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EFFECT OF FEED AND DEPTH OF CUT ON CHIP SHAPE

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Abstract

Machining processes, fundamental to modern manufacturing, require a precise understanding of various parameters, with cutting conditions playing a central role. Optimal feed and depth of cut combinations are critical in achieving efficiency. Tool testing under diverse conditions is imperative to discern effective strategies for productivity enhancement and tool longevity. The chip formation process is a crucial element of production, profoundly influencing machining efficiency. Choice of basic cutting conditions and tool attributes significantly affects chip formation. Feed and depth of cut parameters hold immense importance in machining, impacting chip thickness and morphology. Machining processes encompass turning, milling, drilling, and grinding, each presenting unique challenges related to feed, depth of cut, and chip formation. This review focuses on turning technology, delving into existing research on chip formation, feed rate, and depth of cut. Insights gained from the literature emphasize the need for further research to bridge existing knowledge gaps regarding the intricate relationships between these parameters, particularly under diverse machining conditions. The study highlights the significance of tool testing in achieving optimal machining outcomes and presents a methodology utilizing long-term durability tests to understand the effect of feed rate and depth of cut on chip formation, providing practical insights into tool behaviour and chip morphology.

Keywords: machining; turning tools; chip shape; chip formation

1. Introduction

Machining processes are the foundation of modern manufacturing, with efficiency and accuracy being the most important goals. Achieving these goals requires a thorough understanding of various parameters, among which the choice of cutting conditions plays a key role. The optimum combination of feed and depth of cut are critical factors in achieving efficient machining. Testing tools under different conditions is essential to elucidate the most effective strategies to increase productivity and tool life.

The chip formation process during machining is a critical aspect of production and plays a major role in determining the efficiency of the entire machining process. Chip formation is a complex process in which material separation occurs in the cutting plane, leading to chip formation. At the same time, however, primary, secondary, and tertiary plastic deformation occurs. The choice of basic cutting conditions, together with the choice of tool, its geometry and microgeometry, has a major influence on this process [1], [2]. Understanding and optimizing chip formation is essential to increase machining efficiency, tool life and achieve the required surface quality and dimensional accuracy.

Feed and depth of cut parameters are of critical importance in machining. Feed is the relative movement between the cutting tool and the workpiece per unit time, which, together with the depth of cut, affects the thickness of the chip to be cut. The cutting speed, on the other hand, represents the speed at which the cutting tool moves over the workpiece material and thus influences the chip formation dynamics. The last of the basic parameters is the depth of cut. While, for example, the cutting speed has a dominant effect on the cutting temperature and thus tool life, the depth of cut is a crucial parameter for chip morphology. The interaction of these parameters significantly influences the morphology of the chip, including its shape, size and thickness [3], [4].

Machining processes are diverse and include various methods such as turning, milling, drilling, and grinding. Each process involves unique challenges and requirements related to feed, depth of cut and chip formation. For example, in turning, the rotating workpiece and stationary cutting tool require careful consideration of feed and depth of cut to achieve optimum chip formation. In milling, where both workpiece and tool are moving, achieving the desired chip morphology requires a different approach [5], [6].

2. Literature search:

This chapter provides an overview of existing research on chip formation, feed rate and depth of cut in turning technology and highlights the need for further investigation to fill the existing gaps in understanding their relationship.

In our search for background information for this paper, we looked specifically at sources that addressed chip formation for turning technology. Understanding the relationship between feed rate, depth of cut, and chip formation is essential for optimizing machining processes and improving tool performance. Several studies have addressed these relationships and shed light on the complex dynamics [1], [2], [3], [4], [7].

2.1 Chip formation mechanisms:

Chip formation is a dynamic process influenced by various parameters including feed rate, depth of cut, cutting speed but also other parameters. The basic mechanisms of chip formation are generally divided into continuous and discontinuous chip formation [8]. Continuous chip formation occurs at higher cutting speeds and is characterized by continuous, melting chips. Discontinuous chip formation occurs at lower cutting speeds and results in segmented chips.

