Cycle Time Improvement by Lean Six Sigma for the Cutting Tool Production Line

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ABSTRACT

A cutting tool manufacturing company in Malaysia is facing challenges in fulfilling demand of cutting tool throughout the distribution line. With the rising orders from different countries, the cutting tool manufacturer is trying to improve their production line by reducing cycle time without high value expenditure. This research paper presents an implementation of Lean Six Sigma approach at a cutting tool manufacturing company in Malaysia. The main function of lean six sigma approach is for continuous improvement on the output quality, reducing defects, minimizing waste and minimizing cost in production. With the main objective of reducing cycle time at polishing section, a case study was conducted at the cutting tool manufacturing company in Klang, Selangor, Malaysia. The methodology used for this study is DMAIC which refers to Define, Measure, Analyze, Improve and Control. With the approach of DMAIC, the Polishing section has undergone the cycle time improvement for higher yield in production. Results shows that, with proper implementation, Lean Six Sigma could help in cycle time improvement and problem identification. This research may also help in further development towards the cycle time improvement system for machining oriented manufacturing companies.

Keywords: Lean Six Sigma, DMAIC, Polishing, Drag Finishing

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1.0 Introduction

The current development of manufacturing trend in Malaysia shows that cutting tool industry are experiencing rapid development driven by market demands worldwide. With the high demand across the Asia region, Malaysian cutting tool manufacturer needs to evolve and improvise their production system for better stage of providing the increasing demand [1,2,3].

The increase in demand also struck the ABC cutting tool manufacturer in Malaysia. The new profound opportunity need to be taken but without the proper production line, the company could not attend to the new demand. The management are trying to improvise their production line by implementing Lean Manufacturing into the company [1]. With the previous study done by the management, it is shown that the Polishing Department hold high amount of delay in their process. In order to further improvise the Polishing section, the Lean Six Sigma approach has been selected. The management also seeks to reduce the cycle time of the Polishing section without increasing the cost required.

Lean Six Sigma (LSS) is a team based approach to identify and eliminate waste and complexity in process. It is a management philosophy that focus on a fact-based [4], data-driven philosophy of improvement that values defect prevention over defect detection. It drives customer satisfaction and bottom-line results by reducing variation, waste, and cycle time, while promoting the use of work standardization and flow[5,6], thereby creating a competitive advantage. It applies anywhere variation and waste exist, and every employee should be involved. The Lean Six Sigma have become one of the main continuous improvement tools throughout the manufacturing industry.

This research utilizes the case-based approach to demonstrate the LSS implementation in one of the cutting tool manufacturer in Malaysia. The study was conducted at a real production line at ABC Cutting Tool Manufacturer Sdn Bhd. The ABC management selected the Polishing Section as the area of study. The polishing section uses the drag finishing technology as their polishing method for cutting tool. Currently, the production is practicing Lean Production System where the workers perform their task by following Standard Operating Procedure (SOP) and applying 5S into the area similar like the first phase of companies that practices Malaysia Automotive Lean Production System and gain positive benefits financially and non-financially [1]. Thus, the objectives of this study are summarized as follows:

1) To reduce the cycle time at the Polishing section, 2) To demonstrate the systematic techniques of LSS implementation at the Polishing Section, 3) To create a new cycle time on the PD2i Pardus Drag Finishing Machine and finally 4) To compare the new cycle time with the current cycle time.

2.0 Literature Review

Lean Six Sigma

Lean Manufacturing and Six Sigma have been one of the continuous improvement tools that manufacturers have been using for over 20 years [3,8,9,10]. The lean manufacturing ideology emphasizes that the main "thrust" is by having all of the tools working together to create a streamlined, high quality system that produces products at the demand of the customer with little or no waste. Whereas Six Sigma's foundation is in statistical analysis and within Six Sigma, the common measurement index is defects per million opportunities which could include anything from a component, piece of material, or an administrative form [7].
According to Stephen [11], a pure six sigma approach lacks three desirable lean characteristics:

1. No direct focus on improving the speed of a process.
2. No direct attention to reduction in the amount of inventory investment.
3. No quick financial gains due to the time required to learn and apply its methods and tools for data collection and analysis.

The shortcomings of a pure lean improvement effort were also stated which are:

1. Processes are not brought under statistical control.
2. There is no focus on evaluating variations in measurement systems used for decisions.
3. No process improvement practices link quality and advanced mathematical tools to diagnose process problems that remain once the obvious waste has been removed.

In order to improve the systematic approach, Lean Six Sigma is produced. Lean Six Sigma (LSS) is a methodology that is established through the integration of lean manufacturing and six sigma. Lean Six Sigma strives to reduce waste and complexity internally, while externally deliver the product to the customer at the appropriate quality level and speed which are specified by the market demands [7]. It focuses on the approach of improving quality, increasing productivity, eliminating waste and reducing cost in any organization [12,20]. The LSS incorporate the best techniques, principles and methodologies from both lean manufacturing and six sigma. Research has stated that publication towards Lean Six Sigma continuously increase since 2011 because of the successful stories of world top performing organization using LSS [7].

