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Failure Mode Effect Analysis in Turning of Mild Steel Under MQL Condition

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Abstract: FMEA was commonly used to improve production quality by reducing workplace failures and preventing them from happening. Nowadays, tool failures are the most common problems that can be found in the machining practice. Hence, FMEA was used to reduce tool failure occurrence and improve the production quality. In this paper, FMEA analysis was done for a turning process of mild steel. Several turning operations were done, and the failure mode and failure effect were identified. Then, the tool failure effect was studied, and the causes were generated using the Ishikawa diagram. The occurrence, severity, and detection rating were assigned, and the Risk Priority Number (RPN) was generated. FMEA Risk Matrix was used to help provide a visual aid for classifying and categorizing the level of risk. The highest risk was then identified from the highest RPN value, and the cause and prevention methods were generated for each failure effect cause. This study can be used as a guide or reference in the turning process practice for a more effective process.

Keywords: FMEA, tool failures, turning, lathe, machining

1. Introduction

Failure Mode Effect Analysis, or FMEA, is a well-known risk assessment technique. In the 1960s, it was used for the first time in the aerospace industry. It is now regarded as a fundamental tool in the field of reliability engineering. The goal of FMEA is to look at possible failure modes and the consequences of those failures on the product. Design Failure Mode Effect Analysis (DFMEA), Process Failure Mode Effect Analysis (PFMEA), and Service Failure Mode Effect Analysis (SFMEA) are three different types of FMEA (FMEA). A DFMEA analysis of the product design is required before it is released for production. The DFMEA emphasizes possible failure modes associated with product functions and triggered by design flaws. PFMEA, on the other hand, is used to analyze existing or newly developed processes. It focuses on potential failure modes associated with process safety or efficiency and product functions triggered by a process failure. SFMEA is the last but not least. The purpose of an SFMEA is to assess a product's serviceability. The focus of SFMEA is on the potential problem of maintenance issues and manufactured field failure products as stated by Bluyband & Grabov in 2009. [1].

Excessive power or current intake, excessive vibration or irregular tone, complete tool breakage, rapid degradation of surface finish, and adverse chip forming are all common cutting tool failures in the machining industries, according to Gnanasekaran in 2016 [2]. Different techniques, such as grooving and indentation, microscopic optical microscope, and electron microscope (SEM) scanning, can be used to examine tool wear [2]. The purpose of FMEA implementation is to reduce failures and prevent them from occurring. As a result, there are numerous FMEA objectives. According to Carlson in 2016 [3], the main aim of FMEA is to improve the manufacturing process design. FMEA is also used to investigate and determine safety hazard preventions to keep product performance from degrading. It is used to develop

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plan verification and improve the test in System FMEA or Design FMEA. Furthermore, FMEA is used to develop the Preventive Maintenance plan for in-service machinery and equipment.

FMEA (Failure Mode Effect Analysis) ensures that a process or procedure runs smoothly in any organization. FMEA is primarily used to determine which process failures will occur, and an FMEA worksheet will be used to determine the problem with the highest Risk Priority Number (RPN). After that, a method of prevention will be devised. Kumar et al. in 2013 [4]. experimented with an HSS end milling tool on a cast iron workpiece in 2013. The failure modes are reviewed using the FMEA worksheet. The following rating is based on the frequency with which the failure occurred. The ranking is done on a scale of 1 to 10, with one being the lowest and ten being the highest, indicating a higher occurrence.

A severity rating then determines the severity of the problem. This rating will assist the engineer in determining and prioritizing which failures are the most serious. The RPN, or risk priority number, is the next option. The total RPN is calculated by multiplying severity, occurrence, and detection. The problem with the highest RPN score is the one that must be completed first. According to the findings, chip packing has the highest RPN score of 392. It was caused by a deep cut, which resulted in low chip dispersion. As a result, the solution is to change the process's feed rate. The next one is due to a lack of coolant in the process. As a result, the tolerance and finished product are subpar. As a result, more coolant is required. Another option is to use air pressure to remove chips and debris from the cutting zone.

In 2014, Parsana and Patel performed a case study and FMEA analysis on a cylinder head. Many machines and operations are used to produce cylinder heads, including finishing, drilling, tapping, and more. As a result, the failure history is examined to determine the most appropriate criteria for ranking the severity of occurrence and detection. First and foremost, each operation's potential failure mode is determined. The possible effects of a failure mode are then noted, along with their severity value. The causes of its prevention are then determined. The RPN will then be calculated. As a result, the RPN value will be determined, and the highest RPN will be determined from the data. According to the analysis, each process has a large number of potential failure modes. The bottom face finishes with smoke or fuel problems, the top face finishes with oil leakage problems, and others have the highest RPN. As a result, those with the highest RPN must be prioritized, and immediate response and preventive measures must be taken to reduce the failure rate. As a result, as stated by S. Parsana & T. Patel in 2014 [5], both time and money can be saved by adhering to the SOP and using the FMEA prevention method.

