Reaching the next performance level in SBQ production – PQA – software based quality and process management*

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Abstract

A competitive landscape pressurizes the steel producers business, zero defect requirements from customers forces the operators for additional efforts in process control and quality management. The so called quality related cost, which include also rework, cost for downgrading or even scrapping of material is already a remarkable lever in a plants profitability breakdown. The introduction of advanced state of the art grades in the product portfolio requires already a budgeting for the expenses for R&D and quality management.

PQA has been developed as a process and quality management assurance software solution next to existing level 2 or level 3 automation systems. It is focusing on the analysis of process data, equipment information, in line quality measurement devices and trend analysis to obtain an answer whether the process is according to definition and expectation and whether the intermediate or final product can be shipped for further processing as prime material.

Advanced analytics which are linked to an expert know how based configuration identifies deficiencies in the production and processing process. An intelligent, state of the art quality rating system evaluates tolerable deviations.

PQA comprises the software platform including the database, data collector from the different sources in the production process and units and the configurator. The core element of the platform is the knowledge based expert know how package defining process and quality defining fundamentals.

The paper describes the structure of the software package, it gives insights on the expert know how package, process and quality evaluation and points out the customer benefits, cost reduction, improvement yield, customer satisfaction increase. An outlook is given on the adaptation of big data analytics and the utilization of AI artificial intelligence modules with the vision of a self-adaptation.

Keywords:process, product, performance, optimization, quality management, expert know how, automation, digitization, quality assessment, quality management, big data analytics, AI artificial intelligence, AHSS multiphase steel grades

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INTRODUCTION

A competitive landscape pressurizes the steel producers business, zero defect requirements from customers forces the operators for additional efforts in process control and quality management. Especially from the automotive sector, the supply of 100% prime quality has become essential and this supply need to be on time. The related quality costs and the yield of first class products define very much the steel companies' profitability and overall success significantly [1]. The introduction of advanced state of the art grades in the product portfolio requires already a budgeting for the expenses for R&D and quality management.

The SMS group company MET/Con has developed a comprehensive solution to assess the product quality over the production and processing chain. Process and production parameters originating from various data sources of the process automation are examined on their impact of quality related characteristics [2], [3], [4].

Expertknowhow and comprehensive operational experience is translated into a quality guideline and a regulation framework as the sensitive core of the PQA solution.

Once implemented, the system identifies immediately steel grade specific, deviations from ideal standard and proposes corrective actions including a final evaluation for each product at each processing step.

The PQA (Product Quality Analyser) system is a substantial tool for root cause quality analysis and provides the required support to the production team. It will become an integral part of the corporate quality management system.

MOTIVATION

Global competition forces the steel companies to satisfy their customers with

- state of the art steel grades,
- premium product quality
- timely delivery
- competitive pricing.

The remaining margin depends very much on the premium a supplier can realize for special/state of the art products and services providing additional value to the customer.

Taking into consideration that the value contribution from scrap/raw material basket (iron ore, coal) to processed galvanized steel is around 100% (**figure 1**), it is obvious that the identification of deficiencies in the process, which will or can lead to quality constraints becomes more and more important. The earlier a critical deviation can be observed, the better countermeasures can be executed in the following processes.

In this regard the PQA system is supporting the idea of dynamic processing by considering qualitative short comings of the material in earlier processing stages by correcting them in later process steps, if considered to be feasible. This decision will be made by the PQA software based on its inherent experience and metallurgical, operational and qualitative know how.