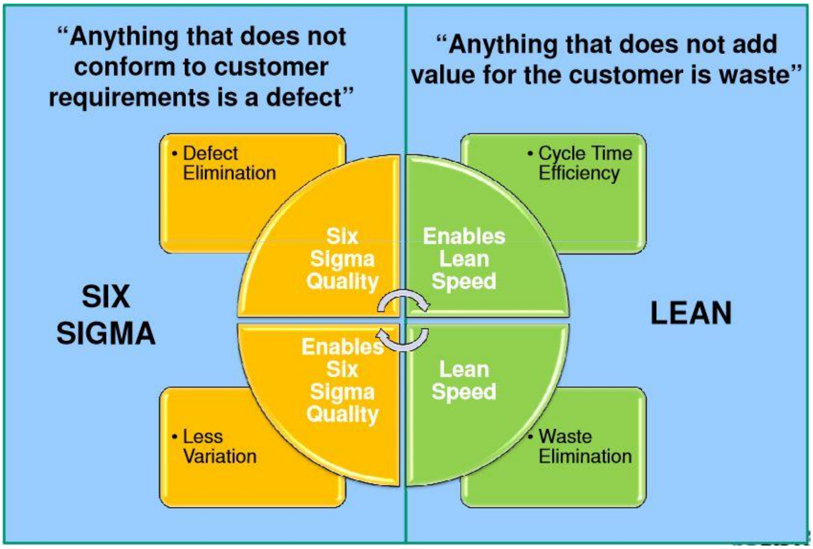


Figure 1: Lean Six Sigma Integration [22]

There are several studies done by researchers towards the LSS system. Qun Zhang stated that out of 116 LSS research publication, 66 (53%) papers are case study based while 50 (47%) papers are theory based. Qun Zhang also provide the research area of LSS papers which mostly focuses on Process Improvement [7]. The process improvement is valuable to the manufacturing industry because it helps in reducing cost and maximizing profit.

The implementation of LSS is always done by using DMAIC which is the abbreviation for Define, Measure, Analyse, Improve and Control [12]. The DMAIC process are integrated from the Six Sigma methodology. This process is done to visualize the conceptual model which enable process improvement as well as retain its performance [11].

The DMAIC method have also shown its success in cycle time improvement. A case study by M.White in a finance group shows that DMAIC is applicable in reduction of cycle time. He stated that the analysis perform by the management team reduce the cycle time for acquiring new credit account from 49 days to 30 days which resulted an annual saving of 300 000 dollars [13]. The results motivates this case study to apply the DMAIC method for cycle time reduction.

The main tools used in developing the LSS and their description of their function are as follows:

1. Cause and Effect Diagram: It is used to identify all the possible causes of a problem and seek to locate the root of the problem from a systemic perspective [14].
2. XY Matrix: It is used to illustrate the correlation of process input to customer output. It also helps in determining the primary factors for Design on Experiment (DOE)
3. Failure Mode and Effect Analysis (FMEA): It is used to identify and fully understand potential failure modes and their causes, and the effects of failure on the system, for a given process [15].

Each of the tools used to record and visualize the system. Even with different functions, the main objective is the same which is to identify the main problem to be tackled.

Drag Finishing

Drag Finishing is a polishing system the ABC Cutting Tool Manufacturer use currently. It is a versatile machining process that is used to improve the surface topology of workpieces [16]. The workpiece are moved in a bulk of abrasives called media. With the relative motion of workpiece and media, material of the workpiece is removed. In contrast to other mass finishing processes, like vibratory or centrifugal disc finishing, workpieces are fixed by a clamping device and media is not agitated in drag finishing. The use of drag finishing has been increasingly widen towards the cutting tool manufacturing process. The mass finishing process enable the manufacturer to reduce their production time and enhance the quality of their workpiece. The process stand out above other type of finishing process because it works faster than the vibratory system due to its high speed and pressure. It also provide no part to part contact because the parts are individual mounted on its own clamping setup. As manual deburring are physically demanding and require great operator skills, the drag finishing can replace the manual labor with a much better precision and repeatability.

The drag finishing system require mass media for the polishing process. It is crucial to understand the effect of different type of media and what its application are for. With different material composition in the media, the polishing effect on the workpiece are also different.

3.0 Research Methodology

For the purpose of this research, the DMAIC methodology has been used. The flowchart as in figure 3.1 shows the process flow of this research.

