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Kunal Ganguly [1)]

1) MT Ghaziabad, UP, India,
kunalganguly1@rediffmail.com

IMPROVEMENT PROCESS FOR ROLLING MILL THROUGH THE DMAIC SIX SIGMA APPROACH

Abstract: *This project aims to address the problems that are facing a large aluminum company in a) Developing Hot Rolling Mill Capabilities for Wider Widths Hard Alloys Rolling and b) Eliminate down time due to strip /coil slippage during hard alloys 5xxx rolling at Hot Mill. The challenge for the company was to cater the fast changing export demand for Flat Rolled products with its existing resources. By applying Six Sigma principles, the team identified the current situation that the rolling mills operations were in. Six Sigma DMAIC methodologies were used in the project to determine the project's CTQ characteristics, defining the possible causes, Identifying the variation sources, establishing variable relationships and Implementing Control Plans. The project can be useful for any company that needs to find the most cost efficient way to improve and utilize its resources.*

Keywords: *Six Sigma, DMAIC Methodology, Aluminum Industry, Hot Rolling*

1. INTRODUCTION

Six Sigma is recognized as a problem-solving method that uses quality and statistical tools for basic process improvements. Six Sigma is now widely accepted as a highly performing strategy for driving defects out of a company's quality system. Six Sigma is defined as a set of statistical tools adopted within the quality management to construct a framework for process improvement (Goh and Xie, 2004; McAdam and Evans, 2004). Statistical tools identify the main quality indicator which is the parts per million (PPM) of non-conforming products (Mitra, 2004). Achieving a Six Sigma level means to have a process that generates outputs with 3.4 defective PPM(Coleman, 2008). Six Sigma is also defined as a multifaceted, customer-oriented, structured, systematic, proactive and quantitative philosophical approach for business improvement to increase quality, speed the deliveries up and reduce costs (Mahanti and Antony, 2005)[1].

The literature suggests the DMAIC and the design for Six Sigma (DFSS) methods as the two most common methodologies to implement Six Sigma, although according to Edgeman and Dugan (2008), the main objectives of the two techniques are quite different. While DMAIC is a problem-solving method which aims at process improvement (Pande et al., 2005), DFSS refers to the new product development. In a recent paper, Talankar et al. (2011) et al. introduced the Six Sigma-based methodology for non-formal service sectors, the framework which explores the quality needs and maps them to define, measure, analyze, improve and control (DMAIC) methodology. Eisenhower (2008) used DMAIC methodology to show that quality performance data expressed as the usual percentage defect rate can be converted into a wide range of vital, Six Sigma metrics and that these can be used to develop insight into a company's quality system. The literature further shows that there are several variations for DMAIC (even if it remains the most commonly adopted methodology) such as Project-DMAIC (P-DMAIC), Enterprise-DMAIC (E-DMAIC) and DMAIC Report (DMAICR). The selection of the methodology, in the end, depends on the specific requirements. In the present work, Project-DMAIC (P-DMAIC) has been used[10].

This project follows the five step methodology used in the Six Sigma process. The reason for taking up the project is highlighted in section 2. The definite step is outlined in Section 3.1 where the problem is identified and specific goals are determined. The measure step is the step that focuses mainly on gathering raw data from the process. This is described in details in Section 3.2 – measure. The third step, analyzing the data will be shown in Section 3.3 – analysis. This is a breakdown of what the gathered data means for the company. In Section 3.4 –improvement opportunities, the suggestions for the company are explained in more details. Improvement opportunities give possible ways to improve the process and finally the methods for sustaining the changes are discussed in Section 3.5. The final section deals with the accrued benefits[2].

2. THE CASE STUDY

The case organization is an integrated Aluminum company. It operates in the entire value-chain from Coal & Bauxite mining to Power Generation to Downstream Products such as Flat Rolled Products (FRP), Foils, & Extrusions. It is one of the largest producers of Primary Aluminum in Asia. It has two plants in the country separated at a distance of approximately 1500 kilometers.