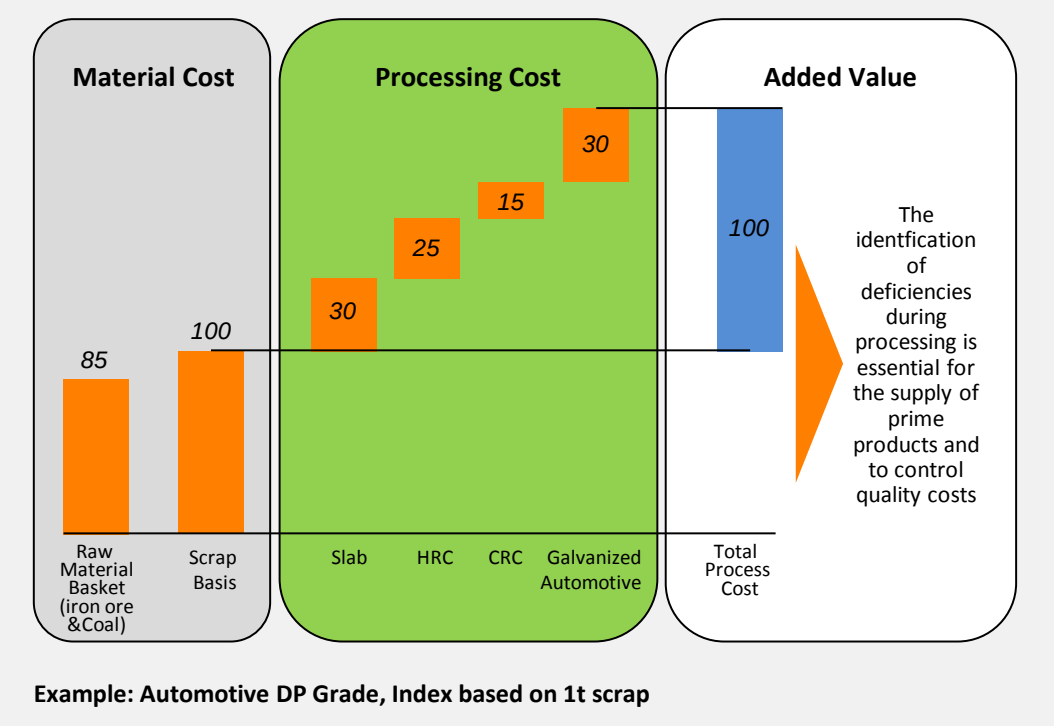

Figure 1: Value Contribution in Steelmaking

OBJECTIVES OF PLANT WIDE PRODUCT QUALITY ANALYSIS SYSTEM

Driven by market developments towards increasing demand for high end products in new market segments for advanced applications (surface quality and superior mechanical properties) customers are requiring for a holistic integrated support in quality optimization and management. MET/Con, a subsidiary of the SMS group, developed and engineered a plant wide product quality assessment system.

The main purpose of the PQA is a decision support to assure prime quality: is the material, intermediate product suitable for further processing or supply?

Signal	Meaning	Consequence
	**Blocked** ◆ Product quality not achieved ◆ Decisive quality parameter out of tolerance	◆ Reassign material to lower quality ◆ Stop further processing – use material as scrap
	**Temporary blocked** ◆ Minor quality or process deviations	◆ Advise the downstream process to counteract quality deviation ◆ Reassign to material with lower quality
	**Approved** ◆ All relevant quality parameters within the limits	◆ Forward the material to the next internal or external process

Figure 2: Quality decision matrix

The integrated solution PQA covers the essential quality aspects of the complete process chain from steelmaking, via hot rolling, cold rolling to final processing in case of strip production.

The main and essential quality aspects are covered and converted into an integrated software solution. The highlights are the following topics:

- Visualization of plant and process conditions related to product quality
- Monitoring of product quality data and interrelations to plant and process status
- Implementation of control actions into automation control loops
- Feedback strategies for operators
- Re-assignment of defective material as an option

Comprehensive process and operational know how as well as years long experience in quality management is applied to define “steel maker´s rules” to support quality decisions.

Three kinds of general standards are analyzed:

- Logical rule
- Metallurgical rule
- Empirical rule.

Figure 3 shows in the quality decision rule matrix different basic examples, the description of the problem and the linked proposed action.

