ furnace evaluation system.

The ArchiTech™ Platform

ArchiTech is GrafTech’s Electric Arc Furnace evaluation tool that enables users to manage their operations data from any web-enabled device. The system was developed by GrafTech’s Technical Service Group and it is designed to capture all the electrical and select non-electrical data from an EAF for complete evaluation, analysis and remedial action when necessary. It is also a powerful diagnostic tool that uses statistical tests and email alerts to capture significant events that affect the efficiency of the operation [5].

The hardware platform is self-contained and requires connections to the existing EAF power metering transformers, PLC platforms, and an internet connection to the remote server. A digital signal processor calculates all electrical quantities – RMS voltage and current, power, power factor, phase sequence, energy, THD – to full accuracy and updates the values to internal polling registers. The repetitive electrical sampling enables power quality analysis to the 15th harmonic. Select non electrical variables are read continuously and include chemical energy, charge weight, alloy additions, tap temperature, hydraulic mast pressure, transformer tap position, as well as various discrete I/O. All data is integrated and transmitted via a TCP/IP connection to a remote server for data archiving and interpretation.

SQL server provides the data storage backend for the varieties of data collected and is used to perform queries, analysis, synchronization and sharing across all data types. This includes serving numerous web-enabled visual management displays, reports, and predictive maintenance tools. The predictive maintenance tools make use of statistical hypothesis tests to identify significant changes that influence the operating characteristics of the furnace. While a definitive root cause is not provided, a variety of email alerts coupled with further evaluation facilitate the investigation process to determine the source of the problem.

Case studies:

1-Hydraulic Pressure Variance at SdI, Engineered Bar Products Division, Pittsboro, USA

The ArchiTech system monitors the hydraulic pressure variance of the individual electrode masts in an effort to quantify the integrity of the regulation system. If the regulation system is setup correctly, the regulator will control the mast movements smoothly resulting in stable power input and consistent hydraulic pressure variances among the phases. If the regulation system is not setup correctly, power input, hydraulic pressures and mast movements can vary wildly. In the case of the later, it usually points to a breakdown in the hydraulic circuit, mechanical system, or a physical change to the regulator set-points/gain curves. To evaluate the integrity of the regulation, a statistical test (F-test) is used to compare the baseline hydraulic variance to a representative sample of the most recent operation. To minimize false positives due to normal variations, the baseline test data is established over several days of operation. When a statistically significant difference in variance is recognized, an email alert is generated notifying operators that something has changed. This prompts an examination of the entire regulation system. Often times a mast will hang up or not come down at all due to a scrap wedge. Other times, one or more roller bearings need adjusted, lubricated, or replaced, as was the case in the example depicted in figure 12.
In this example, the first alert resulted in a response from maintenance to lubricate the rollers. Followed by a second alert which prompted the replacement of four (4) out of the twelve (12) roller bearings (load bearing side of mast). Issues like this, if left unattended, can be expensive in terms of mast damage due to roller friction, premature delta wear from excess lateral movement, increased refractory wear from changes in the arc, electrode breaks from poor system response, and lost production from extended down time.

2-Ladle Slag Line Life improvement at TATA Steel Aldwarke LMF3, UK

The ArchiTech system monitors the electrical operation via a power meter but in addition can collect additional data from the plant PLC. In this case, the transformer tap and the regulator current curve number were collected enabling monitoring of the % usage of "standard heating" and "carbon critical" setups. Figure 13 is an ArchiTech report illustrating the usage of Tap 5:3 (carbon critical) and Tap 5:4 (standard heating). Tap 6 is "emergency heating" for limited use when faster temperature pickup is required.

LMF3 was originally setup to be ultra-safe because of carbon critical grades with a very long arc for a ladle furnace. During discussions in 2014, it became evident that a significant proportion of heats did not require this and there was an opportunity to reduce average arc voltage (Varc) and refractory index (Rind) for "standard" grades. Trials took place to determine the "standard heating" setup and Tap 5 Curve 4 was decided upon and was introduced into operation in Dec 2014.