The need for the project was realized due to a shift in FRP Export Market. The company's export was almost 38% of its FRP production volume to various markets e.g. South-East Asia, Far-East Asia, Gulf countries, Australia, USA and Europe. It was noticed that export market demand is significantly shifting from soft alloys (AA 1xxx series) FRP to harder alloys (AA 5XXX). This shift was an opportunity as well as a threat for organization. Though, the Hot Rolling Mill in the organization was capable to hot roll AA 5xxx series alloys in width up to 1,016 mm, it had serious limitation on Maximum Rolling Load capability. With market demand from overseas being in widths greater than 1.20 meters, it would not be possible to hot roll these products at the existing Hot Rolling Mill, with existing rolling practices. The problems that happened during hot rolling process are enumerated below:

1) Aluminum in purest form is a very soft metal. However, it alloys can vary from being soft to very hard. Its hard-alloy can match with the hardness of steel and thus provide edge to this metal over steel in terms of strength to weight ratio in many of crucial application like auto, aviation, buildings & construction, overhead transmission etc. 5xxx series aluminum alloys (alloyed with Mg element) are very hard / difficult to roll. Whereas as for the case company hot rolling mill is designed for soft alloys. 5xxx rolling falls at the upper boundary of its capability in terms of rolling load and mills capacity.
2) Hard alloy use to get slipped to one side of hot mill and make the mill non-operative. This phenomenon is called slippage. Slippage problem during 5xxx series hot rolling caused huge NRT (Non Rolling Time) losses. This is the 2nd Largest Operational Delay for the mill. Further Hot Rolling Mills is also constraint equipment. The losses in NRT of this equipment had direct impact to the bottom line of the company's FRP SBU.

To meet the market demand of wider width (width > 1016 mm) 5xxx, the company was doing transportation of 5xxx hot rolled coils from it's another plant for further cold rolling process due to mismatch of hot and cold rolling capabilities (with respect to 5XXX alloy FRP) of these two plants.

The project was taken up to make guidelines for building Hot Rolling Capabilities of wider width Hard Alloys (AA5052-1320 mm) and to eliminate Hot Mill down time due to strip / coil slippage during hard alloys 5xxx rolling at Hot Mill[3].

3 APPLICATION OF SIX SIGMA DEFINE, MEASURE, ANALYZE, IMPROVE, CONTROL METHODOLOGY

3.1 Define phase

The objective of this phase was to clearly understand and articulate the current reality and the desired situation. A clear definition of the problem is the first step of a six sigma roadmap.

3.1.1 Defining the problem

After historical data analysis and assessing the present situation, the following problems were identified for the company:

a) The Hot rolling capabilities for AA5052 alloy is for 914 & 1016 mm widths, where as Hot Rolled Coils of widths 1118 and 1320 mm were sourced

from its parent plant located at a distance of approximately 1500 km;
b) There were rejections and mill's down time even from widths 914 & 1016 mm hot rolling;
c) The sourcing time was 47 days resulting in long lead time and transportation cost. This also resulted in transportation damages like water corrosion during transit, damages due to transshipment. Statistical capability was assessed using past data with consideration of slippage phenomenon as defective. The results are shown in Table 1[9].

Table 1: Statistical capability

No. of Items	580
No. of defective	13
Opportunity of defect (per unit)	1
DPMO	22375
Sigma (without shift)	2.0 Long Term
Sigma (with shift)	3.5 Short Term
Cp equivalent	1.2 Short Term

This is formed as a basis for setting up the statistical target for the project. The new target was established as Sigma (short term) as 4 and Cp equivalent short term as 1.3[4].

3.1.2 Voice of Customer

The next step was to determine CTQ (Critical to Quality Characteristics) for the project. The tool used for the purpose was VOC (Voice of Customer). The tool was used in hot mills as the cold mills happen to be their internal customers. The aim was to freeze the parameters for Hot Mill Coil Quality as a good feed stock for Cold Mills. VOC outcome is presented in Table2.

