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RESEARCH ARTICLE

IMPLEMENTATION OF SIX SIGMA APPROACH IN QUALITY CONTROL OF METAL CASTING PRODUCTS MADE FROM GRAY CAST IRON TYPE FC 250: A CASE STUDY IN SMALL AND MEDIUM ENTERPRISES IN INDONESIA.

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Abstract

The "X" company is one of the modern small and medium industries engaged in metal casting in Indonesia. One of the main ingredients used is gray cast iron (ferro carbon) or FC 250. At this time the level of product defects is still at the level of 10.8%. This value is relatively still high enough from the company's decision that is no more than 10% of product defects. This study aims to control product quality through the implementation of the Six Sigma steps. From the results of the study, five types of critical to quality defects have been identified, including: Porous, Displaced Core, Misrun defects, Cleft defects and Cracks. The measurement results have also obtained a level of product disability of one million opportunities (DPMO) on an average of 106,667. This value is equivalent to the Sigma level of 2.76 which indicates that the level of company quality control is still below the average national quality standard. Some recommendations are proposed, among others, through the proper application of standard operating procedures, selection and control of raw materials, improvement of the work environment and improvement of employee performance.

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Introduction:-

Improvement of production quality must be carried out continuously. The success of achieving production targets is largely determined by the quality and performance of the production process on the manufacturing floor. To improve product quality, organizations must understand the characteristics of product defects that are the standard of evaluation of their consumers. Thus, by knowing the types and characteristics of product defects, the company will strive to reduce the level of product defects through improvements to each existing process.

As is the case with manufacturing industries in general, in the metal casting industry, the fulfillment of production quality standards that are a requirement for consumers, must be fulfilled. Considering the high level of competition, it requires each industry to know the existing conditions which are the baseline for measuring the quality of production performance. Various approaches to measure the achievement of production quality targets can be applied, one of them using the Six Sigma approach. Six Sigma is a continuous effort to decrease the variation of the process in order to improve process capability in producing a product (or service) that is free of errors (zero defects-minimum target of 3.4 defect per million opportunities) to deliver value to customers (Gaspersz, 2017).

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The “X” Company, is one of the small and medium enterprises engaged in the metal casting industry in Indonesia. In its efforts to meet production quality standards that are a requirement for its customers, the company continues to make improvements in the quality of its production. Some quality standard certifications that have been achieved include SNI (Indonesian National Standard) in 1995 and ISO (International Standards Organization) certification in 1999. Each month, this company can produce as many as 10,000 - 12,000 tons of products with various types. Some of them are rubber cutter, pulley, impeller pump, gear, spedle couple, giboult join and many types of products produced. Production supplies are mostly distributed to regional companies.

Although its has achieved certification of production quality standards, both national and international, in reality during the course of its production process, the company has not escaped the process mistakes. Based on preliminary research, from October to December 2018, it was found that there is still a level of product defects, which is as much as 10.8% of the average 2,466.67 tons of the amount of raw material used (see Table - 1). Whereas the company itself targets a level of damage of no more than 10% of the processed raw material. This certainly has an influence on the level of production that will be produced. Therefore, to find out the failure rate of the process, it is necessary to study each process through tracking the process flow by measuring the number of defects for each process. Through Table 1, we can find out the level of product defect during the last 3 months, from October to December 2018.

Table 1:-Percentage of Product Defects in October - December 2018

Month	Amount of Raw Materials (Kg)	Types of products	Output						Product Defects (%)
			Good		Reject		Total		
			Kg	Pcs	Kg	Pcs	Kg	Pcs	
October	8,600	Iron fence, Roster, Gears, Fence accessories, Bata press cover, Giboult joint	7365	561	256.8	32	1,439.4	407	9.87%
November	1,800	Cover, Fence, Giboult joint, Well fence	1,003	356	204	34	1,023.4	390	11.3%
December	3,000	Fence, Cyclon, Flank, Giboult joint	1,904	246	339	47	2,243	293	11.3 %
			Average						10.8%

To produce various types of metal casting products, “X” company uses the main raw material is Ferro Carbon (FC 250) Gray Cast Iron (FCK) with chemical composition such as carbon (C), manganese (Mn), Silicon (Si), Pospor (P), Sulfur (S) and other additives such as coke charcoal, diesel fuel and so on.

The level of product defects that occur, basically has not had such a large influence on overall production. However, if left unchecked, it is feared that it will have an impact on production in the future. Therefore, in order to avoid an increase in the number of production defects, it is necessary to anticipate efforts as early as possible from the company, so that the production targets that have been set can be achieved.

To determine the level of quality achievement of the ongoing process, it is necessary to measure using a more comprehensive approach that looks at various aspects and dimensions of quality. The Six Sigma method is one approach that can be used as a tool to measure the expected production quality achievement. This method emphasizes quality improvement through emphasizing the level of production defects from key processes that take place on the manufacturing floor.

The objectives of this research include: 1) Identifying the type of critical to quality (CTQ) in the production process of FC 250 Gray Cast Iron products; 2) Measuring the current level of quality achievement as a performance baseline and basis for determining further improvements in the production process; 3) Analyzing the causes of production defects through the use of statistical tools; 4) Provide recommendations for process improvement and product quality to meet customer satisfaction.

Literature Review:-

Concept of Quality:-

Many people have difficulty in defining quality precisely. According to Crosby (1979) quality is closely related to consumer needs. This definition is not quite right now, this is because an organization that produces a product based

on design criteria, does not always produce a quality product, as desired by consumers. A product will be declared high quality only if the product has met the needs of consumers. Thus, consumers are the main key in defining quality (Hansen & Robert, 1999).

Goetsch and Davis (2000) define quality as follows: "Quality is a dynamic state associated with products, services, people, processes and environments that meets or exceeds expectations". Meanwhile, Assauri (1999), defines quality as factors in a product that causes the product in accordance with the objectives of the product.

