SAND CASTING PROCESS IMPROVEMENT USING LEAN PRINCIPLES

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Abstract

Lean manufacturing is often seen as a set of tools that reduce the total cost and improve the quality of manufactured products. The lean management philosophy is one which targets waste reduction in every facet of the manufacturing business; however, only recently have studies linked lean management philosophies with improving environmental sustainability. These studies suggest that lean manufacturing is more than a set of lean tools that can optimize manufacturing efficiencies; it is a process and mindset that needs to be integrated into daily manufacturing systems to achieve sustainability. The foundry industry, as well as manufacturing in general, has significant challenges in the current regulatory and political climate with developing an economically and environmentally sustainable business model. Lean manufacturing has proven itself as a model for both economic sustainability and environmental stewardship. Several recent studies have shown that both lean and green techniques and "zero-waste" policies also lead to reductions in overall cost.

This paper reviews the literature and some of the lean principles such as the Value Stream Mapping and Waste elimination by implementing 5S in the organization. This paper also aims at reducing lead time by eliminating stress relieving cycle with extended cooling of castings in the mould and stabilize the sand casting process by rationalization of the material grades.

Keywords: *Lean Manufacturing, Zero-waste, Value Stream Mapping, Stress Relieving, Rationalization*

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1. INTRODUCTION

1.1 No Bake Sand Casting Process

No Bake is a casting process that uses chemical binders to bond the molding sand. The sand is then transported to the mold fill station in preparation for filling of the mold. A mixer is then used to blend sand with the chemical binder and the catalyst. When the sand exits the mixer, the binder begins the hardening process.

After the compaction process, a rollover process is used to remove the mold from the pattern box. The mould is then readied for handling the molten metal. After a shakeout process, the molded sand is taken away from the casting. Then various procedures follow including the finishing and the sand can be reclaimed by thermal means.

In the No-Bake resin sand casting process, sand molds are created using a wood, metal, or plastic pattern. Sand is mixed with a plastic binder in a high-speed mixer. This sand is deposited into box containing the pattern and all essential gating, risers and chills for pouring.

The sand mixture sets up hard in a few minutes and the mold is removed from the pattern. Cores for forming internal passages in the castings are made using the same process. Cores are carefully placed into the molds. The molds are then closed and are ready for pouring.

The chemical nature of the binders makes this a highly specialized process that has to been handled with considerable expertise and knowledge.[1]

1.2 Value Stream Mapping

Value stream mapping is a lean-management method for analyzing the current state and designing a future state for the series of events that take a product or service from its

beginning through to the customer. At Toyota, it is known as "material and information flow mapping"[2].

1.3 Stress Relieving

Stress relieving is carried out on metal products in order to minimise residual stresses in the structure thereby reducing the risk of dimensional changes during further manufacturing or final use of the component.

Machining, and cutting, as well as plastic deformation, will cause a build up of stresses in a material. These stresses could cause unwanted dimension changes if released uncontrolled, for example during a subsequent heat treatment. To minimise stresses after machining and the risk for dimension changes the component can be stress relieved.

Stress relieving is normally done after rough machining, but before final finishing such as polishing or grinding.

Parts that have tight dimensional tolerances, and are going to be further processed, for example by nitrocarburising, must be stress relieved.

Welded structures can be made tension free by stress relieving.

1.4 Rationalization

Rationalization means the increase of work process effectiveness on the basis of introducing (rationalizing) arrangements in partial steps of the given activity.

At the rationalizing process it is the improvement of the human activity, increase of its effectiveness; increase of economic efficiency; summary of arrangements for the most effective utilization of work force and technology on the basis of the most modern knowledge of science and technology.

Thus, rationalization means the selection of the right way to the simplification of the production process and process analysis with the goal to reach its purposeful arrangement [3].

1.5 Methodology

The methodology followed is the DMAIC

Define Phase:

Problem Definition

Structural castings are one of the basic raw material for any of the machine tool industry. The cost and quality of these castings play an important role in the profitability of the business. These castings are produced in their own foundry through No Bake Sand Moulding process. There are six grades of castings , 3 Grey cast iron (G2, G3, G4) and 3 Spherodical Graphite Iron (SG1, SG2, SG3) produced using no bake process. Due to the variety of grades there is less stabilization in the production of these castings and more rejections have occurred.

Objectives

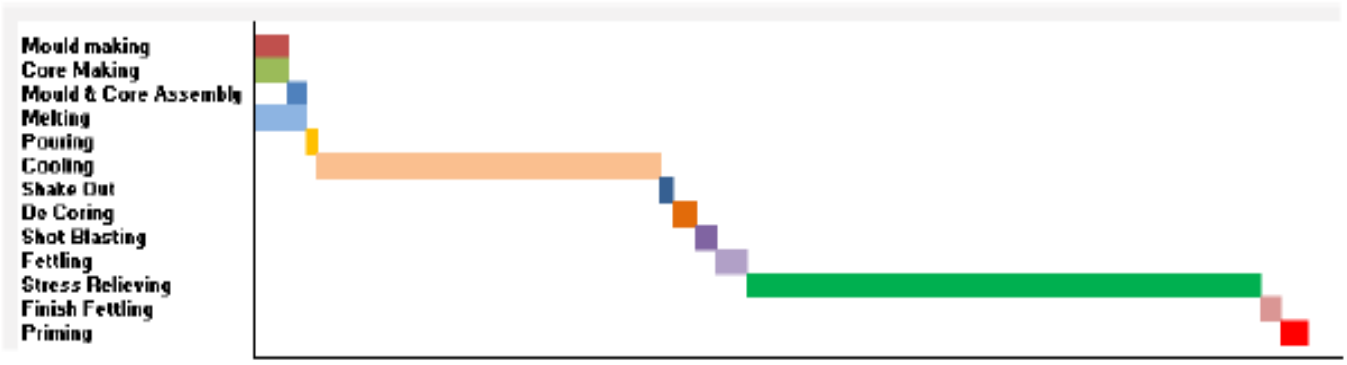
Primary Objective:

To improve sand casting process in foundry, supply improved and reduced cost castings to the Machine tool Industry.

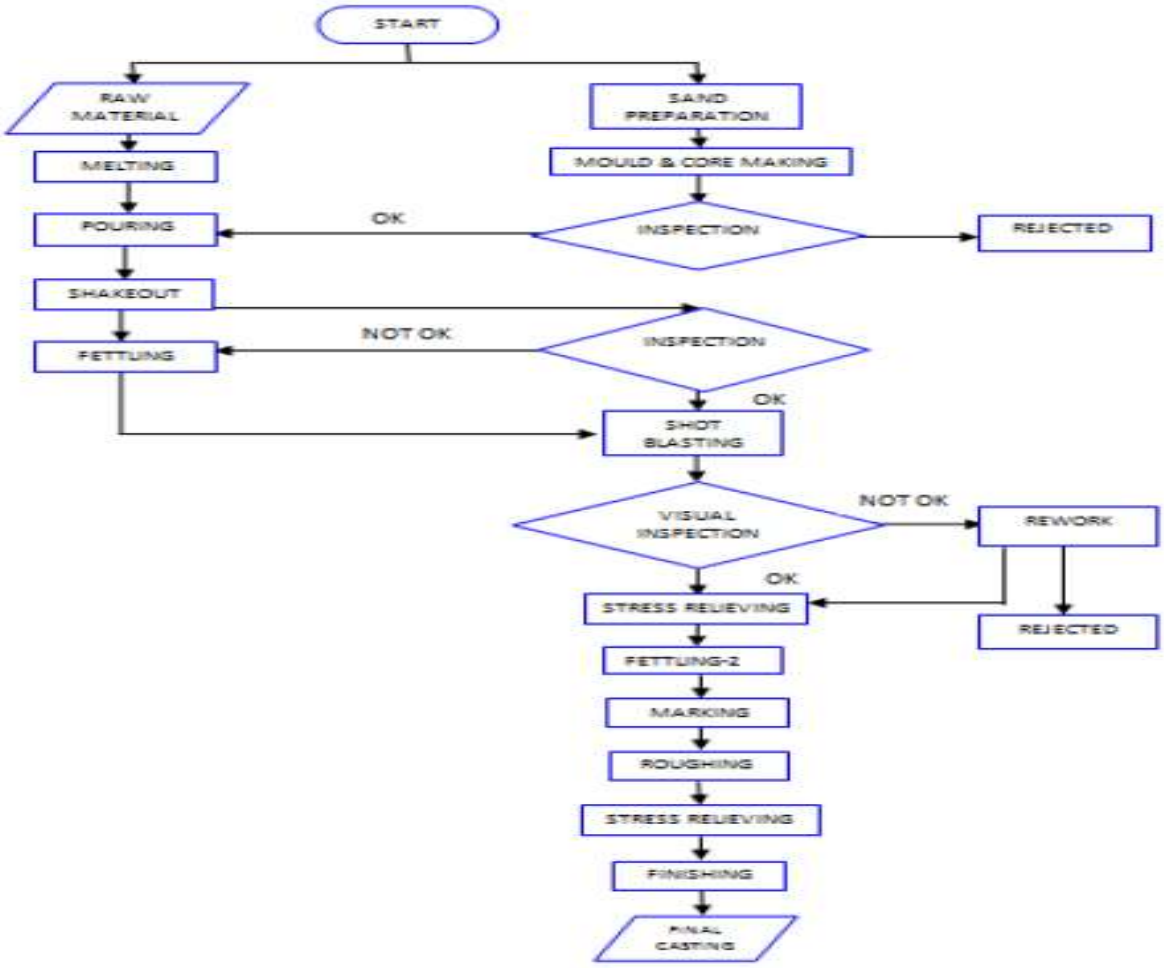
Secondary Objective:

- To reduce lead time by Value Stream Mapping
- To rationalize casting grades and improve productivity
- To eliminate Stress Relieving cycle or do stress relieving only once for critical castings
- To reduce design related defects
- To eliminate 7 wastes applying lean principles