Thus the parameters which emerged out of VOC were Coil Buildup, Thickness, and Composition of Hot Rolled Coils. Based on the outcomes, the scopes of the projects were defined. They were as follows:

a) Save mill NRT by eliminating the instances of strip slippage at the mill
b) To ensure the quality of the Hot Rolled (H.R) Coil (of 5xxx)
c) Establishing Standard Operating Procedure for smooth 5xxx hot rolling at Hot Mill
d) Problem to be resolved in present work stations capability
e) No negative impact on the productivity of the involved equipment[7].

Table 2: VOC outcome

Customer	Sample Comments	Key output characteristic important to customers(CTQ)	Relevant to project
Hot Mill	No down time due to slippage	No strip slippage at Hot Mill	Yes
Cold Mill	No significant deviation from the normal coil buildup	Good Coil buildup	Yes
Cold Mill	No thicker Gauge - No thick gauge beyond attached part id / cold mill capability	No Thicker HR Coil Gauge	Yes
Cold Mill	No gauge variation - No gauge variation in a hot rolled coil	No Variation in H R Coil thickness	Yes
Cold Mill	No composition variation Consistent composition for gauge accuracy	Consistent Composition	Yes
Cold Mill	No side cracks	Side cracks -No side cracks at all	No

3.1.3 Process Mapping

This was done to understand the process in detail. This included the macro as well as micro level of process mapping. The macro level mapping was done using SIPOC (suppliers, Inputs, Process, Output, Customers) concept. SIPOC provides important inputs to monitor products and services provision for customer satisfaction Shirley and Yeung (2009)[13]. The outcome is shown in Figure 1.

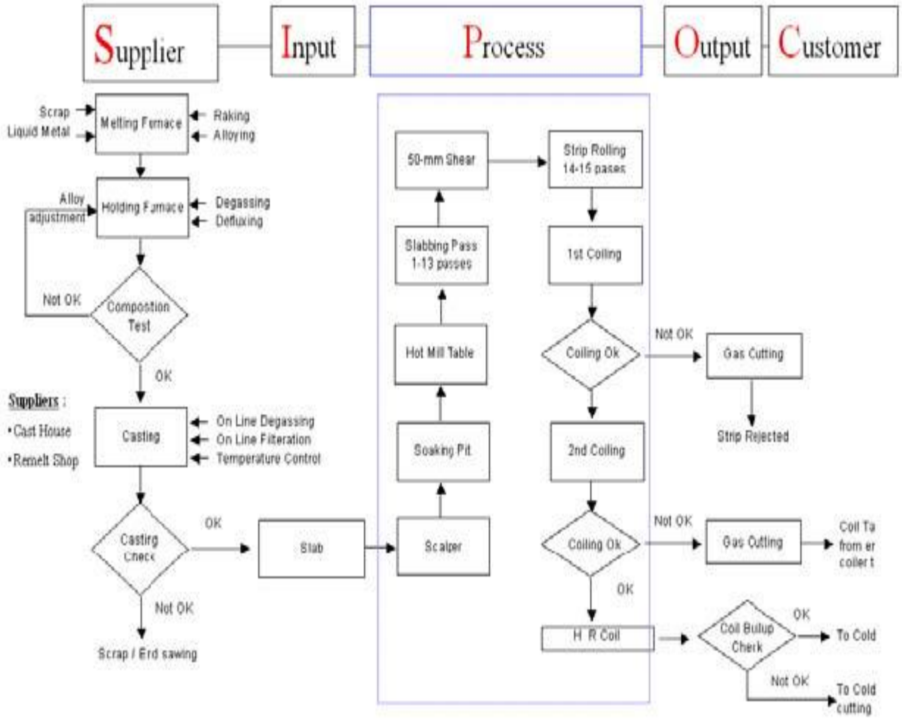


Figure 1: Process Map

3.2 Measure

Under this phase of project, the aim was to identify the root cause of the problem, narrow down to few potential causes, set measurement for the Project CTQs and potential causes, establishing a measuring system that have less inbuilt variability so as it could capture the variation in the process. Thus step followed were:

1 Defining all possible causes
2 CTQ Matrix
3 Defining Performance Parameters
4 CTQs Identification for Measurement System Analysis (MSA)
5 MSA for Coil Buildup[11].

