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Analysis of Pipe Water Inlet EW010 Quality Control Using Six Sigma and Failure Mode and Effect Analysis (Case Study: PT Wijaya Karya Industri dan Konstruksi)

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Abstract. PT Wijaya Karya Industri dan Konstruksi has businesses in the fields of Steel, Plastic, Pressing and Casting (PPC) Manufacturing and heavy construction equipment. The PPC factory produces various kinds of manufacturing components, one of which is vehicle spare parts made from metal which are produced using a casting process. One of the products produced using a casting process is Pipe Water Inlet EW010. There are many Pipes Water Inlet EW010 defective products with an average of 52% defective products in July-August 2023. The research was conducted to analyze the sigma value and determine the factors of product defects and the impact of the defects to provide suggestions for product quality improvement. In this research, the method applied is the Six Sigma method and FMEA, by implementing DMAIC (Define, Measure, Analyze, and Control). From this research, the results showed that the most common defects were Leaking, Pen/core, and Porous, namely 89% cumulative. Pipe Water Inlet EW010 products are currently at level 2.44 sigma so corrective action needs to be taken to reach the six-sigma level. By applying the FMEA method, it can be seen that the most significant and most frequently occurring product defects are caused by poor core quality and work method errors. Therefore, the recommended alternative repair solution is to improve the quality of the cores used and improve work methods. The results show an increase in the sigma level value from 2.44 to 2.86 and a decrease in average defects from 52% to 23%.

Keywords: Failure mode and effect analysis; Pipe water inlet EW010; Root cause analysis; Six sigma

1. Introduction

The manufacturing industry in Indonesia currently plays an important role in the era of infrastructure development and progress in Indonesia. This gives rise to various kinds of competition in business activities between manufacturing companies which are increasingly creative and generate greater profits.

The production process is important for a company, because it is the process that can process a product so that it is ready to be marketed. Quality is something that must be paid attention to and is an important aspect for the progress of a company (Masdalifah, 2019). Quality control

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systems are currently designed and implemented in various industries to anticipate increasing competitive pressures and can reduce quality costs resulting from product nonconformities. The aim of quality control in an industry is to produce consistent products, increase profits and reduce product repair costs by identifying factors that cause defects in products (Ishikawa, 1990). Defective products are products that do not meet specifications or do not reach the specified quality standards so they cannot be reworked (Alfarizi et al., 2023; Andriana et al., 2016; Puspitaloka & Ekawati, 2022). Companies whose main strategy is quality gain competitive advantage in business, because not all companies are able to achieve and maintain high and consistent quality. In this case the company must produce high quality products at prices that can compete with similar companies. One of the objectives of quality control in a company is to reduce the number of defective products so that production costs are not too high and do not disappoint consumers.

Plastic, Pressing and Casting (PPC) factory produces various kinds of manufacturing components, one of which is vehicle spare parts components made from metal which are produced using a casting process. Casting process is the process of making objects by melting metal and pouring it into the mold cavity (Sudjana, 2008). One of the products produced using a casting process by the PPC Factory for use by PT HINO is Pipe Water Inlet EW010. Pipe Water Inlet EW010 product can be seen in Figure 1.

Figure 1 Pipe Water Inlet EW010

In the manufacture of Pipe Water Inlet EW010, defective products were still found, so the company suffered losses due to wasted time and costs, because time that should have been used in the production process was wasted to repair defective products, and it was difficult to achieve the predetermined production targets. The defects in question are defects found in foundry production products, such as leaks, pen/core, porous, cracked, and inappropriate visual shapes.

The maximum average reject standard for Pipe Water Inlet EW010 products set by the PT WIKON PPC factory is 8%. From January 2023 to June 2023, the PT WIKON PPC Factory produces Pipe Water Inlet EW010 with the following reject data:

Table 1 Reject Data on Pipe Water Inlet EW010 Products

No	Month	Number of Goods Production (Pcs)	Number of Reject Items (Pcs)	Total Production Results	Reject Percentage (%)
1	Januari	2007	130	1877	6.48%
2	Februari	2591	163	2428	6.29%
3	Maret	2653	256	2397	9.65%
4	April	2169	253	1916	11.66%
5	Mei	2206	156	2050	7.07%
6	Juni	2095	228	1867	10.88%
Total		13721	1186	12535	8.65%

The reject referred to in the table above is the Pipe Water Inlet EW010 product which has serious defects and cannot be repaired, so the product cannot be distributed to customers and must be melted down again for re-production. The defect factor in the Pipe Water Inlet EW010 product is caused by various aspects, such as mold design, raw material composition, casting method, and factory environment. The casting unit at the PPC factory produces defective products which are quite high causing high costs for repairs. Product quality checks are carried out by the Quality Control (QA/QC) management department through manual product testing. The high number of defective products in the Pipe Water Inlet EW010 product, of course, can be detrimental to the company, therefore the researchers made observations at the PPC factory of PT Wijaya Karya Industri and Construction using the Failure Mode and Effect Analysis (FMEA) method to identify any potential causes defects in products by looking at the Severity, Occurrence and Detection levels to be able to reduce and find alternative ways for the company. Failure Mode and Effects Analysis (FMEA) is a method used to analyze the occurrence of risks or failures in a process and can be applied in various types of manufacturing industries (Susanti, 2015). The DMAIC Six Sigma method is used to help make improvements to the production process so that companies can make improvements to any existing problems (Saputro et al., 2016). To find the root cause of existing problems, the help of Root Cause Analysis (RCA) is needed. Root cause analysis (RCA) is a method for identifying the root causes of functional and operational problems (Jucan, 2005).

