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Research Paper

“EVALUATION OF TOOL WEAR AND TOOL LIFE OF ADHESIVELY MOUNTED CUTTING TOOLS IN TURNING OPERATIONS”

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Abstract: Turning operations are influenced by tool wear and tool life, as well as manufacturing quality, productivity, dimensions and costs. Usually, in conventional cutting tools, mounting occurs in mechanical clamping systems which can generate local stresses, vibrations, assembly complexity and limitation of positioning the tool. Another alternative process is adhesive-based tool mounting where the cutting insert or tool is joined with the tool holder with a high-strength structural adhesive. The present work aims to investigate the wear behavior and useful tool life of the adhesive jointed cutting tools in turning along with an assessment of cutting data. The tool arrangement bonded is assessed under various cutting speeds, feed rates and depths of cut. Progressive flank wear, edge deterioration, and progressive changes at the cutting-edge as a function of machining is used to evaluate tool wear. The useful tool life is defined considering the allowable state of wear and satisfactory cutting ability for the specified tool life. The influence of machining parameters on wear progression and mechanical stability of the adhesive joint is also studied. The outcome will give an enhanced understanding of the feasibility of using a tool mounting with adhesives in conventional turning applications and machining conditions that can lead to controlled wear, stable operation and enhanced tool utilisation during these processes.

Keywords: Adhesive bonding, tool wear, tool life, turning, cutting tool, flank wear.

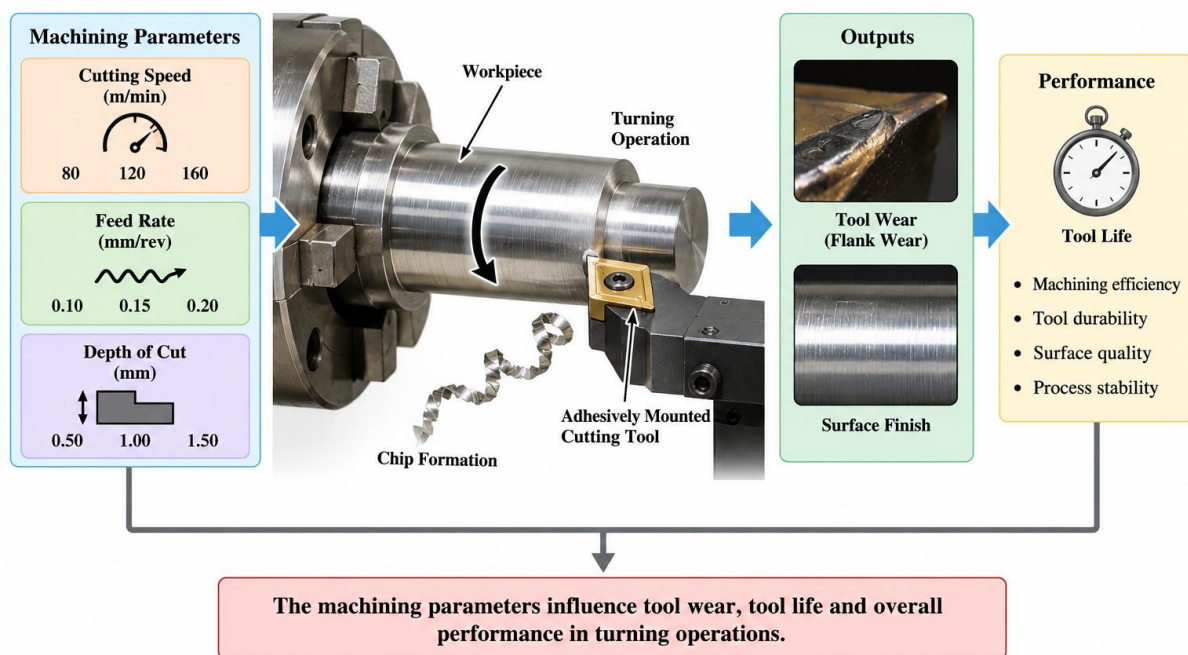
Introduction:

In manufacturing industries, the turning is one of widely used operations to manufacture cylindrical parts with the required dimensions and geometry and surface quality. The goal of turning is to continuously remove material from a rotating workpiece by the interaction between the workpiece and a stationary cutting tool. The speed of execution of this process is influenced by various factors such as cutting speed, cutting tool feed rate, depth of cut, materials of the cutting tool and the work material, cutting temperature, vibration and the type of tool holder.