Rule	Examples		
	Problem	Solution	Benefit
Logical rule	Thickness in hot strip mill with up-trend, but still in tolerance	Feed forward expert advice to the cold rolling mill: "Reduce speed for adjustment at rollstand"	Stood within thickness-tolerance in cold rolling mill
Metallurgical rule	Carbon content of the melt too low	"Lower dewpoint in the galvanizing furnace to avoid further decarbonizing"	Melt saved and reprocessing for order avoided
Empirical rules	Too much entrapped slag at tap	"Lower cleanliness status of melt and assign to lower applications"	Early identification of quality issues and assignment of melt to maximum appropriate application
Pro-active production supervision rule	Roughness with trend in the skin pass mill, but decreasing	Early warning "new workrolls in skin pass mill required"	Trend stopped before damage done

Figure 3: Quality decision rule matrix

Figure 4 gives an example how operational know how and experience can help to correct quality non-conformities at later process steps for instance by cutting off deviations before the next process step, such as thickness deviations at the end of the coil.

As an example the methodology for the rules structure is shown for one specific steel group for one specific process stepin the following table.

ULC / IF / steel grades, steel group 201 - 299

No	Process	Rule definition	Data interface	Process data acc. to interface list	Unit	Exceeded limit	Conditioning Actions Definitions	Influence to Quality C / I / S	Status	Reference Document	Affected downstream process
1	Hot metal Des-plant	Non De-sulf hot metal	Desulf_S_content_hot_metal	Desulf content before start blowing	wt% S	> 0,015%S	Additional time for secondary desulfurization at LF, increase CaO amount	Inner quality	Not valid for deep drawing application	duty book – steelplant chapter 3.1	Advice to Quality Department
2	BOF tap	EMF O free	BOF_EMF_measurement_O_free	EMF_O_free	ppm	Ofree > 1050 ppm	Scarfing – code 2 Check Al level at LF final sample	Cleanliness	On hold	duty book – steelplant chapter 3.2-3.3	
3	BOF tap	High amount of entrapped slag	BOF slag retain dev slag amaount or manual event	Manual or slag-retaining device	kg/ t steel	Slag amount > 9 kg/t	Deslagging of the slag if possible and renew the slag Increase the amount of CaO/Al addition (60/20 kg in small portions)for slag forming at LF	Cleanliness	Not valid for deep drawing application	duty book – steelplant chapter 3.3	Advice to Quality Department
4	BOF tap	BOF tap	BOF_FeO_content_tap	PLC laboratory	FeO content too high	>FeO>22%	Increase the amount of CaO/Al addition (60/20 kg in small portions)for slag forming at LF until slag becomes green colour	cleanliness	On hold	duty book – steelplant chapter 3.4	
	RH		BOF_P_content_actual_final BOF_C_content_actual_final	P-, and C-content out of limit	wt%	C act- Clarget P actual>Pact.	Target Analyse Level 4 – end of blowing	cleanliness	On hold		Advice to Quality department for re-scheduling/rebooking