2. Method

The flowchart of the steps to address the issue in this study can be seen in Figure 2.

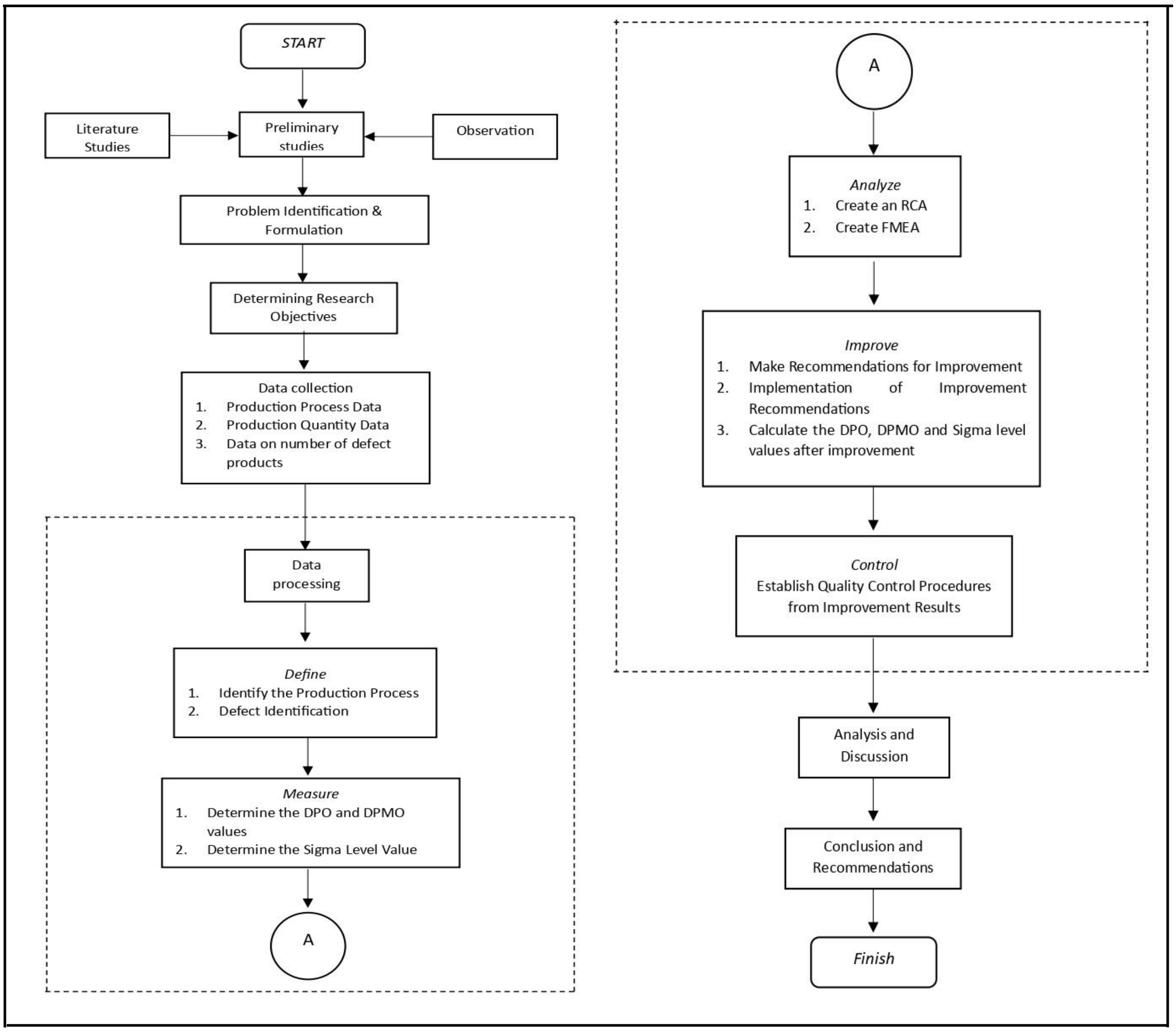


Figure 2 Flowchart

The following are the research stages conducted using the Six Sigma and FMEA methods: The first step is to conduct direct field observations and literature studies. Observations were conduct directly at the Plastic, Pressing and Casting (PPC) Factory Casting unit of PT Wijaya Karya Industri and Construction. Observations were carried out on defects in the Pipe Water Inlet EW010 product, by directly observing the production process starting from the melting of material to the finishing process. After the problem is found, the next step is to determine the topic of the problem that will be researched through literature study. The aim of the literature study is to obtain sources that can support problem solving in a production process. The types of literature used in this research include journals and books regarding Quality Control, Six Sigma, FMEA, RCA and supporting documents from companies.

The next step is collecting data. In this research, the data used is primary data and secondary data. The primary data required for this research is defect data for Pipe Water Inlet EW010 product and data for complete risk analysis, such as data on effects and causes of failure and indicator values from FMEA. This data was obtained by collecting information and conducting interviews with the head of the production engineering department, head of the QA/QC department, and field operators. Secondary data is data that indirectly provides information to researchers through interviews and company documents. The secondary data needed in this research is data on production quantities and the number of defects in Pipe Water Inlet EW010 product and existing FMEA analysis data.

