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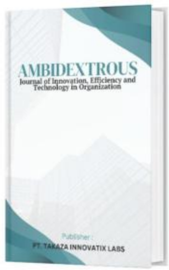

Optimization of Cutting Tool Life of Tensile Test Specimens Through Kaizen Application of Milling Jig Height Redesign

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Abstract: *Cutting tool utilization in CNC milling processes is often inefficient when tool wear is concentrated on a limited section of the cutting edge while other sections remain usable. This condition may increase tool consumption, tool replacement frequency, production downtime, and machining costs. This study aims to optimize cutting tool life in the production of tensile test specimens through the application of Kaizen by redesigning the height configuration of a milling jig without modifying the existing CNC program. A descriptive qualitative approach was employed using the Plan-Do-Check-Act (PDCA) cycle. Data were collected through direct observation, documentation of tool wear and machining results, jig dimension measurements, trial runs, and tool usage records. The improvement was implemented by changing the jig configuration from a 20 mm lower jig and 20 mm upper jig to a 60 mm lower jig and 10 mm upper jig, thereby shifting the workpiece position toward a less-worn section of the cutting edge. The results indicate that the jig modification increased cutting tool life by approximately 50% and reduced the consumption of new cutting tools by approximately 50%, while maintaining the dimensional quality and surface condition of the tensile test specimens. The improvement demonstrates that a simple and low-cost Kaizen intervention can optimize cutting tool utilization, reduce process waste, and improve machining efficiency without requiring changes to the CNC program. This finding provides a practical approach for continuous improvement in machining operations, particularly in small-scale manufacturing and laboratory-based production processes.*

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Introduction

The manufacturing industry currently faces increasing demands to improve production process efficiency, maintain product quality, and reduce operational costs to compete in the global market. One cost component that continues to be a concern is the use of cutting tools in CNC milling processes because tool wear directly affects surface quality, dimensional accuracy, production downtime, and cutting tool replacement costs. Various studies have shown that machining process optimization is determined not only by cutting parameters but also by cutting tool utilization strategies and continuous improvement of production systems so that tool life can be increased without sacrificing machining quality (Jia et al., 2022; Asadzadeh et al., 2022). On the other hand, the Kaizen philosophy has become a widely applied approach in industry because it can eliminate waste through small improvements carried out systematically and continuously (Sundararajan & Terkar, 2022).

In manufacturing practice, Kaizen implementation focuses not only on increasing productivity but also on optimizing the use of production resources through simple engineering improvements that significantly impact operational efficiency. This approach aligns with the concept of continuous improvement, which emphasizes the elimination of non-value-added activities (waste), including waste resulting from replacing cutting tools that still have usable cutting edges. Therefore, integrating improvements in work methods, jig and fixture design, and maximizing cutting tool capacity utilization is a relevant strategy for increasing milling process productivity while reducing production costs (Sundararajan & Terkar, 2022; Meher et al., 2022).

Problems encountered during the tensile test specimen manufacturing process in the materials testing laboratory indicated that the specimen height was only 15 mm, while the effective length of the available CNC milling blade was approximately 80 mm from the zero Z-offset point. This condition resulted in the cutting process utilizing only the lower edge of the cutting tool, while most of the other cutting edges remained sharp and unused. As a result, wear occurred locally at the tool tip, requiring the operator to replace the tool with a new one to maintain the product's dimensional quality even though more than three-quarters of the blade length was still usable. This condition constitutes a form of waste that increases consumable costs, increases downtime, and reduces manufacturing process efficiency (Asadzadeh et al., 2022; Jia et al., 2022).

Various studies on milling process optimization have focused primarily on adjusting cutting parameters such as cutting speed, feed rate, depth of cut, cooling systems, and the implementation of sensor- and artificial intelligence-based tool wear monitoring systems. These approaches have proven effective in increasing cutting tool life, but generally require changes to machine parameters, investment in additional equipment, or the development of relatively complex control systems. In contrast, studies on optimizing cutting tool life through simple mechanical modifications to jigs or fixtures without changing CNC programs are still relatively limited, making them an important research opportunity for development, particularly in the tensile test specimen manufacturing process (Asadzadeh et al., 2022; O'Toole & Fang, 2023).

