Blackstone Synergy Consulting Group
Blackstone Synergy
“transforming lives through business excellence”

The process capability mapping at Apex Steel

1. Reheating furnace – water blast scale remover bay –rougher mill – CLUSTER-1

A. Analysis of productivity parameters :

A.1. Reduction in furnace passage time:

a. Charge **pre-heat to around 500-700 degrees Celsius** to enable shortening of lead time to heat up the charge to the desired 1200 degrees Celsius and thereby help improve on the **charge - discharge cycle time through the furnace.**

b. Current trends in the reheating furnace always accelerate the charge from levels of cold start (almost the room temperature of typically around 35 degrees Celsius) to a gradual level of 200-300 degrees Celsius in the initial 25% of the furnace length and then to levels of 500-650 degrees Celsius at the 45-65% mark before switching over to the optimum levels of 1200 degrees Celsius in the last 25% of the length of the furnace. In this gradual progress, the charge heat gets dissipated while simultaneously adding heat as the equilibrium conditions are never attained and hence the heat exchange is fundamentally flawed.

c. Metallurgical changes occur in the configuration of both the charge and the refractory and need to be discussed in detail at this juncture to analyze the impact in the productivity and the efficiency of the reheating furnace. The thermal expansion is sporadic and sharp in the enthalpy system of the charge thereby causing abrupt disruptions in the configuration of the charge structure. The levels of crystalline and amorphous regions change sharply and so do areas of t_g and the plasticity within the structure. The internal heat levels within the billets also do vary as per the metallurgical structure and consequently the resultant changes to breakaway plasticity is determined by the factors of thermal graph within the passage and the retention of heat within the furnace as a function of the thermal strains within the refractory lining of the walls.

d. Configuration changes simulation

Charge density at consistency points would envisage a **grain distribution in the structural configuration** of the run down billet prior to the rolling bay. That is the foundation for ensuring **uniformity in the dimensional changes in plasticity** during the rolling at given contact duration and with given surface friction conditions and the corresponding productivity levels.

Illustrations in the following passages shall clarify the conceptual coordinates for bringing in fundamental changes in the reheating furnace

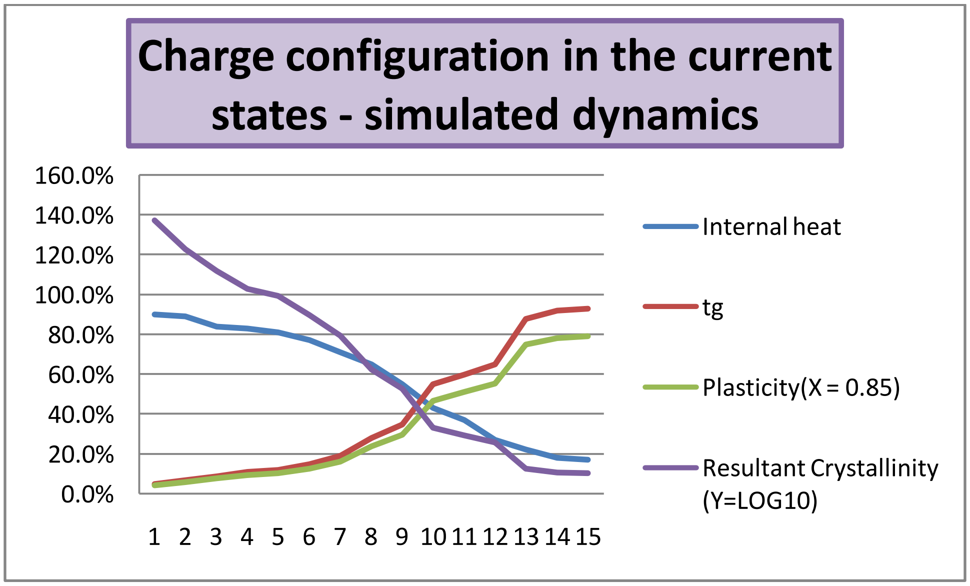
State-1: current states of the reheating furnace – simulated mapping

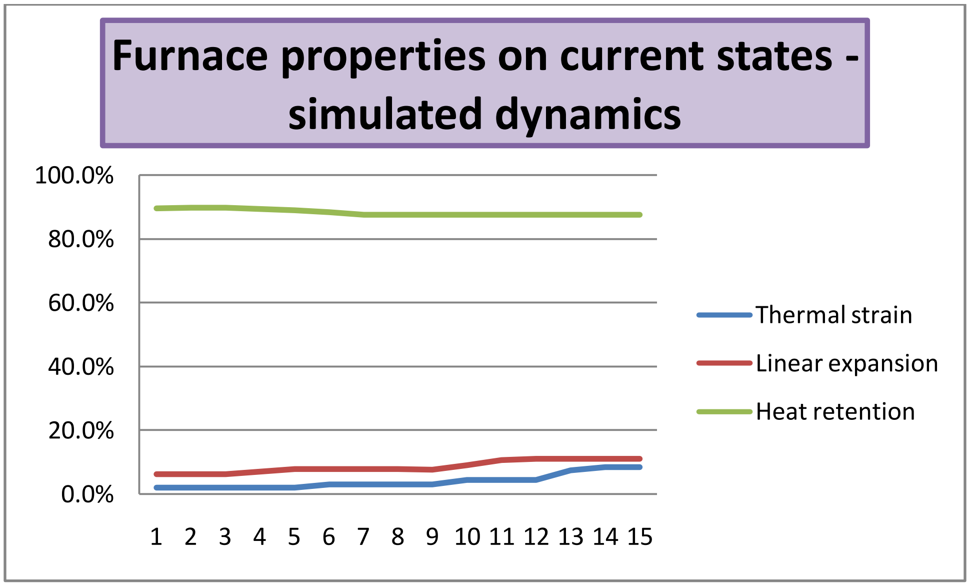
SIMULATED STRUCTURAL DYNAMICS OF THE CHARGE IN THE REHEATING FURNACE							
CHARGE CONFIGURATION CHANGES				REFRACTORY DYNAMICS			RESULTANT ST(surface temperature) DYNAMICS
Internal heat	t_g	Plasticity(X = 0.85)	Resultant Crystallinity (Y=LOG10)	Thermal strain	Linear expansion	Heat retention	Surface Temperature (ST) in the charge
90.0%	5.0%	4.3%	137.2%	2.0%	6.2%	89.7%	33.2%
89.0%	7.0%	6.0%	122.5%	2.0%	6.2%	89.7%	35.2%
84.0%	9.0%	7.7%	111.6%	2.0%	6.2%	89.8%	37.5%
83.0%	11.0%	9.4%	102.9%	2.0%	7.0%	89.5%	40.3%
81.0%	12.0%	10.2%	99.1%	2.0%	7.8%	89.0%	43.6%
77.0%	15.0%	12.8%	89.4%	3.0%	7.7%	88.3%	46.2%
71.0%	19.0%	16.2%	79.2%	3.0%	7.8%	87.6%	49.4%
65.0%	28.0%	23.8%	62.3%	3.0%	7.8%	87.6%	54.2%
55.0%	35.0%	29.8%	52.7%	3.0%	7.7%	87.6%	60.4%
43.0%	55.0%	46.8%	33.0%	4.5%	9.0%	87.6%	65.8%
37.0%	60.0%	51.0%	29.2%	4.5%	10.7%	87.6%	70.2%
27.0%	65.0%	55.3%	25.8%	4.5%	11.0%	87.6%	76.0%
22.0%	88.0%	74.8%	12.6%	7.5%	11.0%	87.6%	80.0%
18.0%	92.0%	78.2%	10.7%	8.5%	11.0%	87.6%	83.0%
17.0%	93.0%	79.1%	10.2%	8.5%	11.0%	87.6%	83.0%

