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Continuous Improvement Methodology for Improving Manufacturing Processes and Product Quality in a Foundry Industry

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Abstract: ***In recent times the companies stay in a regular changing world where in customers call for better products, higher quality and shorter delivery times. To reach these customer requirements, companies depend on continuous improvement to attain their goals. Continuous Improvement (CI) is the methodology for making improvements to products, services or processes. It refers to the process upgrades which are undertaken in stages, separated by a period of time. its major goals is for increasing profits, reducing costs, and accelerating innovation. This paper is focused on the improvement of manufacturing processes and product quality in a foundry industry. The Continuous Improvement methodology based on PDCA- KAIZEN approach adopted for this research. Proper and effective tools where used for this approach. As a result of this improved process flow and high product qualities are achieved.***

Keywords: KAIZEN, PDCA, SIPOC, FMEA, COQ, 5S

1. Introduction

Companies around the globe facing new challenges every day; globalization has accelerated opposition among them and eliminates commercial distance, any enterprise can also have a right away competitor located within the other side of the world. The market has advanced additionally, breaking the vintage paradigm in which the producer dictates the selling rate, now, the market and/or costumers are the ones that establish the expenses and because they have more than one alternatives as capacity providers, they are also demanding higher quality, quicker response time and better production flexibility. The word "Continuous Improvement" is associated with an expansion of organizational developments which includes the adoption of "lean manufacturing" techniques, Total Quality Management (TQM), employee involvement programmes, customer support projects, and waste reduction campaign [5].Continuous development is a culture of sustained improvement targeting the elimination of waste in all processes of manufacturing and strategies of a company. Continuous Improvement refers to the process improvements that are undertaken in stages, separated by a period of time. This paper mainly focused on the Continuous Improvement methodology using PDCA - KAIZEN approach to improve manufacturing processes and sub-processes and rectify casting defects and rejection in a Foundry Industry. The production, defect, inspection data of six months is collected to evaluate the performance of the company. Process flow chart,SIPOC diagram, Activity Network Diagram,5S score are used to document the reality of the organization.Pareto chart, Cause and Effect, Time study, Cycle time balancing,FMEA are used for Defect/Rejection study and finding solutions and counter measures. Cost of Quality analysis is used to compare the expenses of the organization before and after the implementation of Continuous Improvement methodology. The adoption of Continuous Improvement using PDCA - KAIZEN improved the Operation Path time, 5s score, reduction in rejection percentage and COPQ.

2. Methodology

The methodology adopted for Continuous Improvement is based on PDCA - KAIZEN approach .PDCA is Plan Do Check Act cycle and KAIZEN implies steady continual change for enhancing quality aspects [4].PDCA is an interactive 4-step control method used in industries for the efficient and Continuous improvement of manufacturing processes and products [5]. it is also referred to as the Deming circle/cycle/wheel, the control circle/cycle, the Shewhart cycle, or plan – do – study – act (PDSA).Dr. Walter A. Shewhart and Dr. W. Edward Deming introduced PDCA the concept for productivity management, and continuous quality improvement of processes and products.KAIZEN is the Sino-Japanese phrase for "improvement". Kaizen is a continuous procedure, the purpose of which is going beyond productivity improvement, it is also a technique that, implemented correctly, humanizes the place of job, eliminates excess hard work, and teaches employees to carry out experiments on their work the usage of the scientific approach and how to learn to spot and avoid wastes in commercial enterprise strategies [6].

3. Company Background

The company is an ISO 9002 company stared in fully equipped to manufacture all kinds of Ferrous Castings weighing from 20 kg to 8000 Kg single piece.It has an area of 21500 square meters and an optimum capacity of 18000 tonnes/annum.The High Pressure Line is a semi-automatic machine for mass production.Here,Grey Iron and SG Iron castings of different grades and size are produced for the domestic and international markets. Automotive castings such as, valve Housings, flywheels, pulleys, manifolds, brake drums etc, are manufactured and dispatched from here.Complex high precision items like cylinder block and cylinder heads are also manufactured in this company. Parts of Pump, Machine tools, Wind turbine parts etc are the other products manufactured here. Currently the company facing many problems in the manufacturing process and the product quality. It is mostly observed in the manufacturing of cylinder frame castings. Since it is a continuous and bulk manufacturing process, a methodology which is ease in implementation and minimum cost is applicable. Therefore, the company implements Continuous Improvement methodology for identifying the defects and problems in process, products and services. The process is continued for sustained improvement.

