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Secured EAF-performance through process discipline including con-straints of raw material and experience

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Electric Arc Furnace (EAF) steelmaking plays a central role in the transition toward low-carbon and re-source-efficient steel production. Increasing energy costs, environmental regulations and needed raw mate-rial flexibility demand continuous improvements in energy efficiency and process performance. The operat-ing personnel in steelmaking plants getting younger, more than 10 years in the same profession has be-come rare. Building and maintaining dee-p-experienced staff as well as achieving highest level of safety is difficult.
This paper outlines key strategies for reducing electrical energy and material consumption in EAF opera-tions through advanced process control, supportive smart-tools, and real-time data utilization. The integra-tion of smart add-ones around the EAF combined with dynamic furnace control systems, including elec-trode regulation, foaming-slag con-trol, and optimized oxygen and carbon injection, enables more stable process conditions, increased safety and lower downtimes.
Raw material flexibility in EAF steelmaking is becoming increasingly important as the availability of high-quality scrap declines and competition for scrap intensifies which makes the entire situation even more dif-ficult. The need to work with ore-based iron units is driven by quality requirements and the demand for cleaner steel. As a result, advanced pro-cess control and adaptive operating strategies are essential to maintain productivity, energy efficiency, and final steel quality under more variable raw material conditions.
Well-proven and reliable solutions for EAF process optimization from scrap yard until tapping are presented in this paper.

KEYWORDS: RELIABILITY; EAF PROCESS CONTROL; RAW MATERIAL FLEXIBILITY; DYNAMIC EAF CONTROL; SUPPORTIVE SMART TOOLS.

INTRODUCTION

The steel industry is facing challenges with respect to globalization, decarbonization, raw material availabil-ity or even staying attractive as employer for the younger generation. The main questions are: how will the raw material situation look after most blast furnaces are shut down? Which design features or smart tools around the main equipment are needed to ensure highest flexibilities in raw material usage and highest productivity, with lowest operational costs and highest possible safety for humans? How to ensure that a limitation in workforce and experience does not have a major impact in productivity and safety?

This paper will address and briefly discuss these three

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main topics in each case and give an overview to overcome the challenges:

1. raw material flexibility, to be prepared for most developments;
2. supportive and proven tools around the EAF to increase safety and lower costs;
3. how to overcome constraints in experience and maintaining experience.

RAW MATERIAL FLEXIBILITY

Most forecasts show a difficult future regarding scrap availability with useful quality and density, especially after most integrated plants transformed to Electric Arc Furnace operation which will lead to an overall in-creased scrap usage. An increased number of scrap buckets per heat, due to low scrap density and/or a higher percentage of ore-based material usage to overcome trace elements due to lower scrap quality, will force steel mills in future to either substitute scrap with other materials or to invest in one own scrap pro-cessing equipment.

Ore-based material usage in an EAF

Steel plants which were producing advanced steel grades based on 100% scrap in the past will most prob-ably be using ore-based material in future to keep qualities and cleanliness as it was. Former integrated plants who want to keep their advanced steel grade qualities as well with their new EAF-production route have to use up to 40% ore-based material like PI, DRI or HBI; maybe even more. Not all ore-based raw materials could be charged in unlimited quantities with the scrap bucket, not all mate-rials could be used in combination without negative influences on each other and, finally, an increased us-age of DRI or HBI will lead to decreased productivity and increased operational costs, especially if the EAF is not designed for such a usage.