Debashish Banerjee: ASSERTION-1:
Conceptually, enlarged crystals get formed on spatial reduction in the initial stages of thermal expansion

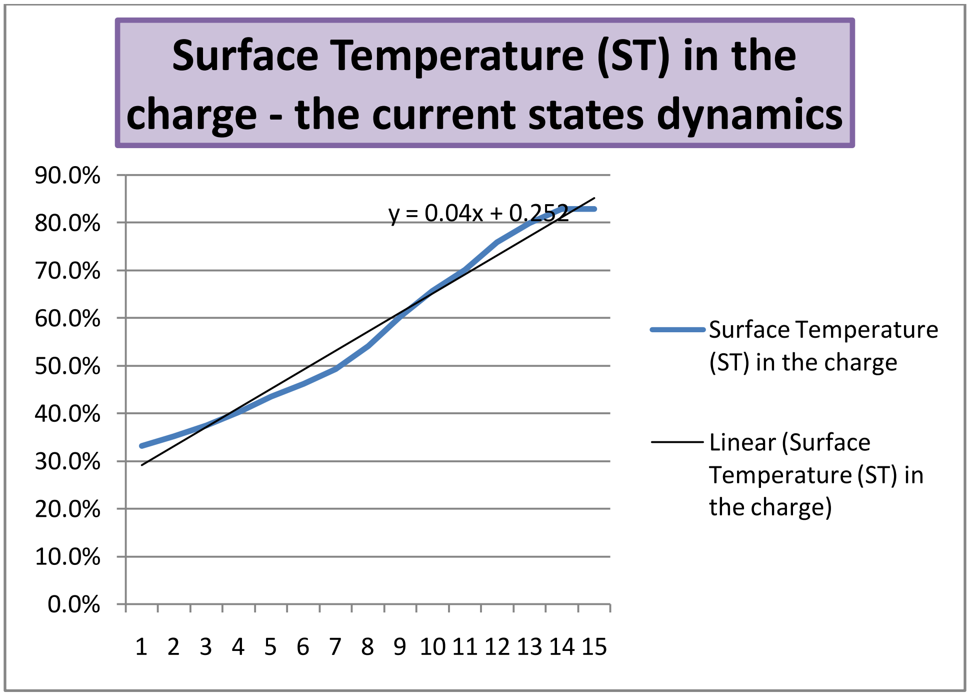
Debashish Banerjee: ASSERTION-2:
The refractory dynamics is a direct link to the configuration of the thermal decomposition within the charge - since the key determinant for the enthalpy exchange is the ability of the "heat substrates" to achieve equilibrium over a smaller trajectory change rather than give in to prolonged effects resulting in abrupt disruptions in the structure and consequently only able to achieve near-equilibrium conditions rather than consistent and firm coordinates.

Debashish Banerjee: ASSERTION-3:
The charge moves in a larger trajectory of thermal changes and consequently lead to structural configurations that are relatively arrayed over larger differences internally - a veritable problem for the subsequent drawing and rolling in process; yet quantified only in the breaking work and the related tensile properties of the finished rolled product.