Fig. 12 - Hydraulic Pressure Variance Alert

Fig. 13 - Voltage tap and current curve characteristics

Fig. 14 - Evolution of Arc Voltage and Refractory Index at LMF3
Figure 14 shows that during 2015 the average Varc reduced from 150 to 145 volts and Rind from 65 to 62. The variations over time are due to fluctuations in usage of “standard heating” from 10 to 40% depending on grades being produced. The 5% reduction in average Rind has resulted in an improvement in slag line life of 3 heats representing ~75 fewer slag lines per year. Future plans include adjustments to the “standard heating” setup to reduce Varc and Rind further as well as operator training to increase the % usage of standard heating without risking carbon critical grades.

3-Optimization of EAF electrical parameters at Ferriera Valsabbia, Italy

In August 2015, Ferriera Valsabbia modified the EAF transformer connection type to increase the average operating secondary voltage. The primary of the EAF transformer was modified from a 15 kV primary (Delta/Delta) to a 30 kV primary (Star/Delta). This modification resulted in an increase in available secondary voltage along with higher active power (MW) and lower power-on time.

The ArchiTech EAF analysis supported the optimization of arc stability and arc voltage throughout the process. Several adjustments were performed to the furnace power program and EAF operating points to reach the desired final settings.

As illustrated in figure 15, the active power increased by 11% from September to November 2015 and by a further 4% from December to January 2016. Consequently, power-on time decreased by 7% from September to November 2015 and by another 1% from December to January 2016. Initially, the average arc voltage (i.e. arc length) increased by 7% while the slag index increased by 20%. These conditions were not acceptable for the furnace operation and further improvements in October/November 2015 were necessary. Final adjustments to the furnace operating points were performed in January to increase the arc voltage and active power while maintaining the slag index at an optimum level.

In summary, the change in the EAF transformer connection and subsequent power program adjustments resulted in a 16% increase in active power and a 8% reduction in power-on time.

CONCLUSION

Case studies clearly underline the benefits of both the ALX graphite electrodes and the ArchiTech furnace evaluation system. With ALX:
- Reduction in stub losses resulting in improved net specific consumption up to 15%.
- Reduction in top joint electrode breakages.
- Improved furnace availability and associated dilution of fixed costs.

In addition, a reduction in CO2 emissions can be anticipated (1 metric ton of graphite consumed emits 3.66 metric ton of CO2), up to 1,500 MT per year. However, one has to remember that the ALX electrode is not the electrode solution for all EAF applications. It is available in diameters 600, 700 and 750mm only and is designed to address chronic stub losses issues in locations where electrode breakage rates are reasonable (below 3%). It also provides opportunities for increased active power input into the EAF thanks to the higher current carrying capacity.

With ArchiTech:
- Statistical based alerts and reporting tools to help identifying and managing unexpected changes to the EAF operation.
- Remote and local service connection for better customer collaboration and remedial action.
- Continuous monitoring for EAF and LF optimization. Reduction in operating costs.

GrafTech customer technical service engineers are available to help you identify ALX and ArchiTech opportunities at your EAF.

ACKNOWLEDGEMENTS

- Thomas Fregonese, Antoine Peter – ArcelorMittal Differdange
- Michaël Szefer, Benoît Calleux, Olivier Gervais – ArcelorMittal Esch-Belval
- Vadim Kobernik – Oskol ElectroMetallurgical Kombinat
• Dan Keown, Damon Keck - Steel Dynamics, Engineered Bar Products Division, Pittsboro.
• Melvin Holmes, Scott Jackson – Tata Steel Aldwarke
• Pierluca Levrangi - Ferriera Valsabbia
• Davide Vezzani, Thierry Finot, Vladimir Toumanov, Terry Wells – GrafTech

REFERENCES


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