5	BOF	Tramp elements out of range before tapping	BOF_Cu_content_actual_final, BOF_Cr_Content_actual_final BOF_Ni_content_actual_final BOF_Sn_content_actual_final	Cu-, and Sn-content exceeded	wt%	Cu=0,120% Sn=0,015%	Add Ni to compensate Cu/Sn – content Target: Sum 0,200% = (%Cu + %Cr + %Ni + %Sn) Decrease Soaking furnace temp. at HSM	Cleanliness Surface quality (edge defects)	On hold	duty book – steelplant chapter 3.7.2	Advice to HSM (furnace adjustment
7	RH	Ladle non-clean	LF_ld_non_clean	Manual event	--	--	----	cleanliness		duty book – steelplant chapter 3.6	
8	RH	Tramp elements out of range	LF_Cu_content_actual_final, LF_Cr_content_actual_final LF_Ni_content_actual_final LF_Sn_content_actual_final	Cu-, and Sn-content exceeded	wt%	Cu=0.120% Sn=0,015%	Add Ni to compensate Cu/Sn – content Target: Sum 0,200% = (%Cu + %Cr + %Ni + %Sn) Decrease Soaking furnace temp. at HSM	Cleanliness Surface quality (edge defects)	On hold	duty book – steelplant chapter 3.7.2	Advice to HSM (furnace adjustment
9	RH	Much entrapped slag/bad slag condition	RH_much/bad_slag_cond	Manual event	--	--	Add CaO/Al (60/20 kg) in small portions	Cleanliness	On hold	duty book – steelplant chapter 3.6	
10	RH	Vacuum pressure low	RH_vacuum_pressure_low	Pressure inside vessel min	mbar	> 5	Check the final C – content after vacuum treatment	Cleanliness inner quality	On hold	duty book – steelplant chapter 3.6	
11	RH	Ti level not in relation to C+N	RH_Ti_content_actual_final RH_C_content_actual-final RH_N_content_actual_final RH_O_content actual_final	Ti /C /N /O content actual_final			Check the C/N relation %Ti = (4x%C + 3,42 x%N + 1,5 x %S)	Cleanliness	On hold	duty book – steelplant chapter 3.7.2	
12	RH	C content out limit	RH_C_content_actual_final C_Target_final	C actual content	wt%	ΔC >0,005	If C actual content exceed the C target content advice to quality department	Surface Quality	On hold	duty book – steelplant chapter 5.2.2	Advice to quality department
13	RH	Si content out of limit	RH_Si_content_actual_final Level 4_Mn_content_Target	Si_actual_contai_final	wt%	> 0,06%	Pay attention for dip coating processing	Surface Quality	On hold	duty book – steelplant chapter 3.7.2	Advice to HSM (descaling) and dip coating
14	RH	Nb content out of limit	RH_Nb_content_actual_fina Level 4_Mn_content_target	Nb_actual_content_final	wt%	> 0,04%					
14	RH	Al insol > 20 ppm	RH_Alsol_content_actual_final RH_Alsol_content_actual_final	Alsol actual – Alsol actual = Al insoluble	ppm	> 25 ppm	Increase calm time > 5- 10 min if possible	Cleanliness	On hold	duty book – steelplant chapter 3.2-3.3	
15	RH	N level out of limit	Level 4_N_target_max RH_N_content_actual_final	N_actual_final N_target_level 4.	ppm		If N actual content exceed the N target content advice to quality department	Cleanliness	On hold		
16	RH	Calm time	RH_treatment_end CCM_id_slide_gate_open	Time end RH>>CCM start time	min	< 25 min	Target calm time > 35 min	Cleanliness	On hold	duty book – steelplant chapter 3.6	