Gantt Chart

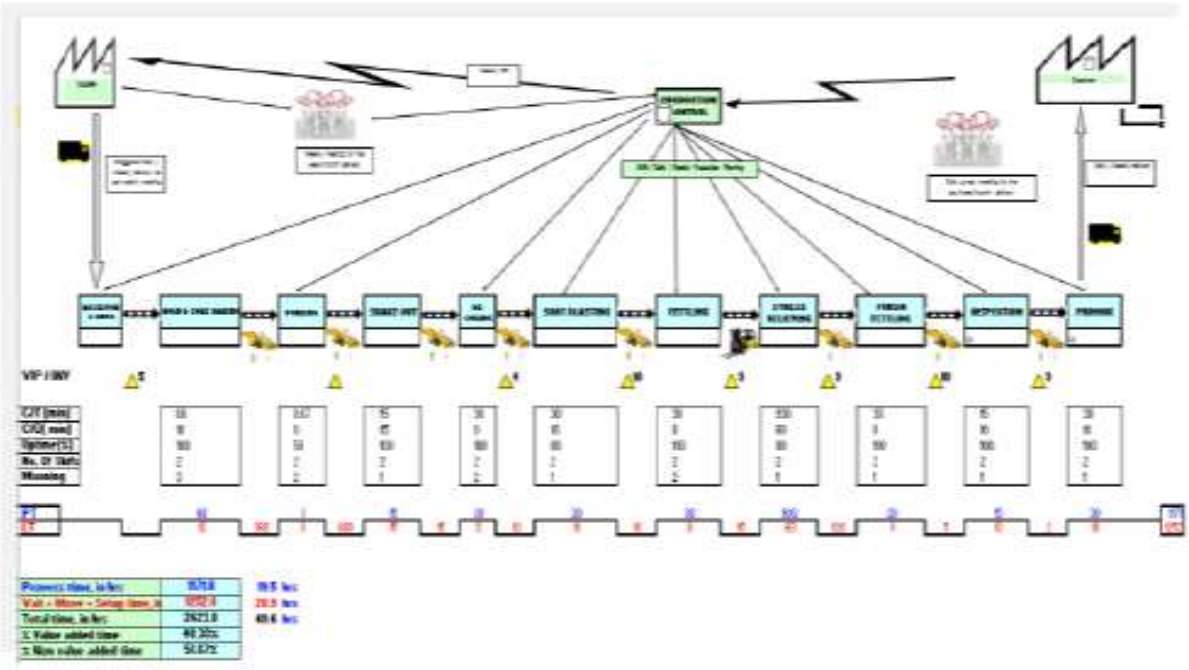


As is Process Map



Measure phase

Current State Value Stream Mapping



Process time, in min	1171.0	19.5 hrs
Wait + Move + Setup time, in min	1252.0	20.9 hrs
Total time, in min	2423.0	40.4 hrs
% Value added time	48.33%	
% Non value added time	51.67%	

Takt Time calculation

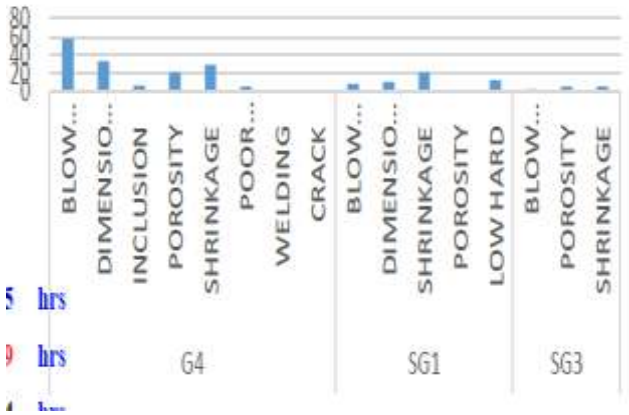
Working shift per day = 2
Working hours per shift = 9½ hours
Available time per shift = 570 minutes
Tea break per shift = 2breaks * 10 minutes= 20 minutes
Lunch break per shift = 30 minutes
Down time per shift = 0
Net working time per shift = [available time- (breaks+break down)]=[570-(20+30+0)]=520
Customer demand per day = 20 Nos or 10000kg
Takt time = Available production time/Total daily quantity required=1040/20= 52minutes

Rejection Details

- Overall casting rejections(For Financial Year Apr 2014- Mar 2015)

Total Supplied Qty	**6369**		
Sal. & Rej. Qty	**1254**		
Percentage	**19.69%**	196900	2.3
Salvaged Qty	**963**		
Salvaged Percent	**15.12%**	1,51,200	2.5
Rejected Qty	**291**		
Rejected Percent	**4.57%**	45,700	3.3

- Type Of Defects Found Gradewise



✓ More number of defects are found in grades G4 and SG1

✓ Based on the percentage, SG1 stands 1st with more percent of rejections. Since the process of producing castings of grade SG is complicated than producing castings with grade FG.

- Top Components Rejected

DIVISION	Machine type	RAW MATERIAL CP. No.	ITEM DESCRIPTION	NO OF REPEATS	GRADE	PATTERN
VMC	BMV45+	R0530074503	Cross slide	45	G4	Wooden
VMC	BMV50	R0530073603	Table	16	G4	Wooden
VMC	TCV300	R0506993702	Table	12	G4	Wooden
HMC	TMC1000	R0501502900	BEARING BLOCK	12	SG1	Wooden
VMC	BMV50	R0530081904	Milling head	11	G4	Wooden
VMC		R0596598201	Cross slide	10	G4	Wooden
VMC	BMV45+	R0530079400	Milling Head	9	G4	Wooden
HMC	400E	R0595925900	Pallet	9	SG1	
VMC	Chandra+	R0500012700	Column	8	G4	Wooden
HMC	HSTC 3070/4070	R0596365800	TABLE	8	SG1	Wooden
HMC	HSTC	R0596365700	Table	8	SG1	Thermocole
HMC	HSTC30/4070	R0596506000	Table	8	SG1	
VMC	BMV80	R0530097503	Table	6	G4	Wooden

✓ After analysing the rejection data, we found that out of the 5 structural components (Table, Cross slide, Milling Head, Column & Base) the most rejected components are Table & Cross slide. Hence these two structural components are considered for study & experimentation.