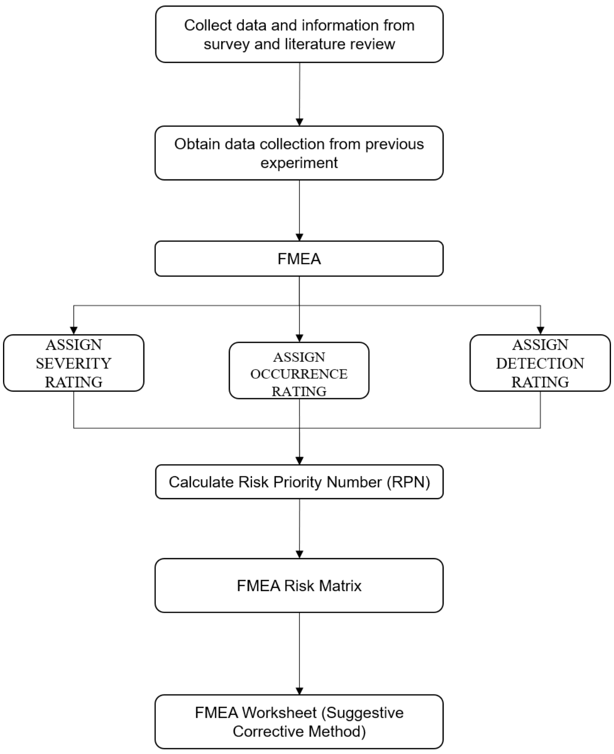

Fig. 1 - Process flow chart

Drilling, milling, and turning are standard practices in conventional machining workshops. One of the major problems of those machining processes is the tool life itself. After the tool reaches its maximum potential, the failure tool rate will increase drastically and fracture. Thus, frequent tool substitution is done to having a better machining process. Besides, another problem that commonly faces in the machining process is chip formation. The most desirable chip formation is a continuous chip, resulting in a good surface finish since the cutting process is stable. However, improper machining will cause bad chip formation, such as ribbon chip type. The chips are bonded together and forming long coils of chips. This type of chip will cause harm to the operator. Furthermore, surface roughness is also an issue that needs to face in improper machining. Low surface finish will reduce the fatigue strength, wear resistance, corrosion resistance, and product's commercial value. In addition, tolerance accuracy will also decrease. For example, a small and complicated design needs minimal tolerance. If the tolerance difference is too big, the product or the structure will lose its value and function. All these problems will cause an increase in the production time and increase in cost value due to the frequent substitution of the tool, extra finishing process for better surface finish, and others. According to Kumar, in 2013, the most crucial factor affecting its finish outcome is the milling cutter's role. It will affect the accuracy of the product and another major factor in the cutting tool's life itself. The whole process will fail, and the dimensional accuracy and finish product will be affected due to tool failure. These failures may cause by the cutter properties, design parameters, machine properties, workpiece properties, or the milling process itself. Hence, Kumar et al. in 2013 (Kumar et al., 2013) mentioned that failure mode analysis is critical to identify the causes of improper milling and end milling process effects.

As a result, earlier research data is utilized to determine what is causing the tool failure. The root cause of problems is identified using a method such as a cause and an effect diagram. Processes such as Occurrence Rating, Detection Rating, and Severity Rating are done to get the RPN or risk priority number value. Finally, an FMEA worksheet is filled out, and each issue is investigated for a preventative approach. FMEA forecasts difficulties and faults consequently, leading to more excellent product quality.

2. Methods and Material

The flow chart for the FMEA process is shown in Figure 1. A turning process experiment done by Kifli et. al in 2012 [6] will be used as a reference for the FMEA analysis. The result and discussion then will be supported by data from articles, journals, and review papers. These details are gathered and analyzed into keywords. The journal contains a wealth of information on the use of FMEA in the industry. Mild steel is used in this process. First, the turning process is performed in three different modes: dry, wet, and MQL. Throughout the process, each condition uses the same material and tool. The tool wear image can be observed by the SEM (Scanning Electron Microscope) function after every 50mm of cutting length. This process is repeated until the cutting length reaches 1000mm. Other conditions, such as Dry, Wet, and MQL, are used in this process (palm oil, olive oil, corn oil, and soybean oil). Finally, tool flank wear and surface roughness data are measured and recorded in a table. As a result, the most effective cutting parameter will be chosen. Tool wear, surface roughness, and chipping formation were the failure modes observed during the experiment. After the data has been collected, the FMEA analysis can be initiate. The first step is to identify the various failure modes that could occur during the turning process. The severity, occurrence, and detection ratings are then assigned correctly. The RPN value, also known as the Risk Priority Number, is calculated by multiplying the severity, occurrence, and detection ratings. The critical risk can then be determined using the RPN value. The FMEA Risk Matrix was implemented as a visual aid for the operator to determine which failure class. Finally, the causes of each failure effect were identified, and the appropriate prevention method was implemented.

Table 1 - Experimental condition [6]

Machine Tool	Lathe machine (PINACHO SP/165)
Work specimen	
• **Material**	AISI-1045 mild steel
• **Size**	Φ 38 mm x 600 mm
Cutting tool	
• **Cutting insert**	CCGT 060204-PF Insert Grade QX520
• **Cutting holder**	SDJCR2020K11 External Tool-holder
• **Working tool geometry**	-6, -6, 6, 6, 15, 75, 0.8 (mm)
Process parameter	
• **Cutting velocity, V_c**	1400 rpm
• **Feed rate, S_o**	0.20 mm/rev
• **Depth of cut, t**	1 mm
MQL supply	Air: 5 bars, Lubricant: 50 ml/hr. (through flow meter)
Flow rate for flooding	11 ml/sec
Environment	Dry, wet (flooding) and Minimum quantity lubrication (MQL)
Composition of coolant used in MQL application	Vegetable oil (100 ml), Food grade emulsifier (100 ml) and water (800 ml)

3. Result and Discussion

3.1 Ishikawa Diagram

The potential failure effect is an effect that may occur because of the process's failure modes. Hence, a brainstorming session is used to investigate the possible impact. The failure modes in this study were chosen from a previous experiment conducted by Kifli et al in 2012 [6] . The study identified three failure modes in the turning process: tool failure/wear, surface roughness, and chip formation. As shown in Fig. 2, problems may arise due to the brainstorming session due to four causes: the MQL parameter, cutting parameter, workpiece parameter, and lubricant properties themselves. The nozzle distance, position, angle, and input pressure used to spread the MQL and flow rate of the MQL itself make up the MQL parameter. Meanwhile, the depth of cut, cutting speed, and feed rate of the turning process are the standard cutting parameters. Furthermore, lubricant properties parameters such as evaporation rates, viscosity, and the type of lubricant used all play a role in the tool failure problem.