After collecting data, the next step is data processing using the Six Sigma method. The purpose of data processing is to provide solutions and resolve a problem that is a research topic. The implementation of Six Sigma follows the DMAIC cycle (Define, Measure, Analyze, Improve, Control), where these steps are repeated steps or form a quality improvement cycle using the six-sigma methodology.

The defining stage is the first step in the DMAIC Six Sigma cycle, namely identifying the product manufacturing process by determining the SIPOC (Supplier-Input-Process-Output-Customer). After identifying the product manufacturing process described through SIPOC tables and diagrams, the next step is to identify what types of defects are found in the Pipe Water Inlet EW010 product. The second step in the DMAIC cycle is the measure stage, namely calculating process capability. After the process capability results are known, process identification is carried out using a control chart. Then proceed with the calculation of DPO (Defect per Opportunity), DPMO (Defect per Million Opportunities) and sigma level to determine product quality in a production process. The third step in the DMAIC cycle is the analysis stage, namely the phase where researchers try to find out the reasons for a failure. The analysis stage is the stage where the cause of the error is identified. Tools that can be used at this analysis stage are Root Cause Analysis (RCA) and FMEA. This tool is used to explain what factors can cause problems, such as: humans, machines, materials, methods and the environment. To find out the type of defect that has the most impact, you can use the Failure Mode Effect Analysis method, to see the RPN value. So, you can see the impact of failures that occur. The fourth step in the DMAIC cycle is Improvement, namely in this phase measurements and recommendations for improvements are made to product defects found in production results. In this phase, post-repair DPMO and Sigma Level calculations are carried out to see the production quality of the proposed improvements made. The final step in the DMAIC cycle is the control stage. This stage aims to evaluate and monitor the results of improving quality. The results of quality improvement are documented and provided to the company which is useful as a corrective action for future process implementation.

Finally, the researcher needs to conclude the research findings and provide Recommendations. The conclusion will provide the final answers to the analyzed problems according to the problem statement in the introduction. Recommendations will contain suggestions for improvements to be implemented or maintained.

3. Results and Discussion

The process of making the Pipe Water Inlet EW010 using the casting method consists of several stages as in figure 3.

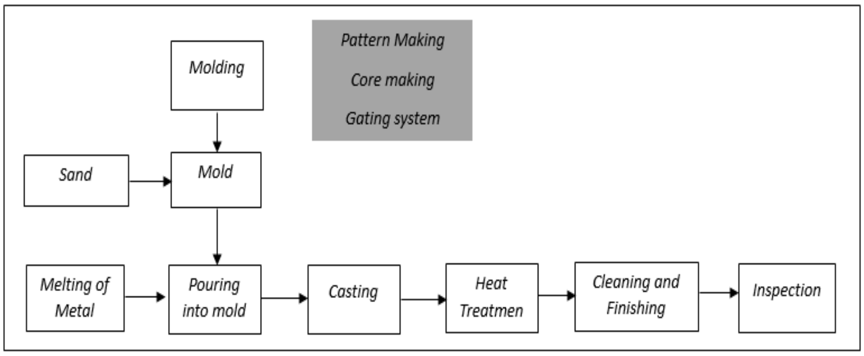


Figure 3 Casting Process Flowchart

The first step in making the Pipe Water Inlet EW010 is making mold. There are two types of molds used for the Pipe Water Inlet EW010 casting process, namely Expendable Mold and Permanent Mold. Expandable mold is a mold that can only be used once during the casting process. The Pipe Water Inlet EW010 has a complex product shape and dimensions, so the manufacturing process requires the help of an additional mold, namely a sand core mold. Sand core is very helpful in the process of making metal products with complex shapes and small dimensions. The PT Wijaya Karya Industri and Construction PPC factory has 7 sand blowing machines for making sand cores. The following is a picture of the sand core making process and casting process as shown in figure 4.

a b c

Figure 4 a. Sand Core Making Process, b. Melting of Metal, c. Casting Process

Permanent Mold is mold used for the metal casting process and can be used repeatedly. In the process of making the Pipe Water Inlet EW010, liquid metal is poured into a permanent mold along with a sand core and flows using gravity to form the desired product, this process is called gravity casting.

The next process in making Pipe Water Inlet EW010 products is melting material. Melting of metal is the initial process in the metal casting process. The material used for the process of making the Pipe Water Inlet EW010 is AC2B, which is a combination of aluminum and silicon. Smelting of AC2B material is generally carried out in an induction melting furnace with a temperature of 650 °C – 900 °C. The material melting process is generally carried out at the same time as the sand core making process. After the material is melted, the melted material is then taken to the holding furnace using a transfer leader to be stored so that the temperature of the molten metal is maintained before the molten metal enters the next process, namely the casting process. After the metal is melted and the mold is ready to be used, the next process is that the liquid material in the holding furnace is poured into the mold with a liquid metal temperature of around 800°C. This process is known as pouring into mold. The pouring speed needs to be paid attention to in order to maintain the temperature and fluidity of the molten metal so that premature cooling (cold shuts) does not occur. The standard pouring time set by the PPC factory is 4-6 seconds. Fourth is the casting process. The liquid metal that has been poured into the mold is then left for several minutes in the machine, generally for 4-5 minutes until solidification occurs. This process is called the casting process. The casting process used to make the Pipe Water Inlet