Of these factors, tool wear is especially significant as it has a direct impact on the machining quality and its economic efficiency. During continuous process between cutting tool and the work piece, friction, heat generation, mechanical loading and material removal will occur at

the tool surface. As machining progresses, these effects will gradually alter the geometry and condition of the cutting edge. Excessive wearing can cause the workpiece surface texture to become dull and make dimensional errors, make for high cutting forces, unstable machining and will cause the cutting tool to fail.

The tool life is the time during which a cutting tool can be used satisfactorily and cut to a predetermined wear or failure limit. Goal of prolonging the life of tools in manufacturing is crucial for the benefits of lower machine downtime due to frequent tool changes, lower tooling expenses and production costs. Hence, it is vitally important to understand the nature of the wear behaviour and its affecting factors to come up with more reliable and cost effective machine system.



Traditional methods of attaching cutting inserts to the tool holder use screws, clamps, wedges or other mechanical means. These systems are generally accepted, but consist of a number of individual parts and can lead to high point loads in the tool-holder interface. The vibration and displacement of tools and non-uniform load transmission during machining also may be caused by incorrect clamping. This restriction has spurred investigation into other techniques for joining and supporting cutting tools.

The other method of attaching the cutting element to the tool holder is the adhesive bonding technique. Here, a proper adhesive bonds the tool to the holding surface of the tool in order to create the joint. Modern structural adhesives can effectively transfer mechanical load(s) across a relatively larger area of surface. As a result, adhesive mounting can / may decrease the need for mechanical fastening elements and the stresses over the bonded area can be relatively uniformly distributed.

But an added adhesive layer in a machining setup presents critical engineering issues, too. During turning, high temperatures and friction heat near the cutting zone, repeated mechanical loading, vibration and cutting forces act on the tool. These operating conditions

may affect the quality of an adhesive joint in terms of its strength and failure. The performance of the cutting tool bonded onto the substrate, therefore, must not only match the bond strength, but also follow the progressive wear of the cutting edge and the service life for satisfactory performance.

Flank wear, crater wear, edge chipping, abrasive wear, adhesive wear, diffusion wear and thermal damage are all potential forms of tool wear in the turning process. Of these, flank wear is often simply employed to determine the condition of the tools in practice because it occurs at the clearance face of the tool, close enough to its performance capability and dimensional accuracy. Generally, the more adverse the machining conditions, the faster the rate of flank wear will occur.

One parameter that is commonly found to be significant in Effect of Tool wear is cutting speed, which can increase as speed increases, hence increasing the temperature at the tool–workpiece interface. Feed rates determine the amount of chip load and cutting forces, and the depth of cut determines the amount of cutting edge involved with the work material. These parameters have a scattering influence on both wear behavior and mechanical loading behavior passing through the adhesive joint.

In the case of adhesively mounted tools, it is therefore a question whether the bonding can provide the required stiffness and positional stability of the tool during the useful life of the bit. For some machining applications, it may be practical to use adhesive mounting when the adhesive joint can hold up to the expected gradual and predictable wear of the cutting tool. However, a breakdown in the adhesion after use can mean much less use than intended for such an attachment, as can too much vibration, or a sudden change in the tool's position.

The main objective of the present research is hence the assessment of tool wear and tool life of adhesively mounted cutting tools in turning process. Turning experiments conducted with different cutting conditions can be used to witness wear and establish the life for the acceptable performance of the cutting tool. This investigation can be used to understand the influence of cutting parameters, stabilities of the adhesive mounted pieces, tool degradation and machining performance.