Based on these problems, this study aims to optimize the service life of cutting tools through the application of Kaizen by redesigning the height of the milling jig so that the cutting area can be shifted to the part of the blade that is still sharp without changing the existing CNC program. This research is urgent because it offers a practical, low-cost, easily replicated solution, and is able to reduce consumable tool waste, reduce operational costs, reduce tool change times, and maintain the quality of machining results. The novelty of this research lies in the application of the Kaizen philosophy through simple engineering in the form of changing the height configuration of the milling jig as a method to utilize the entire effective length of the cutting tool, in contrast to previous studies that focused more on optimizing cutting parameters and digital technology-based cutting tool wear monitoring systems (Sundararajan & Terkar, 2022; Jia et al., 2022; Asadzadeh et al., 2022).

Research methods

This study uses a descriptive qualitative approach with the Kaizen method implemented through the Plan-Do-Check-Act (PDCA) cycle as the primary approach in improving the production process. The qualitative approach was chosen because the research is oriented towards identifying the causes of waste, implementing corrective actions, and evaluating the results of improvements based on real-world conditions. Creswell and Creswell (2023) state that "qualitative research begins with assumptions and

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the use of interpretive frameworks that inform the study of research problems addressing the meaning individuals or groups ascribe to a social or human problem" (p. 41). Meanwhile, Sugiyono (2022) explains that qualitative research is used to examine natural objects, where the researcher acts as the primary instrument in obtaining data directly. In this study, the Kaizen philosophy is used as a continuous improvement approach to optimize cutting tool utilization by modifying the dimensions of the milling jig so that wasteful cutting tool use can be minimized (Imai, 1986; Sundararajan & Terkar, 2022).

The research instruments consisted of machining process observation sheets, documentation of cutting tool conditions before and after Kaizen implementation, jig milling dimension measuring tools, trial run results documentation, and tool usage records during the production process. Primary data were obtained through direct observation of milling activities, blade wear conditions, tensile test specimen dimensional quality, burr formation levels, and changes in cutting tool life. Secondary data were obtained from CNC milling machine operating standards documents, DMG Mori DuraVertical 5060 machine specifications, and literature related to Kaizen and machining process optimization. Emzir (2022) explained that qualitative data analysis is carried out through data reduction, data presentation, and conclusion drawing so that the information obtained can describe the phenomenon systematically. Therefore, the data analysis technique in this study was carried out descriptively by comparing process conditions before and after Kaizen implementation based on indicators of changes in cutting contact area, milling quality, burr formation, and increased cutting tool life (Groover, 2020; Jia et al., 2022).

The population in this study is all activities of the tensile test specimen manufacturing process using a CNC milling machine at the Material Testing Laboratory of Pelita Bangsa University. Considering that this research is a process improvement study, the sampling technique used purposive sampling, namely selecting the production process that experiences the most dominant cutting tool waste due to wear concentrated on the bottom of the blade. Sudaryono (2023) stated that purposive sampling is a sampling technique based on certain considerations according to the research objectives so that the selected samples are truly able to provide relevant information to the problems studied. The research sample is a milling process of tensile test specimens with a workpiece height of 15 mm using an initial configuration of a 20 mm lower jig and a 20 mm upper jig, then compared with the improved configuration of a 60 mm lower jig and a 10 mm upper jig to evaluate changes in cutting tool life and production process efficiency.