EW010 is gravity casting, which is a casting process using the help of gravity. After hardening, the cast metal is removed from the mold and then left for some time before the next process is carried out. The gravity casting machine and process can be seen in figure 7. Fifth is heat treatment. Casting products generally do not have hardness that meets standards, so additional processes are needed, namely heat treatment. Heat treatment is a process that uses controlled heating and cooling to modify the structure of a metal. The use of heating or cooling is usually at extreme temperatures to achieve the desired hardening results

The Pipe Water Inlet EW010 castings do not yet have a perfect visual shape, so a cleaning and finishing process needs to be carried out to improve the quality and visual refinement of the product so that it matches the initial design plan. The cleaning process for the Pipe Water Inlet EW010 product includes several stages, namely the process of dismantling the sand core using a bobok drill, cutting off parts that are not needed using a chainsaw, then to get a product that looks clean and neat, the cleaning process is carried out using sand blasting, a grinder and a rotary machine. The final stage is the inspection stage. The final stage of the production process for making the Pipe Water Inlet EW010 is the inspection stage which consists of checking the quality of the castings, measuring dimensions, visual checks, and so on. The purpose of the inspection process is to determine the quality of the cast product and to ensure whether the cast product is suitable for use or not. If a cast product is found to be defective and unfit for use, the cast product will be repaired or re-melted for re-production.

Production data and Pipe Water Inlet EW010 defect data were obtained from the QA/QC (Quality Assurance/Quality Control) department of the PT Wijaya Karya Industri and Construction PPC factory. The available data is weekly data for each type of defect. The data that researchers use is production data and inspection results. Meanwhile, in chapter 1 of the introduction, the researcher describes the number of rejects from January to June 2023 and the reject standards set by the company. The reject data is data obtained from improvement results, namely products that have gone through an improvement process. The following is data on the type and number of defects in the Pipe Water Inlet EW010 product on June 26 – August 25 2023.

Table 1 Data of Types and Number of Defects 26 June-25 August 2023

Date (2023)	Production	A	B	C	D	E	F	G	H	I	J	K	Defect	%
26–30 June	301	15	30	4	92	17	2	0	0	0	0	0	160	53
03–07 July	298	0	27	11	84	57	0	12	2	0	0	0	193	65
10–14 July	285	0	38	20	61	27	0	4	2	7	3	0	162	57
17–21 July	365	5	67	1	106	81	0	0	2	4	1	10	277	76
24–28 July	370	0	31	1	92	46	0	0	2	2	0	0	174	47
31July–4 August	274	0	18	3	43	45	0	13	0	1	0	0	123	45
7–11 August	326	1	28	0	84	46	0	21	0	0	0	0	180	55
14–18 August	300	6	33	0	42	51	0	0	0	0	0	0	132	44
21–25 August	355	0	17	7	37	24	0	0	0	0	0	0	85	24
Total	2874	27	289	47	641	394	2	50	8	14	4	10	1486	52%

Explanation of the type of defect

A. Misrun
B. Porous
C. Lenting
D. Leaking

E. Fungal
F. Cracked
G. stamp
H. Short cut
I. Gmpl
J. Deflates

Data processing stages were carried out using the six-sigma method. The steps taken in implementing the six-sigma method are the DMAIC cycle. The DMAIC stage in six sigma consists of Define, Measure, Analyze, Improve, and Control.

Define is the first stage in the DMAIC cycle, this stage includes identifying the product manufacturing process, identifying the main process, determining customer needs and CTQ (Critical to Quality). The following is a Pareto diagram of defect data for the Pipe Water Inlet EW010 product. The diagram shown in figure 11 below is defect data resulting from the production of the Pipe Water Inlet EW010 for 2 months, starting from June 26 to August 25, 2023.