4. Continuous Improvement Implementation

Using PDCA - KAIZEN methodology, promoting a Continuous Improvement environment in the company for the manufacturing of engine cylinder frame. Different statistical tools are used for analysing the current variations and errors in manufacturing processes and also the rejection rate of castings.

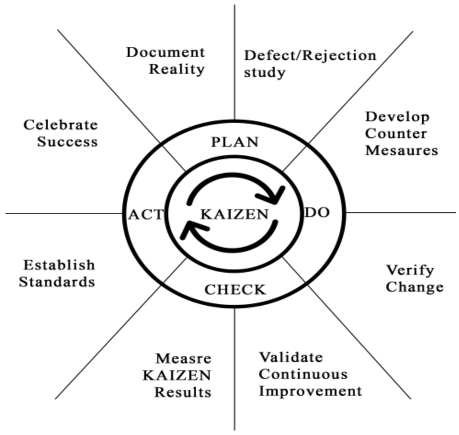

Figure 1: Illustration of PDCA - KAIZEN methodology

4.1 Plan Phase

Current situation such as production strategies, rejection details, quality aspects, Improvement scopes are observed in this phase. Adequate data are collected and evaluated to find the root cause of variation in processes and product quality. Documenting reality and Defect/Rejection study are the two sections in plan phase [5].The tools for documenting reality used are Process flow chart,SIPOC diagram, Activity Network Diagram, Time study of different workers,5s score(current).

4.1.1 Document Reality

A process flowchart is a graphical illustration of a manufacturing process through a flowchart. it is used as a means of getting a top-down information of how the process works, what steps it includes, what occasions change results, and so on.

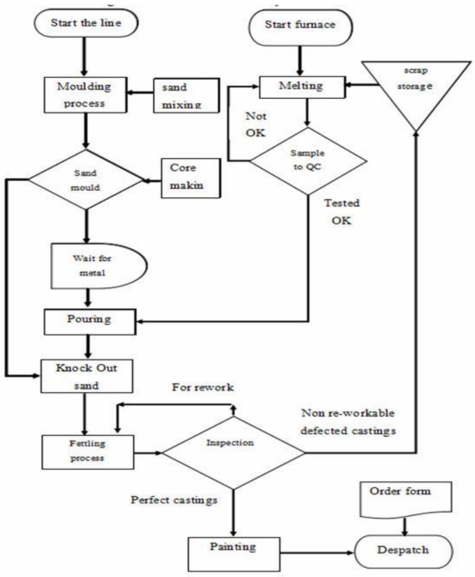

Figure 2: Process flow chart for cylinder frame

The acronym of SIPOC is Suppliers, Inputs, Process, Outputs, and Customers. It is a tool that summarizes the inputs and outputs of one or more processes in form. And each element will be the columns of the table.

Suppliers	Input	Process	Output	Customers
Supply to Control room	Electric power supply	Switch ON the line from control room	Sensors and devices	
Power pack	Hydraulic Power	Oil level is checked in the power pack	Pressure for hydraulic arms and pistons	>Melting > Pouring >Fettling
Contra mix	Green Sand	Prepared sand reaches the top bunker from the Contra Mixer		
Engineering Department	Aluminium pattern of cylinder frame	Pattern mounted securely in the browser	Strong hold to withstand impulses	
Return from the line	Mould box	Mould boxes place on top of the turning table of the machine and sand fills in it		
Compressor	Compressed air supply	High impulse compresses the sand to create the mould	Impression of the patterns	
Core shooter and hand core making	Sand Core	After venting cores are placed manually	Venting for gas escape	
High pressure	Hydraulic clamp	Boxes are closed in the turnover section and clamps into a single mould	Mould box for pouring	

Figure 3: SIPOC diagram for moulding

Ongoing situation of all the core process such as melting and pouring, moulding, core making, cleaning and finishing and inspection are evaluated separately for effective results.

Next step in documenting reality is the identification of operational sequence of various process activities. Activity Network Diagram is used here.An Activity Network Diagram is a diagram of task activities that shows the sequential relationships of processes using arrows and nodes.