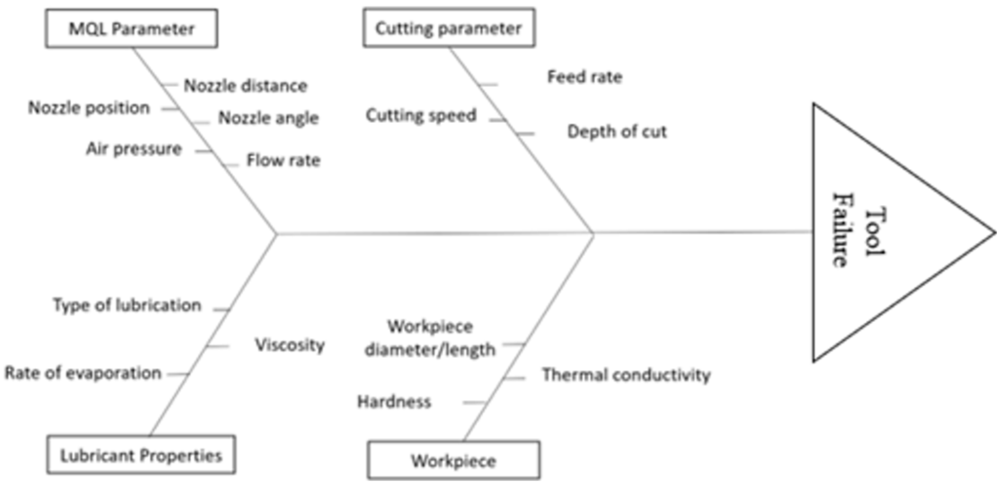

Fig. 2 - Ishikawa diagram on tool failure

3.2 Detection Rating

When the detection rate is high, it indicates that the failure effect is difficult to detect. The higher the detection rating, the higher the difficulty for the failure effect to be detected. The details on detection rating are shown in Table 2. The detection rating with value of 1 indicates that the failure effect is entirely prevented as it is too apparent. Thus, the failure is known as 'error-proof". A possible example of failure effect with the rating of 1 is the problem can be detected at an early stage which is. For example, the compatibility of the tool holder and the tool bit, the shape or size of the jig or fixture with the workpiece material and so on. Meanwhile, failure mode score ranges from 2,3, and 4 can be detected with the naked eye before, during, and after the turning process, respectively. For example, score of 2 can be detected at the early process, where the failure leads to vibration due to loosening jig or fixture holder. For the score of 3, the failure is detected during the process, whereas the tool breakage, chip formation, and other failure effects might occur. Lastly, the score of 4 indicates that the failure effect can be detected as the process's outcome, such as the tool wear formation and the quality of the finished product in terms of surface finish and shapes and the tool wear evolution.

Next, under the criteria of the measuring device used to measure the product quality, the rating will be 5 and 6. In these criteria, the failure effect can only be detected with a specific measuring device. For the score of 5, the detection category is moderate as the failure effect can be detected with a simple measuring device with simple steps such as vernier caliper, micrometer screw gauge, and others. Meanwhile, a score of 6 indicates that the detection rating for the failure effect category is low. The failure effect can be detected with a built-in automated measuring device with extra complicated steps. For example, the material tolerance measurement needs to be precise and can only be measured by the Coordinate Measuring Machine, Talysurf, and others. For scores of 7 and 8, the failure effect can only be detected with more complicated measuring devices. For a score of 7, only a built-in automated measuring instrument with a single step may identify the failure's impact, such as a dynamometer used to measure cutting force. Meanwhile, for a score of 8, the failure effect can only be detected using a built-in automated measuring device with an extra step, such as a thermograph to measure cutting tool temperature and an SEM or Scanning Electron Microscope to observe tool wear rate after machining. The failure effect detection is very remote for a score of 9 and can only be detected during random audits or inspections. Finally, the failure effect for 10 indicated that the failure is present, but it is impossible to detect.

3.3 Occurrence Rating

The higher the occurrence rating, the more likely the process will fail. The occurrence rate is assigned using a rating scale of 1 to 5, as shown in Table 3. A failure rate of 1 indicates that the failure occurs only once during the process, while a rate of two, on the other hand, denotes a meagre chance of failure. The occurrence ratings of 3 and 4 indicate a high and medium probability of failure, respectively. Finally, a failure occurrence rating of five indicates that the failure could not be avoided, and the failure effect will most likely occur regardless of the circumstances. For example, failure effects such as tool temperature and tool wear could not be avoided even with the suitable coating, lubricant, or cutting parameters. With proper prevention methods, however, this failure effect occurrence rating can be reduced.

Table 2 - Detection rating

Detection Rating	Description	Category of Detection	Criteria
10	Impossible to be detected	Absolute Uncertainty	
9	Only be detected during random audit or inspection	Very Remote	-
8	Only be detected with built in automated measuring device with extra step (Thermograph, SEM) E.g., tool temperature, tool wear	Remote	Measuring Device on Internal Process (Equipment) Aspect
7	Only be detected with built in automated measuring device with simple step (Dynamometer) E.g., cutting forces	Very Low	
6	Only be detected with automated measuring device (CMM, Talysurf) E.g., Tolerance, Surface Roughness	Low	Measuring Device for Production Aspect
5	Detected with simple or manual measuring device without complicated step (Vernier caliper, micrometer screw gauge etc.)	Moderately	
4	Easily detected with naked eye after the process	Moderately High	
3	Easily detected with naked eye during the process	High	Naked Eye (Without any aid)
2	Easily detected with naked eye at the beginning of the process	Very High	
1	Failure effect is fully prevented as it was obvious and easily detected. (Error proof)	Almost Certain	-

Table 3 - Occurrence rating

Occurrence Rating	Description	Likelihood of Failure
5	Failure occurrence is very high (could not be avoided)	Very High
4	Failure occurrence is high	High
3	Failure occurrence is medium	Moderate
2	Failure occurrence of occurring is low and rare	Remote
1	Failure does not occur at all during the process	None

3.4 Severity Rating

The higher the severity rating, the more significant the failure effect is. As shown in Table 2, the severity rating is divided into different groups, and the severity rating range will be from 10 to 1. If the process fails to meet safety and regulatory requirements for the first grouping, the severity will be highly hazardous or hazardous. It can endanger the operator without warning. For example, tool breakage is categorized as highly dangerous. The failure effect can cause severe injury to the operator if the tool breakage is bound to break without warning because, during the turning process, the spindle is rotating at high speed. When tool breakage occurs, the pieces of tool bit that broke will probably fly directly to the operator at high speed and could lead to serious injury. For the continuous chip failure effect, the score will be 9. The formation of the long and tangled chips can be observed clearly during the turning process and easily avoided with proper precaution steps.