Furthermore, Assauri (1999) explains that quality is influenced by several factors, namely: 1) The function of a product, a product that will be produced should pay attention to the function for what the product is used or intended, so the products produced must be able to really fulfill the function. Fulfillment of functions affects consumer satisfaction, thus the quality of a product depends on fulfilling the function of product satisfaction that can be achieved. 2) Outward appearance, one of the important factors in determining the quality of a product that is also a consumer's interest, namely the appearance of the product outside. The outward appearance of a product is not only visible from the shape, but also the color and packaging, and 3) The cost and price of a product will be able to determine the quality of the product produced. Usually products with high costs or prices, show the quality of the product is relatively better. Vice versa, products with low costs can show the quality of these products is relatively low.

Based on these definitions, it can be concluded that the quality of a product is determined by the overall nature, characteristics and interrelated factors contained in the product that must be in accordance with the objectives for what the product was created, especially to meet consumer needs.

According to Reksohardiprodjo & Gitosudarmo (1986), to produce quality products, companies need to have quality standards that must be achieved. Several important aspects in maintaining product quality standards include: 1) Considering competition and the quality of competitors' products; 2) Quality must match the selling price; 3) Considering the usefulness of the final product; 4) there needs to be formed a team consisting of those working in various fields.

Metal Castings Quality Testing: -

The process of checking the results of castings is part of the task of Quality Control both on the raw material for products received (incoming materials) and on products that have been completed. This inspection process focuses more on the physical properties of the material or product resulting from possible defects, both external and internal defects. Metal or steel objects that have gone through the heat treatment process are usually very likely to occur cracks in the skin, but the casting material usually tends to internal defects, such as porous or hollow.

For the advanced process, especially the production process on casting objects, such as gear blanks, pulleys and other component materials will usually be detected after the work process continues, if so, this will be very detrimental especially if the work is nearing completion, both losses in terms of time, workmanship costs, electricity costs, labor and others. Therefore, examination of raw materials, especially pouring materials, requires special attention and appropriate inspection methods. However this examination may not result in defects or damage during or after the examination in contrast to testing the mechanical properties of the material referred to as damaging (Destructive Testing of Materials / DT). This check is called a non-destructive test (NDT = Non-destructive Test). (Sudjana, 2008)

The importance of testing the material or product, various methods are strived so that this process does not hamper the production process, sometimes inspection of this material is considered a waste of time. Therefore the selection of the right inspection method becomes very important, for that examination of materials or products is grouped into two types, namely: examination of external defects and examination of internal defects.

Checks for surface defects: -

According to Sudjana (2008), an examination of external defects is carried out to determine the state of defects in the outside of the workpiece or product material, this defect is very common in steels that have gone through a heat treatment process where there is a very high inner stress or a structural transformation process that occurs unbalanced (non qilibrium).

In practice, this external defect testing can be done by the die penetrant method. If you look at the inspection efficiency of the available methods, the easiest and cheapest way is visually or with the worker's vision, but due to various limitations, visually it is not enough even with the help of a microscope. Although someone's vision is trained enough to detect the state of external defects, but the external defects are not necessarily outside the range of human vision, because what is meant by external defects are defects not in the core of the metal, for example defects in pipes or tubes, defects outside can occur inside the pipe or tube that is difficult to reach even though using a microscope. Examples of external defects in cast products can be seen in Figure 1.

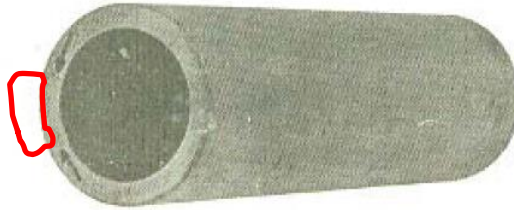


Figure 1:-Defects in the AISI 52100 steel pipe: cracks in the inside of the pipe

Checking the external surface defects can be done using a die penetrant. This method is the easiest and fastest way to check for defects, although it still requires visual accuracy to determine the position and state of the defect. This checking method uses 3 elements consisting of: 1) Using a Cleaner is a cleaning liquid that works to clean dirt from the surface of the workpiece; 2) Using Penetrant which is a liquid element that has fine crystals so that if sprayed on the surface of the workpiece it can seep into cracks; and 3) Using the Developer which is a liquid that forces the penetrant liquid out of the crack in the surface of the workpiece.

Checks for internal defects:-

Sudjana (2008) also explains that defects in the internal parts of the product cannot be detected visually and this defect often results in losses in the production process, and can even be fatal due to damage caused by damaging other parts, especially if this object is a component of the component others in an assembly. Therefore this examination of defects needs to be done carefully using the correct method.

Internal defects are very common in foundry products where there are air cavities or inhomogeneous mixtures that cause graphite to accumulate in certain areas so that cast objects become porous on the inside. Likewise, shrinkage often results in distortions on the inside which result in cracks. As a preventive measure is to place the channels appropriately in the appropriate position, although there is no guarantee that porous can be avoided.

This method of checking internal defects can be carried out in various ways including by X-rays. A careful inspection can show the shape and position of defects in including external defects on the back or under the surface. Likewise, shrinkage will be detected by this check.

Sand Mold Casting:-

The process of forming workpieces by the method of pouring molten metal into sand molds. In a simple sand mold can be interpreted as a cavity formed by eroding various forms of objects in the chunks of sand which then the cavity is filled with metals that have been melted by heating (molten metals).

Sand mold casting for forming objects through the casting to be made and treatment so as to complete the parts that fit the shape of the workpiece in order to obtain a perfect form fit with what we want. Parts of this sand mold include (Sudjana, 2008): 1) Pattern, mall or model (pattern), which is a shape and size of objects that are the same as the original shape of the desired object, this pattern can be made of wood or plastic which will be formed in sand molds in the form of cavities or called molds if the model this is released into which liquid metal is poured; 2) Core, is a special part for which serves as a frame to protect the structure of the model to be formed, so that the thickness of the walls, holes and special shapes of casting objects will not change; 3) Cope, which is half of the top part of a sand mold; 4) Drag, which is the lower half of the sand mold; 5) Gate is an open hole where liquid metal is poured into the mold between the core and drag; and 6) Riser is a discharge hole provided for the flowing of molten metal from the mold and a small reserve of liquid metal solution.