Table 1: Data for Activity Network Diagram

Activity	*Predecessor*	*Duration*
Sand mix -A	-	8min
Pattern fix-B	A	45min
Core making-C	A	20min
Moulding-D	CB	5min
Melting-E	C	90min
Tapping/pouring-F	DE	15min
Fettling - G	F	48min
Inspection - H	G	10min

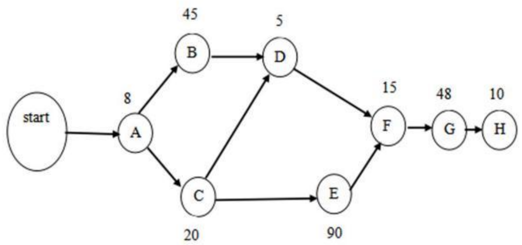

Figure 4: Activity Network Diagram for cylinder frame casting

Currently the activity takes a lot of time when compared with past records. The sequence or the operation must be carried out in shortest possible time and this is termed as Optimistic time.

Another important parameter in the study of current situation is the time study of workers. Time study sheets are used for collecting this data [6].The data valid and affective for a group of workers performing similar tasks

Table 2: Time study of workers

S. no	*Name*	*Duration*	*Observed time*
1	Operator1	Swing frame grinder	25min
2	Operator2	Swing frame grinder	21min
3	Operator3	Swing frame grinder	15min
4	Operator4	Pneumatic Chipping hammer	23min
5	Operator5	Pneumatic chipping hammer	21min
6	Operator6	Pneumatic chipping hammer	23min
7	Operator1	Finishing tools	10min
8	Operator2	Finishing tools	8min
9	Operator3	Finishing tools	9min

Work place organizing - 5S is a workplace organization and management methodology which uses 5 Japanese words seiri, seiton, seisō, seiketsu, and shitsuke [5].The current situation of workplace and for studying knowledge of workers about workplace management is understood by conducting a survey. Questions related to workplace management and the answers from workers are taken for the survey. It is observed that, the workers of the organization does not have any idea of KAIZEN and 5S and its importance.

4.1.2 Defect/Rejection study

Casting defects fluctuating in every month. Rejection and rework of castings adversely affect the development of the firm. Production delay, rework cost, cost of scrap, despatch delay are some of the major impacts. Currently the company has an average rejection percentage 16.37%.Pareto chart is the tool used to highlight the most important among the defects [1].

Table 3: Data for Pareto analysis-cylinder frame

Defect	Total	Cumulative	Cumulative %
Sand inclusion	422	422	46.56
Cold joint	269	691	76.27
Blow hole	72	763	84.23
Mould break	64	827	91.28
Scabbing	39	866	95.58
Cracks/tears	31	897	99
Knockout defect	9	906	100
Total	906		

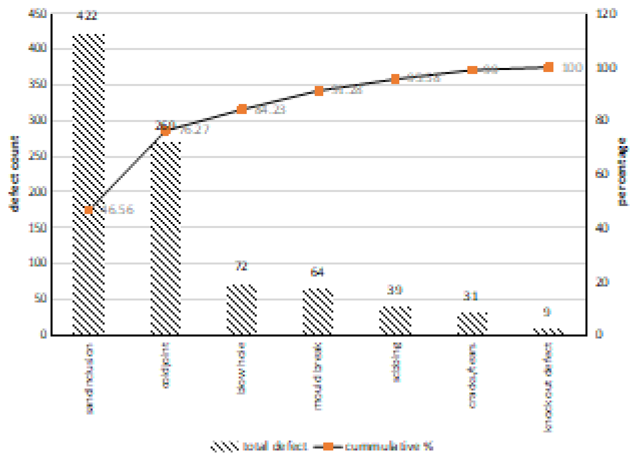

Figure 5: Pareto chart for cylinder frame casting defects

From the Pareto chart, 85% of total rejections are due to sand inclusion, cold joint, blowhole and mould break. These are the Vital few. There are various factors which causes these defects and it can be categorized into five areas such as Method or Process, material, people, environment and machine.

Cause and Effect Diagram, Fishbone diagrams or herringbone diagrams is an effective tool for foundry industries which helps in brainstorming to identify possible causes of problems and in determining ideas for sorting out. The Root cause analysis for each potential defect in castings are carried out and determined its possible solution.

It is essential to identify all-possible causes of defects and thus a cause and effect diagram has constructed in order to identify and display the possible causes of that particular defect.5Why analysis is done using brainstorming sessions with officials and workers and careful observation of the activity which is the basis of Cause and Effect diagram.