Review of Literature:

In the study of Arrazola et al. (2009), the different machinability characteristics of two titanium alloys, Ti6Al4V and Ti555.3, were studied and the difficulties of the material machining were discussed. The authors noted that the titanium alloys were not very easy to machine due to their thermal and mechanical properties. Their research indicated that there is close interaction among both material characteristics, cutting conditions, and tool behaviours, particularly if cutting forces such as tool deterioration are taken into account. It is useful work to consider the effect of workpiece material and machining parameters on the performance of the tools.

Wyen and Wegener (2010) studied the effects of cutting-edge radius on cutting forces while machining titanium. They found that the forces acting on the cutting tool can vary even if the cutting-edge geometry is changed slightly. The importance of selecting a proper cutting-edge geometry for stable cutting and tool wear progression has been emphasized as high cutting forces may lead to higher tool loading, which in turn can lead to tools wear.

Under the progressive wears and uncertainties of the machining conditions, Pal et al. (2011) investigated the cutting condition selection by considering tool wear monitoring. The study

clarified that in most cases, cutting tools do not break instantly when the machining, but there is a gradual change of their situation with the machining. The authors have emphasized the importance of observation of tool wear and found the right cutting conditions in order that the tool life may be extended and unexpected tool failure may be avoided.

Siddhpura & Paurobally (2013) gave a review of various methods to predict flank wear in turning operation. One of the most common and useful measures that they became aware of for judging the condition of a cutting tool was flank wear. They also found that accurate wear prediction allows to estimate remaining tool life and the time of the tool change, which were found to be important for their review. This is directly applicable to the studies in which flank wear is used as the tool-life criterion.

Bhuiyan et al. (2014) studied the determination of tool wear, surface roughness, formation of chips and used multiple sensors in the process of turning. Their studies revealed that tool wear is correlated to variations in surface quality and chip behavior. From this study, it is concluded that sensor-based monitoring can be beneficial in the diagnosis of tool condition during machining. This type of monitoring can aid in improved tool change decisions and process control.

Maia et al. (2015) investigated three wear mechanisms and determined tool life during turning processes using acoustic emission (AE) signals. The authors discovered that acoustic emission might offer valuable data regarding condition of cutting-edge during machining. They also aided in determining the point of excessive tool wear. The contribution of the study is the combination of tool-condition monitoring and real application of assessing tool life.

Zhao et al. (2017) actually studied the influence of the new cutting-edge radius on the surface roughness and the tool wear while hard turning the steel AISI 52100. The study demonstrated that the advanced geometry had a significant effect on the surface roughness and the wear performance. The authors found that, the selection of the cutting-edge radius is one of the key factors of achieving stable cutting performance and controlling cutting tool wear for the tool with high cutting-edge precision.

In this study, the tool life in turning operations was predicted by application of neural networks and image-processing methods, as proposed by Mikołajczyk et al. (2018). Their studies revealed that such phenomena as the modern computational methods exist and can be used to identify the wear pattern and estimate the life of a cutting tool. It illustrated the possibilities of using intelligent monitoring systems to minimise the risk of inferior tool failure and increase machining reliability.

Uysal et al. (2019) studied turning performance of bonded cutting tools, using epoxy-based nanocomposite adhesive with nanographene and multi-walled carbon nanotubes (MWCNTs). Their work is very similar to adhesive mounted cutting tools, in that they looked at what happens during actual turning operations. This study showed that adhesive system properties can impact on the overall stability of the cutting tool as well as tool performance.

The surface finish of the medium-carbon-steel parts was obtained by the turning process using adhesive bonded and conventional cutting tools and was compared by Jachak et al. (2021). This is a very pertinent study because it took adhesive bonded cutting tools as a factor into consideration in a turning operation. The authors demonstrated in practice that adhesively mounted tools can be finding suitable use in turning and that they can be compared with conventional tool-holding methods in terms of their performance in turning.

Stribick et al. (2024) conducted a feasibility study of small diameter drills manufactured with adhesion bonds in manufacturing CFRP parts. While it turned out that their efforts were centered on drilling, nonetheless the results offer insight into the load-bearing capacity of adhesive joints during machining. The study corroborates the notion of whether adhesive bonding could be considered as a method for cutting-tool applications with a well-designed and prepared joint.