Furnace properties on current states - simulated dynamics

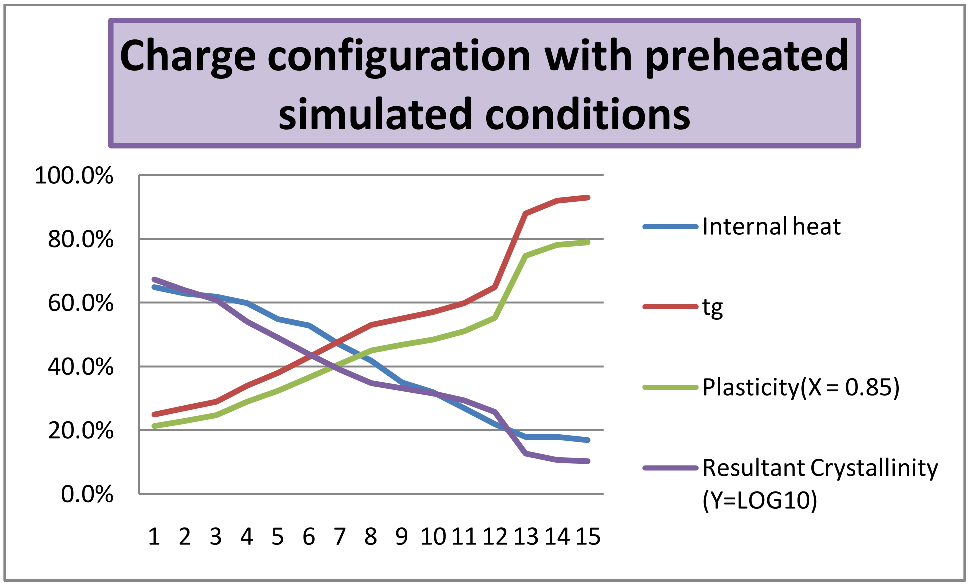


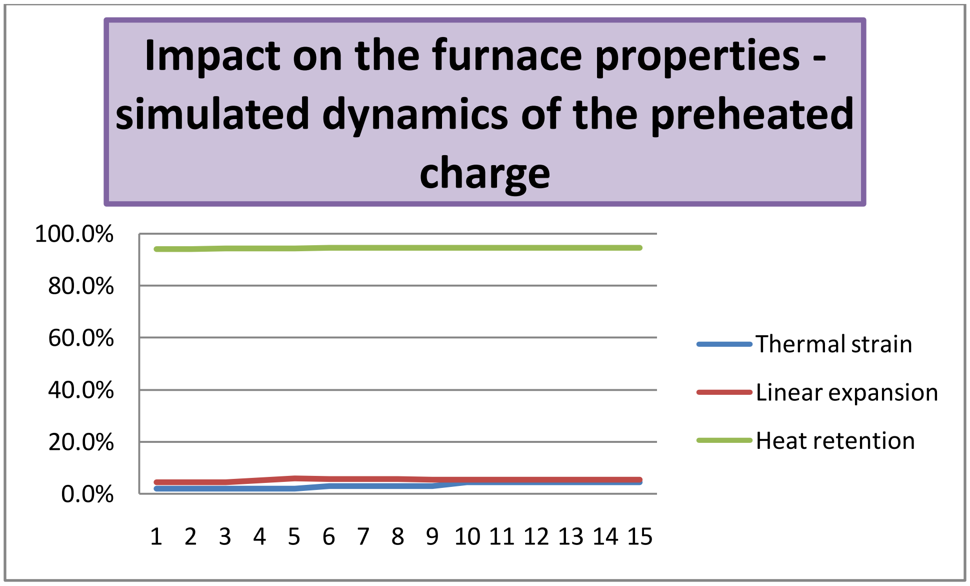
Surface Temperature (ST) in the charge - the current states dynamics

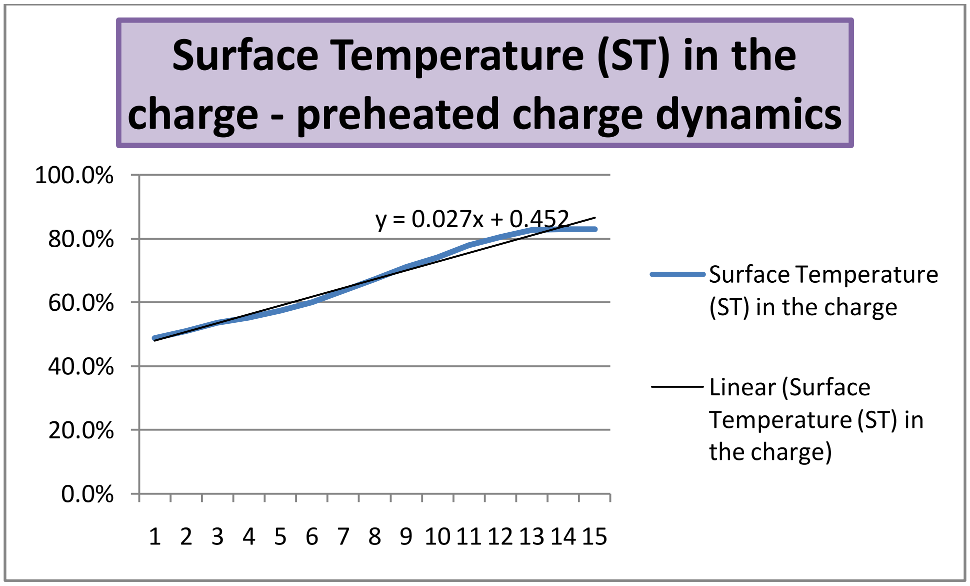
State-2: Preheating the charge to 300-400 degrees Celsius – simulated dynamics

SIMULATED STRUCTURAL DYNAMICS OF THE CHARGE IN THE REHEATING FURNACE							
CHARGE CONFIGURATION CHANGES				REFRACTORY DYNAMICS			RESULTANT ST(surface temperature) DYNAMICS
Internal heat	t_g	Plasticity(X = 0.85)	Resultant Crystallinity (Y=LOG10)	Thermal strain	Linear expansion	Heat retention	Surface Temperature (ST) in the charge
65.0%	25.0%	21.3%	67.3%	2.0%	4.5%	94.1%	48.8%
63.0%	27.0%	23.0%	63.9%	2.0%	4.5%	94.2%	51.1%
62.0%	29.0%	24.7%	60.8%	2.0%	4.5%	94.3%	53.6%
60.0%	34.0%	28.9%	53.9%	2.0%	5.2%	94.5%	55.3%
55.0%	38.0%	32.3%	49.1%	2.0%	5.9%	94.5%	57.5%
53.0%	43.0%	36.6%	43.7%	3.0%	5.6%	94.6%	60.2%
47.0%	48.0%	40.8%	38.9%	3.0%	5.6%	94.6%	63.7%
42.0%	53.0%	45.1%	34.6%	3.0%	5.5%	94.7%	67.2%
35.0%	55.0%	46.8%	33.0%	3.0%	5.4%	94.7%	71.2%
32.0%	57.0%	48.5%	31.5%	4.5%	5.4%	94.7%	74.2%
27.0%	60.0%	51.0%	29.2%	4.5%	5.4%	94.7%	78.0%
22.0%	65.0%	55.3%	25.8%	4.5%	5.4%	94.7%	80.5%
18.0%	88.0%	74.8%	12.6%	4.5%	5.4%	94.7%	82.7%
18.0%	92.0%	78.2%	10.7%	4.5%	5.4%	94.7%	83.0%
17.0%	93.0%	79.1%	10.2%	4.5%	5.4%	94.7%	83.0%

Debashish Banerjee: ASSERTION-4
Preheating the charge configures the thermal decomposition of the compounds and hence align the structural matrices to predictable and consistent "heat substrates" - the essence of quickening the equilibrium heat and ensuring high thermal retention by the refractory lining. **ENERGY EFFICIENCY AND PRODUCTIVITY are the key derivatives of these initiatives as is showcased in the illustration**