2.3 Analyse Phase

- TO REDUCE DESIGN RELATED DEFECTS IN THE CASTINGS IN TABLE & CROSS SLIDE

TABLE	REJ %	8.455
	SAL%	4.065
	OVERALL	12.52
CROSS SLIDE	REJ %	1.85
	SAL%	9.95
	OVERALL	11.8

1. Table

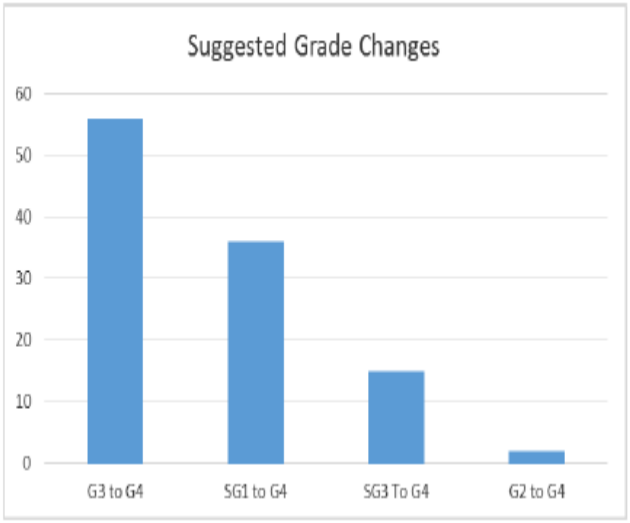
- The castings of table differ in sizes based on the model of machine tool and its use.
- From the analysis it was found that more rejections are in HSTC table which is a SG casting.
- Other Tables are made of grey iron and the rejections are less compared to HSTC table

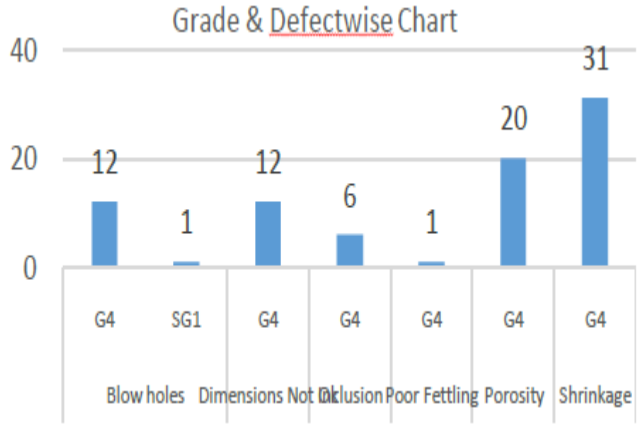
2. Cross Slide

- Most of the cross slides were rejected because of the shrinkage in the lead screw bore area which was machined unnecessarily.

	Total Quantity Produced	Rejected Quantity	Percent Rejection
HSTC TABLE	76	26	34.21%
OTHER TABLE	776	63	8.12%

Hence the suggestion for rationalising the grades was arrived and the part nos which are to be rationalised was identified based on their application, size and model.





- To reduce this defect shrinkage, chills were introduced and a core with large bore size was made and the machining was eliminated.

MATERIAL NO	Part Description	Machine Type	Total	Material	Design
R0530079400	BMV 45+ MILLING HEAD	BMV 45+	333	G4	No m/cing at Lead screw area
R0506993702	BMV45+ TABLE	BMV 45+	250	G4	No m/cing at Lead screw area
R0530074503	BMV45+ CROSS SLIDE	BMV 45+	240	G4	No m/cing at Lead screw area
R0530073603	BMV 60 TABLE	BMV 60	173	G4	No m/cing at Lead screw area
R0530081904	BMV 60 MILLING HEAD	BMV 60	154	G4	No m/cing at Lead screw area
R0530149401	BMV 60-CROSS SLIDE	BMV 60	151	G4	No m/cing at Lead screw area
R0506994002	BMV45++ CROSS SLIDE	BMV 45++	108	G4	No m/cing at Lead screw area
R0537716301	BMV 51 TABLE	BMV 51	96	G4	No m/cing at Lead screw area
R0537743701	BMV 35-CROSS SLIDE	BMV 35	96	G4	No m/cing at Lead screw area
R0537741102	Table BMV 35	BMV 35	94	G4	No m/cing at Lead screw area
R0537744501	BMV-35MILLING HEAD	BMV 35	88	G4	No m/cing at Lead screw area
R0537720503	BMV51 CROSS SLIDE	BMV 51	83	G4	No m/cing at Lead screw area
R0537729603	BMV 51MILLING HEAD	BMV 51	72	G4	No m/cing at Lead screw area
R0530130401	(VF30CNC CHANDRA) MILLING HEAD	VF30 CNC CHANDRA	39	G4	No m/cing at Lead screw area
R0596380700	CROSSSLIDE HSTC 3070	HSTC 3070	37	G4	No m/cing at Lead screw area
R0596506000	MILLING HEAD BT 40 HSTC VE	BT 40 HSTC VE	29	G4	No m/cing at Lead screw area
R0537760602	BMV 65 MILLING HEAD	BMV 60	25	G4	No m/cing at Lead screw area
R0530079601	BMV 60+ MILLING HEAD	BMV 60+	23	G4	No m/cing at Lead screw area
R0596380800	CROSS SLIDE HSTC 3050-VE Ø32 BS	HSTC 3050-VE	20	G4	No m/cing at Lead screw area
R0537760203	BMV 65 TABLE (1500mm X 650mm)	BMV 65	19	G4	No m/cing at Lead screw area
R0530093402	MILLING HEAD (VF30CNC VS)	VF 30 CNC VS	18	G4	No m/cing at Lead screw area
R0530036301	BMV70 & 80-MILLING HEAD	BMV 70 & 80	17	SG1	No m/cing at Lead screw area
R0530150901	BMV45+ RECEIVER (INTEGRAL)	BMV 45+	16	G4	No m/cing at Lead screw area
R0530088801	BMV60 ++ TABLE	BMV 60++	14	G4	No m/cing at Lead screw area
R0530089902	BMV60++ CROSS SLIDE	BMV 60++	14	G4	No m/cing at Lead screw area
R0537760301	BMV 65 CROSS SLIDE	BMV 65	13	G4	No m/cing at Lead screw area
R0596413501	CROSS SLIDE HSTC-3050	HSTC 3050	13	G4	No m/cing at Lead screw area
R0596380600	HSTC 3070 / 4070 CROSS SLIDE	HSTC 3070 / 4070	12	G4	No m/cing at Lead screw area