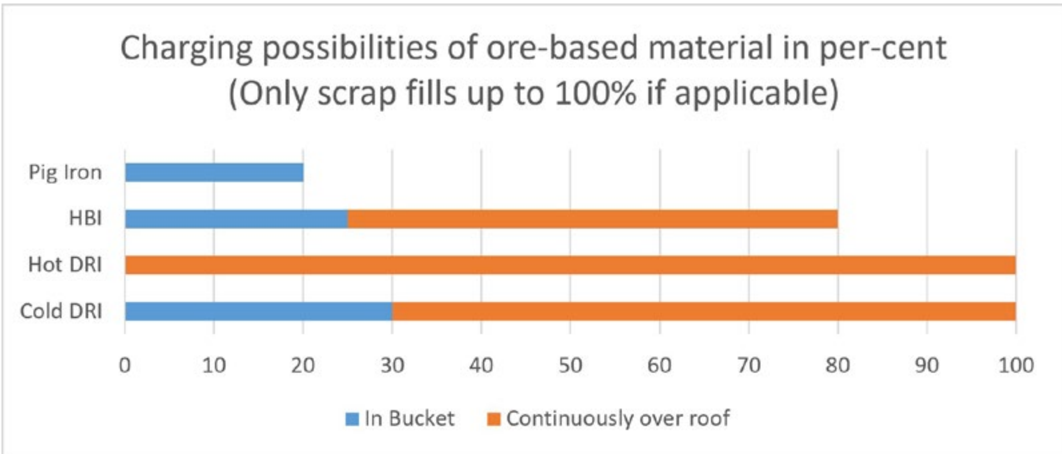

Fig.1 - Ore-based material usage in EAF.

Figure 1 shows the different possibilities of using ore-based material in an EAF. Pig iron, if not granulated, could physically not be charged continuously over roof because it is too heavy for bins and belts. A theoretical process of 100% HBI would be possible, but this will end up with a negative impact on productivity, energy and refractory. The size of the briquettes itself, mostly the chemical composition and therefore the entire melting behavior does not allow a profitable HBI usage of 100%. Globally no well-known steel-plant is constantly using HBI above 50% for a reason. Cold-DRI as well as Hot-DRI could be fed continuously over the roof up to 100%. Main operational costs for the EAF in between 100% scrap operation with a standard quality and 100% Hot-DRI through the roof based on standard quality is nearly equal.

DRI charged within the scrap buckets has its limitations because this dense material is creating icebergs which are hard to melt. For an efficient melting process such heavy and dense material needs to be charged low in the bucket to have a quick contact to the liquid heel. Having the possibility of using Hot-DRI is rare and if so, it would make no sense to charge a limited amount of Hot-DRI within the scrap bucket and lose all the benefit of increased temperature, therefore this version is not shown in figure 1. The percentages of DRI or HBI charged within the scrap bucket could vary, based on amount of hot heel or num-

ber of scrap buckets charged per heat for example.
If we combine the usage of different ore-based materials within one heat, the process tuning is even more difficult. 50% scrap usage together with 40% HBI continuously over the roof and 10% PI in the scrap bucket as example: The PI will keep the steel temperature longer on a cold level and the carbon out of the PI is very late available in the melt (>1580 °C). It is essential to find the correct raw material scenario to ensure the needed steel quality on lowest possible price base which is at the same time the most OPEX (operational cost) friendly process for the EAF.

The EAF design itself

The EAF design itself plays an important role to be efficient for specific raw material scenarios. As easy example let us compare the upper shell for an EAF with mainly scrap operation versus an EAF which is designed for DRI melting. The scrap furnace generally has a higher upper shell to create more volume. Target generally is to reduce the number of scrap buckets as much as possible per heat. One charging cycle/roof opening costs around 10 kWh/t of steel on energy losses. A DRI upper shell on the other hand does not need any volume for charging; therefore, DRI furnaces normally have low upper shells which create several benefits. Main benefit is a reduced water-cooled surface which ensure lower heat losses to the cooling water. Another benefit is the entire electrode handling because a shorter stroke ends in a more stable and reactive regulation.
Different scenarios need different design solutions to ensure most efficient process conditions, but what happens if an all-in-one solution is needed because flexibility is one of the main criteria? Following, figure 2 provides an overview over technical design adaptions to ensure a high raw material flexibility as well as efficiency using an EAF.