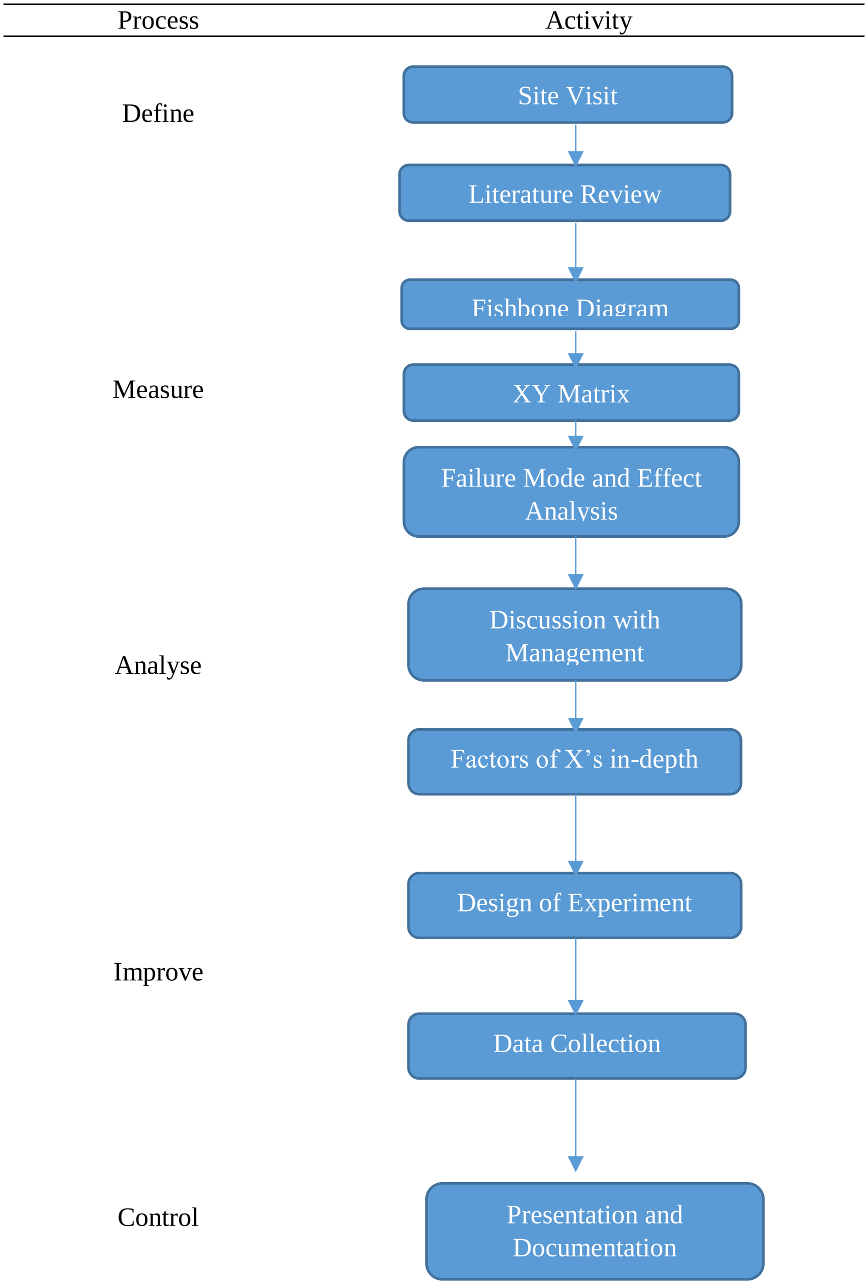


Figure 2: DMAIC Methodology

3.1 Define

The cutting tool manufacturing company where this project was applied operates in the Klang Valley area. The main activity of this company are producing high precision solid carbide tool for distribution in 35 different countries from Western Europe, Scandinavia, Asia, South America and Australia. The company main problem is the increasing amount of orders for the cutting tools. With the current production line, it would be difficult to fulfil the high demand of the cutting tool. The company provide the area of study within the polishing department where high product delay located within the polishing process which disrupt the production flow of the cutting tool. So, the main objective of this study is to reduce the cycle time at the polishing section.

3.2 Measure

In order to find the main problem related to the cycle time of the polishing section, a cause and effect diagram is developed as in figure 3.2. The analysis shows several problem affecting the long cycle time.

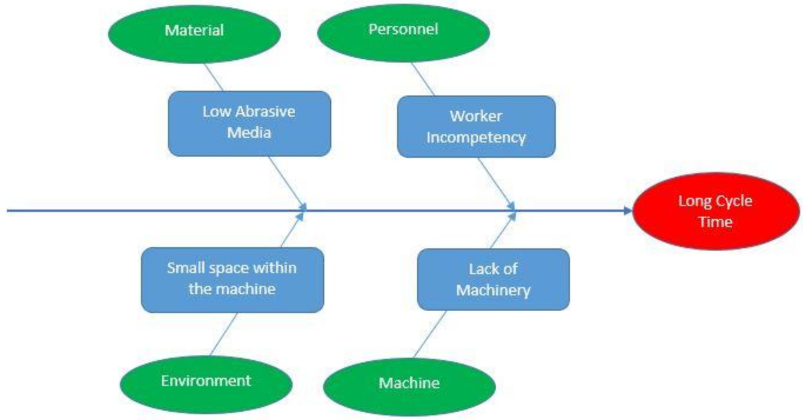


Figure 3: Fishbone Diagram

By using the problem listed in the cause and effect diagram, an XY matrix has been made to prioritize the potential X that greatly affect the polishing section cycle time. Table 3.1 below illustrate the process of XY matrix.