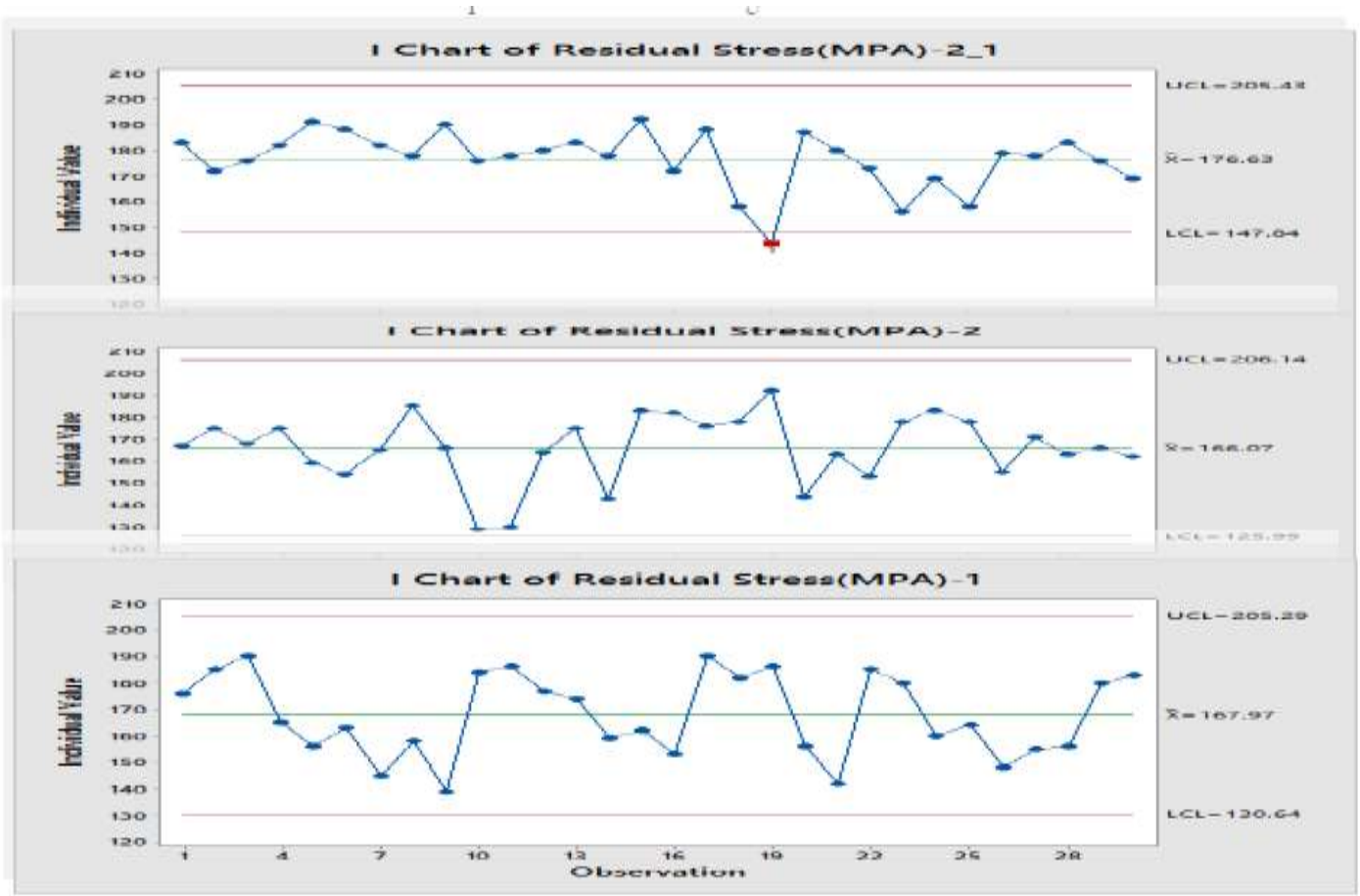
To Eliminate Stress Relieving

1. Part numbers that undergo stress relieving are identified

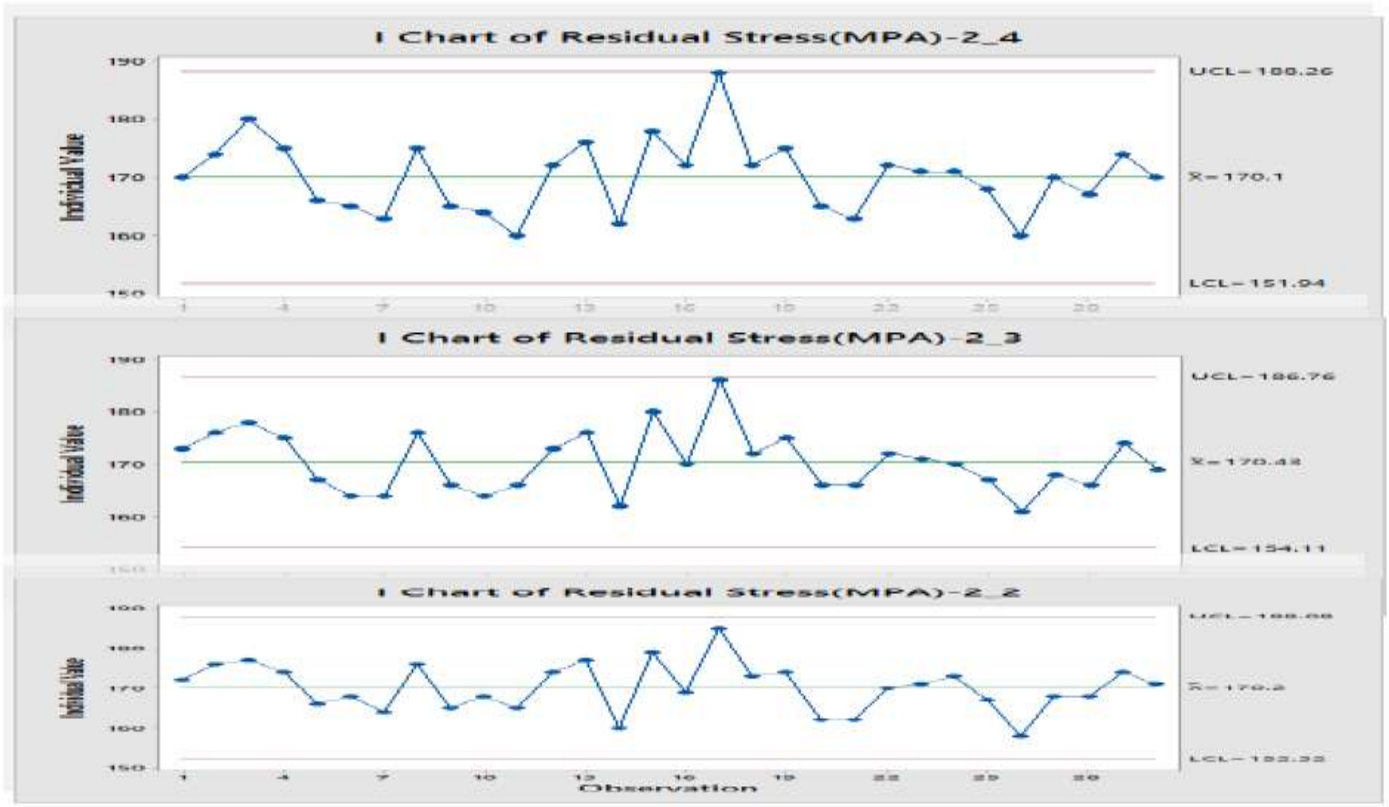
Raw Material CP No	Part Description	Machine type	Total	Tonnage	Total Tonnage	Stress Relieved
R0530079400	BMV 45+ MILLING HEAD	BMV 45+	333	215	71595	Yes
R0506993702	BMV45+ TABLE	BMV 45+	250			No
R0530074503	BMV45+ CROSS SLIDE	BMV 45+	240			No
R0530073603	BMV 60 TABLE	BMV 60	173			No
R0537740506	BMV45+ MACHINE BASE	BMV 45+	161	1035	166635	Yes
R0530081904	BMV 60 MILLING HEAD	BMV 60	154	425	65450	Yes
R0530149401	BMV 60-CROSS SLIDE	BMV 60	151			No
R0537740505	BMV45+ MACHINE BASE	BMV 45+	112	1035	115920	Yes
R0500003901	KNEE SIZE - 2		111	245	27195	Yes
R0500079901	FEED GEAR BOX SIZE - 2		110			No
R0506994002	BMV45++ CROSS SLIDE	BMV 45++	108			No