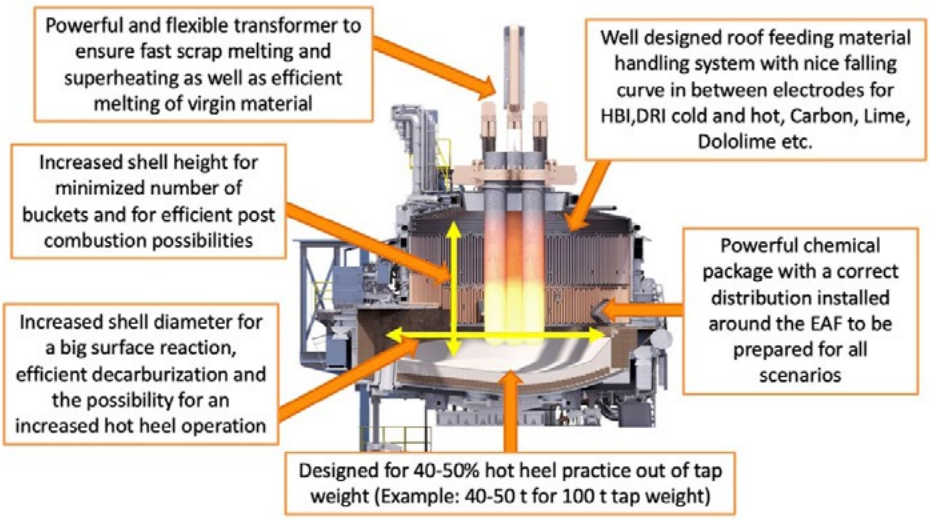

Fig.2 - Design features for high efficiency [1].

SUPPORTIVE AND PROVEN TOOLS AROUND THE EAF

More and more supporting tools around the EAF are meanwhile state-of-the-art in many steel plants. The philosophy of zero-man-on-the floor with safety fences around hazard zones should help to reduce accidents down to zero.

Which supporting tools around the EAF are existing and how proven and reliable are they?

<u>Advanced slag door to clean the slag tunnel and maybe even push the scrap inside the EAF during operation</u>
Nearly all equipment suppliers have at least one solution for a new generation of EAF-slag-door. In the standard design the slag door is lifted by a chain and lowered due its own weight. If slag is accumulated in the tunnel, it will not be possible anymore to fully close the door. New generations are equipped with hydraulic cylinders to be able to lower the door completely and to control the opening rate to create a controlled slag flow. Most of these slag doors have the possibility for cleaning the tunnel and push or,

even better, pull the slag with a horizontal movement. Using a forklift for slag door cleaning and scrap pushing is not common anymore and in quite some plants already forbidden. Some of those new door design installations are heavy, additional hydraulic close to the EAF is not really welcome due to additional possible safety issues; such complex equipment with additional cooling water usage and increased maintenance effort are as well.

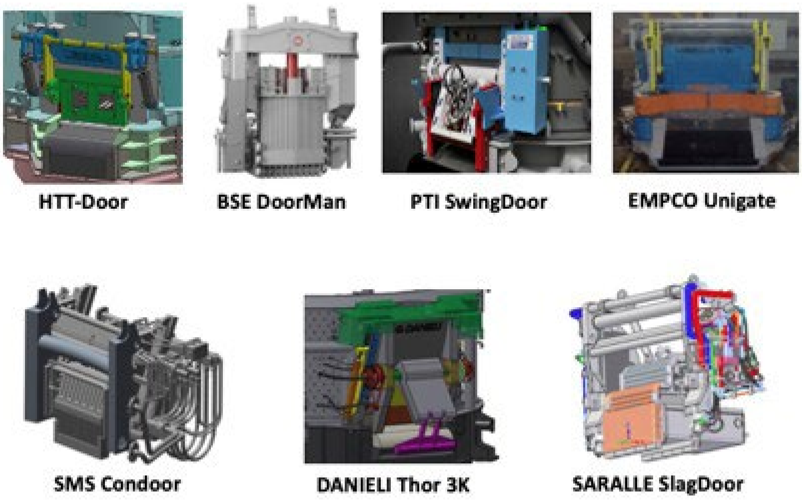

Fig.3 - Extract of some available slag doors of the new generation [2].

On the other hand, such new slag doors helping to avoid close contact to the EAF during operation and therefore it will increase the safety level combined with a controlled slag flow. An external door pusher which could be moved away from the EAF slag door (mainly by rail-tracks), and therefore away from heat and radiation in combination with an advanced slag door—just for having the opportunity to close the door and control foaming slag flow—could be a good alternative for achieving the same safety level with a higher flexibility and higher availability.