Figure 4: Example for PQA rules for one specific steel group

Taking all gathered quality related process information into consideration including specific process events a quality decision support base is provided.

One strategic core component of the PQA solution is the link of different information and data to each other by comparing them with actual process data and observation. With reference to the requirements of the TS16949 in chapter 4.1 which is the basis for automotive production

in terms of quality supervision and process monitoring, PQA monitors, analyses and compares process data with specifications and defines actions to meet the requirements by using metallurgical and operational experience in actual context.

PQA will be include specific and customized input data:

- product standards, e.g. DIN, EN, ISO, ASTM et al.
- specific customer specifications: e.g. Mercedes, Toyota, Ford, GM, Exxon, Petrobras
- end use and final application: egexposed part
- metallurgical and operational experience and specific customer know how.

Every decision of the PQA is an individual one, which is based on the information which is given by interfaces from order information, specifications and standards compared with actual process parameter evaluated and prioritized with contextual metallurgical experience and engineering know how like depicted by the screenshot of **figure 5 and 6**. These features make this system an indispensable tool for the successful operation of modern state-of-the-art steel plants.

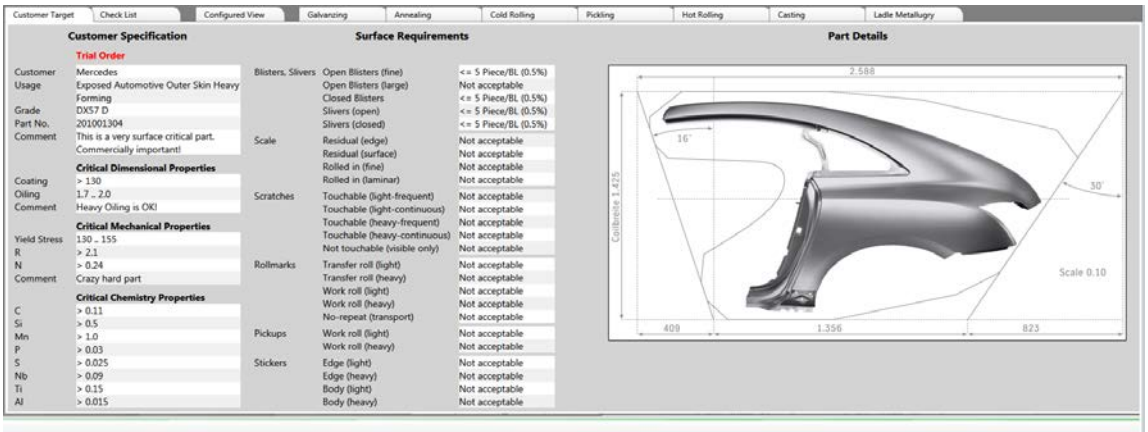

Figure 5: Example of quality information interface: rules and standards

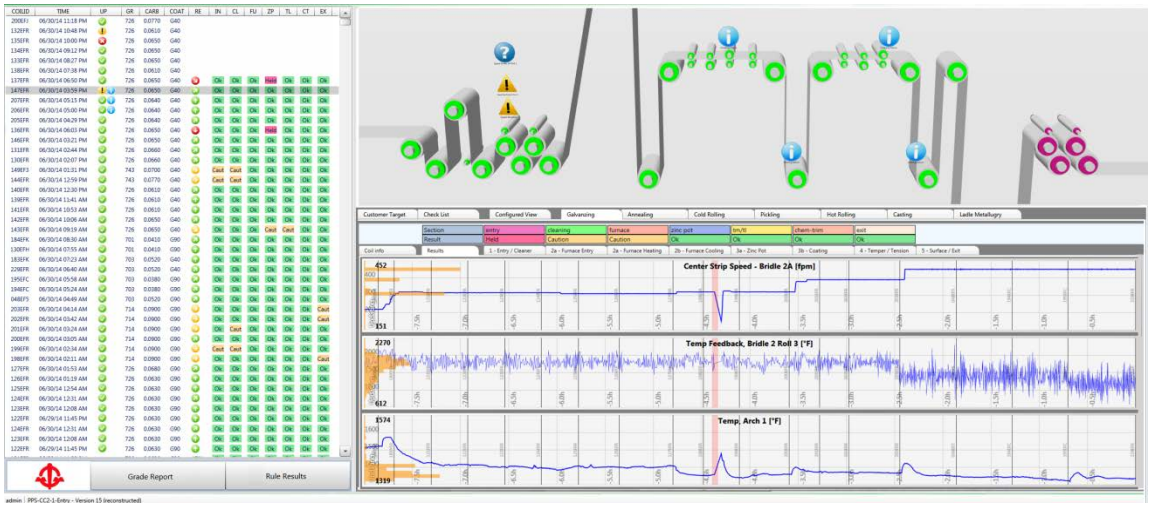

Figure 6: Example of quality information interface: process

QUALITY MONITOR

Essential part of the PQA system, as it is a modular software architecture, is Qualitor Monitor. It acts as an integrative interface between the operator or quality manager and the software and data warehouse.

The Quality Monitor provides comprehensive, compiled information and data. It is a customized information exchange platform.

A reference is shown in figure 7 and comprises, here for reference purposes, the following information:

- Coillistanddescription
- Qualityresult
- Appliedruleset
- Additionalviewsondetails
- Defectmaps
- Selected defect, its density and image (if available)