Table 1: XY Matrix

Y		Long Cycle Time	Low Volume Production	Production Delay	Total
X	Y Weightage	10	8	5	
Lack of Machines		9	8	5	22
Worker Incompetency		6	5	3	14
Low Abrasive Media		8	7	5	20
Small space in Machine		2	2	2	6

Based on the XY matrix, the high rate of severity goes towards the lack of machinery and low abrasive media.
A failure mode and effect analysis (FMEA) was also done focusing on the effect of long cycle time. For better understanding, the severity, occurrence and detection are defined as in table 3.3. By using these criteria, a FMEA table was constructed as in table 3.2. This table shows the potential failure modes, potential failure effects, potential failure causes and the current process control that was used.

Table 2: Failure Mode and Effect Analysis

No	Process Step	Potential Failure Mode	Potential Failure Effect	SEV	Potential Cause	OCC	Current Process Control	DET	RPN
1	Take tools from tray	Tool Drop	Damaged tool, Increase cycle time	7	Worker Incompetency	2	Use Pallet	1	14
2	Put tools into machine	Tool Drop	Damaged tool, Increase cycle time	7	Small Space in Machine	2	Placed SOP	1	14
3	Set Program to the machine	Wrong Program	Higher cycle time	7	Worker Incompetency	2	Placed SOP	5	70
4	Take tools out of the machine	Tool Drop	Damaged tool, Increase cycle time	7	Small Space in Machine	2	Placed SOP	1	14
5	Clean tools	Tool Drop	Damaged tool, Increase cycle time	7	Worker Incompetency	2	Use Pallet	1	14

Table 3: Definition on severity, occurrence, detection and Risk Priority Number

No	Criteria	Definition
1	Severity	Severity of impact of failure event. It is scored on a scale of 1 to 10. A high score is assigned to high impact events and vice versa.
2	Occurrence	Frequency of occurrence of failure event. It is scored on a scale of 1 to 10. A high score is assigned to frequently occurring events and vice versa.
3	Detection	Ability of process control to detect the occurrence of failure events. It is scored on a scale of 1 to 10. A failure event that can be easily detected by the process control is assigned to low score and vice versa.
4	Risk Priority Number	The overall risk score of an event. It is calculated by multiplying the scores for severity, occurrence and detection.

According to the FMEA result, the high risk problems goes towards worker incompetency and small space.

After the measurement phase, the primary Y has been selected as cycle time. With the analysis of fish bone diagram, XY matrix and FMEA, a table of X's have been constructed as in table 3.4.

Table 4: Table of X's

X	Fish Bone	XY Matrix Rank	FMEA Rank	New Variable
Lack of Machinery	Yes	1	-	X1
Low Abrasive Media	Yes	2	-	X2
Worker Incompetency	Yes	3	1	X3
Small Space inside Machine	Yes	4	2	X4

3.3 Analyze

Each of the X's were being follow up towards the company management. The explanation towards the follow up are as follows.

X1 Lack of machinery

The Polishing department have 3 drag finishing machine that could cater to standard size cutting tool and 2 polishing machine for micro tools. Since the order on standard size cutting tool increased, the number of drag finishing machine for standard tool needs to be increased. With the high price of the machine, the management has decided not to buy another machine because of the inconsistency of the ordering pattern. The ordering data for cutting tool could be seen in figure 3.3 in monthly basis.

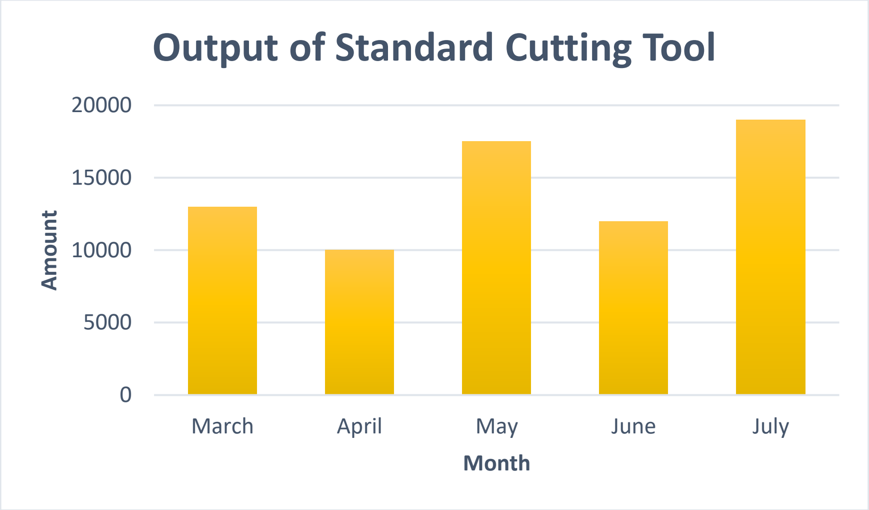


Figure 4: Total order output from March to July

X2 Low abrasive Media

The Polishing department uses H media which is made of walnut granulate. The media affect the speed of polishing by their abrasiveness. According to the cycle timetable from ABC Cutting Tool Manufacturing Sdn Bhd, the H media require an average of 7 minutes to complete 1 cycle of polishing. The company management has decided to change the media with a higher rate of abrasiveness called the T media. The difference between both H and T media could be seen in the table 3.5. Analysis on the new media could be seen in the "Improve section" of the methodology.