Stages of Metal Casting with Sand Mold: -

Stages of making sand molds: 1) Compaction of printed sand on a pattern; 2) Releasing the pattern from the print sand _ the print cavity; 3) Manufacture of inlets and risers; 4) Coating of the print cavity; 5) If the castings has an inner surface (for example: a hole), then a core is installed; 6) Integration of molds; 7) Ready to use. Figure 2, describes the stages of metal casting using sand molds as follows.

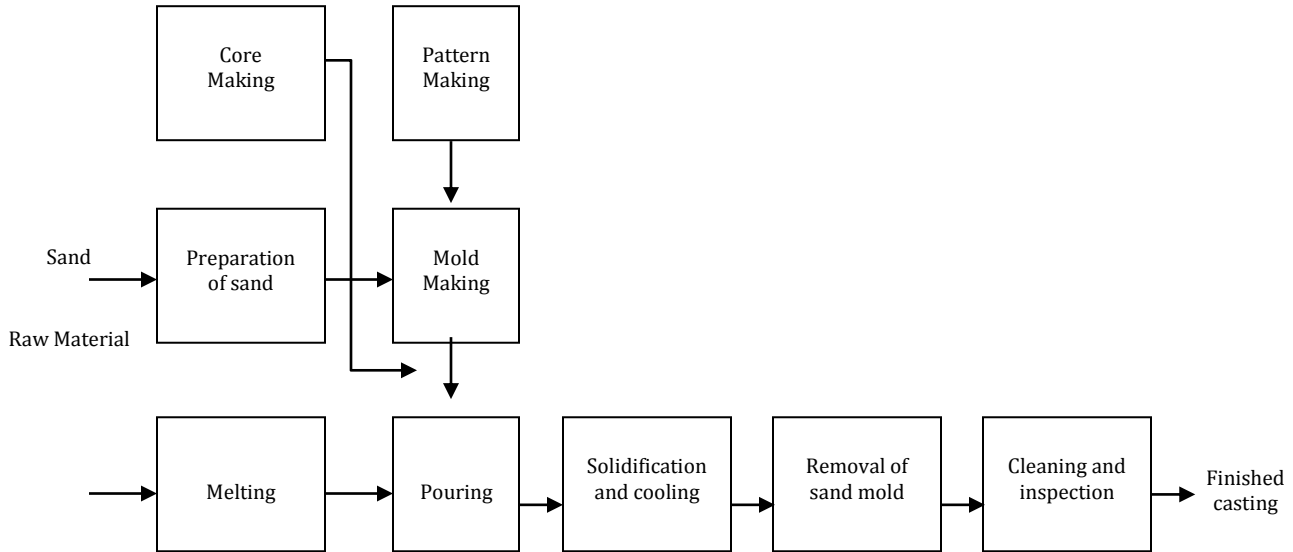


Figure 2:-Stages of making sand molds

Six Sigma Concept: -

Six Sigma is a systematic tool or method used for process improvement and new product development based on statistical methods and scientific methods to reduce the number of defects that have been defined by consumers. Six Sigma was born in Motorola in 1979 out of a decision about quality problems and regarding or referring to six standard deviations (Greek letters, Sigma is used by statisticians as a symbol of standard deviation) (Gasperz, 2002). Six Sigma was first implemented by Motorola in 1986. It is a dramatic method of quality control and improvement that is an effort to improve quality with a failure rate close to zero (zero defects). The level of quality achievement according to the level of production defects in the Six Sigma method can be seen in Table 2.

Table 2:-Sigma levels based on DPMO and COPQ

Sigma Level	Defect Per Million Opportunity (DPMO)	Cost Of Poor Quality (COPQ)
1- Sigma	691,462 (Low competitive)	Cannot be measured
2- Sigma	309,538	Cannot be measured
3- Sigma	66,807 (National Industries)	25 - 40% of sales
4- Sigma	6,210 (USA Industries)	15 - 25% of sales
5- Sigma	233	5 - 15% of sales
6- Sigma	3.4 (World Industries)	< 1 % of sales

(Source: Gasperz, 2002)

Six Sigma is an effort to mobilize organizational assets and projects that are specified to have lasting effects and meet soft goals through a five-stage approach. Six Sigma is an active mobilization of statistical tools that seeks to remove variation, defects, and waste from all business processes that are associated with significant financial results. Basically, customers will be satisfied if they receive the value as they expect. If the product (goods or services) is processed at the Six Sigma quality level, the company may expect 3.4 failures per million opportunities (DPOM) or expect that 99.99966 percent of what the customer expects will be in that product. Thus, Six Sigma can be used as a measure of industrial system performance targets on how well a product transaction process is between suppliers (industry) and customers (markets). The higher the achievement level of Six Sigma, the better the performance of an industrial system (Gasperz, 2017; Wahyuni et al, 2015).

Quality Control Stages in the Six Sigma Method: -

The quality improvement process in Six Sigma is known as DMAIC (Define, Measure, Analyze, Improve, and Control). DMAIC is a process for continuous improvement towards Six Sigma targets. DMAIC is carried out systematically, based on science and facts.

If the Six Sigma concept is to be applied in manufacturing, then consider the following six aspects: 1) Identification of product characteristics that will satisfy customers (according to customer needs and expectations); 2) Classifying all quality characteristics as individual CTQ (critical to quality); 3) Determine whether each CTQ can be controlled through controlling material, machinery, work processes; 4) Determine the maximum tolerance limits for each CTQ as desired by the customer (determine the USL and LSL specification limits of each CTQ); 5) Determine the maximum process variation for each CTQ (determine the maximum standard deviation for each CTQ); and 6) Change the design product or process in such a way that make reaches the target value of Six Sigma, which means it has a process capability index, minimum C_p equals two ($C_p > 2$). (Gaspersz, 2002).