R0537716301	BMV 51 TABLE	BMV 51	96			No
R0537743701	BMV 35-CROSS SLIDE	BMV 35	96	240	23040	Yes
R0537741102	Table BMV 35	BMV 35	94			No
R0537744501	BMV-35MILLING HEAD	BMV 35	88	135	11880	Yes
R0537720503	BMV51 CROSS SLIDE	BMV 51	83			No
R0500069000	TABLE SIZE - 2		80	300	24000	Yes
R0537729603	BMV 51MILLING HEAD	BMV 51	72	395	28440	Yes
R0500063300	H.V. SADDLE SIZE - 2		71	148	10508	Yes
R0506904205	TABLE (SURYA / CHANDRA)	SURYA/CHANDRA	70			No
R0500002102	HORIZONTAL COLUMN SIZE - 2		69			No
R0537768600	BEARING BLOCK BMV 65	BMV 65	57	10	570	Yes
R0596365800	HSTC TABLE-3070	HSTC 3070	54	200	10800	Yes
R0500029401	OVER ARM SIZE - 2		52			No
R0500064100	U SADDLE SIZE - 2		50	90	4500	Yes
R0537740507	BMV45+ MACHINE BASE	BMV 45+	50	1035	51750	Yes
R0596362400	HEIGHT BLOCK - 150MM		49	125	6125	Yes