Table 5: Difference between H and T Media [10]

H Media	Type	T Media
	Picture (Zoomed In)	
Smooth surface finish	Surface Finish	Rough surface finish
Low abrasiveness	Abrasiveness	High abrasiveness
0.8 – 1.3 mm	Grain Size	1.5 – 2 mm
Walnut granulate with polishing paste	Material	Polyethane with SiC added as an abrasive

X3 Worker Incompetency
There was no direct data that could relate the increase of cycle time with the incompetency of worker. The company management has provided several training such as 6S Induction Safety training and on the job training. Without related data, the management decided to focus on the media change only.

X4 Small Space inside the machine
The same goes toward the small space issue. There is no data that could define how many seconds the cycle time increase at the polishing section due to the small space issue. Since the area inside the machines are fixed from the manufacturer, the only improvement could be done is increase the safety awareness.

3.4 Improve

At this stage, a design of experiment has been made where the T media test was done to reduce the cycle time for polishing department. The details for this experiment are as follow.

3.4.1 Experiment Setup

All the drag finishing test were carried out in the Pd2i Pardus Drag Finishing machine with a standard of 35 rpm table speed and 85 rpm head speed. The workpiece are dipped into the media at the depth of 30 mm and the rotation of the machine were set to clockwise direction. The tests were done at such constant conditions as to avoid any external factors that may affect the polishing rate on the workpiece. After performing several tests using the H media, the measurement of polishing rate could be determined at the end cutting edge and peripheral edge radius. It is noteworthy to remember the purpose of this study is to determine the new cycle time for using the new media and observation towards the polishing effect done by the new media. Thus, several workpiece were tested at different time for better observation on the polishing effect. The workpiece was mounted on the machine-table via rigid clamping accessories to counter the vibration effect. The testing setup were shown as in Figure 3.4.

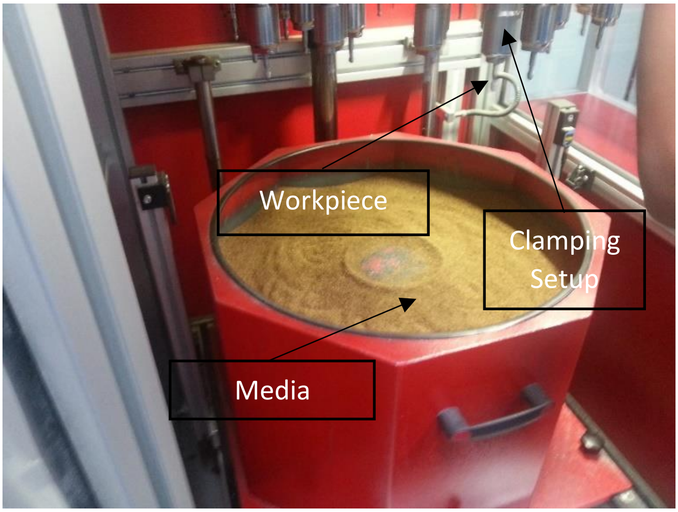


Figure 5: Testing Setup in PD2i Pardus Drag Finishing

3.4.2 Workpiece Material

In this study, the workpiece used is standard 4 flute square end mill with the diameter of 10 mm and 12 mm as in figure 3.5. Each of the workpiece has a standard total length of 72 mm. These workpiece are made of tungsten carbide as the main material for the end mill. The material are being prepared in the CNC grinding machine to form the shape of square end mill. The important mechanical properties of tungsten carbide are listed in the table 3.6 below.

Figure 6: 4 Flute Square end mill

Table 6: Properties of Tungsten Carbide [23]

Properties	Value
Melting Temperature	2785 °C
Boiling Temperature	6000 °C
Ultimate Tensile Strength	344 MPa
Young Modulus	530 – 700 GPa
Poisson Ratio	0.31

3.4.3 Data Collection Plan

The data collection plan was developed following the standard polishing steps by using different type of media and time. A check sheet was created for the purpose of this study as in figure 3.6. The data collection could be done by using the measurement technique as follows:

1. Cutting Edge Radius
   The rounding of cutting edge were measured by using the Zoller PomSkpGo microscopic workstation with a built-in camera and an integrated desktop PC, installed with commercial digital imaging software called 'POM-Tool 1.14'. Photographs of end cutting edge and peripheral cutting edge were taken and analysed in the POM-Tool software giving the exact radius of the cutting edge. The results of the reading could be seen as in figure 3.7. Each reading were repeated 3 to 5 times and the average was calculated to ensure the

precision and repeatability. This average value was compared with other readings to create a graph for the T media behaviour.

Sample Time			

Before		After	
Radius	Standard Deviation	Radius	Standard Deviation

Sample Time			

Before		After	
Radius	Standard Deviation	Radius	Standard Deviation

Figure 7: Check sheet for data collection

Figure 8: POM-Tool 1.14 Software

2. Visual Comparison
   The edge rounding photographs were taken by using Dinolite microscopic workstation with high definition images as in figure 3.8.

The photographs were taken at the end face surface of the end mill. This images were taken only for observation purpose of this study where the effect of polishing done by the media towards the end mill.