Research Methodology:-

To measure the achievement of production quality, carried out using the Six Sigma Method. In analyzing using this method, also carried out 5 important stages consisting *Define* (defining the problem), *Measure* (measuring the level of the problem), *Analyze* (analyzing the cause of the problem), *Improve* (corrective action to the problem) and *Control* (production control). To obtain the desired data, especially for the purposes of later analysis, using the 5 stages contained in the Six Sigma method. The five stages in the Six Sigma method include:

Define (D)

This step is to define the action plans that must be taken to implement improvements from each stage of the key business processes (Harahap et al, 2018). Define is the first operational stage in the Six Sigma Quality Improvement Program. The main activities in the define phase include:

Determination of Six Sigma project criteria	Project selection is based on market / consumer needs that are aligned with the capabilities and objectives of the organization
Personal determination, roles and responsibilities	Each individual has an important role in efforts to control product quality. Therefore, individual roles and responsibilities need to be aligned with work in each of their fields
Determination of training needs	An understanding of Six Sigma needs to be given to every individual in the project, especially to the persons responsible for controlling product quality
Determination of key processes and their customers	For selected Six Sigma projects, key processes, process sequences and their interactions with customers (internal / external) involved in each process must be defined
Identify customer specific requirements	Six Sigma projects should be able to accommodate the needs of customers and translate them into processes and technical needs of operations
Six Sigma project statement	The Six Sigma project statement is the essence of the plan or definition of the Six Sigma program to be implemented

Measure (M)

Measure is the second operational step in improving quality with Six Sigma. There are three main activities that must be carried out in this stage, including:

Activity - 1	Determine the key quality characteristics (critical to quality - CTQ), which are directly related to the needs of the product users (customers)
Activity - 2	Develop a data collection plan for measuring baseline performance, both at the process, output or outcome level
Activity - 3	Measuring current performance, at the process level, the output or outcome level to be set as the initial performance baseline on Six Sigma

projects

Measure is the second operational step in the Six Sigma quality improvement program. The formula for calculating the value of DPO (Defect per Opportunity) and DPMO (Defect per Million Opportunity) is:

$$DPO = \frac{\text{Number of defective products}}{\text{Production amount} \times \text{CTQ "potential"}} \quad (1)$$

$$DPMO = DPO \times 1.000.000 \quad (2)$$

Analyze (A)

Analyze is the third operational step in the Six Sigma quality improvement program. The main activities in the analysis phase include:

Activity - 1

Analyze the level of process stability and process capability based on internal and external organizational performance

Activity - 2

Analyze performance improvement targets and key quality characteristics (CTQ) that need to be improved

Activity - 3

Analyzing the sources and root causes of failure that have an impact on product quality

Improve (I)

Quality improvement is the fourth operational step in the Six Sigma quality improvement program. After the sources and root causes of the problem are identified, it is necessary to establish an action plan to carry out quality improvement. To carry out process and quality improvement, the 5W - 2H method can be used. 5W-2H are: what, why, where, when, who, how and how much. Table 3, shows examples of instruments that will be used to design the improvement process.

Table 3:-Examples of 5W-2H Instruments

Type/ Level	Stages of 5W-2H	Description	Action
Main Purpose	What	What is the main target of quality improvement	Formulate targets according to user needs
Reason for Use	Why	Why is the action plan needed? A description of the usefulness of the action plan taken	
Location	Where	Where will the action plan be implemented? Do these activities have to be done there?	Changing the sequence of activities or combining activities that can be carried out together
Sequences	When	When will the action plan activities be best implemented? Can the activity be carried out later?	
People / Implementers	Who	Who will work on the action plan activity? Are there other personnel who can carry out the action plan? Why should he carry out these actions?	
Method / How to Implement	How	How to work on the action plan activities? Is the method currently used the best method? Are there other easier and best ways to do it?	Simplify existing corrective action planning activities.
Costs / Benefits	How much	How much does it cost to carry out the action plan activities? Will it have a positive impact on revenue and costs after implementing the action plan?	Choose the most effective and efficient corrective action plan.

Control (C)

It is the last operational stage in the Six Sigma quality improvement program. At this stage, the results of quality improvement are documented and disseminated, best practices that are successful in improving standardized and disseminated processes, procedures are documented and used as standard work guidelines. A list of data needs to be analyzed is presented in Table 4.

Table 4:-List of Data Needs for Each Stages of Analysis.

Six Sigma Stages	Main Activities	Data and Information Needed	Physical Evidence/Sources
Define	Determination of focus on quality control	<ol style="list-style-type: none"> The company's superior products Types and product defect criteria (Critical To Quality) 	<ul style="list-style-type: none"> Secondary data from the company
	Structure, roles, responsibilities (champion, master black belt, green belt and quality team)	<ol style="list-style-type: none"> Organizational structure and the relationship of responsibilities and roles in quality control Personal, position and main tasks 	<ul style="list-style-type: none"> Diagram of organizational structure Job description Employee list (name, assignment, work experience)
	Quality control training and workshop	<ol style="list-style-type: none"> Training that has and will be carried out is related to production quality control The aims, objectives and benefits of conducting training Topics and materials provided during the training Participants who take part in training activities Implementation times 	<ul style="list-style-type: none"> Report on workshop / training activities Handout / workshop material Attendance list of trainees
	Key processes	<ol style="list-style-type: none"> Production process flow chart Material flow diagram (production layout) System diagram for each key process 	<ul style="list-style-type: none"> Production layout Process chart
	Quality standards of customer needs	<ol style="list-style-type: none"> Company product quality standards Data about customer complaints on product quality Image of good products and defective products 	
Measure	Measuring baseline process quality performance	<ol style="list-style-type: none"> The number of defective products in several key processes. Number of rework products on products that are considered defective. 	<ul style="list-style-type: none"> Form data collection of defective products in the company
Analyze	Identify the causes of defects that occur in the product	<ol style="list-style-type: none"> Worker behavior that causes errors in the process and product defects Condition of raw materials used and their impact on product quality Engine conditions (damage, engine age, engine capacity and performance) and their impact on the product 	<ul style="list-style-type: none"> FMEA Form
Improve	The mechanism of improving product quality at the company	<ol style="list-style-type: none"> Quality improvement measures, especially in the process and product fail. Recommendations for process improvement efforts 	<ul style="list-style-type: none"> 5W2H Form
Control	Standards and procedures	<ol style="list-style-type: none"> Standard operational procedures (SOP) for 	<ul style="list-style-type: none"> Quality Manual

	for quality control processes	each process in the company 2. Recommendations for improvement of existing SOP	<ul style="list-style-type: none"> SOP
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Result:-