2. Residual stress(Mpa) after and before Stress Relieving

- Residual Stress level in mpa before Stress Relieving

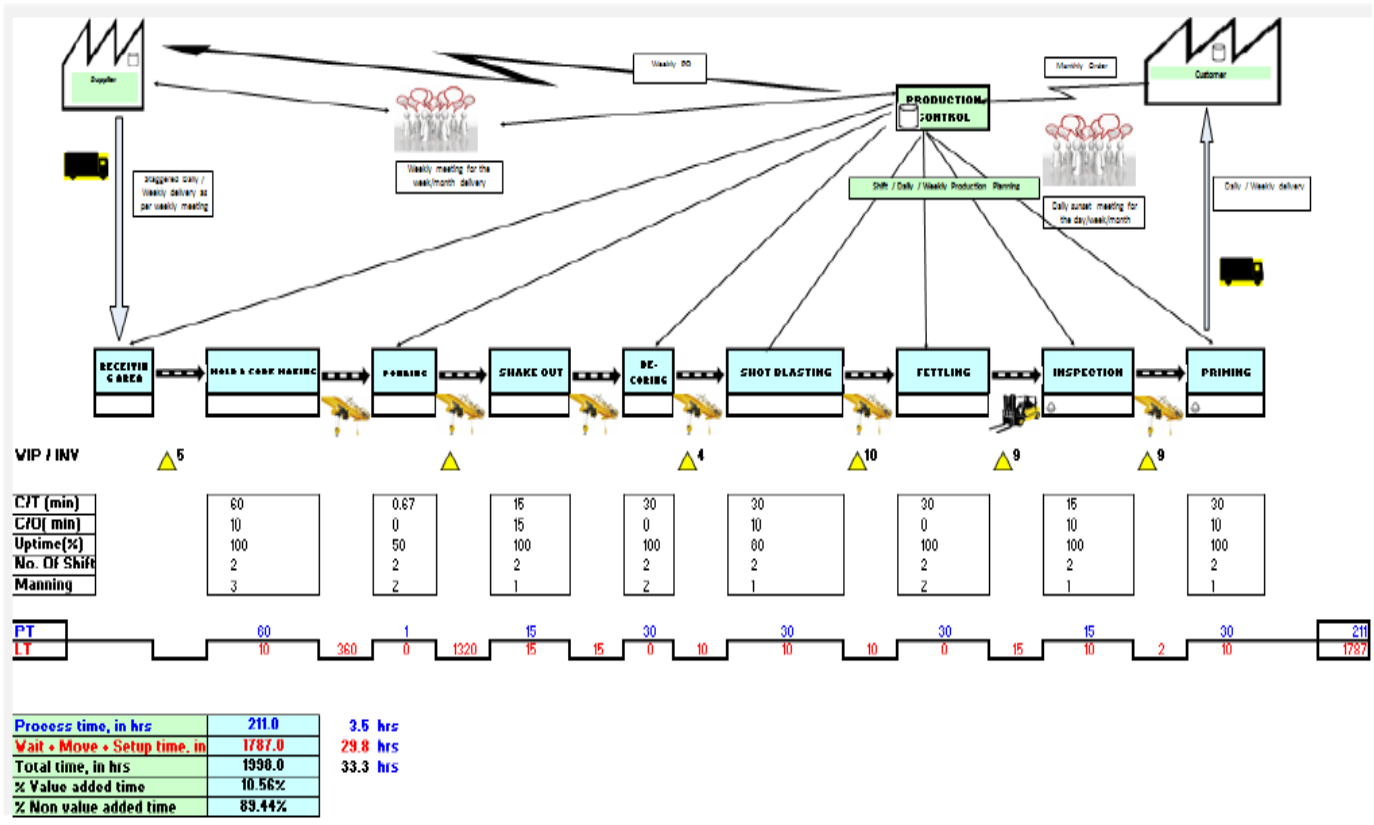


- Residual Stress Level in mpa after Stress Relieving



2.4 Improve Phase

Future State Value Stream Mapping



Process time, in hrs	211.0	3.5 hrs
Wait + Move + Setup time, in hrs	1787.0	29.8 hrs
Total time, in hrs	1998.0	33.3 hrs
% Value added time	10.56%	
% Non value added time	89.44%	