Charge configuration with preheated simulated conditions


Impact on the furnace properties - simulated dynamics of the preheated charge

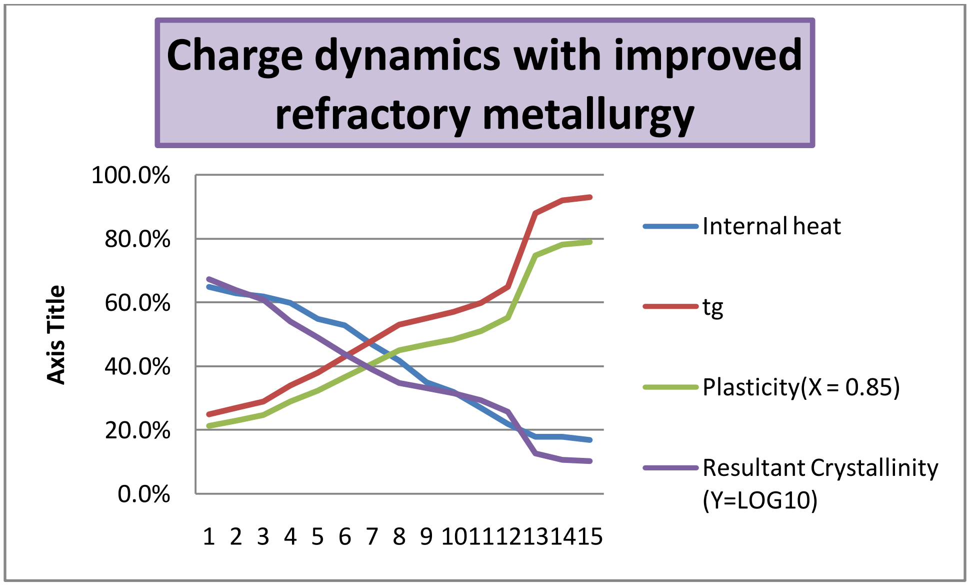

Surface Temperature (ST) in the charge - preheated charge dynamics
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
y = 0.027x + 0.452
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Surface Temperature (ST) in the charge
Linear (Surface Temperature (ST) in the charge)

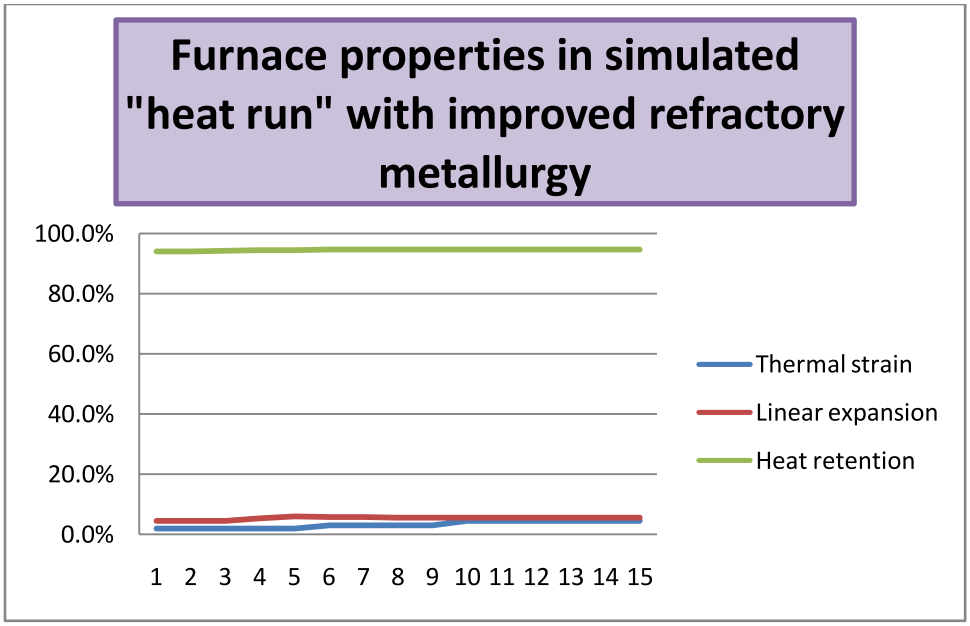
State-3: Refractory - improved metallurgy for higher thermal creep curve area

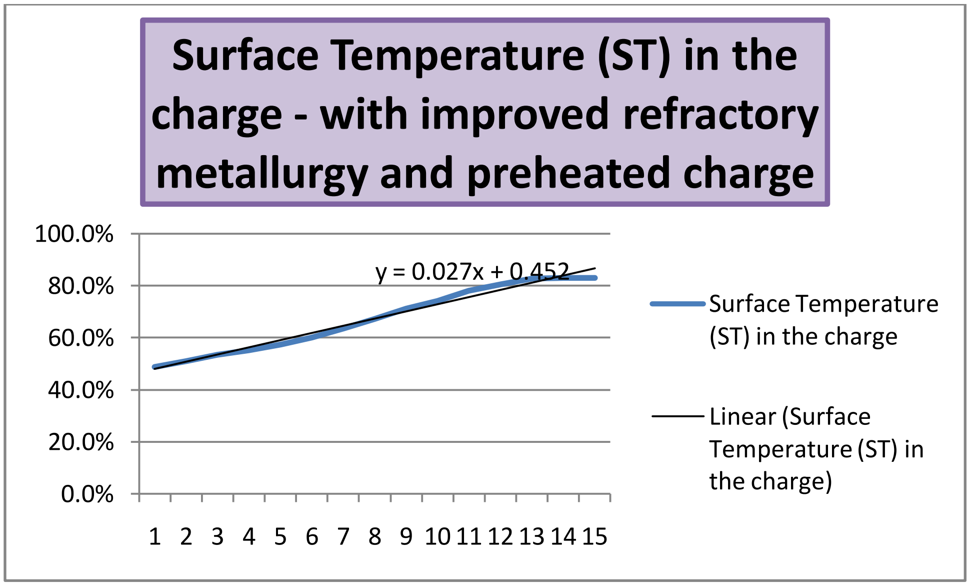
SIMULATED STRUCTURAL DYNAMICS OF THE REFRACTORY IN THE REHEATING FURNACE							
CHARGE CONFIGURATION CHANGES				**REFRACTORY DYNAMICS**			**RESULTANT ST(surface temperature) DYNAMICS**
Internal heat	t_g	Plasticity(X = 0.85)	Resultant Crystallinity (Y=LOG10)	Thermal strain	Linear expansion	Heat retention	Surface Temperature (ST) in the charge
65.0%	25.0%	21.3%	67.3%	2.0%	2.6%	97.1%	48.8%
63.0%	27.0%	23.0%	63.9%	2.0%	2.6%	97.1%	51.1%
62.0%	29.0%	24.7%	60.8%	2.0%	2.6%	97.1%	53.6%
60.0%	34.0%	28.9%	53.9%	2.0%	2.7%	97.2%	55.3%
55.0%	38.0%	32.3%	49.1%	2.0%	2.9%	97.2%	57.5%
53.0%	43.0%	36.6%	43.7%	2.2%	2.8%	97.2%	60.2%
47.0%	48.0%	40.8%	38.9%	2.2%	2.8%	97.2%	63.7%
42.0%	53.0%	45.1%	34.6%	2.2%	2.8%	97.2%	67.2%
35.0%	55.0%	46.8%	33.0%	2.2%	2.8%	97.2%	71.2%
32.0%	57.0%	48.5%	31.5%	2.5%	2.8%	97.2%	74.2%
27.0%	60.0%	51.0%	29.2%	2.5%	2.8%	97.2%	78.0%
22.0%	65.0%	55.3%	25.8%	2.5%	2.8%	97.2%	80.5%
18.0%	88.0%	74.8%	12.6%	2.7%	2.8%	97.2%	82.7%
18.0%	92.0%	78.2%	10.7%	2.7%	2.8%	97.2%	83.0%
17.0%	93.0%	79.1%	10.2%	2.7%	2.8%	97.2%	83.0%