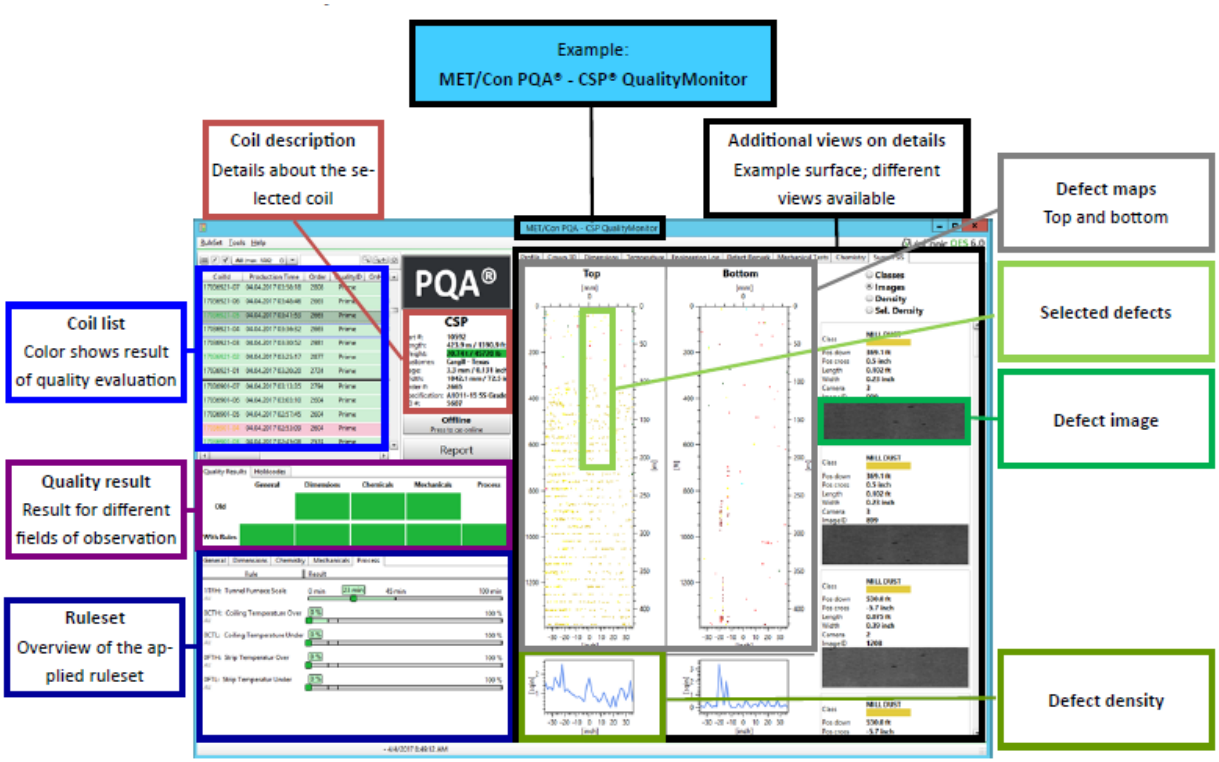

Figure 7: Qualitor Monitor interface to operator

ADVANCED ANALYTICS CAPABILITIES WITH DATA CORRELATOR MODULE

Root cause failure analysis is applied to improve further the process understanding and perform trouble shooting in complex environments.

Since high-quality and verified data with a given extent (completeness, longer period) are available with the PQA® system big data analysis can be applied within the PQA® system. Hitherto unexplained phenomena, unrecognizable relationships and missing plausibility's can be investigated using modern statistical methods to derive patterns and causalities.

The module "DataCorrelator" uses the data available from the PQA® system for further analysis. An intelligent software library provides various statistical methods of examination for data correlation.

Troubleshooting with the DataCorrelator module is performed most efficiently on the historical data set of a particular set of variables (such as suspicious parameters or process areas). DataCorrelator allows easy selection of variables, simple sorting of the data to be checked and loading into this area of database with a secure strategy (data flow limitation and priority ranking). Therefore, the network and databases are not extensively debited.

For a meaningful cause analysis, the data are prepared and/or corrected. This cleanup functionality is an essential component of the DataCorrelator module. The sorting out of implausible data or the replacement by a configurable value is possible.

The complex analysis can be graphically evaluated and, if necessary, exported to other modules. The analysis and results are stored in a library so they can be repeated later with the same settings and other time periods.TheDataCorrelator analyses a big amount of data to find correlations and conjunctions which can be converted to quality procedures and parameter tuning, especially in case of failures with unknown root causes.