In this study, the results are described according to the stages in the Six Sigma approach. The results of the analysis of each stage can be described as follows:

Stage – 1: Define






This stage is the first step whose main goal is to identify the main problems that are a priority in improving the quality of products and processes in the company. Some important activities in this stage include:

Determination of Quality Control Focus: -

Determining the focus of improvement and quality control using the PPI Method, is done by first identifying the types of damage (Critical to Quality - CTQ) that often occurs in casting products. Basically, many types of defects may occur in the product during the metal casting process. But in reality, only a few types of defects are dominant and often occur in casting products, especially in the type of gray cast iron.

Referring to the national standard, that the target value of disability seen based on the quantity of production (in tonnage units), is 6-10%. Whereas the company targets a damage level of no more than 10% of the processed raw material. Several types of product defects that often occur along with their description are presented in Table 5.

Table 5:-The five dominant types of product defects (CTQ)

CTQ	Type of Product Defect	Description	Picture
CTQ - 1	Air cavity or porous (micro porosity)	This type of defect is usually caused by oxidized molten metal, low pouring temperature, insufficient drainage of drain and ladle channels, too slow pouring, pouring plates and wet duct system, permeability of imperfect molding sand.	
CTQ – 2	Shifting core	This failure is caused by improper core installation so that the core is shifted, the metal cannot fill the cavity between the mold and the core which is too narrow because the metal solidifies quickly.	
CTQ - 3	Freezing too early (misrun)	Foundry that has hardened before all mold cavities are filled completely. This is due to the very low melting metal fluidity, low pour temperature, and slow pouring speed	
CTQ - 4	Product shrinkage cavity	Depression that occurs on the surface or inside the casting due to the shrinking hardening	
CTQ - 5	Product cracks (hot cracking)	Metal cracking at the point of experiencing high stress due to the inability of the metal to shrink naturally.	

Various types of product defects above can occur in all types of products that are produced through the casting process using mold sand. The following graph displays the number of defective products taken during the preliminary study, as presented in Figure 3.

Based on the histogram in Figure 3, it is seen that the highest frequency of product defects is in the production of Giboult Joint 3 "PVC (poly vinyl carbon). Giboult Joint product is an additional component that functions as a component of connecting water pipes or oil that is widely used by companies such as drinking water companies.

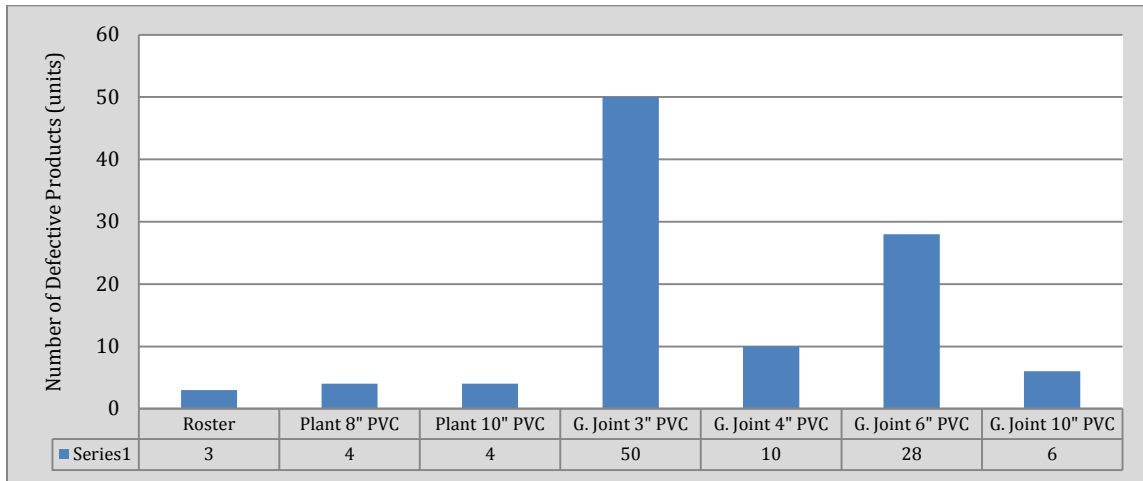


Figure 3:-Product Defect Histogram

Key processes:-

In general, the casting process starts from raw processing to produce finished products can be illustrated in the diagram as shown in Figure 4.