Offgas measurement devices for safety and process control

The energy losses to the furnace offgas play a major role in the energy balance of an EAF. These losses can be reduced by using dynamic process models in combination with real-time offgas monitoring, which together are controlling the process in a closed loop by closing the mass balance over carbon using the CO and CO_2 readings, together with the offgas temperature and speed/flow at the exact same spot before the offgas post-combustion starts. With the same offgas monitoring system including a water sensor, the mass balance can be closed together with an increased safety level. Leakages in the roof, sidewall or burner panels could be indicated by such sensors.

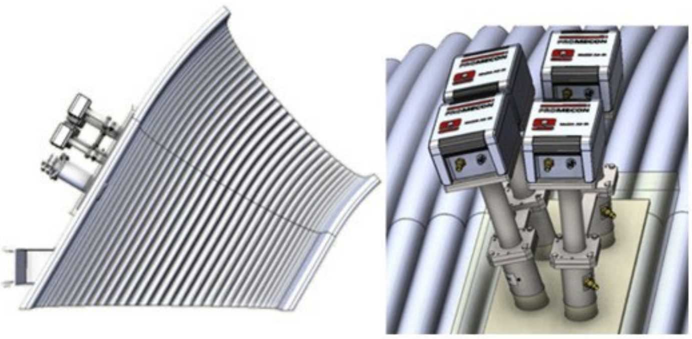

Fig.4 - Infrared oof-gas measurement [3].

A modern offgas sensor based on Infra-Red technology is shown in figure 4, which provides real-time read-ings without any lances going in the offgas duct and requir-ing little installation and maintenance efforts. Equipment availability is unbeatable since there is no installation in-side the duct. What is still insufficiently done—regardless of system or supplier—is the integration into the EAF pro-cess control system. Real cor-rections, interventions or at least pop-up windows with alarming due to the offgas readings are not done so far.

Manipulators or robots around tap-hole area as well as for temperature and sampling

Probably the most common and well-known areas for supporting tools nowadays are the temperature and sam-pling robots or manipulators. Temperature measurement and samples must be taken regularly and in most cases through the slag door. Fully automated robots can do these jobs including change of cartridges, sending these samples as well to laboratory is not yet often observed in real working order.

As second possibility—with a manipulator—whereas the most dangerous job is done by the tool, but one person around the slag door area is still needed to change car-tridges and prepare the probes.

Fig.5 - Fully automated EAF T+P robot (temperature and probe) [4].

Today most of the jobs around the taphole are still done manually in steel plants. If the furnace had an un-foreseen delay, or the EBT-filling was not done correctly, a non-free-opening can happen, and it is neces-sary to open the taphole with an oxygen lance. This could be a very hard and dangerous job but depending on access it gets com-plicated quickly. Manipulators for an automatic or at least semi-automatic oxygen blowing can support in this re-spect and in most cases, it saves time as well.

The other problem can be a blocked taphole with unmol-ten pieces, which are "rolling" into the taphole during tap-ping and this needs to be removed before taphole filling. Taphole pusher systems have been developed to sup-port here. Both systems—the oxygen lance as well as the pusher—are important tools to ensure an increased safe-ty around the EAF during operation and in-between the heats and they are available nowa-days from most sup-pliers. Since these tools are mounted directly at the EAF lower shell it is ensured, that the lance or the pusher hits the taphole correctly regardless of furnace angle. Chang-ing oxygen lances, adding ignition support on these lanc-es or tracking the lances during oxygen blowing with the correct pres-sure is the challenge here. These are mostly the reasons why solutions mentioned tend to take more time compared to doing it manually even if it works me-chanically unrestricted.

Fig.6 - Tap hole pusher (left and center) and oxygen lance (right) [4].

The tap hole pusher itself is generally easier. No consumable components, no ignition needed and so on. Finding and adjusting the correct force of pressing is the key here. If some unmolten parts really stuck in-side the taphole and the pusher is using a lot of force a possible worst-case scenario will be pushing the taphole bricks entirely inside the EAF.

Taphole filling and observation to see if the taphole is free and clean can also be done fully automated from the pulpit as shown in figure 7. This application is getting more popular as there are reliable and fast solu-tions available. Steelmakers see this as one of the best developments with respect to safety and productiv-ity as in several plants, turn-around times have been cut down to lower than 45 seconds only.