Any malfunction concerning machinery or equipment failure that could affect output would vary from 8 to 6. If the loss could cause the system to break down, such as belting issues, motor problems, and others, the failure would be very high. This type of failure effect needs to be avoided as the machine breakdown would increase maintenance time and delay the production system. The failure effect, such as tool wear rate and high cutting temperature, will be scored with six under the moderate severity category. Moreover, under the equipment or machine failure aspect, the increase in cutting force will be categorized as low with a score of 5. The cutting force is correlated to the tool wear failure effect, where the cutting force increases prominently with the tool wear.

The description for the score of 5 is that the failure effect might lead to a loss in the primary function where the machined part could not be reworked, and the probability of the product turning into scrap is high. For example, a decrease in the finish part's accuracy and reduction in product tolerance will cause changes in product geometry. If the dimension is smaller than the expected value, the product will turn into scrap, but if the product's dimension is larger than the expected value, the product can be re-machine again. However, for the score of 4, the probability of the product to turn into scrap is lower, where the criteria for 4 is poor surface finish and surface irregularities that lead to degradation of the product standard. This failure effect can easily be reworked by undergoing extra steps such as polishing, grinding, etc. For the score of 3, the severity is categorized as very minor, where the failure effect can cause increased friction in the product due to low surface roughness. For 2, the discontinuous chip is considered minor as it is the most desirable type of chip for a ductile material. This type of chip still could injure the operator or damage the surface roughness if it is not adequately handled. However, this type of failure effect does not significantly affect the production value of the turning process. Lastly, the lowest score of 1 indicates that there is no failure effect occur. Hence, the severity of the failure effect is none.

Table 4 - Severity rating

Severity Rating	Description	Category	Criteria
10	Fail to Meet Safety and Regulatory Requirement	Highly hazardous	• Endanger operator without warning (Tool breakage)
9		Hazardous	• Endanger operator with warning (Continuous chip)
8	Machine or equipment failure that could affect the productivity	Very High	• Machine breakdown (belting, motor, spindle and etc)
7		High	• Increase in tool wear rate • Increase in cutting temperature
6		Moderate	• Increase cutting force
5	Loss or Degradation of Primary Function (Probability of product to turn into scrap is high)	Low	• Decrease in accuracy of finish part • Causes change in geometry • Reduce tolerance of the product
4	Loss or Degradation of Primary Function and Secondary Function (Probability of product to turn into scrap is low and can be reworked)	Very Low	• Surface irregularities • Degradation of standard • Poor surface finish
3		Minor	• Increase friction of the product
2		Very Minor	• Discontinuous chip
1	None	None	• None

3.5 Risk Priority Number (RPN Value)

The brainstorming method yields a total of 12 potential failure effects. The potential failure effects are divided into two groups: tool failure and chip formation. The Risk Priority Number (RPN) for each potential failure effect is calculated as shown in Table 4. As a consequence, the greatest RPN value is linked to a higher cutting temperature and a faster rate of tool wear. Cutting temperature and tool wear rate are inextricably linked. As the temperature of the cutting tool rises, the rate of tool wear increases. Critical failure impacts include high cutting temperatures and an increase in tool wear rate. It might result in additional challenges, such as burn scars created by high temperatures and poor production value, such as dimensional accuracy, surface polish, and other aspects, especially on the workpiece.

Tool breakage, on the other hand, is the failure effect with the lowest RPN value. Despite the high severity of tool breakage, the detection and occurrence rates are lower. This is because the tool breakage failure effect did not occur once during the mild steel fabrication process. As a result, the event receives a rating of 1. Meanwhile, with a score of 2, the tool breakage failure effect can be easily detected during the process as the failure effect is very apparent. As a result, the tool breakage's RPN value is low.

Chip formation, which is a continuous type of chip, has the second lowest RPN value. The chip that is produced with the presence of coolant is tubular throughout the experiment. When machining brittle materials, this chip is inevitable. This type of chip, on the other hand, is the most desirable when machining ductile materials. No extra pressure or force is applied to the tool when the chips are broken off regularly. As a result, lower power consumption and longer tool life can be achieved. However, establishing a threshold for FMEA should not be used since every possible impact must be considered. The failure effect must still be regarded as RPN values between 240 and 14 since it impacts tool life. For example, even if tool breakage is readily detectable, the severity is still quite severe. There is a chance that failure will occur. For a better machining process and longer tool life, any failure consequence must be avoided.

Table 5 - RPN value

Problem	Potential Effect	Occurrence	Detection	Severity	RPN
Tool failure	Increase cutting force	3	7	5	105
	Increase cutting temperature	5	8	6	240
	Tool breakage	1	2	10	20
	Decrease accuracy of finish part	3	5	4	60
	Poor surface finish	3	4	3	36
	Causes change in geometry	3	5	4	60
	Degradation of standard	3	4	3	36
	Change in tolerance	3	6	4	72
	Surface irregularities	3	7	3	63
	Increase in tool wear rate	5	8	6	240
Chip formation	Continuous type chip	2	4	9	72
	Discontinuous type chip	4	4	2	32

3.6 FMEA Risk Matrix

The risk matrix is divided into three groups, as indicated in Table 6: low risk, medium risk, and high risk. Low risk, for example, is assigned a number between 1 and 35. The value for RPN from 36 to 104 is categorized as medium risk, while the level is indicated as green. Finally, high-level priority risks are categorized from 105 to 500. The greater the danger, the higher the importance of the preventive method's action plan. As seen in Figures 3 through 7, the left-hand side provides the occurrence rating, while the horizontal numbering displays the severity level. In the FMEA risk matrix, only the numbers 1 through 5 are utilized. Combining the risk matrix from detection ratings 1 to 5 may result in a 3D cube-shaped FMEA risk matrix. The left-hand side indicates the occurrence rating, while the horizontal numbering reflects the severity rating, as illustrated in Figures 3 through 7. Only the values 1 to 5 are used in the FMEA risk matrix. A 3D cube-shaped FMEA risk matrix may be created by combining the risk matrix from detection ratings 1 to 5.