3.2.1 Defining possible causes

Cause and effect analysis technique was used to identify all the causes as shown in Figure 2. Cause & effect matrix was used to prioritize the potential causes as shown in Table 3. Failure Mode Effect Analysis was also used in capturing potential causes. This was the outcome from a brainstorming session of the concerned managers. Based on the above steps, the major causes were identified in 5xxx Hot Rolling. The causes identified were : Slab temperature, Soaking pit temperature, Uniformity of Soaking pits, Slab Soaking Practices, Mill- operators speed reduction, Coolant flow/temperature/pattern.

3.2.2 Defining Process Parameters

In this step, the project deliverables were defined. For the project, Unit (project Y) was defined as each H.R coil of 5xxx. Unit specifications were defined as “no slippage at entry/exit coiler”. Defect was defined as strip slippage during entry and exit in the coiler which makes them unsuitable for further cold rolling[12].

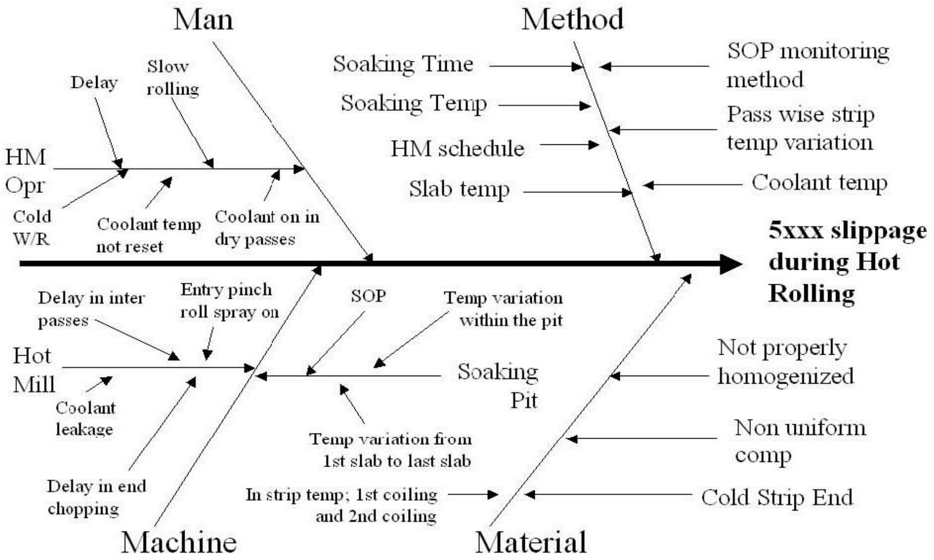


Figure 2: Cause and effect diagram

Table 3: Cause and effect Matrix

2 nd Level Matrix						
Customer Expectation		Composition	Coil Buildup	Slippage	Gauge	Total
Importance		3	5	9	4	
Composition Uniformity		5			5	
		15	0	0	20	35
Liq / scrap charging		0			0	
		0	0	0	0	0
Degassing		0				
		0	0	0	0	0
Scalping thickness		0		4		
		0	0	36	0	36
Soaking Time	0	0	5	7	5	
		0	25	63	20	108
Soaking Temp	0		7	8	5	
		0	35	72	20	127
Temp variation in the pit	0		5	6	5	
		0	25	54	20	99
Soaking SOP	0		8	8	8	
		0	40	72	32	144
HM Operator	0		5	8	7	
		0	25	72	28	125
Incoming slab temp	0		7	8	8	
		0	35	72	32	139
Hot rolling schedule	0		4	3	4	
		0	20	27	16	63
Coolant temp schedule	0		5	5	2	
		0	25	45	8	78
Pass wise strip temp variation	0		7	8	8	
		0	35	72	32	139
Coolant temp	0		2	3	3	
		0	10	27	12	49
In-strip coiling F temp	0		7	8	8	
		0	35	72	32	139
In-strip coiling S temp	0		7	8	8	
		0	35	72	32	139
Total		15	320	684	276	

Identified X's - After Cause & Effect Matrix

* Composition
* Soaking Time
* Soaking Temp
* Temp variation in the pit
* Soaking SOP
* Incoming slab temp
* Hot rolling schedule
* Hot Mill Operator
* Coolant level schedule
* Pass wise strip temp variation
* Coolant temp
* In-strip coiling F temp
* In-strip coiling S temp - Coil Temp

3.2.3 Establishing measuring system

In this step, the work was to establish the measuring system and validate it. For the project, the Y (deliverables) and X (Causes) were established and validated. The results are shown in Table 4.