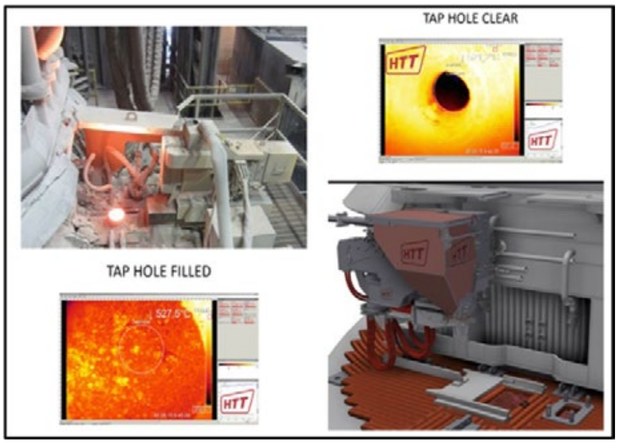

Fig.7 - Automatic tap hole filling device [5].

Electrode handling

With tools like shown in figure 8, the number of electrode breakages can be reduced as there is no risk an-ymore of too low or excessive torque and/or damaged nipples. If the electrodes are connected piece by piece from top it is working like an endless electrode and less entire electrode changes are needed. The thermal shock by bringing a new electrode column to the EAF with a cold tip is therefore reduced and the used piece is not oxidizing in the storage stand, which results in a lower overall consumption and tip loss-es. Furthermore, no person is needed on the EAF roof anymore to guide the crane driver and check the connections.

Fig.8 - Electrode handling and jointing [6].

Humidity sensor behind refractory

Every now and then, steelmakers are reporting about serious breakouts in lower shell of the EAF due to water accumulating behind the bricks coming from small leakages, where the water is not directly evapo-rated. This can happen, when the EAF is stopped, and the furnace roof is closed for example or if a leakage is directly facing the refractory gap or if the safe version of shell cooling is used (pressureless spray cool-ing). This water is destroying the refractory material or is pushing the bricks inside the furnace when heat-ed up and so leaving gaps, where the steel/slag can cut the lower shell plate.

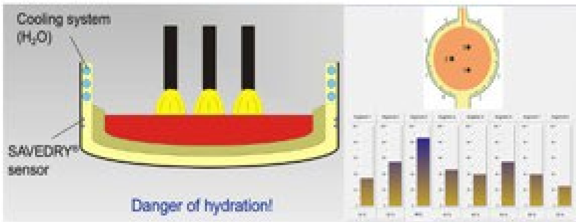

Fig.9 - Humidity measurement behind refractory [7].

When humidity accumulates behind the bricks, an alarm is created warning the operator. Often in these cases, leakages are detected in a following check of the furnace.

<u>Pressureless cooling – safety and costs</u>

The spray cooling is more than just a supportive EAF tool. As long as safety is the main concern, this topic simply cannot be omitted. If a water-leakage occurs, which can never be fully avoided in a melting or refin-ing unit, the amount of water which enters the EAF is significantly lower with < 0,1% compared to a pres-surized tubular cooling system, where the water has around 4-5 bar in the water-cooled panels itself.

Furthermore, maintenance efforts and spare part cost are less compared to tubular cooling especially if due to a high refractory-wear-index copper is needed, which could be avoided by placing the nozzles correctly and with different flows with the spray-cooled system.

Fig.10 - Spray cooled EAF equipment [8].

The overall amount of cooling water is normally reduced, but maximum the same compared to tubular de-sign. Finally, there is a higher equipment availability as with a small water leak, the EAF has not to be stopped due to a limited risk of accidents, and also a simple patch could be welded from the cold outside within 20-30 minutes in case of a larger leak instead of changing panels that is dangerous and may take hours.

Consistency and reproducible operation as much as possible in respect to product variety and raw material changes is one of the main keys to ensure highest productivity in combination with lowest operational costs. A stable and constant amount of hot heel is very important to achieve these goals. Another point where long-term expertise is needed to be able to judge correctly the amount of real hot heel (without re-maining amount of slag). Cameras, laser or radars are just able to measure distances which ends up in in-accurate results from the entire input (steel and slag) without even knowing actual bottom shape (ramming material shape). The real amount of liquid steel remained unknown. A new tool is now able to calculate the real amount of liquid steel remaining after tapping due to weight differences and resulting movements of the furnace during tilting.