Process Fmea

Failure Mode and Effect Analysis

Item Name: Moulding of all Items	FMEA Team:	Prepared by:	
		FMEA Date (Orig):	Revision:

Process Function / Requirements	Potential Failure Mode	Potential Effect(s) of failure	SEV	Potential Causes/ mechanism(s) of failure	OCC	Current Process Controls	DET	RPN	Actions Recommended	Resp.& Target Date	Actions Taken	SEV	OCC	DET	Future RPN
Guide Pin dimension checking For Round (18.86±0.06) For flat (20.86±0.06)	Guide pin dimension <18.80mmfor round < 20.80 for flat	Shift		Usage of worn out guide pins & closing pins		Using micrometer daily									
SAND PREPARATION	Less green compressive strength (Below 0.6kg/cm²)	Swelling		Improper Mulling time(Below 2½ Min.)		Work instruction									
To prepare sand to produce moulds		Mould Damage		Less Bentonite % (<0.375%)		Work instruction									
		Blow holes		High moisture in the moulding		Check in lab									
MOULDING To prepare molds which can hold the liquid metal till it solidifies	Low mould hardness (<70)	Sand Inclusion		Poor ramming (Air pressure less than 5.5 kg/cm²)		Hardness testing 1/40 molds Pressure guage									
	Improper cleaning of moulds	Sand Inclusion		Less time air blow & Less pressurised air below 5.5 kg/cm²)		Visual & Work instruction									
	Improper mould seating	Mould lift		Improper mould level checking		Work instruction									
				Metal Projection on seating area of moulding box		Visual									
	Improper closing	Mould broken		Improper guide of closing pins with bushes		Visual & Work instruction									
	Improper Clamping	Sand drop		Over tightening of moulds		Visual & Work instruction									
		Sand crush		Over tightening of moulds		Work instruction									
		Mould lift		Loose Clamp		100% Checking									

2.5 Control Phase

Control Plan

		TITLE:											
		Control plan											
		DEPARTMENT:				CLASSIFICATION:					REFERENCE:		
		FOUNDRY				Control Plan							
Product Family Name : Castings					Key Contact / Phone :					Customer Engineering Approval/Date (If Req'd) :			
Model Numbers :					Core Team :					Customer Quality Approval Date(If Req'd) :			
Supplier /Manufacturing Unit : BFW FOUNDRY					Supplier /Manufacturing Unit Approval/Date :					Other Approval/Date (If Req'd) :			
Part /Process Number	Process Name/ Operation Description	Machine, Device, Jig Tools For Mfg	Characteristics			Special Char. Class	Methods		Sample		Control Method	Reaction Plan	Process Owner
			No.	Product	Process		Product/Process/Spec	uation Measurement Techni	Size	Freq.			
	Raw material testing	Lab Equts.			Material content		FORM	Incoming inspection	**	**As per FORM	Incoming inspection records	Segregate & move to 'REJECTED' area	
	Core Gum			Gum quality				Visual	100%	Continuous	Visual check by Op.	Rejected & notify supervisor	
	Clay washer			Clay washer quality				Visual	200%	Continuous	Visual check by Op.	Rejected & notify supervisor	
					Faulty material sent by supplier							Notify RMC	
	Sand mixture preparation	Sand-Fixed vol. hopper		Wt. of Sand,Resin,Hexa				Load cell/salter balance	100%	Continuous	Process log sheet, Failsafing for resin load cell	Adjust & notify supervisor	
		Resin-load cell/Vol. cont.			Load cell/Salter bal. condition						Calibration	Ask for calibration	
					Resin measuring jar cleanliness			Visual	100%	Continuous	Cleaning of jar as per schedule	Clean resin jar	
		Hexa-load cell/salter bal			Operator knowledge						Work instruction	Educate operator	
	Sand mixing	Sand mixers		LOI & Transverse					1 per M/c	Daily	Run chart in shop	Adjust in subsequent batches	
					Air Temperature				100%	Continuous	Visual checking	Notify supervisor	
					Cycle time						Automatic calibrated timers	Ask for calibration	
	Core making Air blow & level ejector plans	Air gun, Aluminium rod for leveling		Core box free from burnt sand, Ejector pin level				Visual	100%	Continuous	Visual insp. Of cores,Process log sheet	Segregate cores & notify supervisor	
					Operator knowledge						Work instruction	Educate operator	

3. CONCLUSION

- Projected Cost Savings

FOUNDRY PROJECT COST SAVINGS					
		VOLUME (2014-15) in metric ton	TOTAL COST	VOLUME(2015-16)in metric ton	TOTAL COST
ELIMINATION OF STRESS RELEIVING	Supplier-2 (1572 Tonnes) at Rs 4.50/kg	1572	7073847	2360	10620000
	Supplier-2 (1522 Tonnes) at Rs 4.50/kg	1522	6085000	2283	10273500
LEAD SCREW NON MACHINING COST	M/c ing Cost & Weight reduction Cost	2000	2522734	3000	3784101
RATIONALISATION OF GRADES	SG1 to G4	2000	1258110	3000	1887165

- The lead time was reduced from 40.4 hours to 30.3 hours
- The shrinkage defect was eliminated in HSTC table after the grade was changed to G4.
- Process FMEA and Process Control Plan was developed to control the process.

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