Based on the reviewed studies, it is evident that tool wear and tool life are functions of various factors including cutting speed, feed, cutting forces, tool geometry, material of the work piece, and tool-holding condition. There has been considerable research already undertaken on the topic of wear monitoring, flank-wear prediction, acoustic-emission analysis, sensor-based monitoring and tool-life prediction. On the other hand, there are a number of smaller-scale studies that looked at mounting cutting tools with adhesive bonding. Little work has been reported on the direct assessment of tool wear and tool life of adhesively attached cutting tools during turning operations, however. The majority of studies that are available deal with conventional cutting tools or with adhesive bonded tools primarily within the context of surface finish and feasibility or structural behaviour. This leads to a demand for more experiments to gain insight in the behavior of programmed adhesively mounted tools over time and how they wear, stabilize and their different degrees of design influence. Therefore, further experimental testing is required to understand how such tools behave over time and the effect of machining parameters like cutting speed, feed and depth of cut on tool wear, tool stability and the useful life.

Objectives:

1. To experimentally evaluate the wear behaviour of adhesively mounted cutting tools during turning operations under different machining conditions.
2. To determine the tool life of adhesively mounted cutting tools and analyse the influence of cutting speed, feed rate, and depth of cut on tool deterioration.
3. To assess the stability and suitability of the adhesive mounting arrangement during progressive tool wear and identify machining conditions that provide satisfactory cutting-tool performance.

Research Method:

This study used the experimental research method to study the wear behavior and the tool life of cutting tools that were adhered during external cylindrical turning. The experiments included the study of progressive tool wear along with the study of the "useful life" of the cutting edge when machining parameters, cutting speed, feed rate and depth of cut are varied. Workpieces were chosen to be mild steel cylindrically due to their regular use in industry and suitability to conduct controlled turning experiments. Carbide cutting inserts were used as the cutting tools. The usual mechanical clamping system was replaced with a specially designed tool holder to which the cutting insert was joined with a strong adhesive.

The surfaces in contact with the cutting insert and the tool holder were carefully cleaned and prepared before the adhesive was used, to eliminate oil, dust, rust and other contaminants. This layer of adhesive was evenly spread over the mounting surface. The insert was placed at the desired cutting angle, and then it was cured completely before cutting.

Dry turning was used on a conventional centre lathe. The main independent variables for the machining were the cutting speed, speed of travel and depth of cut. In each parameter, there were three levels which were set as the low, medium and relatively high condition of the parameter in the machining process.

The experimental runs were designed such that various combinations of such machining parameters could be tried systematically. The tool was examined after fixed machining intervals in each trial of the machining. Flank wear was monitored and served as the main criterion of the deterioration of the tools. The following observations were also made: edge chipping, movement of the adhesive joints, displacement of the tool and visible damage to the height bonded area.

The tool life was determined based on the entire machining time of the cutting tool as it is satisfactorily produced until a preset tool wear limit is reached. The practical tool-life criterion is set to be about 0.30 mm flanks wear. This cutting-edge wear limit or observation of severe cutting-edge damage, adhesive-joint instability prevented the continuation of the experiment.

The experimental results obtained were analysed to determine the optimum condition for tool life and minimum wear respectively. The cutting speed, cutting feed rate, depth of cut, wear progression, and stability of the adhesive mount has also been compared.

Analysis of the Study:

Table 1. Machining Parameters and Their Levels

Machining Parameter	Level 1	Level 2	Level 3
Cutting Speed (m/min)	80	120	160
Feed Rate (mm/rev)	0.10	0.15	0.20
Depth of Cut (mm)	0.50	1.00	1.50