Debashish Banerjee: ASSERTION-5

The refractory material is the key determinant - working on improving the modulus properties and metallurgical achievement of a significantly larger stress-strain curve area through the primary creep coordinates to the secondary creep and effectively changing the thermal fatigue curve of the wall - shall ensure significantly lower thermal strains and linear expansion leading to high retention of heat


Charge dynamics with improved refractory metallurgy
Axis Title
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Internal heat
tg
Plasticity(X = 0.85)
Resultant Crystallinity (Y=LOG10)


Furnace properties in simulated "heat run" with improved refractory metallurgy
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Thermal strain
Linear expansion
Heat retention



Advanced notes on the simulation series for States-1 through 3:

i) The enthalpy states in the furnace have significant influences on the properties of the rolling in as much as the drawing of the billets in the red-hot semi-molten state is a function of the relative regions of crystalline concentrates and the trade-off with the malleable proportions; the consistency in the configurations within the clusters being the key differentiating elements for improvements in both the aspects of line productivity and cutting edge quality in the areas of tensile properties and metallurgical strength of the finished products.

i.a) The first in the line of importance in this furnace dynamics is the charge configuration for metallurgy and internal heat. The billets are usually an assortment with varying degrees of compressive strength and cluster orientation of the molecules thereby inherently defining wide bandwidths of internal heat across the cross-section of the charge itself. The thresholds of internal heat provide a significant challenge for the furnace heat to change the levels in the given timeline thereby forcing the line foreman to regulate the flow of the charge to allow heat to escalate to desired or sub-optimal levels. The treatise above is an attempt to simulate the possibilities with an increasing of the charge thresholds for the internal enthalpy at the start of the reheating process in the furnace.

The key enthalpy threshold-change related derivatives in this initiative are:

i.b) The preheating is designed to augment the sensible heat levels to 300-400 degrees Celsius implying proportionate levels of increase in the internal latent heat and thereby preparing the substrates for quicker assimilation of the external enthalpy percolation into the structure and allowing a significantly higher trajectory graph area for the quantum of heat changes – a driver derivative to ensure consistency and narrower bandwidths of crystalline and malleable portions trade-off in the substrates of the charge. This is an important consequence that influences drawing and rolling properties.

i.c) Structural studies for the charge configurations and the changes within the furnace span are required to be analyzed and correlated with the enthalpy configuration to predict the properties of a given heat in the aspects of rolling and drawing quality in the value chain. The simulation herein attempts to matrix the variables and the parameters that link intrinsically to create major nodes of influences although the influences are largely hidden owing to subtle impact on the structural derivatives of the billets and the subsequent impact on the drawing and rolling in the value chain.

The three major parameters in the simulation chart are:

1. Charge configuration changes with Variables – Internal Heat, t_g or glass transition temperature, plasticity and the resultant crystalline trade-off as a function of plasticity.
2. Refractory dynamics with Variables – thermal strain, linear expansion and heat retention
3. Surface temperature dynamics with Variables – surface temperature in the charge through the heat span

ii) Mathematical expression of the factors of metallurgy influencing the charge characteristics is an important functionality of the simulation initiative herein:

ii.a) Functionality of internal heat at the different coordinates of the heat span are purely metallurgical in the derivatives and would be influenced by the nature of the billet and the structural orientation of the material. Consequently, the mathematical expression is a function of the relative levels of thermal decomposition within the clusters at the beginning of the heat and right through the duration of the run through the furnace (heat span).

The graphical area described by the coordinates of the internal heat are indicators of the quantum of enthalpy changes going into the process of establishing the thermal decomposition; conceptually, higher the area described within a given heat span, greater shall be the levels of decomposition achieved and higher shall be the consistency in getting the trade-off between the crystalline and malleable zones within the clusters – veritably the major determinants for drawing and rolling in and influencing significantly the tensile properties and the creep characteristics of the finished rolled products.

The major determinants for productivity and quality are the equilibrium coordinates of the heat quantum. Mathematically, a threshold heat quantum needs to be exchanged to achieve the equilibrium for the structural orientation of the charge in a given heat span; essentially implying that the metallurgy is an independent variable; the timeline is a constant and the quantum of heat required to achieve the equilibrium threshold is the variable dependent on the metallurgy.

Thus the expression could be **$(\zeta m) = f(\delta q) + t_0$**
where :
(ζm) = summation of the metallurgical coordinates inclusive of the spatial configuration within each given material in the charge cluster

$f(\delta q)$ = functional dependent variable – the enthalpy changes required during the heat span

t_0 = the heat span determined by the desired productivity needs for a given charge to dwell in the reheating furnace ii.b) The furnace dynamics as determined by the quality of the refractory lining is another key determinant and shall have the following expressions of the elements leading to the mathematical statement:

1. The modulus properties of stress-strain curve in the thermal plane in the primary creep zone and the resulting area of the primary creep curve – the major determinant influenced by the heat absorption and retention trade-off of the material – silica rich or alumina rich refractory or a judicious hybrid with the selection of granules to define the porosity of the refractory compound – a factor that influences creep curve configurations through external contaminants and residual interferences. Higher areas in the primary creep curve and the relative insensitivity to the thermal range as implied through the thermal modulus of the refractory compound are the major lookout properties for the selection of the furnace.