Fig.11 - HMI screenshot of hot heel measurement results.

How to combine all this additional information and how to implement the supportive tools

All mentioned supportive tools in this chapter, all measured values and process data from and around the EAF, can be processed in the new generation dynamic process models to adapt online the working profiles with the consequence to improve the overall efficiency of the EAF. With a control architecture as per figure 11 for example, savings in conversion cost as well as a production increase can be theoretically achieved.

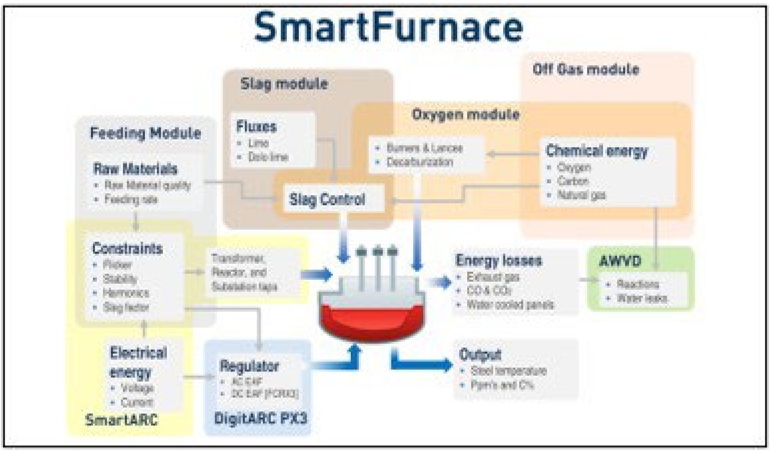

Fig.12 - Possible structure of modern EAF control [9].

This will be the future, and this will be the way to really achieve "Industry 4.0" standards and something like "zero man on the floor". These ideas and these advertisements have existed for years, but the reality still looks different. Holistically such a fully automated interlocking structure is simply not yet running or achieved. Where is the Electric Arc Furnace in operation, where for example above average CO emissions measured during scrap melting is automatically treated by changing slightly injector setpoints to be more over stochiometric to support post combustion in the shell? Where is the EAF in operation where continuous slag analysis lead to a system self-adjustment of CaO, MgO or carbon adding during the process or simply improving foaming slag?

Once again: this should be and this will be the future, now the reality shows that we are not there yet. The previously mentioned tools around the EAF already help to get more information and to avoid having people working in hazard zones, which is an important step, but the journey is not over.

HOW TO OVERCOME CONSTRAINTS IN EXPERIENCE AND HOW TO MAINTAIN EXISTING KNOWLEDGE

This is probably the most important and the most difficult topic and, at the same time, a priority all over the world. One point right from the beginning: there will be no straight answer, there is no single solution which always helps. Just a few points that could help to push the development into the right direction.

To understand actual upcoming problems or challenges, first in many plants must be understood the development and the change of people, including their way of thinking. Working behavior has changed quite a lot over the past 10-20 years, especially when you compare older generations with younger ones.

This is less about "better vs worse" and more about different priorities shaped by technology, economy, and culture. The main issue is this shift of "working attitude" which a steel plant, that is mostly located outside cities and far away from interesting "hot spots", operating 24/7 in a severe, dirty and hot environment not really offer. Work is nowadays just a part of life and there is no duty or identity anymore. Personal fulfilment matters more than stability. Strong emphasis on long-term security and staying at one company 30 years or more was normal in the past. Today job-hopping every two to five years is normal, where fast growth and flexibility is priority. This comes primarily at the expense of experience. Fixed working hours and, of course, working shifts as well during weekend, with a strict hierarchy and understandably "presence at work", was status quo and standard versus remote work and flexible hours.