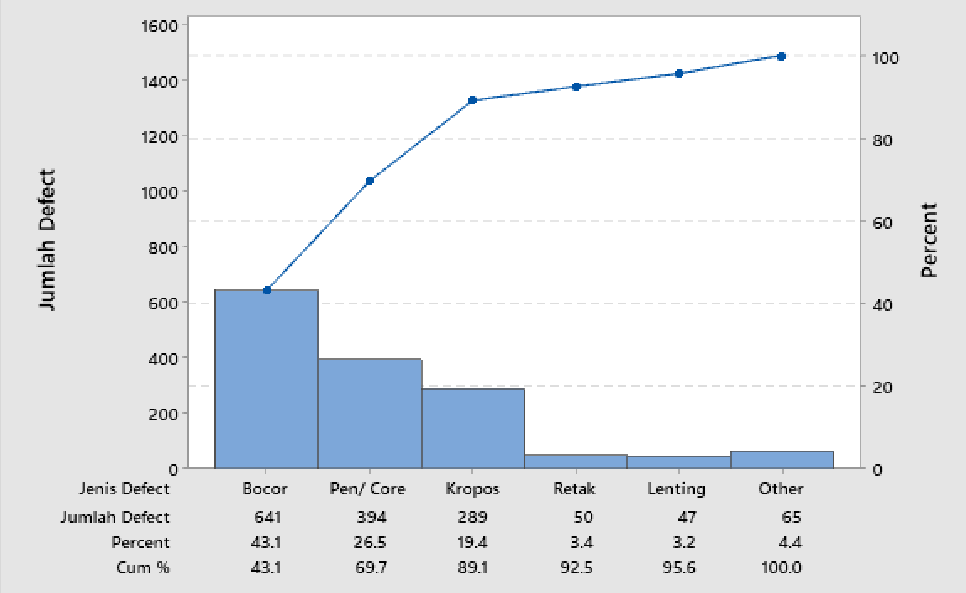


Figure 11 Pareto diagram number of defects 26 June-25 August 2023

From the Pareto diagram above, it is known that there are 3 types of defects that occur most frequently. The types of defects most often found in Pipe Water Inlet EW010 products are leak at 43.1%, pen/core at 26.5%, and porous at 19.4%. Of these three types of defects, they represent 89.1% of the total defects or as many as 1324 defective products found in the Pipe Water Inlet EW010 product contain defects.

The next stage in the DMAIC cycle is the measure stage. At this stage, the Defects Per Million Opportunities (DPMO) value and the sigma level value are calculated. The data calculated is the number of defects in the Pipe Water Inlet EW010 product from 26 June - 25 August 2023. CTQ (critical to quality) in this research is determined based on the type of critical defect in the Pipe Water Inlet EW010 which affects the quality characteristics of the production results. From the research results it can be seen in figure 11, that the response variables which are critical to quality (CTQ) include leaking, porous, and pen/core. To make it easier to analyze table 2 data on the type and number of defects for 26 June-25 August 2023, the author created a table of the percentage of defects per week for the Pipe Water Inlet EW010 product as follows:

Table 3 Percentage of defective products per week

No	Date (2023)	Production	*Defect*	Persentase
1	26 – 30 June	301	160	53%
2	03 – 07 July	298	193	65%

No	Date (2023)	Production	*Defect*	Persentase
3	10 – 14 July	285	162	57%
4	17 – 21 July	365	277	76%
5	24 – 28 July	370	174	47%
6	31 Juli – 4 August	274	123	45%
7	7 – 11 August	326	180	55%
8	14 – 18 August	300	132	44%
9	21 – 25 August	355	85	24%
	Total	2874	1486	52%

The calculation of DPO, DPMO, and Sigma Level on the quality of the Pipe Water Inlet EW010 product is as follows:

I. DPO (Defect per Opportunities):

$$\text{DPO} = \frac{Total\ number\ of\ defects}{Number\ of\ units\ \ \mathbf{x}\ \ CTQ}$$

$$\text{DPO 1} = \frac{160}{301\ \mathbf{x}\ 3} = 0.17718715$$

$$\text{DPO 2} = \frac{193}{298\ \mathbf{x}\ 3} = 0.21588367$$

$$\text{DPO 9} = \frac{85}{355\ \mathbf{x}\ 3} = 0.07981221$$

II. DPMO calculation

DPMO = DPO x 1000000

DPMO 1 = 0.17718715 x 1000000 = 177187.15

DPMO 2 = 0.21588367 x 1000000 = 215883.67

DPMO 9 = 0.07981221 x 1000000 = 79812.21

III. Level Sigma calculation

$$\text{Level Sigma} = \text{NORMSINV}\left(\frac{1000000 - \text{DPMO}}{1000000}\right) + 1.5 = 2.43$$

$$\text{Level Sigma 1} = \text{NORMSINV}\left(\frac{1000000 - 177187.15}{1000000}\right) + 1.5 = 2.43$$

$$\text{Level Sigma 2} = \text{NORMSINV}\left(\frac{1000000 - 215883.67}{1000000}\right) + 1.5 = 2.29$$

$$\text{Level Sigma 9} = \text{NORMSINV}\left(\frac{1000000 - 79812.21}{1000000}\right) + 1.5 = 2.91$$

Table 4 DPMO and Sigma level value 26 June-25 August 2023

No	Production	Defect	CTQ	DPO	DPMO	Level Sigma
1	301	160	3	0.17718715	177187.15	2.43
2	298	193	3	0.21588367	215883.67	2.29
3	285	162	3	0.18947368	189473.68	2.38
4	365	277	3	0.25296804	252968.04	2.17
5	370	174	3	0.15675676	156756.76	2.51
6	274	123	3	0.14963504	149635.04	2.54
7	326	180	3	0.18404908	184049.08	2.40
8	300	132	3	0.14666667	146666.67	2.55
9	355	85	3	0.07981221	79812.21	2.91
Total	2874	1486	3	0.17249248	172492.48	2.44