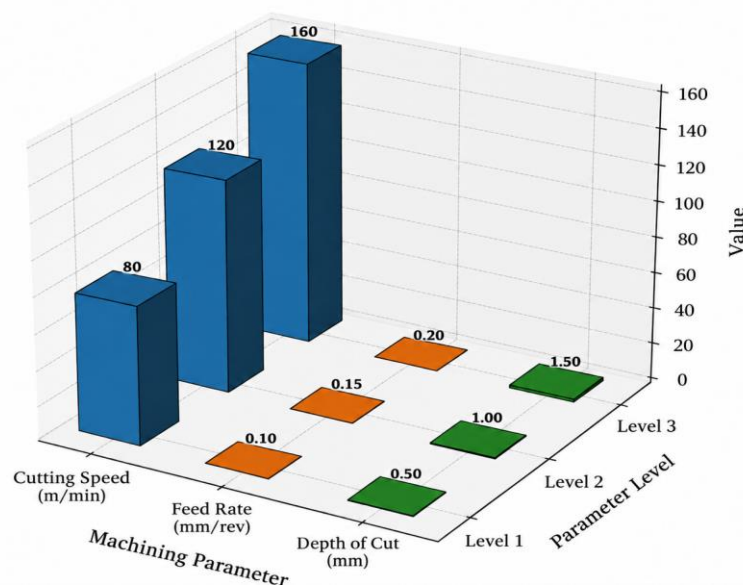


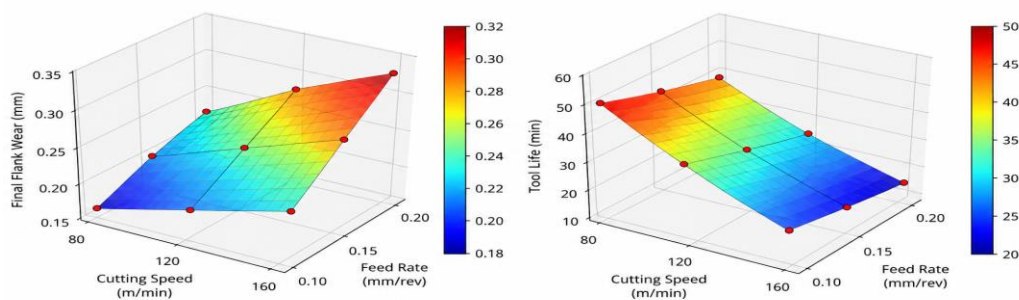
Table 2. Experimental Setup and Material Details

Experimental Factor	Specification
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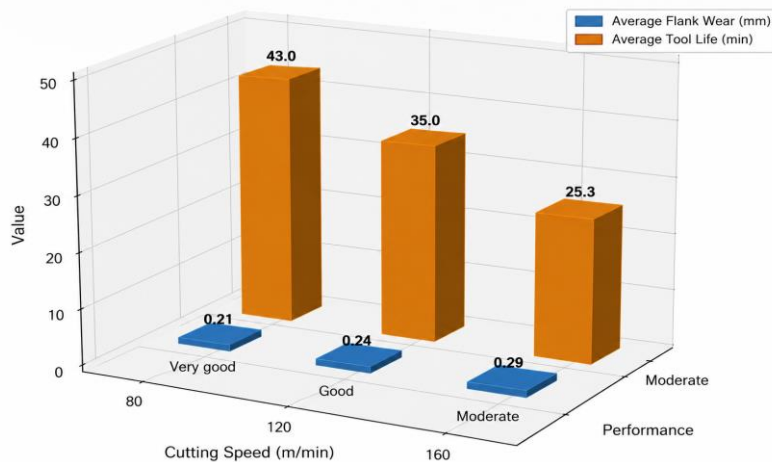
Machining Process	External cylindrical turning
Machine Tool	Conventional centre lathe
Workpiece Material	Mild steel
Cutting Tool	Carbide insert
Tool Mounting Method	Adhesive bonding
Adhesive Type	High-strength structural adhesive
Machining Environment	Dry machining
Primary Wear Parameter	Flank wear
Tool-Life Criterion	Flank wear of approximately 0.30 mm
Number of Experimental Runs	9