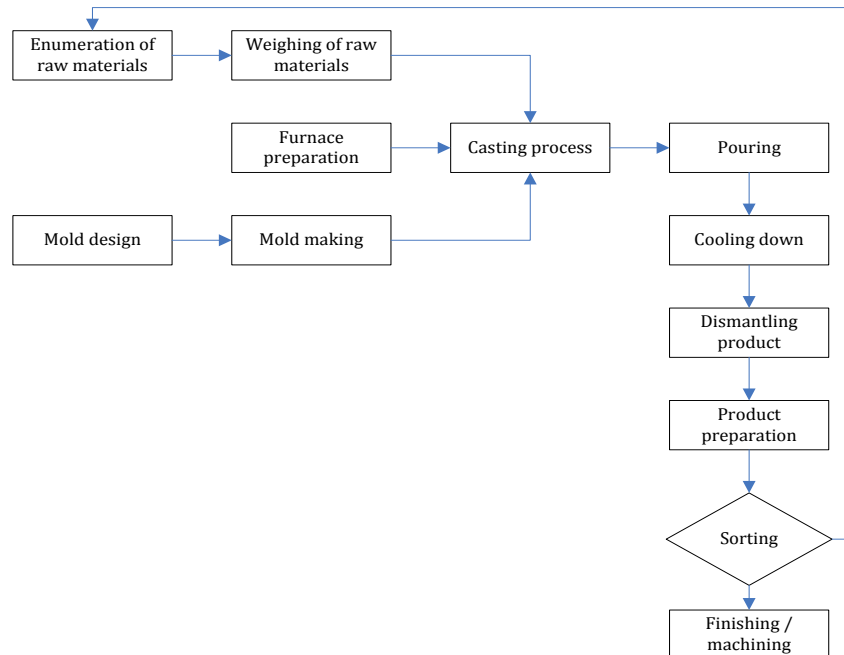


Figure 4:-Diagram of Metal Casting Process

Stage – 2: Measure

This stage is the second operational step in the Six Sigma program. In this stage Baseline measurement of process performance is carried out based on the level of product defects produced which will later be converted into Six Sigma quality standards. Some important activities at this stage include:

Determination of Priority for Improvement: -

This measurement is intended to determine the extent to which the final output of the process can meet customer needs or existing quality standards. Graphically, the determination of priority products that will be the focus of quality control can be seen through the Pareto Diagram as shown in Figure 5.

Performance Baseline Measurement: -

The measurement of the level of quality achievement in this Six Sigma program, is determined based on the level of product defect produced which is converted into a comparison value per one million products produced, commonly referred to as defect per million opportunities (DPMO). The DPMO value is the basis in determining the sigma capability level of the process that has been implemented. Basically, to measure the value of DPMO, it can be done through three levels, including (1) at the process level, (2) at the product level, and (3) at the outcome level.

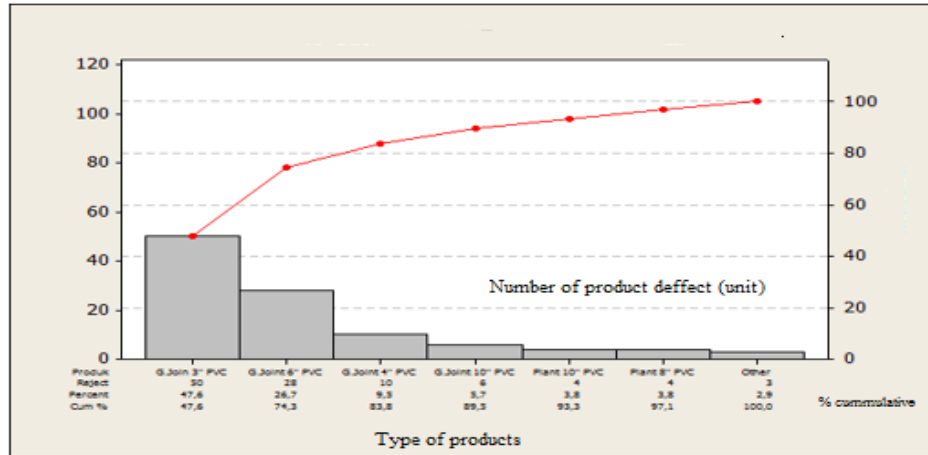


Figure 5:-Pareto Diagram of Product Defects

In this study, sigma capability measurement is done through measurements at the output level. The data analyzed is a type of attribute data in the form of data on the number of defective products (nonconformities) produced during the observation process. The data on the number of defective products of Giboult Joint 3" PVC along with the DPMO value and Sigma capabilities, can be seen in Tables 6.

Table 6:-Sigma Level and DPMO Capabilities in Making Giboult Joint 3" PVC Products

Observation	Number of products inspected	Number of defective products	Number of CTQ	Defect per opportunities	DPMO	Sigma Level
1	25	10	5	0.08	80,000	2.91
2	60	40	5	0.13	133,333	2.61
Average	42.5 or 43	25	5	0.105	106.65	2.76

Based on Table 6, for Giboult Joint 3 "PVC products, from 85 product units examined during the two observation periods, 50 units of the product were found to be defective. So with the level of disability based on five types of disability (CTQ), the DPMO value of 117,647,059 is obtained. This means that out of 1,000,000 products produced during the process, there could be as many as average 106,666 products. With the sigma calculator, a sigma level conversion value of 2.76 is obtained. If referring to the sigma standards contained in the Table 2, shows that the level of quality achievement in the process of making Giboult Joint 3 "PVC is below the average national quality achievement standard.

Likewise in the process of making Giboult Joint 4 "PVC and Giboult Joint 6" PVC, it can be seen that the level of disability per million products (DPMO) on average is 115,000 and 143,333 which indicates that the company's base line quality performance is still low compared with the average national quality of the industry. The average sigma level for each of these products is 2.78 and 2.57. Sigma Level and DPMO of Giboult Joint 4" and Giboult Joint 6" can be seen in Table 7 and 8.

Table 7:-Sigma Level and DPMO Capabilities in Making Giboult Joint 4" PVC Products

Observation	Number of products inspected	Number of defective products	Number of CTQ	Defect per opportunities	DPMO	Sigma Level
1	4	1	5	0.05	50,000	3.14
2	10	9	5	0.18	180,000	2.42
Average	7	5	5	0.115	115,000	2.78

Table 8:-Sigma and DPMO Capabilities in Making Giboult Joint 6" PVC Products

Observation	Number of products inspected	Number of defective products	Number of CTQ	Defect per opportunities	DPMO	Sigma Level
1	5	3	5	0.12	120,000	2.67
2	30	25	5	0.16	166,667	2.47
Average	17.5 or 18	14	5	0.14	143,333	2.57

Stage 3: Analyze

To find out the causes that cause two types of dominant disability (porous and shifted core), it can be done using the Fishbone Diagram. To find out the possible causes of the two types of disability, an interview process is carried out to related parties, in this case conducted to the Representative Manager (MR) in charge of carrying out direct supervision of the work of the operator.