2. The secondary creep elasticity as defined by the coordinates as well as the nature of the curve for the fatigue zones are the other key determinants and shall require sustain evaluation under high density cycles of thermal peaks and troughs in simulated lower heat spans to evaluate the suitability of a refractory compound. Intense laboratory evaluation of the stress-strain curves; the determination of the secondary creep point and the mapping of the fatigue curve are all necessary to home in on the right choice for the compound to be used for the refractory lining.

3. The elements for the mathematical expression shall be the heat retention property – an independent variable, the thermal strain and the linear expansion – the twin properties that define the dependent variable grid and with n_0 – the number of thermal cycles in a given heat span being the constant.

Thus the expression shall be:

$$\zeta h = f(\ln(\sigma s)) + n_o$$

where

ζh = the heat retention variable; essentially assumed an independent function since it is a derived function of a cluster of variables. This is a summation of the enthalpy exchanges and hence is the quantum of heat left retained as a derivative at the end of the heat span.

$f(\ln(\sigma s))$ = the function of the thermal strain and the linear expansion as a logarithmic inverse function to express the inherent relationship between the two variables in relation to the derived property of the quantum of heat retained.

n_o = the estimated number of thermal stress cycles established in the heat span; herein assumed a constant for the given furnace conditions and the lead time established by the operative for discharging.

iii) The surface temperature on the charge as a function of flame characteristics in the last quarter of the heat span is a critical variable and hence requires a detailed mapping of the causal links to evaluate and monitor the performance indicators. However, notwithstanding the popular concepts doing the usual rounds in the hot rolling industry, the role of the preceding concepts in defining the substrate preparation for the roughing mills drawing and eventual rolling cannot be negated.

In this section, we shall examine the elements defining the flame characteristics and the related influences on the surface temperatures of the charge critically.

e) Blowing power of the fan is a critical element that is the determinant for the heat distribution in and around the flame in the discharge zone of the reheating furnace.

The following case study of the blower motor dynamics in a reputed hot rolling mill shall illustrate the issues related to the dynamics of heat distribution.

PHASE	**BLOWER MOTOR - fundamental energy data**					
	AMPERES	VOLTAGE	THD%	KW	KVAR	KVA
R	17.2	410.3	2.86%	0.35	1.87	5.63
Y	18.1	411.1	1.95%			
B	16.4	408.8	2.33%			
PHASE IMBALANCES	**10%**	**1%**	**47%**			

BLOWER MOTOR - core energy analysis					
PF	tan ϑ	Phase Angle	Peak i	RMS	CF (Crest Factor)
0.03	5.76	115	13.7	17.2	0.80
			13.7	18.1	0.76
			13.8	16.4	0.84
					11%

Notes on the energy analysis of the blower motor:

1. Motor impedance is high causing sharp drops in the PF – the key indicator for motor efficiency.

2. The obtuse angled phase angle is the main indicator for impedance in the field of the armature.

3. The field is redundant and the high amperes drawn in corresponding to the kW load being generated is an implication that the wiring has ruptures all along caused by high thermal stresses over a longer period of time and was undetected for a long duration runs.

Impact on the process:

1. The air velocity would be subdued causing pockets of high air concentration and hence burning while having large swathes of weak air draft and hence significantly lower levels of combustion. This fundamental disruption in air flow and consequently in the combustion levels causes unequal distribution of heat around the flame – a serious detriment for charge configurations and consistencies in malleability in the material during the upstream processing for drawing and rolling.

2. The distribution of heat on the substrates of the charge around the terminal coordinates in the reheating furnace gets influenced adversely thereby affecting the structural configuration of the billets quite substantially causing wide fluctuations in the malleability of the material being presented for the subsequent drawing and rolling. This is a factor of singular importance in the determination of both the qualitative impact of the upstream processing on the material and on the productivity in the value chain as defined by the dwell time within the furnace prior to the discharge.

3. The retention of heat within the refractory walls around the last quarter of the furnace span gets adversely affected owing to random concentrates of air and the related variations in the combustion levels of the fuel.

f) Fuel dynamics for the furnace:

1. Furnace oil is a refining derivative of the crude oil and hence has a high concentration of static charges during the flow owing to the chemical degradation that happens while overcoming the friction in the fluid field. There are escalation of temperatures while performing the work in overcoming the fluid friction; both mechanical and electrical in nature. Electrical friction caused by the static charge concentrates is significantly higher than the mechanical friction thereby lending credence to the escalation of the fluid temperatures in motion.

2. Furnace oil is characterized by the combustion properties and is a function of the availability of octane-rich components in the fluid chemistry. However, owing to fluid degradation, the combustibility of the furnace oil progressively degenerates and is influenced adversely by the increasing concentration of the contaminants and charges therein.

3. Apart from the varying levels of combustibility across the cross-sections of the fluids, the flow rates are also adversely affected and hence determine the thresholds of combustion caused around the flame.

Following are the properties of the flame that are influenced by the furnace fuel flow characteristics:

1. The flame height and the volume occupied in determining the summation of the combustion.

2. The colors mapped in the flame are a function of the combustion configuration and hence define the all-round thresholds of combustion within the working width and circumference of influence of the flame.

3. The flicker and the changes in the flame characteristics within the timeline of a typical heat span are the other important causal links of combustion that are influenced.

Thus, the solutions for the above mentioned influencing factors of blower and the furnace fuel optimization of flow and combustible characteristics are as follows:

1. Blower motor needs to be connected to the RPC – reactive power controller wherein the THD% is controlled to less than 3% levels through the use of rectifiers for controlling the harmonics in the system; especially in the context of the application of non-linear loads. Also, the RPC is designed to augment the reactive load selectively and improve on the power factor substantially to maintain high levels at all operating periods.

These factors of electrical efficiency shall minimize the chances of motor impedance through the significant reduction in CF – crest factor or multiples of peak current and the baseline RMS current. The thermal stresses related to increased periodicity of peak currents and the magnitude of the peak currents themselves shall be contained at significantly low levels thereby reducing the thermal stresses in the wiring and cable systems.

With improved dynamics for the blower motor, the distribution of heat shall be better around the flame and also the consistency in the flame characteristics shall be maintained over longer runs.

2. The furnace fuel requires the usage of strong anti-static additives for neutralizing the charge concentrates and improving on the flow characteristics. That in turn shall improve on the combustibility of the fuel and ensure an all-round retention of the flame characteristics at optimum levels of consumption of the fuel.