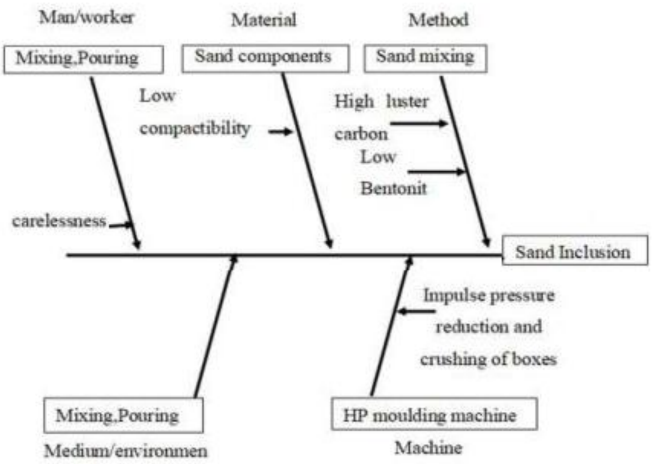

Figure 6: Showing the critical path

4.2 Do Phase

It is the second stage where the observations and information from the Plan stage is taken in to action. The identified problems from the plan stage is validated in this stage. The activities carried out in this phase are, Developing counter measures and the verifying changes for the problems.

4.2.1 Critical path analysis

Using critical path analysis, the Optimistic time is calculated. In order to find the critical path four category of times are need to be determined. Earliest start (ES), Earliest Finish (EF), Latest start (LS), Latest finish (LF).

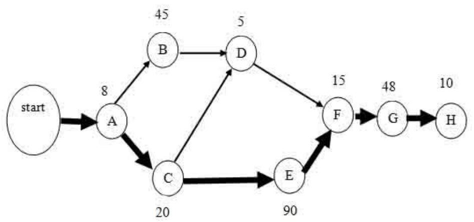

Figure 7: Showing the critical path

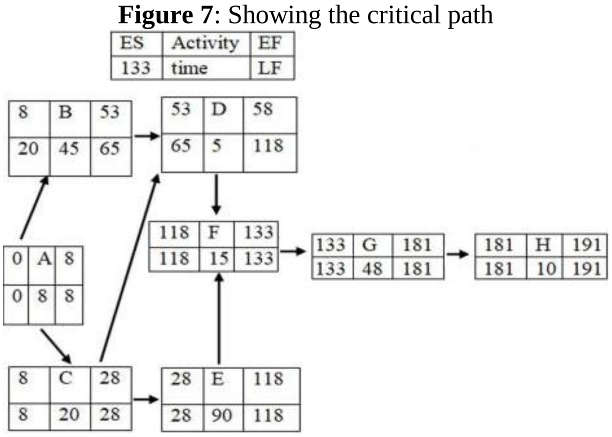

Figure 8: Activity network diagram with ES, EF, LS and LF

Expected Time: The above data, the process likely to be carried out in 175min,it could take 255min or may be faster, in 162 min

$$\text{Expected time} = \frac{\text{Optimistic} + (4 * \text{Most likely}) + \text{Pessimistic}}{6}$$

$$= \frac{162 + (4 * 175) + 255}{6} = 186.12$$

4.2.2 Cycle time balancing

Taken time - It is the time that exactly matches production to demand of the customer [6].The study is done for the month July and &hours of work a day. Excluding weekly off and holidays, the total no of working days is 27.The order for cylinder frame casting is taken as 1000.

$$\text{Taken time} = \frac{\text{Net operating time}}{\text{Customer demand}}$$

$$\text{Taken time} = \frac{27 * 7 * 60}{1000}$$

The taken time for a demand of 1000 castings is 11.34 minutes. Providing a 20% allowance in work, therefore, Taken time = 13.608 rounding off to 14 minutes.

Table 4: Cycle Time Balancing by KAIZEN

Name	Observed time	Taken time	Observed time (after KAIZEN)
Oper1	25min	14min	20min
Oper2	21min	14min	18min
Oper3	15min	14min	14min
Oper4	23min	14min	21min
Oper5	21min	14min	19min
Oper6	23min	14min	20min

Suggesting small changes in the working strategies of workers are tested. The test seemed to be successful that their current time duration for that particular task is observed to be decreasing. The test seemed to be successful that their current time duration for that particular task is observed to be decreasing. Through Continuous Improvement, gradually observed time will precisely matches with the Taken time.