Figure 9: Dinolite Microscopic Workstation

3.5 Control

In this phase, all the process and data are being documented and presented towards the company management. A meeting was held where the presentation on the results of the study was done. All the reports and raw data was given to the company for further implementation.

4.0 Result and Discussion

4.1 Cutting Edge Radius

The reading obtained from the Zoller PomSkpGo were charted into statistical control chart as in figure 10 and 11.

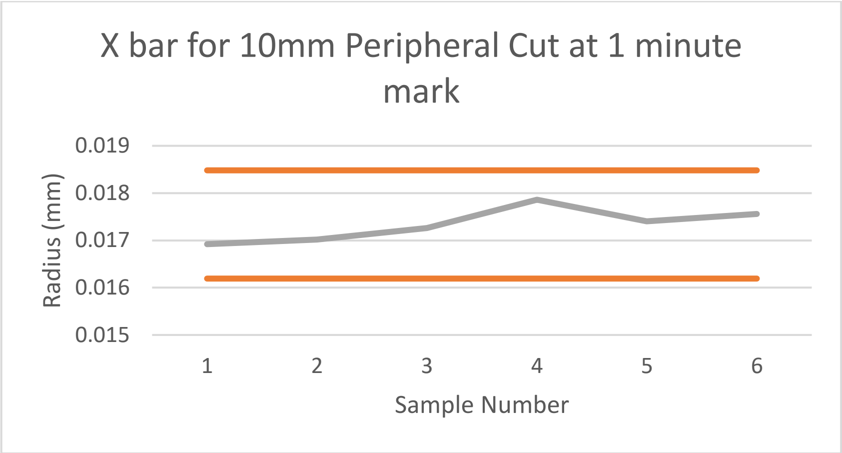


Figure 10: X Bar 10mm End Mill at 1 minute

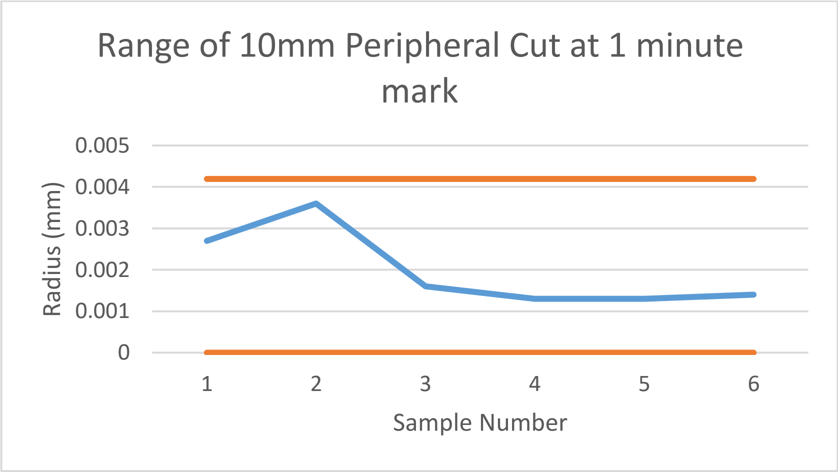


Figure 11: R Chart 10mm End Mill

The same procedure were applied to the 12mm end mill as in Figure 12 and 13.