Table 3. Experimental Tool Wear and Tool Life Results

Run	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Final Flank Wear (mm)	Tool Life (min)
1	80	0.10	0.50	0.18	48
2	80	0.15	1.00	0.21	43
3	80	0.20	1.50	0.24	38
4	120	0.10	1.00	0.22	40
5	120	0.15	1.50	0.25	34
6	120	0.20	0.50	0.26	31
7	160	0.10	1.50	0.27	29
8	160	0.15	0.50	0.29	26
9	160	0.20	1.00	0.32	21

**Table 4. Effect of Cutting Speed on Average Tool Performance**

Cutting Speed (m/min)	Average Flank Wear (mm)	Average Tool Life (min)	General Performance
80	0.21	43.0	Very good
120	0.24	35.0	Good
160	0.29	25.3	Moderate



Results and discussion:

The experimental findings showed that the method of mounting the cutting tool with an adhesive exhibited wear behaviour and life which was influenced by the machining parameters. Cutting speed was the most obvious parameter found to have a significant effect on the deterioration of the tools among the ones that were investigated.

Run 1 Cutting Speed : 80 m/min Feed Rate : 0.10 mm/rev Depth of Cut : 0.50 mm Tool Life 48 min	Run 2 Cutting Speed : 80 m/min Feed Rate : 0.15 mm/rev Depth of Cut : 1.00 mm Tool Life 43 min	Run 3 Cutting Speed : 80 m/min Feed Rate : 0.20 mm/rev Depth of Cut : 1.50 mm Tool Life 38 min
Run 4 Cutting Speed : 120 m/min Feed Rate : 0.10 mm/rev Depth of Cut : 1.00 mm Tool Life 40 min	Run 5 Cutting Speed : 120 m/min Feed Rate : 0.15 mm/rev Depth of Cut : 1.50 mm Tool Life 34 min	Run 6 Cutting Speed : 120 m/min Feed Rate : 0.20 mm/rev Depth of Cut : 0.50 mm Tool Life 31 min
Run 7 Cutting Speed : 160 m/min Feed Rate : 0.10 mm/rev Depth of Cut : 1.50 mm Tool Life 29 min	Run 8 Cutting Speed : 160 m/min Feed Rate : 0.15 mm/rev Depth of Cut : 0.50 mm Tool Life 26 min	Run 9 Cutting Speed : 160 m/min Feed Rate : 0.20 mm/rev Depth of Cut : 1.00 mm Tool Life 21 min

The comparatively low wear of the adhesively mounted tool can be seen in the case of the cutting speed of 80 m/min. The average flank wear of all the three trials at low speed was approximately 0.21 mm and tool life was reasonably high for all the trials with an average of about 43 minutes. This observation shows that the bonded arrangement of tools was able to provide the necessary stability at lower thermal as well as mechanical loads.

If the cutting speed further increased to 120 m/min, gradual increase of flank wear was observed. The average value of wear was about 0.24 mm and the tool life was reduced to

around 35 minutes. This reduction can be correlated with greater friction forces and higher temperatures that develop at the tool–workpiece and tool–chip interfaces.

When cutting speed is 160 m/min, the tool has the accelerated wear progression. The average flank wear rose to ~ 0.29 mm and the average tool life dropped to ~ 25.3 min. This suggests that cutting edge deterioration at high cutting speed was significantly increased.

The lowest tool life was provided for Run 9, which was achieved with a cutting speed of 160 m/min, feed rate of 0.20 mm/rev and a depth of cut of 1.00 mm. Flank wear under these conditions was 0.32 mm and the useful tool life was about 21 minutes. For the cutting edge, the high cutting speed, coupled with the high feed, resulted in a high thermal and mechanical loading situation.

Wear behaviour was also evaluated via feed rate. When the quantity of feed was increased, the cutting tool had to clear more material in each revolution of the workpiece. This is a higher chip load and cutting force. The mechanical stresses on cutting edge and on the adhesively bonded interface of tool–holder increased with the increase of the cutting force.

However, changes in mechanical loading were mainly observed due to the influence of depth of skin. For a larger depth of cut, the area of contact between the cutting edge and the article increased and more material was therefore taken off during each cut. Within the range studied however, the effect of depth of cut was found to have less effect on tool life than the cutting speed.