Based on interviews, identified 3 main factors that cause porous and core shifts in the product. A more detailed description of the causes and consequences of product defects can be seen in the Fishbone Diagram as shown in Figure 6.

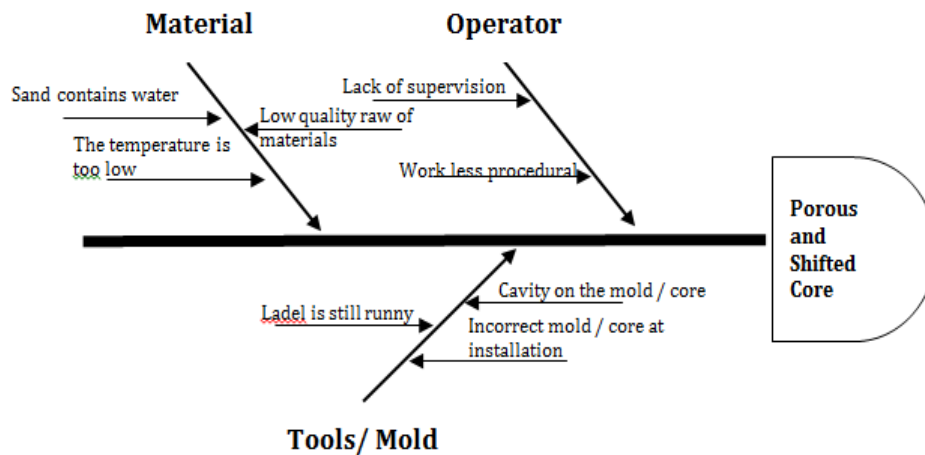


Figure 6:-Fishbone Diagram Causes of Product Defects

Porous in casting products is usually caused by oxidized molten metal, low pouring temperature, insufficient drainage of drain and ladle channels, too slow pouring, pouring plate and wet duct system, permeability of imperfect molding sand, imperfect ventilation holes adequate on the core, so that air cannot escape or get trapped in the metal. Meanwhile, the core shift is usually due to improper core installation. The metal cannot fill the cavity between the mold and the core which is too narrow because the metal freezes before reaching the destination point. Besides this failure is also caused by the core shifting due to the flow of liquid metal because the core of the core is not able to withstand the weight of the core castings.

Basically, the causes of a product defect can be classified into two main groups, namely the controlled cause and the uncontrollable cause. The depiction of the problem through the compilation of cause and effect diagrams can make it easier for companies to classify causes and improvement solutions that can be implemented for each cause of the problem. The causal relationship between the disabilities of the product is presented in Figure 7.

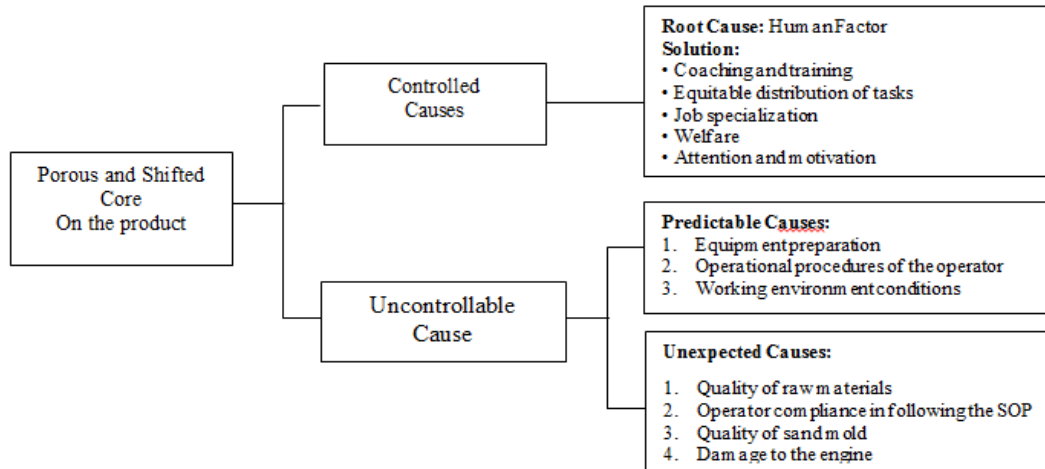


Figure 7:-Diagram of Cause and Effect Relationships of Products Defect

Stage – 4: Improve

Related to the high level of damage that causes porous and core shifts in the product, then as an anticipatory step, a corrective action plan can be implemented as presented in Table 9.

Table 9:-Steps of the Product Defect Repair Plan

What	Why	When	Who	Where	How
Checking and cleaning of ladles before pouring	If there is still water or stone granules in the ladle it can inhibit the drying process of the castings	Before the pouring process	Pouring operator	The process of casting / molding	Checking can be done manually through visual vision. Cleaning the surface of the ladle can be done with a dry cloth
Setting the mold	Ensure that the core position is correct and does not shift from the shaft and ensure there are no cavities in the mold	Before the pouring process	Pouring operator	The process of casting / molding	Visual inspection of molds and cores
Arrangement of pouring procedures	Obtained the results of casting with the same volume and drying	During the pouring process	Pouring operator	The process of casting / molding	Pouring is done in stages with a time gap between the pouring is not too long
Disassembly procedure settings	Incorrect dismantling in time can cause an unnatural hardening process	In the process of dismantling	Operator on dismantling the mold	Molding process	<ul style="list-style-type: none"> • Need accurate data about when the right time in order to obtain the results of castings with perfect density. • If the mold load is heavy enough, it should be lifted with the appropriate operator force
Determining the quality of raw	The striking difference in	The process of preparing	Raw material processing	Enumeration process raw	<ul style="list-style-type: none"> • Operators should understand the

materials	chemical composition contained in the raw material can cause imbalances on each side of the product	raw materials	operator	materials	content of the material to be used. <ul style="list-style-type: none"> Adjust the composition of ingredients by adding additional mixture to the raw material
Maintenance on the machine regularly	A decrease in engine performance can cause shrinkage of raw materials, both in terms of quantity and in terms of quality	Every casting and machining process	All operators	Every process	<ul style="list-style-type: none"> Cleaning before use Periodic and scheduled maintenance Repair / replacement of damaged parts
Management of human aspects	A clear division of tasks, coaching, training, specialization and giving sufficient attention can increase the motivation and discipline of the work of the operator	At every opportunity	Representative management and director	Management	<ul style="list-style-type: none"> Establish two-way communication Provide specific times for discussion in problem solving Briefing every morning before carrying out activities Balancing the workload with workers' compensation Improving the quality of work through coaching and training