Table 6 - FMEA risk matrix

Category	RPN Value	Color
Low	1 - 35	
Medium	36 - 104	
High	105 - 500	

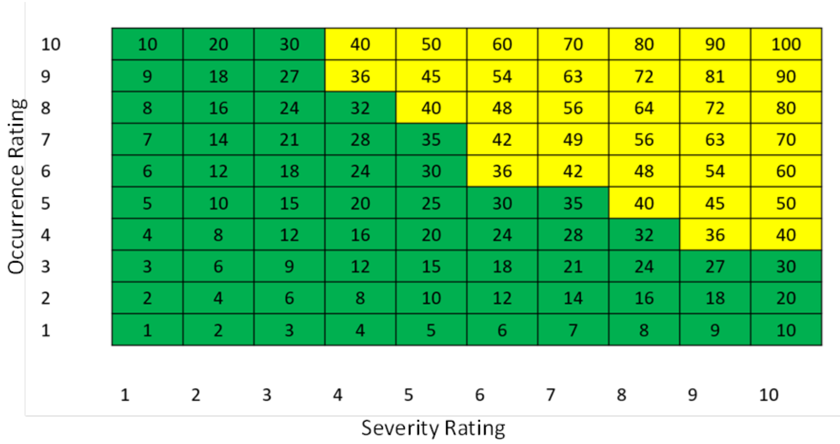

Fig. 3 - Risk matrix for detection rating of 1`

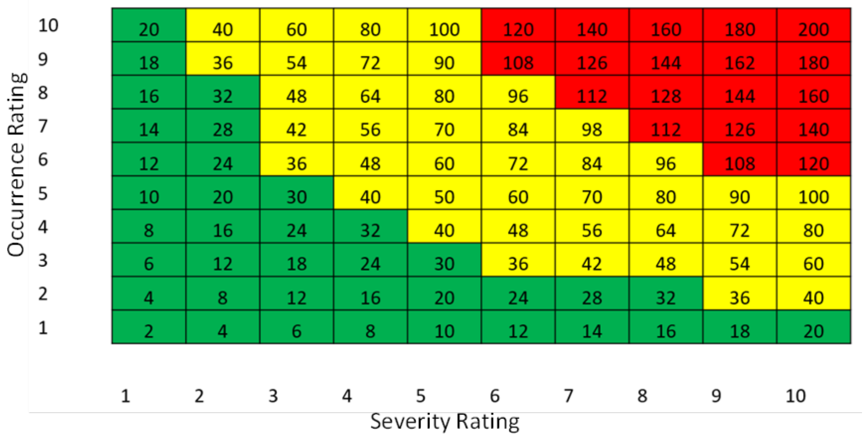

Fig. 4 - Risk matrix for detection rating of 1

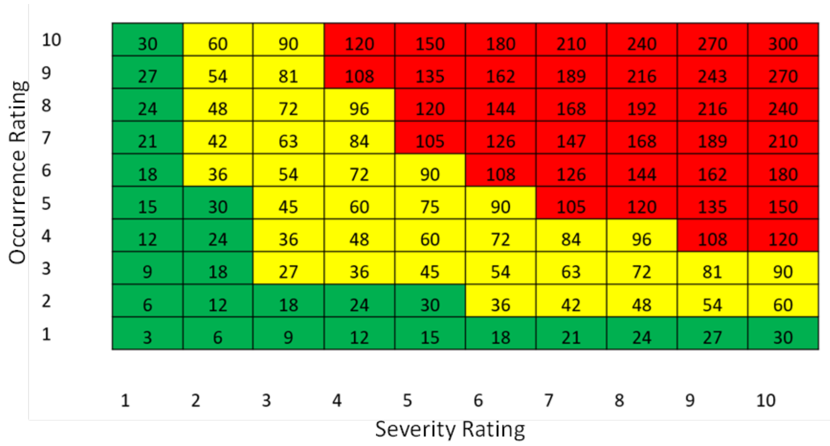

Fig. 5 - Risk matrix for detection rating of 3

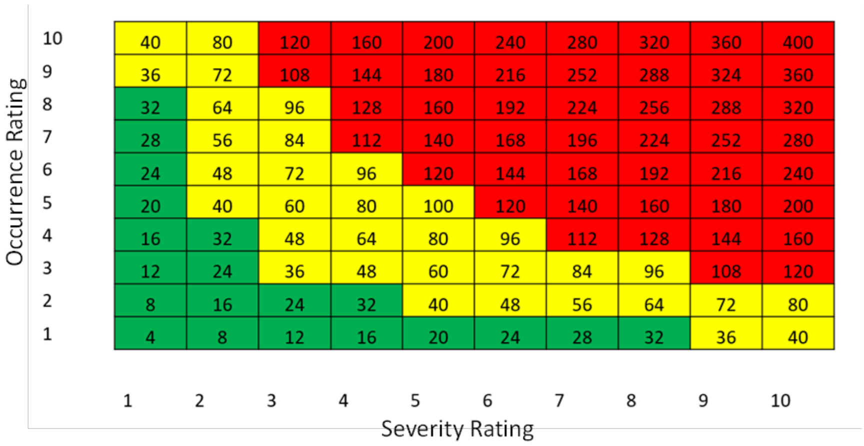

Fig. 6 - Risk matrix for detection rating of 4

Fig. 7 - Risk matrix for detection rating of 6

3.7 Causes & Prevention Method

3.7.1 Causes

The Ishikawa diagram in Fig. 2 with previous research paper is used to investigate the cause for each potential failure effect. The causes for the failure effect are summarized in Table 6. Each of the causes for the failure effect will be explained thoroughly in this subtopic.

One of the potential effects that could cause tool failure was an increase in cutting forces. Low cutting speed, high feed rate, deep cut depth, or the presence of a Built-Up Edge in the cutting tool are all plausible contributors to the increase in cutting force, according to the research. Higher feed rates also usually have been associated with greater cutting forces. According to Sivaraman in 2012 [7], increase in cutting speed will cause reduce in cutting force. When high cutting speed is used, it will cause an increase in temperature. As a result of thermal softening during the machining of the working material, the cutting forces will be reduced [7]. The presence of BUE or built-up edge also could contribute to increase in cutting forces whereas BUE deposit protects the cutting tool's sharpness from coming into direct touch with the workpiece in the case of BUE. As a result, the workpiece and cutting zone will have more contact. As the tool becomes less effective for the machining process due to dullness, more force is needed to machine the workpiece as mentioned by Ahmed et al. in 2017 [8]. An example of a built-up edge can be seen in Fig. 8.