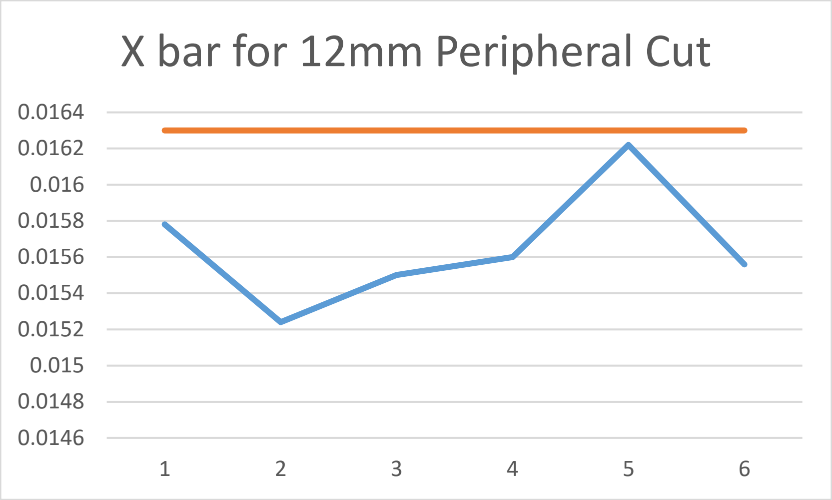


Figure 12: X Bar 12mm End Mill at 2 minutes

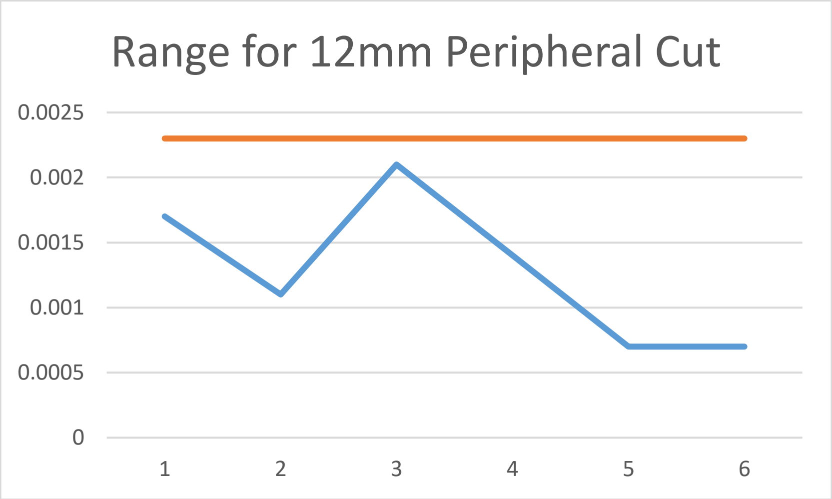


Figure 13: R Chart 12mm End Mill

The results has showed the performance of T Media is far more aggresive than H Media as the end mill could achieve its desired cutting edge rounding at an approximately 84 percent less time required for polishing. With the range chart showing the polishing effect is still below the upper limit of range, it shows that the T media is usable for the production. From the 10 mm diameter of end mill, the standard cutting edge rounding produced by the

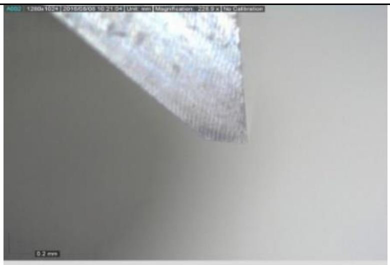
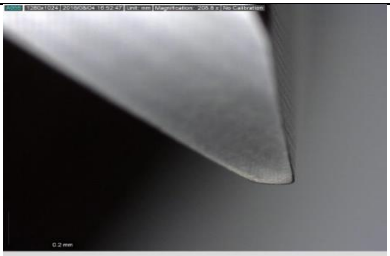
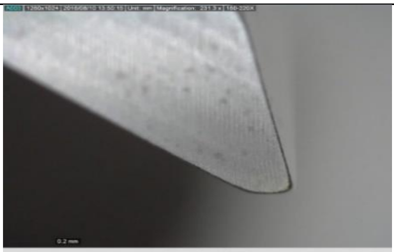
H media is at 0.017 mm with 6 minutes cycle time. As for T Media, the cutting edge rounding of 0.017 mm could be achieved at 1 minute mark. The 12 mm diameter end mill shows the H media achieved the 0.0155 mm rounding at 8 minutes whereas T media could achieve the same result at 3 minutes mark.

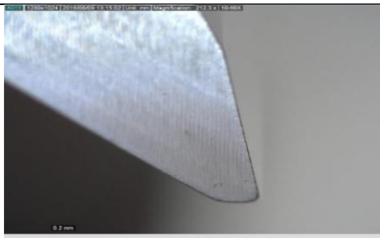
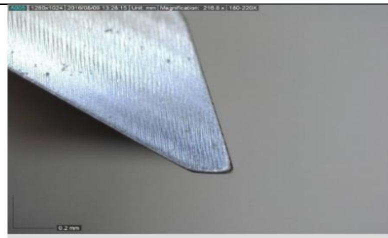
The effect of T media may come from the material itself. The polyethene granulate with SiC abrasive shows a higher abrasiveness in comparison to normal walnut granulate. The results also shows that the bigger size granulate of T media perform well in term of polishing speed for the cutting tools. With bigger granulate size, more surface area of the endmill could be covered and less time is required to achieve the desired effect.

4.2 Visual Comparison

The effect of T Media onto the 10mm endmill could be seen in the table 4.1 below. The images are taken at the corner edge of the endmill.

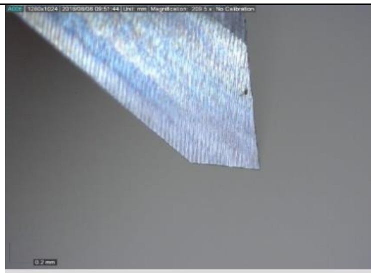
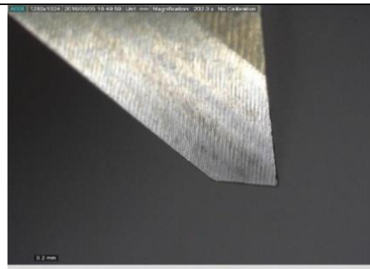
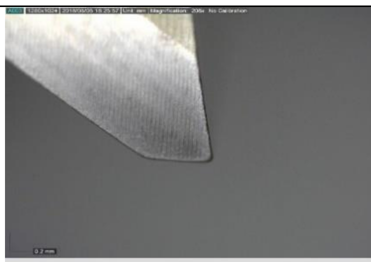
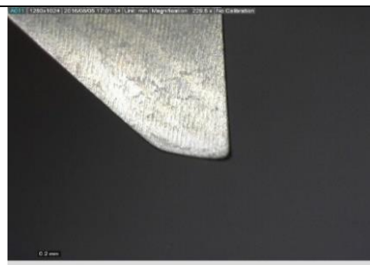
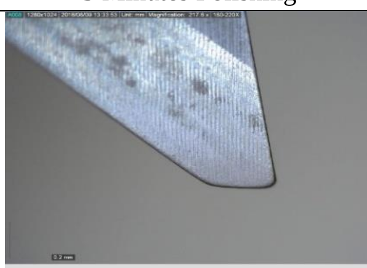
Table 7: Visual effect of T media on 10mm endmill

 Initial	 1 Minute
 3 Minutes	 5 Minutes

 6 Minutes	 8 Minutes

The effect of T Media onto the 12mm endmill could be seen in the table 4.2 below.