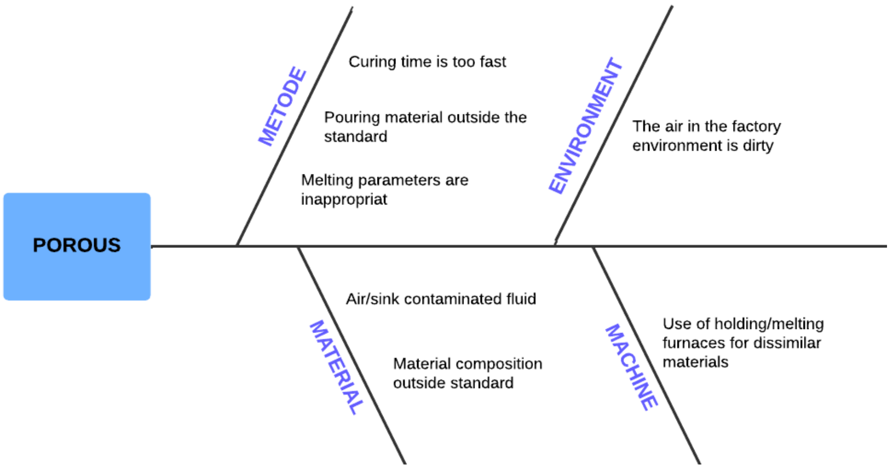
From table 4, it can be seen that the average DPMO value for the quality of the Pipe Water Inlet EW010 product on 26 June-25 August 2023 was 172492.48 with an average sigma level value of 2.44, meaning that this figure is still very far from the 6-sigma level value, so improvements are needed in production quality.

To find out the cause of the high number of leaking, porous and pen/core defects in the Pipe Water Inlet EW010 product, it is necessary to analyze the root cause of the high number of defects. This analysis stage functions to find the root cause of the existing type of disability. Failure analysis and the effects/consequences of failure using the FMEA method can be seen in Table 5 as follows:

Table 5 Failure Analysis Table and Failure Consequences

Activity in process	Failure mode	Effects/consequences of failure
Gravity Casting	Porous	Reject
	Pen/Core	
Leak Test	Leak	Not Good

After knowing the failure that occurred in each process, the next step is to find the root cause of the incident. One method that can be used to find the root causes and causes of defects is Root Cause Analysis (RCA). Analysis of the causes of failure using the RCA method based on each type of failure mode is as follows figure 12:



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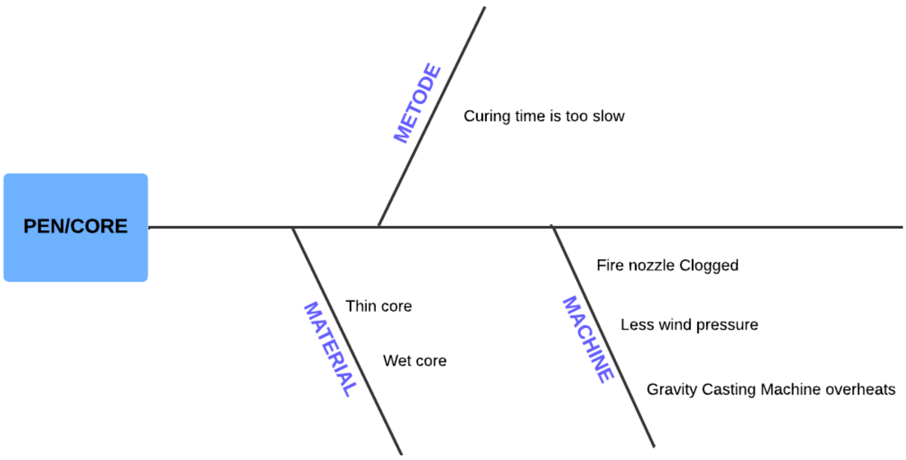

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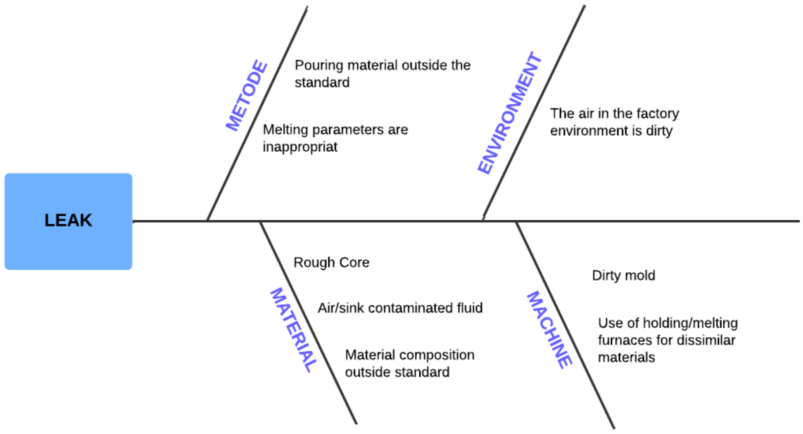

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Figure 12 a. RCA Porous Defect, b. RCA Pen/Core Defect, c. RCA leaking Defect

The results of the Root Cause Analysis (RCA) that have been made will be input into the FMEA analysis, especially in identifying the root causes of potential failures. The purpose of the FMEA analysis is to find suggestions for improvements that can reduce the number of failures and prevent failures in the Pipe Water Inlet EW010 production process. The scores or weight values used in FMEA analysis are obtained from observations, interviews and company FMEA documents. The results of the FMEA analysis can be seen as below table 6.