Statistical data analysis is applying various mathematical methods:

- Descriptivestatistics
- Categorizedandnormalizedhistograms
- Linear correlationcoefficient
- Cross-correlation
- Automaticadjustmentofcategorizedhistograms
- Principal componentanalysis
- Multivariateregression

Data mining andcorrelations

- Discriminantanalysis
- Decisiontreewithruleevaluation
- Decisiontreewithcross-validation
- Component plane of self-organizing map
- Neural networks

Simulation run with historical data can be performed to validate new findings and fine tune new rules. In this regard the vision are self-learning and adapting algorithms working online and utilizing big data volumes (AI artificial intelligence framework utilization)

OPERATIONAL STABILITY AND EXCELLENCE

A PQA solution will become the central tool for product quality analytics and assurance focusing on:

- Stabilizingoperationalperformance
- Improving overall quality management
- Increasing transparency and visibility of quality standards and work on quality optimization
- Enhancedconfidence in qualitydecisions
- Higherstabilityofoperational processes
- Integration of continuous improvement by flexible rule adaption

Following economic advantages and benefits are provided to the operator and user:

- Reduced quality costs by reduction of claim rate and improved delivery performance
- Higheryieldofproduction
- Lessreworkactivities
- Less quality evaluation work by quicker decision making
- Faster quality evaluation and creation of statistics.

IMPLEMENTATION, CONFIGURATION AND REFERENCES

Different steel producers globally have realized the necessity for total quality management. Product quality assessment software solutions are implemented at major plants in US, Europe and China including ArcelorMittal, NLMK, Thyssen for example.

Actually a software package is under implementation at major flat producers in China (BENXI, SHADONG) and in Indonesia at PTKS Krakatau. The solution covers the complete process chain taking steelmaking operation and the continuous casting process into consideration. The hot and cold rolling operation as well as galvanizing and annealing processes are integrated as well.

For Shandong two different hot rolling processes are covered, a conventional hot rolling mill as well as a plate/steckel mill. The required additional plate processing steps (skin pass rolling and thermal treatment) will be described as well. The PQA system will be the key success factor for Shadong to be established as the prime supplier of state of the art superior products to the market.

The latest and the most modern steel plant in the US, configured as a CSP Mini Mill, at BIG RIVER STEEL successfully commissioned the PQA solution, which is covering the complete process route of EAF and secondary metallurgy, CSP casting, reheating, rolling and coiling, pickling and cold rolling, continuous galvanizing. The superior start-up of operation was directly linked to the support of the PQA system. Within 5 month 90% plant utilization could be achieved.

Customers have calculated and examined ROI´s of time frames in the range of one year, while reducing drastically their quality costs, minimizing scrap and rework and maximizing prime yield. Customer satisfaction is improved in general while improving the delivery performance to end customers and service centers.

The PQA solution has been developed for a SBQ (special bar quality) plant including steel production and processing (wire drawing, bright bar). It is implemented as a reference project at SWISS STEEL part of the Schmolz+Bickenbach Group [5].

4 CONCLUSION

The PQA has been developed and is implemented in different plants as a quality decision support solution next to existing level 2 and 3 systems. It is following up a comprehensive approach covering the complete process chain from steelmaking until final processing for flat and long products.

The system monitors, documents and safeguards the process. The PQA can be used as the overall database as a Production Data Warehouse for further quality, process and production analytics as well.

Based on online process event assessment an early identification of “unsuitable” material can be achieved. The basis for this grading process is a pool of experts based knowledge rules.

The software package provides a real time comprehensive product preview. The system tracks the material over the complete process chain and provides all sensitive coil/product data at a glance. In case of deviations PQA issues instructions for actions so that potential shortcomings during the production process are recorded.

PQA is utilized for statistical process and quality evaluations and provides a long term data storage with options of big data analysis and utilization of artificial intelligence modules.

User and customer benefits are: Reliable quality, increased yield, cost reduction, overall performance improvement and satisfied customers.

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