Stage – 5: Control

This stage is an important step in creating a process of continuous improvement towards achieving zero defect conditions. Improving the quality of production is not a one-day work process, but rather a process that needs to be monitored so that the targets set can be achieved, especially in the effort to achieve the highest level of quality achievement through efforts to suppress the factors that can cause product defects or mistakes during the production process. For this reason, a number of proposals that can be applied as a control mechanism for various processes that can cause product defects and the procedure's fatigue can be described in Table 10.

Table 10:-Control Mechanisms

Aspect	Improvement Plan	Control Mechanism
Use of equipment / machinery	Check tools and machines before the process	<ul style="list-style-type: none"> Providing special places and neatly arranged each equipment through the application of 5S principles Provide special time to ensure that the tool / machine is in good condition to avoid process errors that can result in product defects or work accidents
	Procedure for using tools / machines	<ul style="list-style-type: none"> Arrange the rules of the steps for the use of each tool / machine Provide written information in the form of instructions regarding the steps to use the tool and placed in a location

		<p>that makes it easy for operators to know and carry out these steps and procedures, for example: posted on each room, division or on the machine</p> <ul style="list-style-type: none"> • Providing training to each operator on the proper use of tools / machines, both for new operators and old operators
	Tool / machine maintenance	<ul style="list-style-type: none"> • Provides instructions regarding the stages of the maintenance level as well as the schedule for carrying out the maintenance process • Provide special time for cleaning, both before the tool is used and after the tool is used
Utilization of raw materials	Selection of raw materials	<ul style="list-style-type: none"> • The quality of raw materials greatly influences the quality of the product, therefore the selection of the right raw materials should be done starting at the time of procurement, and at the time of storage of materials. • Knowledge of raw material management needs to be increased, especially for operators, this can be done by providing special training on the provision of materials at the beginning of the production phase
	Handling of raw materials (storage and enumeration)	<ul style="list-style-type: none"> • Raw materials should be placed in a closed area, far from the influence of weather conditions (rain and heat). The high water content of the material, can cause oxidation processes and a decrease in the chemical composition of the material • Preparation of material in the form of iron ore grains should be done using mechanical power, so that the level of fineness of the material can be obtained so that the casting results can be better
Management of Operators	Coaching and training	<ul style="list-style-type: none"> • The management needs to draw up training plans both in terms of training material, as well as in terms of implementation time which can improve the operator's insight and skills at work
	Increased work motivation	<ul style="list-style-type: none"> • Work routines can sometimes cause a decrease in concentration and the spirit of workers in carrying out activities. Therefore, management needs to spend a little time so that the motivation of workers increases again. One of them is through togetherness activities, recreation and meetings which are more relaxed, and full of harmony • Providing compensation in accordance with the workload provided • There is specialization in work, so that mastery of tasks becomes more leverage

Conclusion:-

Based on the results of the analysis and discussion carried out in the previous chapter, several important conclusions can be drawn. In the process of defining the problem, through direct observation and measurements using existing statistical tools, it can be seen that there are 5 types of defects that are most dominant and often occur in a variety of casting products. The five types of defects include: (a) Porous defects caused by oxidation of the product during the process (b) Displaced Core Defects caused by improper mold mounting, causing the product dimensions to become inaccurate, (c) Misrun defects, i.e. defects that cause the product to become brittle, which is caused by an uneven hardening process, (d) Cleft defects caused by improper molds or filling into imperfect molds and or improper demolition processes, and (e) Cracks caused by poor quality of raw materials, where the chemical composition contained in raw materials is not balanced, thus causing unequal distribution of resistance, or also due to treatment of products after unprocedural disassembly.

Through observation of the many products produced, it is also known that there are three types of products that often experience disabilities, namely Giboult Joint 3 "PVC products, Giboult Joint 4" PVC, Giboult Joint 6 "PVC. Giboult

Joint products are the main component in the process of connecting water pipes. This product is usually widely ordered by drinking water companies.

From the measurement process that has been done, by calculating the DPMO value and Capability of Sigma, it can be seen that the level of product defect that occurs is still quite high, especially in the production process of the three products above. The average DPMO value produced is 106,666 product defects per 1,000,000 products produced, and with an average quality level value of 2.76 sigma. This value indicates that the achievement of company quality is still below the national industry average, with a quality level of 3.00 with a product defect rate per one million production of 66,807 defective products.

Various causes of dominant disability occur due to human factors that lack discipline in carrying out work procedures, neglect or low awareness of the importance of quality. In addition, defects in the product are also caused by equipment, especially molds and ladles. Defects are also caused by the low quality of raw materials. The imbalance of the chemical composition of raw materials causes various defects.

Some ways that can be applied to overcome the problems that can cause low quality products is by increasing the knowledge and awareness of workers about the importance of maintaining quality. Even though training has been carried out, training must continue to be planned so that the results and quality of the products continue to increase and are highly competitive. In addition, the SOP that has been made by the company needs to be carried out seriously by the workers. For this reason, there needs to be a mechanism that can make it easier for an operator to understand and review existing SOPs, for example by making posters, or flowcharts that are placed in positions that are easy for the operator to see and guide. In addition, before the production process is carried out, special time needs to be provided to ensure that all conditions are ready to operate. Some activities that can be carried out during this preparation period include cleaning equipment / machinery, ensuring the position of the mold, ensuring the condition and availability of materials and ensuring the physical condition of workers, so that work errors that can result in process failures or work accidents can be avoided.

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