Increase in cutting temperature also could lead to tool failure effect. Even though, as stated by Sivaraman in 2012 [7], increase in cutting temperature result in less cutting force and thermal softening during machining process, excessive cutting temperature must be avoided at all. This is because excessive heat temperature will cause rapid tool wear formation which will reduce the tool life. Moreover, it also could lead to fracturing or thermal flaking due to thermal shocks occur at the cutting edge and many more. Increase in cutting temperature usually occurs when friction occurs between the workpiece and the tool flank face during the turning operation. When the cutting speed is increased, the temperature of the cutting tool rises, and the friction coefficient between the cutting tool and the workpiece is reduced. According to Kenny in 2000 [10], friction will produce heat by converting mechanical energy to thermal energy. These defects break as one surface passes over another, causing heat to be generated. Heat is created as a consequence of the breaking of molecular bonds.

Table 7 - FMEA worksheet

Problem	Potential Effect	Occurrence	Detection	Severity	RPN	Causes	Prevention Method
Tool Failure	Increase cutting force	3	7	5	105	i. Low cutting speed ii. High feed rate iii. High depth of cut Presence of BUE (Built-up Edge)	i. Increase/optimize cutting speed. ii. Reduce feed rate. iii. Lower the feed rate and depth of cut. iv. Use proper MQL. Increase rake angle
	Increase cutting temperature	5	8	6	240	i. High cutting speed ii. Low MQL viscosity iii. Low air pressure Low flow rate	i. Reduce/optimize cutting speed. ii. Use high MQL viscosity. iii. Increase air pressure. iv. Increase flow rate. v. Optimize nozzle angle and distance.
	Tool breakage	1	2	10	20	i. Excessive cutting force ii. Low MQL supply iii. Low air pressure input iv. Poor tool selection	i. Reduce cutting force. ii. Use high MQL viscosity. iii. Increase air pressure. iv. Increase flow rate. vi. Use proper tool
	Decrease accuracy of finish part	3	5	4	60	i. Length of workpiece is too long, and the diameter is too small that led to vibration ii. Not enough lubricant iii. Due to lack of tool sharpness The tailstock of the lathe machine was not lock properly	i. Increase the amount of lubricant supply. Make sure to lock the tailstock properly
	Poor surface finish	3	4	3	36		
	Causes change in geometry.	3	5	4	60		
	Degradation of standard	3	4	3	36		
	Change in tolerance	3	6	4	72		
	Surface irregularities	3	7	3	63		
	Increase in tool wear rate	5	8	6	240	i. Low MQL viscosity ii. Due to high temperature at cutting tool. iii. Carbide coated tool	i. Use high MQL viscosity. ii. Use higher air pressure. iii. Use better tool coating. iv. Optimize nozzle angle and distance.

						bit undergo plastic deformation. Air pressure was too low	
Chip Formation	Continuous type chip	2	4	9	72	i. Absent of coolant. Ductile material was used	i. Use proper coolant or MQL. Use chip breaker
	Discontinuous type chip	4	4	2	32	i. Small rake angle of the tool. ii. Presence of coolant Brittle material	-

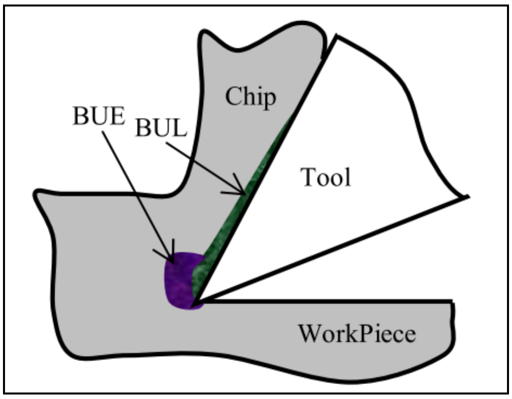

Fig. 8 - Built-up edge in cutting tool schematic image [9]

The next potential effect of tool failure with the lowest RPN value was tool breakage effect. Excessive cutting force or a high cutting temperature can cause tool damage during the turning operation. This failure effect is most common during roughing when a deep cut is utilized to remove material from the workpiece. The average contact stress at the tool-chip interface and contact area increase as cutting feeds increase. When the typical contact stress level exceeds a particular tool-material specific limit, the cutting-edge chips, resulting in tool breakage has been noted by Astakhov in 2007 [11]. Excessive cutting force may also produce abnormally high temperatures in the cutting tool. Friction between the cutting tool and the workpiece generates heat. According to Ogedengbe et al. in 2019 [12], 80% of the heat produced will travel to the chip, 10% to the tool, and the remainder would be absorbed into the workpiece when a low cutting speed is combined with a greater depth of cut, the temperature rises. As the feed rate rises, the chip portion expands, increasing friction. When the cutting tool's cutting speed exceeds its limitations, the cutting tool glows bright red, indicating that high heat is produced in the cutting tool [12]. Similar to the increase in cutting temperature effect, tool breakage occurs also due to low MQL supply and low air pressure input. When high intensity machining process is done, insufficient cooling process will cause an increase in the cutting edges. However, when excessive heating temperature is achieved, the possibility of tools to breakdown or melt will also increase.

Tool breakage may also be caused by incorrect tool material selection for the cutting operation, mainly when the workpiece is stiffer than the cutting tool. Product quality would also be reduced due to the failure effect, which would impact the production value of the final product. those tool failure effect could decrease accuracy of finish part, poor surface finish, causes change in geometry, degradation of standard, change in tolerance and surface irregularities. It was discovered that the lack of tool sharpness is one of the significant factors that contributed to this issue. Moreover, insufficient amount of MQL that was used during the turning process also lead for tool to loses its sharpness at a faster rate over time. Aside from that, vibration has a significant impact on the manufacturing value of surface roughness and polish. After many rounds of turning operation, the vibration issue becomes apparent and severe. The chuck can no longer hold the workpiece securely because the diameter has shrunk too tiny. The process then begins to vibrate at a rapid pace. When the length of a workpiece is too long yet the diameter is excessively small, the vibration of the workpiece increases dramatically. Furthermore, throughout the procedure, the tailstock of the lathe machine is not properly secured [6].