4.2.3 FMEA analysis

Failure Mode and Effects Analysis is used as tool for system reliability observation. The tool identify all the possible failure modes and its effects results in that particular area. Risk Priority Number (RPN) is a measure used for assessing risk in FMEA analysis RPN value 1 represents an absolute best state. The value greater than one shows the level of worst condition and the RPN1000 represents the absolute worse condition.

$$RPN = (S \times O \times D).$$

Severity (S) is a numerical subjective that estimates or ranks the effect of failure which impacts on the customer. 10 (High impact) to 1 (low impact) Occurrence (O) represents a numerical subjective estimates or ranks the likelihood of a failure mode will occur during the production process. 10 (Inevitable) to 1(Not likely to occur) Detection (D) Rank the probability that the failure mode will be detected or corrected 10 (Not likely to be detected) to 1 (Very likely to be detected).

Table 5: FMEA analysis of major defects

S.no	Failure	Failure mode	Failure effect	Failure cause	S	O	D	RPN
1	Sand inclusion	Creates irregularities inside the castings.	Develops internal cracks	Low compactibility of sand	7	9	8	504
2	Cold joint	uneven solidification of two metal streams	Disproportions in dimension	Variation in pouring temperature and time	7	8	8	448
3	Blow hole	Entrapped gases inside the mould	Poor surface finish and dimensional variation	Improper sand combination	8	6	6	288
4	Mould break	Breakage of pattern print in the sand mould	Variation in dimension	Crushing of boxes and machine vibration	5	9	6	270
5	scabbing	A portion of mould or core lifts or breaks and the recess formed is filled by metal	Rejection of casting	Personal carelessness	9	4	8	288

Larger RPN values normally indicate more critical failure modes, this is not always the case. At first Severity rank is given the most weight in risk assessment. Then the combination of Severity and Occurrence (S * O) will be considered. From the FMEA analysis of major defects, the defects that causes major impact in production process are Sand inclusion, Cold joint and scabbing. At the end of the study, several suggestions are strategies are observed for reducing these defects.

Table 6: Defect data for the month of July

Defects	Total number rejected
Sand inclusion	9
Cold joint	5
Mould break	10
Blow hole	5
Cracks/leak	18
scabbing	-
Knock out	-
others	15
Total	62

4.3 Check/Study Phase

Data and results from the DO phase are evaluated here. Results are compared to the expected effects to look any similarities and differences. Check (C) is for determining whether the implementation has brought the planned improvement. The effective method used for this is phase is Cost Of Quality method. (COQ).COQ can represented as sum of two Cost of Good Quality (COGQ) and Cost Of Poor Quality (COPQ).

$$COQ = COGQ + COPQ$$

Cost of Good Quality is the sum of Preventive cost and Appraisal cost. Cost Of Poor Quality is the sum of Internal and External cost.

No: of castings inspected, January2019 to june2019 = 6034
Total no of good castings = 6034-988=5046
Cost for single casting = Rs.3900
Total sales, Jan2019 to Jun 2019 =5046*3900 = 19679400/-
Average COPQ per month = Rs.507662.667/-
Average of Percentage COPQ to sales for a month =19% (18.65%)

COPQ is the sum total of Internal and External failures of the company. In the manufacturing of cylinder frame, its value is 19% of the total sale for the last six months. Using PDCA -KAIZEN methodology, the root cause and possible solution for most of the defects are identified and executed. The COQ for the past six months is compared with the month of July and the check study is conducted. The details of casting rejection and rework cost after performing changes for the month of July in the production of cylinder frame is shown in the table6.

Total casting inspected = 610
Total sales for the month of July
=548*3900=Rs2137200/-
COPQ for July = Rs.186746/-
COPQ to sales for July = 9% (8.1%)

Table 7: Cost analysis for the month of July

Defect	Total number rejected	Internal Failure			External failure
		Cost of rejection Rs.2875/ unit	Reworked/ salvaged quantity	Cost of rework Rs 144/piece	Rejection from customer (60nos)
Sand inclusion	9	25875	-	-	-
Cold joint	5	14375	-	-	-
Mould break	10	28750	10	1440	-
Blow hole	5	14375	4	576	-
Cracks/leak	18	51750	20	2880	-
scabbing	-	-	-	-	-
Knock out	-	-	-	-	-
others	15	43125	25	3600	-
Total	62	178250rs	35	8496	-

The Cost of Poor Quality is decreased from 19% to 9% after the implementation of PDCA -KAIZEN methodology.

4.4 Act phase

Conclusions and standardization about the changes needed to be done for Continuous Improvement are established here.It cannot be considered as the final stage of the process. This phase becomes the input for further improvement and eventually improvement is sustained.