Table 8: Visual effect of T media on 12mm endmill

 Initial	 1 Minute Polishing
 3 Minutes Polishing	 5 Minutes Polishing
 6 Minutes Polishing	 8 Minutes Polishing

4.3 Cycle Time Reduction

From the results taken from Zoller PomSkpGo, the new cycle time could be determined by comparing the desired radius into T media. Both figure 4.5 and 4.6 show the new cycle time for the PD2i Pardus drag finishing machine.

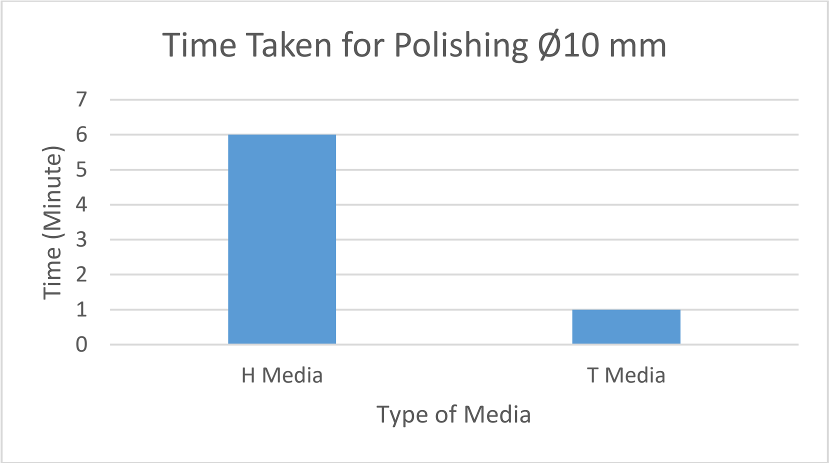


Figure 14: Graph of Media type versus Polishing Time for 10mm Endmill

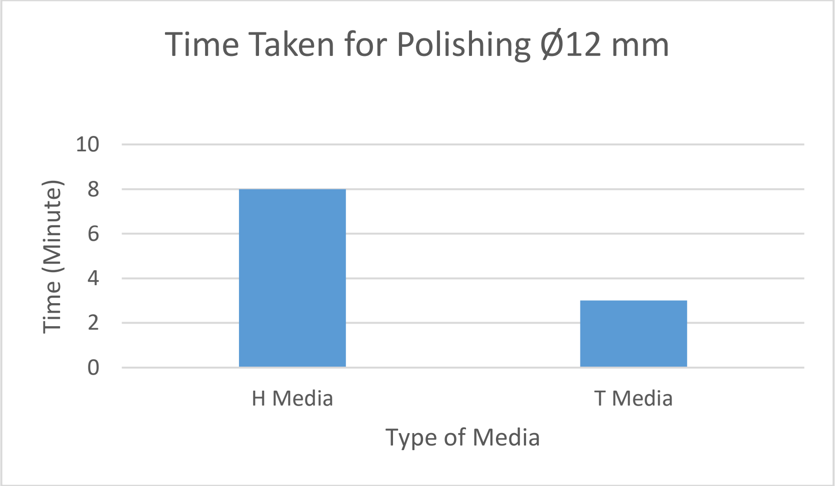


Figure 15: Graph of Media type versus Polishing Time for 12mm Endmill

According to the figures above, both cycle time for 10 mm and 12 mm have been reduced drastically compared to the old cycle timetable. The new cycle time for 10 mm is 1 minute compared to 6 minutes for old cycle time. The cycle time for 12 mm also reduced to 3 minutes from 8 minutes. The reduction of cycle time are achievable due to the media change where higher level of abrasiveness improve the rate of polishing.

5.0 Conclusion

In conclusion, the Lean Six Sigma (LSS) approach by using the DMAIC methodology provide success in improving the cycle time at polishing section. The identification of low abrasive media leads to the management decision on media change. The T media could replace the old H media for drag finishing process due to its higher abrasiveness. With higher abrasiveness, the desired effect of polishing onto the endmill could be achieved with lesser time. This could speed up the process of endmill production in cutting tool company. With lesser time required for polishing, more output could be attain by the company which leads to higher profit. The higher output leads to solvable high demand of cutting tool. With the development of new cycle time, the final objective is achieved.

As for recommendation, the T media polished end mill could be tested with standard milling test in order to make comparison in term of performance with the current standard H media polished endmill. This test could justify whether the T media is better than H media for the cutting tool production.

6.0 Acknowledgement

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