Table 6 FMEA Analysis (Porous)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Gravity Casting	Porous	Reject	8	The fluid temperature is too high	8	Check the liquid temperature at each melting and maintain the temperature parameters according to standards	6	384
				Air/sink contaminated fluid	8	Visually check the outer surface of the ladle / scoop	7	448
				Material composition outside standard	8	Carry out millsheet and actual inspection of materials to be used	6	384
				Use of holding/melting furnaces for dissimilar materials	7	Check the type of liquid in the furnace with a spectroanalyzer	5	280
				Pouring material outside the standard	7	Workers routinely control the pouring duration	4	224
				Curing time is too fast	7	Setting curing time	4	224

Table 7 FMEA Analysis (Pen/Core)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Gravity Casting	Pen/Core	Reject	8	Gravity Casting Machine overheats	7	Check the temperature of the gravity casting machine	3	168
				Thin core	8	Trial use of new sand material	6	384
				Wet core	7	Check the quality of the core to be used	5	280
				Curing time is too slow	7	Setting curing time	4	224
				Fire nozzle Clogged	7	The flame nozzle is cleaned	6	294
				Less wind pressure	7	Check the wind tube	3	147

Table 8 FMEA Analysis (Leak)

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
Leak Test	Leak	Not good Product (NG)	7	Coarse resin core	7	Core inspection by sorting	5	245
				Use of holding/melting furnaces for dissimilar materials	7	Check the type of liquid in the furnace with a spectroanalyzer	5	245
				Material composition outside standard	8	Carry out millsheet and actual inspection of materials to be used	6	336
				Pouring material outside the standard	7	Workers are routinely checked	4	196
				Fluid temperature is too low	8	Check the liquid temperature at each melting and maintain the temperature parameters according to standards	6	336
				Dirty mold	6	Spraying process on the mold surface	3	126
					8	Visually check the outer	7	392

Activity in process	Failure mode	Effects/consequences of failure	S	Causes	O	Control	D	RPN
						surface of the ladle / scoop		
				Air/sink contaminated fluid		Visually check the outer surface of the ladle / scoop	8	392
						Air vent cleaned / added	5	280

FMEA analysis was carried out on the types of defects that often occur in the Pipe Water Inlet EW010 product. The types of defects in question are leaking, pen/core, and crumbling defects which the researchers then used as failure modes in the FMEA analysis. From the FMEA analysis above, it can be seen that the RPN value for each failure mode in the Pipe Water Inlet EW010 product exceeds the value 100. The higher the RPN value, the higher the risk and impact that can cause defects in the Pipe Water Inlet EW010 product and become a priority for repair. The PT Wijaya Karya Industri and Construction PPC factory has standards for the RPN FMEA assessment. If the RPN value is greater than or equal to 100 (RPN ≥ 100), then the factor causing the problem must be given corrective action. Next, the researcher will follow up on the problem by providing corrective solutions to the problem at the improvement stage.

After knowing the factors that cause defects in the Pipe Water Inlet EW010 product through RCA and FMEA analysis, the next step is to make recommendations for improvements to each existing problem. After providing suggestions for improvement, at this stage the researcher will recalculate the DPMO value and sigma level value after the recommendation for improvement. Recommendations for improvement provided by researchers are based on the types of defects in the high category which can be seen in Table of FMEA Analysis above. There are 3 failure modes that need to be given recommendations for repair, including leaking defects, pen/core and porous. Recommendations for improvement can be seen in table as follows:

Table 9 Improvement Recommendations (Porous)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
			The fluid temperature is too high	Control over standard liquid temperature limits
			Dip contaminated fluid	Coating ladle before use
			Material composition outside standard	Remove the mixture of screws and materials from suppliers to check cleanliness and material content
Gravity Casting	Porous	Reject	Use of holding/melting furnaces for dissimilar materials	Allocation of transfer furnaces and ladles according to the number of material types
			Pouring material outside the standard	Calculation of work cycle time and application of SOP when pouring material into mold

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
			Curing time is too fast	Curing time increased

Table 10 Improvement Recommendations (Pen/Core)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
Gravity Casting	Pen/Core	Reject	Gravity Casting Machine overheats	Setting the curing time temperature for the gravity casting machine
			Thin core	Increase resin levels
			Wet core	Maintain humidity in the factory environment
			Curing time is too slow	Curing time is reduced
			The flame nozzle is clogged	Maintenance
			Less wind pressure	Wind valve settings

Table 11 Improvement Recommendations (Leak)

Activity in process	Failure mode	Effects/consequences of failure	Causes	Improvement Recommendations
Leak Test	Leak	Not Good Product (NG)	Fluid temperature is too low	Control liquid temperature standard limits
			Dirty mold	Molds are cleaned before and after the casting process
			Use of holding/melting furnaces for dissimilar materials	Allocation of transfer furnaces and ladles according to the number of material types
			Material composition outside standard	Remove the screw mixture, and check the material from the supplier again for cleanliness and material content
			Pouring material outside the standard	Calculation of work cycle time and application of SOP when pouring material into mold
			Air/sink contaminated fluid	Coating ladle before use, AC4B material is used immediately after the melting process, and cleaning/adding the air vent
			Coarse resin core	Check the quality of the core to be used

Through the recommendations given, the first corrective action taken by the company was that the casting process was carried out carefully and the production process was supervised by skilled and experienced operators. Casting process engineers routinely control the production process in the field, such as paying attention to curing time on machines.