A definite inverse relationship was found between flank wear and tool life. A general trend was that as the final flank wear decreased, the machining life of the tool increased and as the flank wear increased, the tool life decreased. This is valid evidence that progressive flank wear is a good parameter for assessing performance of adhesively mounted cutting tools.

During a majority of the experimental trials, the adhesive joint did not shift. At the lower and moderate cutting conditions, no severe displacing of tools and complete separation of the glue from tools was detected. Here again, it indicates that the adhesive used was strong enough to ensure the carbide insert's adherence during regular turning operations.

With high cutting parameters, especially 160 m/min, a certain stability loss of the tool configuration, as well as a wear rise, was detected. This can relate to more heat generated and mechanical load around the cutting area. This generated heat during machining may slowly affects the mechanical characteristics of the adhesive layer.

The lower cutting condition (80 m/min, 0.10 mm/rev and 0.50 mm depth of cut) yielded the best overall machining performance. In this case, the flank wear was only of 0.18 mm with a tool usefulness of about 48 minutes.

Thus, the research shows that satisfactory performance in turning can be achieved with adhesively mounted cutting tools provided that proper control of the machining parameters is adopted. Lower to moderate cutting speeds are especially advantageous since they will alleviate the "heat load", delay the progression of surface wear and promote joint stability of the adhesive bond.

In summary, the study reveals that the cutting speed has the foremost influence on the useful life of the adhesively attached cutting tool. Feed rate and depth of cut also cause deterioration of the tools, primarily due to increasing mechanical loading. The tool life can then be greatly extended by selecting appropriate cutting parameters, together with the structural integrity of the adhesive mounting.

Conclusion:

The present study investigated the tool wear behaviour and tool life of adhesively mounted cutting tools for turning under various cutting conditions. The experiments indicated that cutting speed, feed rate and depth of cut have a significant effect on the performance and life of the cutting tool.

From the given machining parameters, it is found that the cutting speed is the parameter which affects maximum in terms of tool wear and tool life. The flank wear was less at the lower cutting speeds, resulting in the tool's longevity. As cutting speed increased, wear also accelerated and the tool life rapidly decreased as well. Increased friction and heat in the cutting zone were the primary reason for this behaviour.

The results also indicated that feed rate increased mechanical loading on cutting edge and wear increased with the increase in the feed rate. The depth of cut had significant effect on cutting forces and contact area but had a relative smaller effect on tool life than cutting speed. As both cutting speed and feed rate were increased, the result was the worst cutting conditions were achieved and the shortest tool life was recorded.

The experiential results have identified a definite inverse relationship between the flank wear and tool life. Under the machining condition of cutting speed 80 m/min, feed rate 0.10 mm/rev and depth of cut 0.50 mm, the cutting phenomenon was the least with the value of 0.18 mm of flank wear. The maximum tool life of about 48 min was achieved under the same condition. However, the maximum flanks wear of 0.32 mm was obtained at the highest flank wear rate of 160 m/min cutting speed and 0.20 mm/rev feed rate with tool life established at about 21 minutes.

The adhesiveness durability was good when the machine was operating at low and moderate machine load. There was no significant adhesive separation or significant displacement of the cutting insert was noticed during majority of the experiments. This means that a well-made and cured structural adhesive can provide adequate support to the cutting insert being used during standard turning.

At high cutting velocity, however, during successive cuttings more and more the thermal and mechanical loading will have an impact on the cutting edge and on the adhesive joint. Hence, it is important to select proper adhesive, preparing surfaces, curing condition and machine parameter to ensure satisfactory performance.

In general, the study has shown that the adhesively attached cutting tools can be regarded as feasible alternative tool-holding technique for particular turning operations. With well-determined and suitable machining conditions they perform satisfactorily. Achieving good cutting speed, feed rate, and depth of cut will minimize tool wear, improve tool life and keep the adhesive joint stable. The results of this study can be used as the foundation of further studies using various cutting-tool materials, workpiece materials, methods of cooling and various adhesives, and higher loads during metal cutting.

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