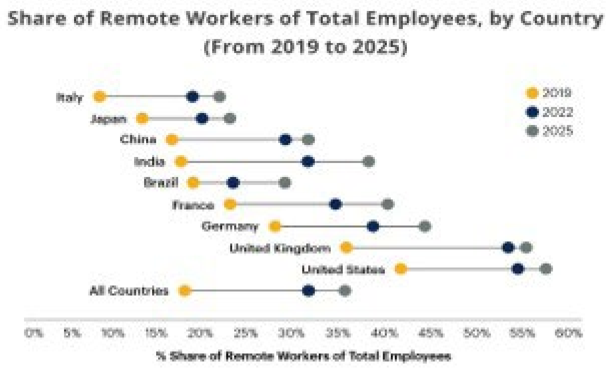

Fig.13 - Change of remote work within 7 years [10].

What hurts the most in first place is finding young people who are willing to work and learn in a steel plant and at best for more than 5 years. Steelmaking, especially if many different high-quality products are pro-duced, is a manufacturing industry which cannot be learned or fully understood after 3 years of working. Digitalization is not yet that developed in the steel industry (like mentioned in the chapter before) and, even if it were, a well-trained and knowledgeable person is always needed in the background to intervene or to react quickly and correctly in case of failure.

A very high level of automatization and digitalization is needed in future to overcome some of these prob-lems and at the same time it is essential that people do from time to time these "automated" jobs manually to learn how it is done. This "manual" knowledge and understanding of the process and the equipment is the base of being able to keep the production alive if certain mechanisms or automatisms failing and it is the base the gain a higher knowledge and confidence level to make correct decisions in critical situations. That is a balancing act which is very difficult to handle. Another example: some plants have already blocked the opportunity to manually interfere or adjust chemical and electrical setpoints if certain circumstances are changing. This will lead to a situation in future where operators, even if some are willing and know how to, are not able to adapt the process in a more efficient and safe way because the allowance is gone. A real understanding of processes and equipment from the people working on-site every single day will increase availability and decrease unforeseen delays.

A major target for the upcoming years should be the introduction of another level of automatization and digi-talization in combination with constant training and support of operators and maintenance. Flexible working hours and remote work is with above mentioned points still not realized but a situation is created where constant work (manual training sessions for example excluded) in severe conditions are minimized. Knowledge and deep expertise of workers participating in production and maintenance is one of the three pillars for business success. A human's willingness to contribute more and taking ownership increases if this human feels more as part of the "journey" and being involved in companies development instead of be-ing just "employee".

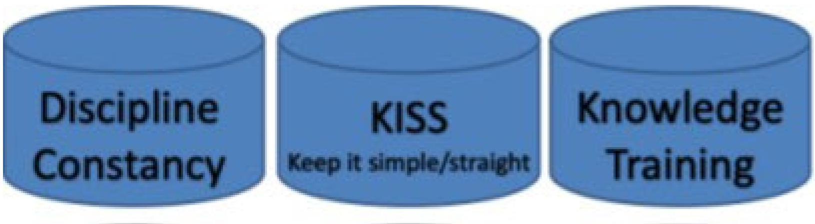

Fig.14 - Three pillars of success in production.

A major steel manufacturer in the US has implemented a bonus payment system which is as well creating some additional incentives. If the productivity is above defined target the employees receiving additional bonus which creates on top a feeling of being more honored in the entire business success and workers support each other beyond departments and core-equipment.

The importance of workers with their knowledge should not be neglected: this is the foundation of a suc-cessful cost-efficient steel production.

SUMMARY

Electric Arc Furnaces are very flexible in terms of raw material input, but some design features should be followed to combine this flexibility with the greatest possible efficiency. The integrated plants who will soon convert to electric steelmaking already studied their possibilities in raw material input and their most effi-cient way to keep their portfolio. Existing electric steelplants understand increasingly that an invest in scrap yard and own scrap cleaning as well as processing equipment together with an upgrade inside the melt shop—implementation of bins and belts for roof feeding or a modified lower shell to carry a bigger hot heel as example—could be beneficial upgrades in future.

Safety and efficiency play a key role in modern steel plant operation to be competitive on the market as well as being attractive for new operators or engineers to work in a challenging environment. Technologies, which are satisfying both aspects, have been developed and are meanwhile state-of-the-art with acceptable availability and accuracy. After all, workers are still the key. They are operating and maintaining the equip-ment, which can either produce in the most efficient way, quickly reacting to changing circumstances with a shop pacing and melt shop organization that ensures a most beneficial production based on knowledge and experience, or it could end up differently.

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