Table 4: Identifying the deliverables and causes

Major Y	**Specification Limit**	**Data Type**
No down time at Hot Mill due to slippage of 5xxx strip	No strip slippage	Ok / Not Ok (Discrete)
Minor Y (Indicator)		
Strip slippage at entry coiler	Gas cutting Strip Rejection	Ok / Not Ok (Discrete)
Strip slippage at exit coiler	Gas cutting Thicker gauge coil	Ok / Not Ok (Discrete)
Strip slippage at exit coiler	Telescopic coil need outer / inner wraps dressing of HR coil	Ok / Not Ok (Discrete)
Identified X's - 2 level cause & effect matrix		
Composition	Composition Standard	Continuous
Soaking Time	SOP (Standard Operating Procedure)	Continuous
Soaking Temp	SOP T (-0, +10°C)	Continuous
Temp variation in the pit	-10 to +10°C	Continuous
Soaking SOP	SOP	
Incoming slab temp	470±10°C	Continuous
Hot rolling schedule	17 Passes in 17 min	
Coolant temp schedule	to fix	
Pass wise strip temp variation	to fix	Continuous
Coolant temp	50-55°C	Continuous

3.3 Analysis

In this phase of the project the aim was to establish the base line of the project, its performance criteria by finalizing its target. Thereafter, hypothesis was established and tested to validate its contribution and finally potential causes were listed out. Finally a theory was proposed for best explanation of the problem. Thus basic steps followed under this phase were defining performance objectives, identifying variation sources and establishing process capability. In the analyze phase, different statistical tools were used. MS Excel and Minitab software was used for analysis purpose. The highlights of the analysis are mentioned in following sub sections[5].

3.3.1 Slippage vs. Rolling Ingot Widt

Data collected for the purpose and tabulated. The results are shown in Table5. The results clearly indicate that the problem is with wider width out of two widths that were being rolled.

Table 5: Slippage vs. rolling ingot width

Width	**Data**	**Total**
914	Count Sum of Slippage	252 1
1016	Count Sum of Slippage	541 15
Total Count of Alloy		793
Total Sum of Slippage		16

3.3.2 Slippage vs. Coil Temperature

Data collected for the purpose and regression analysis was done. The results are shown in Figure3. The results clearly indicate that there is a correlation between coil temperature and slippage phenomenon. Lower coil temperature contributes to slippages at hot mill.

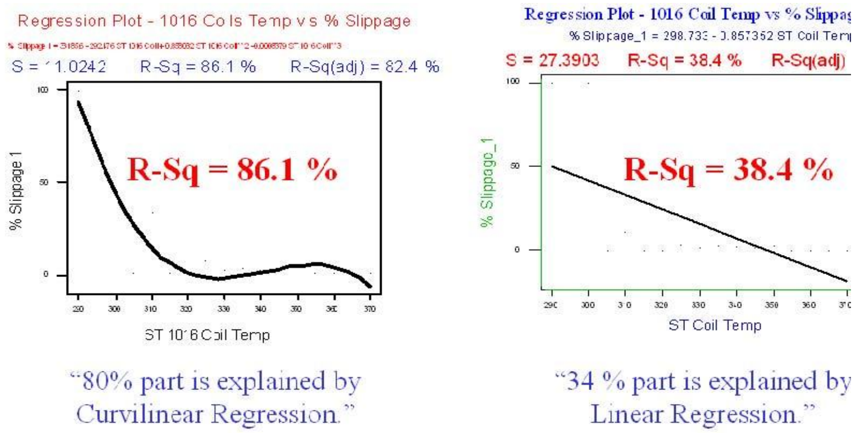


Figure 3: Slippage vs. Coil Temperature

3.3.3 Coil Temperature vs. Slab Temperature

Coil temperature is function of slab temperature and rolling parameters. A pit contains 16 Rolling Ingots. These ingots were rolled to Hot Mill Coil. Slab and coil temperature were measured for a pit. The results are shown in Figure 4.The results indicate that Coil temperature has strong positive correlation with slab temperature. Higher slab temperature will have higher coil temperature[6].