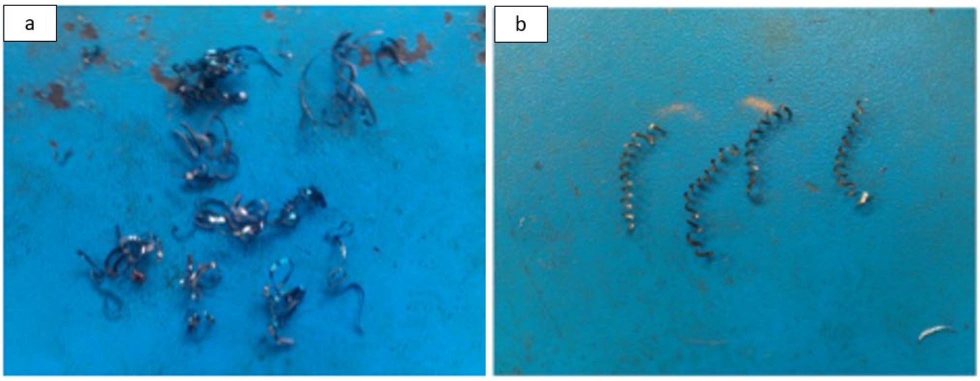

Fig. 8 - (a) Continuous chip during dry machining; (b) discontinuous chip during MQL cutting [6]

3.7.2 Prevention Method

As illustrated in Table 21, many factors may lead to any given outcome. With appropriate planning and preventive methods may prevent each of these failure effects. First, lowering the cutting speed may minimize the rise in cutting forces. However, another issue, such as a poor production value, may arise if set too low. As a result, the responsible operator must know the best cutting speed for a specific material. In addition, the feed rate and cut depth must be decreased due to the cutting pressures increase as the feed rate and depth of the cut increase. This is because, more pressure and energy are required to remove more material from the workpiece when a high feed rate or depth of cut is utilized has been noticed by Rasidi Ibrahim et al. in 2017 [13]. Furthermore, to avoid the development of a Built-Up Edge, proper lubricant amount was used to minimize the friction. Finally, a high positive rake angle may decrease the likelihood of a built-up edge forming on the cutting tool.

Meanwhile, as we all know, friction between the workpiece and the cutting tool is one of the most common reasons for rising in cutting temperatures. First and foremost, the cutting speed must be optimized depending on the material of the workpiece in order to ensure the best machining process with low cutting temperature. Ye et al. in 2011 [14], mentioned that, due to the heat from the cutting tool is passed to the workpiece in a shorter amount of time, the cutting temperature will increase as the cutting speed increase. Furthermore, the operator also must utilize appropriate MQL selection with an acceptable flow rate and air pressure input to effectively decrease the cutting tool's temperature. It was also observed that the air pressure of 5 bars and MQL viscosity used by Irwan Kifli et al in 2012 [6] are ineffective in lowering the cutting tool temperature. Therefore, the optimum air pressure input is 7 bars, and palm oil is the optimal MQL as the higher air pressure enables the MQL to enter the cutting zone more effectively and keeps debris out of the cutting zone. According to Rahim and Dorairaju in 2018 [15]., high air pressure also aids in producing tiny droplets that provide efficient lubrication to the tool chip contact.

Palm oil will also be chosen since it has a greater viscosity and has been shown to have superior cooling qualities than other oils, including maize oil, soybean oil, and olive oil. In 2011, Rahim and Sahara demonstrated that palm oil might decrease the thrust force and torque during the machining process by reducing friction and heat production between the tool-interface chip. Palm oil is proven to be the best coolant among the four MQL types tested, with a 31% improvement over the dry cutting process. Teo and Yassin in 2015 [16] found that greater viscosity provides superior lubrication characteristics. Furthermore, Teo in 2014 found that high MQL viscosity has a thicker molecular layer of lube fluids, which increases the lubricating characteristics. Triglycerides in palm oil may maintain stronger intermolecular interactions as the temperatures rises [17].

For better MQL delivery, the operator must also adjust the angle and distance of the nozzle. In 2018, Rahim and Dorairaju [15] claiming that the optimal distance is 6mm to 7mm, depending on the nozzle diameter and angle. When the distance between the tool and the cutting zone is short, MQL will only cover a tiny part of the cutting zone. However, when the distance of the nozzle is too far, the spread of the MQL will be large and the MQL will lose its concentricity. Therefore, the cooling and lubricating characteristics of the MQL will be poor and ineffective [15]. Besides, the nozzle angle must be selected properly for optimum MQL delivery. It was noted that the lowest cutting tool temperature can be detected at the nozzle angle of 20° [18]. Furthermore, tool breakage must be avoided to pre wasting time and money on frequent tool replacements. A few phases must be improved to prevent tool damage during the cutting process. First, the selection of the appropriate cutting tool is a critical stage in the machining process. The hardness of the cutting tool must be higher than the workpiece itself. Similar to reducing the cutting force effect, the feed rate and depth of cut also must be minimized. Tool temperature is, once again, one of the most critical contributors to the effect of tool breakage failure. As a consequence, a suitable MQL parameter must be used for the turning process. To fully use the lubricant's cooling qualities, the air pressure and flow rate employed throughout the operation must be increased. Smaller droplets with a high density are formed when high air pressure is combined with MQL's high viscosity. Because the droplet particles are smaller, they may reach the cutting zone more quickly, effectively decreasing the cutting tool temperature. When low air pressure is used, the MQL is more likely to condense before the process starts because to the high temperature in the contact zone. Thus, greater air pressure input reduces the possibility of droplets condensing in the environment by delivering MQL to the cutting zone faster [15]. Besides, coating layers on the cutting tool also has been widely used in the machining process whereas it will help enhance the cutting tool life. Coating will act as a protective layer for the tool and improves the machining performances. It has been proven that coating help in dissipating heat efficiently. Thus, it will help in reducing the thermal formation at the tool-workpiece interface.