3. Validation of the actions can be ensured through the understanding of the following case study derivatives:

Flue Gas Analysis of the Reheating furnace

Timeline	Flue Gas temperature	Oxygen %
t1	755	23.8
t2	757	22.8
t3	754	24.2
t4	755	21.6
t5	758	20.77
Average	**755.8**	**22.63**

1. Higher flue gas temperature implies a lowered gradient with the final temperature of the furnace i.e 1200 degrees Celsius and in turn shall cause major deficiency in energy conservation and effective thermal decomposition in the substrates of the charge in the reheating furnace.

2. A high concentration of oxygen also implies higher combustibility losses.

Ideally, the flue gas temperature should be 30-35% of the terminal temperature of the furnace and the oxygen level should be less than 5% to ensure improved energy conservation, higher effective thermal decomposition of the charge and higher combustibility retention of the gases produced by the fuel within the reheating furnace.

b. The **ID – induced draft air preheat** defines the charge heat up characteristics and plays a key role in reducing the lead time to convert the charge into a state of easy disintegration at the rolling. The final charge temperature after the roughing mill interference should be in the bandwidth of **700-800 degrees Celsius for good rolling performance** of the material and for realizing the **desired hardness characteristics definitive of the residual carbon content.**

2. Granular configuration in the charge for effective rolling:

c. The **plunger actuation cycles** would require simulation with the **synchronization** of the related links of **charge cycle** and **furnace run time**, induced draft preheat levels and the **flame colors** to ensure **flow equilibrium** and consequent realization of the **discharge properties** to enable efficient downstream processing.

d. The **de-scaling of the oxidation layer** would have to be guided through a **cluster of lead indicators** that could enable the production team to monitor the changes in the process. Some of the indicators could be as follows:

1. **Surface speed changes of the charge** at each pass to evaluate the mass changes.

2. The **dimensional exposure** and the **corresponding volume of water** used in each batch would need regulation at the **water blast scale remover** for powerful estimation of de-scaling properties.

3. Combining the data of agenda-2 with that of agenda-1 would clarify the state changes prior to the rolling bay and would significantly help estimate **structural granular consistency** in the charge, the **effective hardness** as defined by the carbon and other important mineral composition and finally the all-important **rolling properties.**

4. **Vibration analysis on the rougher mill** during the **reversal process** shall help estimate the **rolling gap** and the corresponding **dimensional changes in the charge**. The damping mechanisms for the vibrations need to be evaluated and restored during the shutdown maintenance to maintain a **narrow bandwidth of the vibration domain.**

5. Free-state gauge between the rolling rolls would clarify **roll gap after n-specified reversals.** The roughing mill performance shall go a long way in maintaining the right **configuration of the grain matrix in the structure.**

3. Energy management and re-engineering : Analysis of relevant parameters

- **Heat losses management**

a. The major heat losses are in the **scaling up of the charge from room temperature to a level of 1200 degrees Celsius** – the temperature gradient being too high. SOLUTIONS ENVISAGED:

1. The charge could possibly be **heated up to a level of 500 degrees Celsius prior to the feed.** This is possible by **routing the flue gas over the charge bay.** A special design needs to be in place and the fabrication could be done locally at a reasonably low cost.

2. The **ID (induced draft) air needs to be heated up** by routing it through a **jacket heated up by the flue gas** prior to introduction into the furnace.

3. The **refractory lining needs to be thickened** way beyond recommendation levels by at least **25%;** the investment in beefing up the refractory lining would be well worth the investment in terms of energy savings and productivity improvements by virtue of significant reduction in the down time in the furnace.

4. Sensible heat losses from the furnace body need to be contained through **effective laggings of insulation** all around; again an investment worth the try since the **energy savings coupled with productivity gains** could be enormous meriting a **payback of 2-3 months**.

5. **Flue gas analyzer** studies would need to be conducted after the **predetermined "n-heats"** to enable effective **monitoring and corrective actions.**

b. **Burner management** is an effective tool in maintaining the right **charge chemistry** and subsequent **rolling performance**. SOLUTIONS:

1. **The flame length** should be ideal and not hitting the **refractory wall** and with an **inclined axis**.

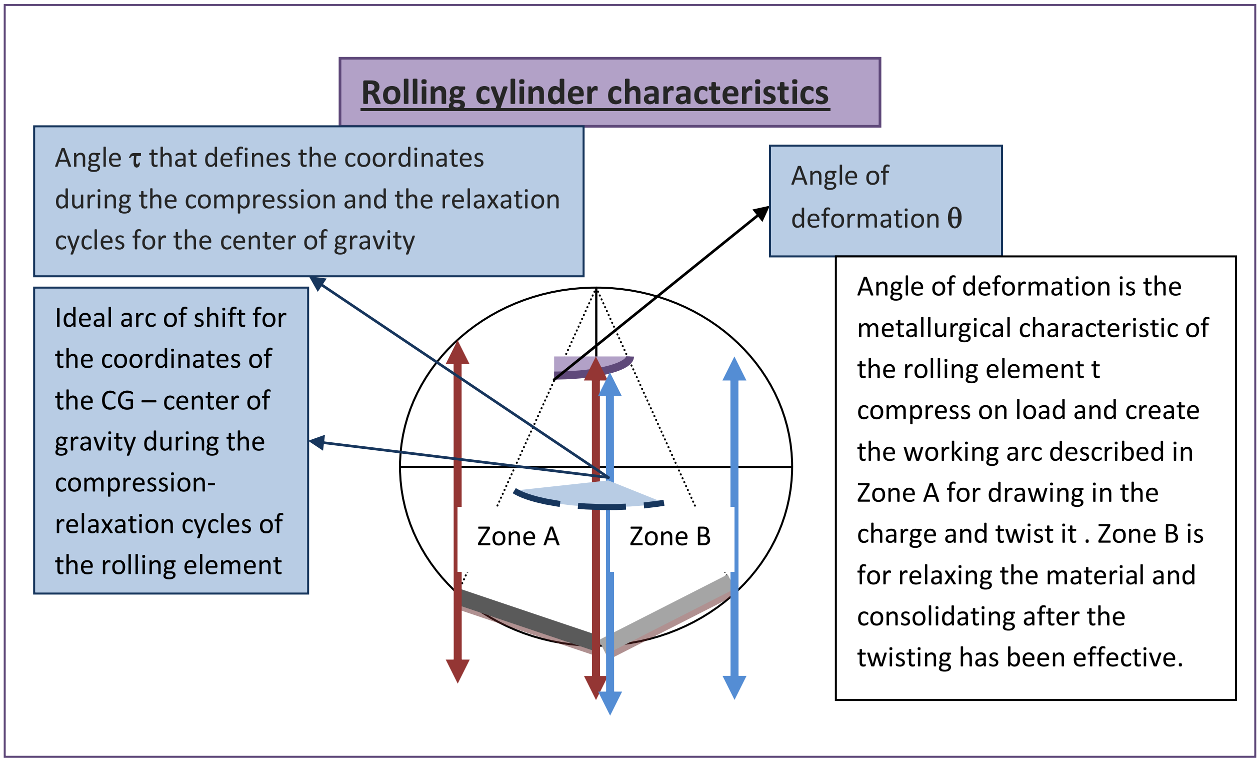
2. The **chemistry of the discharge** needs to be tested with **different flame color simulations** and the length adjusted accordingly at **optimal points**.