4.4.1 KAIZEN Newspaper

The KAIZEN newspaper is tool used to carry out visible control at the process of continuous improvement itself. It is an essential part of kaizen activities or Lean management. It is a visual management tool used to manage the progress of KAIZEN activities. In this company, publishing a Kaizen newspaper helps to achieve targets and problem rectification

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and eventually improves the process development and product quality. It is an effective visual standardize tool for monitoring continuous improvement in every department. It documents the progress of activities for Improvement in the organization and must be standardized for future.

Department :
Line :

KAIZEN NEWSPAPER

Root Cause Identified | Countermeasures established | Countermeasure complete | Problem resolved

PROBLEM			SOLUTION			IMPROVEMENT TRACKING		
Date	Originator	KAIZEN Opportunity	Owner	Root Cause	Counter Measures	Est date of completion	Status	Actual date

Figure 9: Designed KAIZEN newspaper

4.4.2 Introducing 5S audit Check Sheet

The audit is carried out in regular time periods for effective organization of workplace. The paper also suggested to form a team for performing this audit [9].This visual methodology easily depicts the flaws and lacks in workplace management and also helps to sorting out the problems.

Department : | **5S Audit Check Sheet** | Completed by:
Supervisor : | | Date :

1-Very poorly | 2-Poorly | 3-Fairly | 4-Well | 5-Very well

S No	Description						Marks
1	**SORT(SEIRI)** - What is needed and remove the rest.						
1.1	Have all the unnecessary items removed?	1	2	3	4	5	
1.2	Tools are located in most convenient location?	1	2	3	4	5	
1.3	Is the workplace have only essential items?	1	2	3	4	5	
	Total / Full mark	15					
	Acquired marks / 15 x 100						
2	**SET IN ORDER (SEITON)** - Every thing is in its place.						
2.1	Work area and walkways are unobstructed?	1	2	3	4	5	
2.2	Visual Control methods adopted to prevent mix-up of castings?	1	2	3	4	5	
2.3	Safety equipment are in place and up to date?	1	2	3	4	5	
2.4	Personal belongings stored in lockers provided?	1	2	3	4	5	
2.5	Have Storage indicators(boards,signs) properly for separating ares for good and defective castings?	1	2	3	4	5	
	Total / Full mark	25					
	Acquired marks / 25 x 100						
3	**SHINE(SEISO)** - Cleaning and ways for cleaning.						
3.1	Work floor are kept clean?	1	2	3	4	5	
3.2	Machines,Tools and equipment's are free from dirt, leaks and spillages?	1	2	3	4	5	
3.3	Anyone for periodic inspection/maintenance?	1	2	3	4	5	
3.4	Do the works regularly clean their tools and machines without telling?	1	2	3	4	5	
3.5	Is there any High level of Cleanliness & maintenance schedules are displayed?	1	2	3	4	5	
	Total / Full mark	25					
	Acquired marks / 25 x 100						
4	**STANDARDIZATION(SEIKETSU)** - Make standard						
4.1	Is stock control is established?	1	2	3	4	5	
4.2	Standardization of Maintenance,Storage of Files for workplaces?	1	2	3	4	5	
4.3	Improvement ideas are generated and carried out regularly?	1	2	3	4	5	
4.4	Are the workers aware of their responsibilities?	1	2	3	4	5	
	Total / Full mark	20					
	Acquired marks / 20x100						
5	**SUSTAIN(SHITSUKE)** - Maintain standards for sustained improvement.						
5.1	Regular training programme about kaizen is working out?	1	2	3	4	5	
5.2	KAIZEN news paper are used effectively?	1	2	3	4	5	
5.3	Last weeks improvement procedures are carried out?	1	2	3	4	5	
5.4	Educating every one about the important of KAIZEN and 5S?	1	2	3	4	5	
	Total / Full mark	20					
	Acquired marks / 20x100						

Figure 10: 5S Audit check sheet

5. Conclusion

This paper executes the systematic application of PDCA - KAIZEN methodology in a foundry industry. The root cause for the defects had been successfully determined. Corrective action to overcome this quality problem had suggested. It is found that the implementation of PDCA - KAIZEN methodology had improved the production process of cylinder frame in the industry. The research findings show that, the operation path time reduced by 5min, the percentage of rejection reduced from 16.37%% to 9.5% and the COPQ to sales percentage for the month of July is reduced by 10%.

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