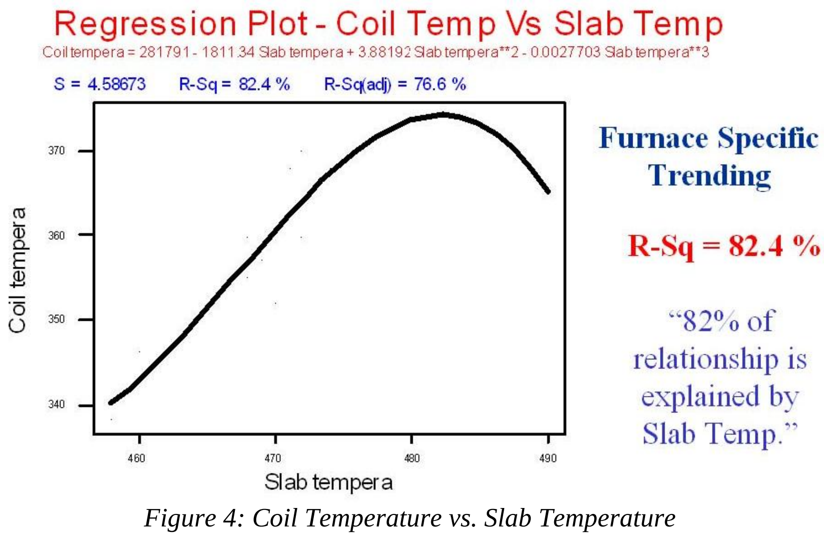


Figure 4: Coil Temperature vs. Slab Temperature

3.3.4 Coil Temperature vs. Mill Parameters (Rolling Time, Rolling Speed, Rolling Load)

Data collected for the purpose and regression analysis was done. The regression analysis indicated that rolling parameters along with slab temperature have correlation with coil temperature (R-sq 82 %). The parameters were Slab Temperature, Rolling Load, and Time Duration & Average Speed of Rolling.

3.3.5 Coil Temperature vs. Hot Mill Operators

In this step, the variation in coil temperature with respect to operators was analyzed. For the analysis purpose, one way ANOVA was conducted through Minitab software. The findings are shown in Table6. Since P -value < 0.05 we concluded that there is operator wise variation in coil.

Table 6: One way ANOVA: Coil temperature vs. Operator

Source	DF	SS	MS	F	P
Operator	7	10137.6	1448.2	16.11	0.000
Error	785	70573.3	89.9		
Total	792	80710.9			

3.3.6 Hot Mill Operators vs. Slippage

In the next stage, slippage event with respect to mill's operators were monitored. This was to check operator's influence of slippage phenomena. It was observed that the slippage occurrence was unevenly distributed among operators. Some operators have relatively more slippages.

3.3.7 Soaking Pits vs. Slippage

Data collected for the purpose and tabulated. The results are shown in Table7. It was observed that the slippages phenomena are uniformly distributed to all soaking pits except soaking pit # 2. The conclusion drawn was that there is no contribution from soaking pits. Chi square hypothesis test was not applicable as the response count was less than 5.

Table 7: Soaking pits vs. slippage

Soaking pit	Total Slab Rolled	Slippage Count	% Slippage
1	107	2	1.9
2	137	0	0.0
3	110	3	2.7
4	138	6	4.3
5	130	2	1.5
6	171	3	1.8

3.4 Improvement

In this phase of project the aim was to validate the causes identified through data analysis done in analyze phase. Based on the finding from the previous stages, literature survey for AA5052 alloy properties was done. Based on literature survey and findings from improvement phase a small set of DOE (Design of Experiments) was conducted. In Improvement phase, the deliverables identified were: Screening the potential causes, Discovering variable relationships, establishing operating tolerances and proposing solutions. The steps are discussed in the sub-sections[8].