3. Simulation of the **flame parameters** needs to be **synchronized** with the **surface speed** at the water mill, the rougher mill during the reverses and the subsequent rolling performance in terms of **exposure time to rolling**, **hardening properties of the material post-rolling** and the **material chemistry** as also the **tensile behavior** of the final product.

4. The linkages of the properties during the **progression of the discharge** for a **given set of flame parameters** need to be studied carefully to home in on the right **properties in the reheating furnace**.

5. **Documentation of the simulation tests** as described above and the subsequent **scheduling of such tests** at regular intervals shall bring in major **savings in energy** and the commensurate advancements in **overall productivity in the value chain.**

4.Rolling mill performance factors – CLUSTER-2



Rolling cylinder characteristics

Angle τ that defines the coordinates during the compression and the relaxation cycles for the center of gravity

Ideal arc of shift for the coordinates of the CG – center of gravity during the compression-relaxation cycles of the rolling element

Angle of deformation θ

Angle of deformation is the metallurgical characteristic of the rolling element t compress on load and create the working arc described in Zone A for drawing in the charge and twist it . Zone B is for relaxing the material and consolidating after the twisting has been effective.

The key features of the rolling element that make for good rolling properties are as follows:

<u>1. Resilience of metallurgy:</u> the arc of deformation is a measure of the resilience within the metallurgical structure in as much as it allows the zone A arc to prolong under compressive forces during the rolling cycle and retain the original coordinates to a larger extent during the relaxation cycle exemplified by the zone B dynamics that helps in drawing forward the twisted element.

<u>2. Compressive forces and elasticity in the zone A:</u> The bite of the rolling element into the charge is determined by the magnitude of the compressive forces and the arc extension allowed by the deformation angle. The drawing and twisting are almost simultaneous rolling actions and depend on the relative linear speeds between the rolling arc in zone A and that of the charge in the identical time coordinates; the delta between the linear speeds defining the twisting angle and the compressive deformation at the points along the arc shall define the magnitude of the drawing effective in the structure.

<u>3. The center of gravity in the rolling element</u> assumes several coordinates during the compression and relaxation cycles and the range is determined by the arc angle τ as in the illustration. The magnitude of this arc angle depends on the structural compactness of the rolling element and the elasticity of the material to accommodate the wider changes in the coordinates in response to the compressive and the relaxing segments of the rolling cycle.

a. **Roll positioning** and the **pressure transmission geometry** would be an important parameter to work on for monitoring the productivity and the rolled properties. Indicators for the same might be :

1. Marking the **contact arc through markers on the rolls** and comparing **stability after predetermined n-runs.**

2. Generating **pressure impressions** on the reinforced carbon rich material to evaluate the **roll load distribution** – an important rolling parameter and comparing after the predetermined n-runs as in agenda-1 above would be an important criterion and should be done through **correlation with the strain tests and twisting properties of the final product on a rigorous note.**

3. The **surface speed determination** of the charge **across the rolling bay** would be a powerful indicator of the effectiveness of the rolling. **Monitoring and benchmarking** this shall be a strong check point to control productivity as well as quality parameters.

4. The **roll gap monitoring** after the said **n-runs** would be another of the key indicators that would help influence productivity and quality.

5. **Dimensional variances of the rolls and blanks f**or the TMT bars would need religious tracking and corrections to ensure the realization of the twin objectives of productivity and the quality.

Concluding steps:

1. Work on the charge and the refractory wall is of paramount importance as explained in the treatise to ensure optimized productivity, energy conservation and yield improvements as also get significant mileage on the quality derivatives of the finished rolled products.

2. The detailed check sheets for effective monitoring on the performances of the furnace oil and the blower are important derivatives. These shall include the simulation charts and metallurgical mapping of the charge configurations required for effective thermal decomposition mapping and getting the right data to conclude on the changes within the reheating furnace are prerequisites in getting the optimized productivity and quality derivatives.

3. Roughing mill check sheets for effective control and monitoring of the performances in the rolling mill are required.

4. The rolling element has to be monitored and evaluated for the rolling and relaxation zones and coordinated for validation through the quality monitoring of the tensile properties of the finished rolled products.

5. Each heat needs to be tracked for reproducibility and traceability yo ensure consistency **between the production batches in terms of the desired rolled properties and the smooth run of the products through the lines.**

Phase-1 conceptualization of augmented business transformation modeling - process optimization phase

Parametric optimization of the process

Parameter	Variable	Action	Week-1-2	Week-3-4	Week-5-6	Week-7-8	Week-9-10	Week-11-12
Productivity in Reheating furnace-water mill-rougher mill - CLUSTER-1	Charge pre-heat	Fabricating for directing the flue gas over the charge		🟩				
	Charge density planning,execution & monitoring	Timing mass and volume insertions in each batch over a period	🟩					
	ID fan optimization	Calculating the total cfm at furnace equilibrium and matching the same	🟩					
	Flame optimization		🟩					
	ID air preheat			🟩				
	Plunger sequential timing synchronization		🟩					

Productivity in Rolling mill - CLUSTER-2	Rolling parameters optimization	Simulation exercises of material chemistry and hardness-tensile matrix with process parameters		🟩	🟩			
	Indicators tabulation for routine quality checks	Practical check sheet creation, conformance, evaluation of causal links and establishment of foll proof systems of detection with reasonable accuracy and recommendations that deliver solutions			🟩	🟩	🟩	🟩
	Laboratory tests synchronization with process parameters				🟩	🟩	🟩	🟩
	Predictive Analytics and decision tree creation for potential trouble location				🟩	🟩	🟩	🟩
	Decision trees for trouble shooting				🟩	🟩	🟩	🟩

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Creating the turnaround algorithm