One of the biggest defects in the Pipe Water Inlet EW010 product is the pen/core defect, which is caused by the sand core being damaged during the casting process. The second recommendation that was implemented was KH 7904 sand with a resin content of 1.75%, increased to 2.0%. This can increase the strength of the sand core, thereby reducing the presence of pen/core defects in the Pipe Water Inlet EW010 production results.

The biggest cause of leak defects is porosity. Products using AC4B material are very susceptible to air contamination, so defective products are often found, such as porosity, shrinkage and leaks. AC4B is a material that is commonly used in automotive products because its quality is quite good, but the failure rate for products cast using this material is very high. The next recommendation that is implemented is to use additional materials, namely Titanium (0.019 wt % and 0.029 wt %) to reduce defects in the casting results. The next recommendation that is implemented is that materials from suppliers are checked again for cleanliness and the material content contained, to ensure that the products used are clean and comply with standards. The next recommendation that is implemented is that workers are routinely monitored for their work. The duration of pouring molten metal into the mold must comply with standards, because this greatly influences production results. The standard for pouring into mold is 4 to 6 seconds. This can be done by calculating the cycle time in the pouring process to see any improvements. The next recommendation that is implemented is to use machines well, efficiently and under control, and routinely provide maintenance to the machines used, so as to improve good production quality.

Through the implementation of improvements made by the researcher, the researcher then observed the production quality and number of defects during September-October 2023. The following is the data and types of defects in the Pipe Water Inlet EW010 product after the improvement:

Table 12 Data of Types and Number of Defects 04 September-27 October 2023

Date (2023)	Production	A	B	C	D	E	F	G	H	I	J	K	Defect	%
04 – 08 Sept	200	6	9	2	15	12	0	0	0	1	1	0	46	23%
11 – 15 Sept	311	0	22	1	26	19	0	0	3	1	0	0	72	23%
18 – 22 Sept	370	2	17	0	31	28	0	0	2	3	5	0	88	24%
25 – 29 Sept	172	2	9	1	18	7	0	0	0	3	0	0	40	23%
02 – 06 Oct	335	1	11	8	29	13	0	0	0	0	1	0	63	19%
09 – 13 Oct	128	0	7	0	52	8	0	0	1	8	1	0	77	60%
16 – 20 Oct	468	10	22	1	19	31	0	0	3	1	0	0	87	19%
23 – 27 Oct	298	2	9	0	21	18	0	2	1	2	0	0	55	18%
Total	2282	23	106	13	211	136	0	2	10	19	8	0	528	23%

Explanation of the type of defect

A. Misrun
B. Porous
C. Lenting
D. Leaking
E. Fungal
F. Cracked
G. stamp
H. Short cut
I. Gmpl
J. Deflates

The calculation of DPO, DPMO and sigma level after implementing improvements uses the same calculation as the previous calculation. Data on DPO, DPMO and Sigma Level values on the quality of the EW010 Water Inlet Pipe product after repairs are as follows:

Table 14 DPMO and Sigma level value 4 September -27 October 2023

No	Production	Defect	CTQ	DPO	DPMO	Level Sigma
1	200	46	3	0.07666667	76666.67	2.93
2	311	72	3	0.07717042	77170.42	2.92
3	370	88	3	0.07927928	79279.28	2.91
4	172	40	3	0.07751938	77519.38	2.92
5	335	63	3	0.06268657	62686.57	3.03
6	128	77	3	0.20052083	200520.83	2.34
7	468	87	3	0.06196581	61965.81	3.04
8	298	55	3	0.06152125	61521.25	3.04
Total	2282	528	3	0.08716628	87166.28	2.86

From table 4.14, it can be seen that the average DPMO value for the quality of the EW010 Water Inlet Pipe product after controlling workers, changing the type of sand and improving work methods is 87166.28 with an average sigma level value of 2.86, meaning there is an increase in production quality from before the repair. It can be seen that in October, weeks 1, 3 and 4, production quality improved with a sigma level value of 3.

After implementing the improvement recommendations, the final stage in the DMAIC cycle is the control stage. The control stage is carried out to control the production process so that it is able to maintain product quality or improve quality. Therefore, it is necessary to take control measures, namely by implementing the QCPC (Quality Control Process Chart) and IK (Special Instructions) standards that have been made by the company. Apart from that, productivity and production quality must always be controlled every day by reviewing check sheets and daily production reports filled in by field operators. This can help the quality control division to review work results and production problems every day, and the engineering division can take corrective action if there are problems in the production process.

4. Conclusion

In the production process of Pipe Water Inlet EW010, there are three types of biggest defects found namely leak defects, pen/core, and porous which are depicted through the Pareto diagram. Analysis of the causes of defects in the Pipe Water Inlet EW010 product was carried out using the DMAIC six sigma method, namely by identifying problems in the process of making the Pipe Water Inlet EW010 product and determining the CTQ (Critical to Quality) value. The results of the implementation of improvements showed a decrease in the DPMO value and an increase in the sigma level value. The initial value of DPMO was 172492.48, decreasing to 87166.28 after implementing the improvements. Meanwhile, the sigma level value was initially 2.44 after implementation, increasing to 2.86. Based on these results, implementing the improvements made can improve the quality of the EW010 Water Inlet Pipe product, although not significantly. This happens because not all proposed improvements can be carried out and the causes of failure in the casting production process are caused by various factors.

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