3.4.1 Screen Potential Causes

As discussed in the previous sections, from the data analysis, following variables emerged out. The deliverables (Y) being Slippage and Causes (X) being Soaking Pits , Slab temp, Slab Width, Coil Temp, Mill Speed / Power / Load , Rolling Duration.

During rolling work, rolls generate pressure on the material being rolled and under compressive stress material starts flowing when beyond its yield stress. Temperature loss and uneven temperature makes the differential back pressure from the material to work roll and the differential material flow at both of the edges. This leads to curving of material and thus shifting to a side. This makes the slippage phenomena happen.

3.4.2 Discover Variable Relationships & Propose Solutions

Literature study indicated that 5xxx alloy have relatively higher strength at elevated temperature and also exhibit rapid gain in strength with the drop in temperature. The melting range of the alloy being 610-660°C, we had a scope for raising slab temperature from 510°C to 600°C. To cross validate the findings, DSC (Differential Scanning Calorimeter) was performed on AA5052 alloys. DSC Analysis for AA5052 Alloy indicated the lower melting point to be greater than 600°C establishing the scope for higher temp homogenizing practices. Since, raising temperature also have cost aspect, we had to raise the temperature to its optimum level i.e. to the level where we are able to get the satisfactory result. Raising temperature will make the alloy softer and thus less back pressure. Event of slippage can be reduced for existing widths. Raising temperature may make the alloy sufficiently softer to roll wider width alloys.

3.4.3 Establish Operating Tolerances & Pilot Solutions

To achieve this DOE (Design of Experiments) were conducted to validate our findings and explore the possibilities for wider width rolling. The DOE plan was framed and the experiments were conducted. The problem statement was "To reduce the number of slippages". The DOE plans were full factorial 2X2. The input variables were temperature (560°C and 570°C) and soaking time (8 and 10 hours). The results of DOE are mentioned in Table8.

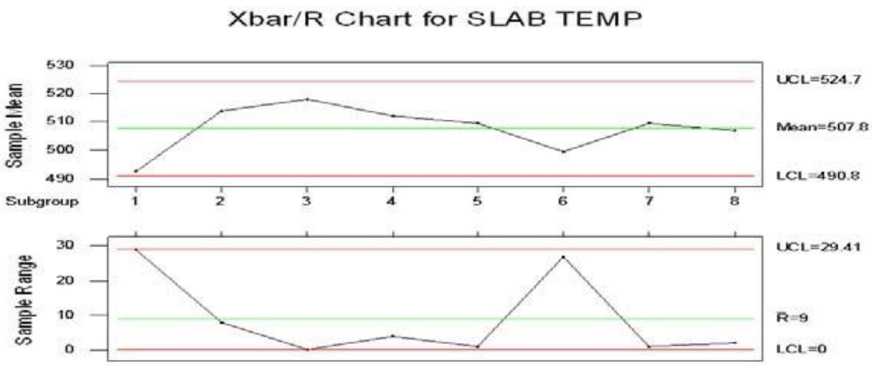
Table 8: Results of DOE

DOE No.	DOE	No. of slabs rolled	No. of Slippages	%	DPMO	Remarks
1	575°C / 10Hrs	122	0	0	0	Good Performance
2	575°C / 8Hrs	120	0	0	0	Good Performance
3	560°C / 10Hrs	76	3	3.95	39474	Practice Discontinued
4	560°C / 8Hrs	Not Done				

From the findings of DOE, it can be seen that DOE # 1 & 2 i.e. 575°C-10 / 8 has performed well in comparison to 560°C-10 hrs. Out of this finding there was no meaning to take trial with DOE # 4 i.e. with 560°C – 8 hrs. The optimum result decided was 575°C for 8 Hrs.