The research procedure was carried out following the Plan-Do-Check-Act (PDCA) cycle as the basic concept of Kaizen. The Plan stage was carried out by identifying wasteful use of cutting tools through observation of the milling process and analyzing the causes of wear that only occurs on the bottom of the blade. The Do stage was carried out by engineering the dimensions of the milling jig by increasing the height of the lower jig and adjusting the upper jig so that the workpiece position shifted to the area of the blade that was still sharp without changing the CNC program that had been used. The Check stage was carried out through trial running to evaluate the quality of the specimen dimensions, the condition of the cut surface, the level of burr formation, and increasing the service life of the cutting tool. Next, the Act stage was carried out by setting the improved jig configuration as a new work standard if all quality parameters showed results in accordance with specifications. According to Imai (1986), the PDCA cycle is the basis for implementing Kaizen which emphasizes continuous improvement through the processes of planning, implementation, evaluation, and standardization. With these stages, this research is expected to be able to produce increased efficiency in cutting tool usage, reduce consumable waste, and reduce operational costs of the milling process (Sundararajan & Terkar, 2022; Groover, 2020).

Results and Discussion

Before implementing Kaizen, the tools used consisted of:20 mm bottom jigAndtop jig measuring 20 mm.With this configuration, the cutting position of the 15 mm high tensile test specimen rests entirely on the lower edge of the blade. This results in a very short tool change cycle due to rapid local wear occurring in the lower area of the total blade length 80 mm from the zero Z-offset point.

The application of the Kaizen idea was carried out by re-engineering the dimensions of the tool. The arrangement was changed to**60 mm bottom jig**And**10 mm top jig**By raising the bottom of the jig from

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20 mm to 60 mm, the workpiece is lifted vertically. The technical logic of this improvement is considered very effective because:

1. **Program Efficiency:**Changing the cutting position does not require changing or modifying the main CNC G-code program. This minimizes the risk of operator program input errors because position adjustments are mechanically accommodated through physical changes to the jig.
2. **Maximum Utilization of Cutting Edge:**The blunt cutter section (bottom tip) is now outside the workpiece contact area, while the sharp cutter section (top/middle tip along the 80 mm capacity from the zero Z-offset point) advances as the new main cutting executor to cut the specimen to a height of 15 mm.

The following is a comparison table of the performance of the tool arrangement before and after the implementation of Kaizen:

Observation Parameters	Before Kaizen (Initial Condition)	After Kaizen (Jig Modification)
Bottom Jig Size	20 mm	60 mm
Top Jig Size	20 mm	10 mm
Maximum Specimen Height per Milling	15 mm	15 mm
Installed Blade Length Capacity	80 mm (from the zero Z-offset point)	80 mm (from the zero Z-offset point)
Blade Contact Area	Just rest on the bottom of the chisel	Moving on to the still sharp center section
Tool Life	Low	Increased by 50%
New Tool Consumption per Month	Tall	Experienced a decrease of 50%

Evaluation of the product quality showed that the workpiece dimensions remained within the permitted tolerances. Directly transferring the cutting area to the sharp cutter section also improved the workpiece surface roughness and minimized burrs caused by dull chisels.

Conclusion

The results of the study showed that the application of Kaizen through redesigning the height of the milling jig was able to optimize the service life of cutting tools in the process of making tensile test specimens without requiring changes to the CNC program. Modifying the jig configuration from a combination of 20 mm and 20 mm to 60 mm and 10 mm successfully shifted the cutting area from the bottom of the worn blade to the center where it was still sharp. This improvement increased the service life of the cutting tool by about 50 percent, reduced the consumption of new tools by 50 percent, and maintained the quality of the dimensions and surface of the machined results according to specifications. These findings prove that the Kaizen approach through simple mechanical engineering is able to reduce waste, increase the efficiency of resource use, and reduce the operational costs of the milling process without additional technology investment.

This study still has limitations because it was only conducted on one type of CNC milling machine, one type of cutting tool, and one workpiece characteristic so that the results cannot be generalized to the entire machining process. In addition, the evaluation of tool life improvement is still based on implementation observations without quantitative measurements of wear levels using special instruments. Future research is recommended to test this method on various types of materials, tool geometries, and different cutting parameters supported by economic analysis and quantitative wear measurements. Practically, the results of this study can be an alternative low-cost improvement for the manufacturing industry in optimizing cutting tool utilization, reducing the frequency of tool changes, increasing productivity, and strengthening the implementation of a culture of continuous improvement.

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