Vibration is the next primary source of workpiece quality deterioration in terms of production value. It was discovered that during Kifli's testing in 2012, the tailstock did not lock securely. As a result, a complete workpiece setup must be done properly. The tailstock must be examined after the installation and before the turning process was done. For better tailstock grip performance, the lathe's centre point holes are free of chips. Moreover, the usage of tailstock/s centre also can be used to hold extra-long workpiece with small diameter. This will help to minimize the vibration of the workpiece during the turning process. Furthermore, owing to the loss of cutting tool sharpness caused by repetitive cutting, the lubrication supply must be increased. Cutting tool life may be enhanced by utilising the right MQL setting [6].

For tool wear potential effect, the preventive measure is quite similar to other tool failure effect such as tool breakage, cutting temperature and others. Similar to reducing the cutting temperature, optimized MQL delivery is required. For improved MQL delivery, a higher air bar pressure is required. Higher air bar pressure may decrease tool wear rate, according to Yassin and Teo (2014), as increased air pressure produces smaller particles, which enable them to reach the cutting zone more rapidly and offer more excellent cooling characteristics. Furthermore, the MQL flow rate may be raised since a greater flow rate improves heat dissipation efficiency owing to a more significant lubricant effect that reduces friction [15]. It was also observed that when the carbide coating tool undergoes plastic deformation, the wear rate quickly rises. A multilayer coating is preferable to a single coating layer in tool life to address this issue. An increase in coating thickness may enhance tool life, according to Abdoos et al. in 2019 [19]. Furthermore, selecting the suitable coating for the cutting tool will minimize tool wear. The lengthy chip may be prevented by utilizing coolant during the creation of a continuous chip. When heated chips are exposed to coolant or air, the chips are quenched, making them hard and brittle and easier to break down. Furthermore, the chip breaker application may aid in the avoidance of continual chips. Chip breakers come in a variety of shapes and sizes, including step, groove, and clamp. This continuous chip issue must be avoided because the lengthy and tangled chip causes pain to the operator and has sharp edges that may harm the workpiece surface.

4. Conclusion and Recommendation

4.1 Conclusion

In a nutshell, the first goal of this research, which was to develop a process failure mode and effect analysis (P-FMEA) for the turning process, was met. The turning process has been identified, as well as potential failure mechanisms. The failures with the highest risk priority number were chosen from the analysis findings. In addition, the second goal, which is to develop a preventive strategy and a research plan, has been completed. The causes of each failure effect were discovered through this research, and a preventative system was created as a result. As a result, this study may be used to help avoid turning process failure by planning a preventive step before the process begins.

Last but not least, the study's goal had been achieved. The optimized parameter may extend the tool wear and life thanks to the preventive technique that was devised. Furthermore, prevention is the most effective way of lowering quality expenses. The critical failure effect was observed to grow in tool wear temperature and rate with a score of 240. This failure impact is due to the fact that when the cutting temperature rises, the tool wear rate increases. Furthermore, friction at the cutting zone contact caused both failure outcomes. The optimum MQL value, according to the research, is crucial in managing the cutting tool temperature.

i. In terms of air pressure input, it was clear that 5 bars were insufficient to effectively feed the coolant. As a result, a higher air bar of 7 is required to meet the MQL standard. Higher air pressure combined with a high MQL viscosity will result in tiny, dense particles. The heat will be trapped in the droplets, which will then wash away at a faster rate.
ii. Furthermore, MQL offers greater lubricating capabilities due to its high viscosity. Palm oil has been shown to have excellent lubricating properties. Palm oil's high lubricating characteristics make it ideal for lowering cutting tool temperatures by minimizing friction between the cutting tool and the workpiece. As a result, the workpiece's quality and the manufacturing process may be enhanced.
iii. Additionally, nozzle distance and angle have a considerable impact on tool wear and temperature. The nozzle distance from the cutting zone should not be too big or narrow, since this would limit the efficiency of the MQL lubricant or coolant qualities. The nozzle angle that was suggested was 20°.

iv. Furthermore, a lack of lubrication has affected product performance and quality, resulting in inaccurate dimensioning and a poor surface finish. As a result, the MQL flow rate must be raised. However, if the flow rate is too high, extra MQL will be squandered, causing the machining zone to become clogged.

Other issues, such as vibration, must also be addressed since the product's quality may be adversely impacted. The operator must secure and adequately attach the workpiece during the installation process. When a loose workpiece is thrown out of the chuck, it may cause vibration and harm to the machine and the operator. The tool breakage impact has the lowest RPN value, according to the FMEA study of the turning process. The detection and occurrence rating is low despite the high severity rating since the failure is simple to identify and does not occur during the turning process. Most of the problems were categorized into various levels using the FMEA risk matrix. The high risk is indicated by red, medium risk by yellow, and low risk by green. Green color risk is occasionally acceptable because it has a low severity rating or a low occurrence rating, as the risk does not occur more than once throughout the procedure, like the tool breakage effect. Implementing a threshold inside the FMEA process, on the other hand, is not advised since every failure must be prevented due to there is a chance that additional issues may arise.

4.2 Recommendations

From the research study, a few improvements can be made to improve the quality of the process.

i. For the ease of tool breakage detection method, a tool breakage sensor can be used. For example, a pneumatic pressure sensor can detect chipped or broken drills and taps in the machining process. This is to prevent the tool breakage from happening where it could lead to machine breakdown at its worst.
ii. Nozzle parameters also must be optimized for better MQL supply. A better position, angle, diameter, and nozzle distance must be appropriately selected for efficient MQL cooling and lubricant properties.

Action must be taken based on the prevention method listed. A re-evaluation of the severity, occurrence, and detection value can be improved, and the RPN value can be reduced. The latest and previous RPN values can be compared. In terms of detection value, the detection rating can be improved by using more advanced equipment to ease detection for the failure effect.

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