3.5 Control

Under this phase findings were summarized in a manner that will reflect in process variables for the sustenance of improvements. The deliverables of this phase were Development & Implementation of Control Plans, Institutionalizing Improvement and Monitoring Process for sustenance. Under these steps, measuring system was established for key process variables that emerged out from the analysis phase. A control plan was established based on the analysis of process variables under changed practice for continual monitoring of the processes. This involved analysis of Process variables of best performance and process capability. This control plan served as guide line for operators to follow the process and process control team to ensure smooth working of the mills with good and consistent quality of output stock. A sample control chart for slab temperature is presented in Figure5.



- **Consistent Slab Temp;**
- **Point # 1 is low as the pyrometer got out of order during second slab / first coil temp reading.**
- **Later on the pyrometer was replaced.**

Figure 5: Control Chart for Slab Temperature

In the control phase, measuring system was established and control criteria were fixed. In the previous phases, Causes (X) was determined. Now standard norms were fixed for all major Xs i.e. Elemental Composition, L/C temperature, Slab temperature, Coil temperature and Work Roll temperature. Appropriate MSA norms were established and put into practice. A process capability report before and after the project is presented in Table 9 clearly indicating improvement.

Table 9: Capability compared: before and after the project

S.No.	Parameters	UOM	Old Process*		New Process		Remarks
			Mean	Cpk	Mean	Cpk	
1.a	Slab Temp	°C	460	0.37	510	0.79	LSL kept at higher level ie 490°C due to Cap on Max Hot Mill Current because of Mill Gear Box
1.b	Slab Temp	°C	460	0.37	510	2.07	LSL - 460°C; Post new gear box installation
2.a	Coil Temp	°C	335	0.53	360	0.96	LSL kept at higher level ie 345°C due to Cap on Max Hot Mill Current because of Mill Gear Box
2.b	Coil Temp	°C	335	0.53	360	1.59	LSL - 335°C; Post new gear box installation
3	Mill Load	Ton	715	0.17	603	1.27	
4	Mill Power	KW	2486	0.05	2307	1.16	
5	Mill Speed	MPM	89	0.04	99	0.80	

*** Old Process - Before Six Sigma Project / New Process - After Six Sigma Project**

4. BENEFITS ACCRUED

It can be said that the project was able to meet its intended ambition for establishing hot rolling capabilities for 5xxx alloys. The benefits realized are as follows:

1) The cycle time was reduced from 47 days to 20 days, resulting in a huge inventory reduction and better order compliance.

2) Slippage problem was eliminated. It was observed in the project that the temperature loss was the major reason for slippage. To resolve this, work was initiated in two directions: a) to reduce the heat loss by installing monitoring on coil rolling time, idle time and coil to coil time b) Raising average rolling temperature from 510 to 575°C i.e. keeping the slabs hot enough so that any heat loss from the rolling ingot may not have any negative effect on its roll ability and c) Raising temperature though it had a cost implication. DOE was conducted to have optimized raise in temperature. We have a further scope for raising temperature from 575 to 610°C.

3) Trials with wider widths were successful. This resulted in huge saving. Rise in temperature and adjustment in slab length led to roll wider widths. Reducing slab length was a trade off in between productivity and developing hot rolling capability and the management opted for roll-ability.

4) By establishing process controls, smooth operation was ensured. Developing equipment / process capabilities helped in de-constraining the supply chain bottlenecks. This helped not only in sound inventory control system, but also a judicious balancing between conflicting cost and benefits along with speedy delivery to customers, which is one of vital requirements in this era of lean manufacturing.

5) With the help of this study, it was possible to develop hot rolling practices for 5xxx stocks at

Hot Mill. This helped the company to remain in market without any big investment of new stronger hot rolling mills. A new strong rolling mill will have its gestation period of minimum two and half year. The company is in process of installation of a wider width and stronger Hot Rolling Mill but till it's commissioning, it can continue to serve this product in the market.

6) the most important benefit realized was that the project had a long lasting impression and a thorough learning that can act as a foundation for future projects. There was a great learning in wide aspects of management concepts and related applications[14].

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