In turning technology, chip formation is a critical aspect that directly affects machining efficiency and product quality. The basic mechanisms of chip formation in turning include continuous chip formation, discontinuous chip formation, and built-up edge (BUE) formation [9], [10]. Continuous chip formation is pronounced at higher depths of cut, while discontinuous chip formation prevails at lower depths of cut.

2.2 Effect of feed rate on chip formation:

Researche and Rezayi Khoshdarregi [11] highlighted that increasing feed rate in turning leads to greater chip thickness, which affects the chip shape and the forces applied during machining. In addition, higher feed rates can promote the transition from continuous to discontinuous chip formation.

Feed rate plays a critical role in chip formation. This research is already very old as it was found in Merchant (1945) that an increase in feed rate leads to thicker chip formation, but the information found is still generally valid. This is attributed to the fact that more material is removed per unit time, which affects the morphology of the chip.

2.3 Effect of depth of cut on chip formation:

The depth of cut significantly affects the chip morphology during turning. At lower depths of cut, the chip is thinner and more continuous, whereas at higher depths of cut, thicker, segmented chips tend to form [12]. Depth of cut also affects the temperature distribution at the tool-chip interface, which has an effect on the mechanisms of chip formation [13].

2.4 Combined effect of feed and depth of cut:

The combination of feed rate and depth of cut significantly affects the chip shape during turning. Studies by Boothroyd and Knight [12] have shown that changes in these parameters lead to changes in chip morphology. Higher feed rates and depth of cut tend to produce thinner, more continuous chips, while lower values lead to thicker, segmented chips.

Optimizing the interaction of feed rate and depth of cut is critical to achieving the desired chip morphology and machining efficiency. Research by Tlusty [14] and Barry and Byrne [15] highlighted that the optimum combination of these parameters can lead to improved chip formation, reduced tool wear and improved surface quality.

2.5 Gaps in existing knowledge:

Although extensive research has been conducted on chip formation, feed, and depth of cut in turning, there are significant gaps in the understanding of their complex interplay. Further research is needed to elucidate the exact relationships between feed rate, depth of cut and the resulting chip shape under different machining conditions, considering factors such as tool geometry, workpiece materials and lubrication techniques. Especially recently, these experiments are not sufficiently published, and for modern tool types, actual chip formers with multi-layer coatings provide high machining performances today.

3. Methodology

The process of testing cutting tools involves examining the behavior of the tools under different operating conditions to determine the ideal combination of cutting parameters. The aim of this investigation is to strike a balance between achieving high material removal, reducing tool wear, and improving surface quality. To this end, tool testing is generally divided into two basic approaches: long-term testing and short-term testing.

In long-term testing, tools are subjected to long-term machining operations, which allows their durability and performance to be assessed over a longer period under normal machining conditions, as is normally the case in practice. This approach provides insights into the tool's ability to resist wear and maintain cutting performance under continuous use. Short-term testing, on the other hand, involves evaluating tool performance over a shorter period, usually focusing on specific cutting conditions to quickly evaluate tool behavior under controlled conditions. These tests are usually conducted under increasing conditions from very mild to very high.

Each of these approaches has advantages and disadvantages. Long-term testing provides a comprehensive understanding of the wear and life characteristics of the tool under realistic production conditions. It offers insights into how tools behave over longer lifetimes, and thus helps in tool selection for longer machining operations. However, long-term testing requires a significant investment of time and resources.

Short-term testing, on the other hand, offers a quick evaluation of tools that enables the rapid identification of suitable cutting conditions for specific applications. This approach is particularly useful for initial tool selection or when exploring new cutting strategies. However, its drawback is the limited insight it provides, as it may not capture long-term wear patterns and sustainability of tool performance.

In this paper, we consider the long-term test as it is significantly more revealing than the short-term test in terms of practical application. In the context of finding the optimal combination of feed and depth of cut

It is the aim of this paper to show the practical application of the long-term durability test with the significant effect of the combination of depth of cut and feed on the shape of the resulting chip. The influence of the shape of the formers and the geometry of the cutting edge itself can also be seen in the individual tests.

The experimental methodology was designed to investigate the effect of feed rate and depth of cut on chip formation. The setup involved a comprehensive approach including machine specifications, cutting tools, workpiece material, measurement tools and a systematic experimental procedure.

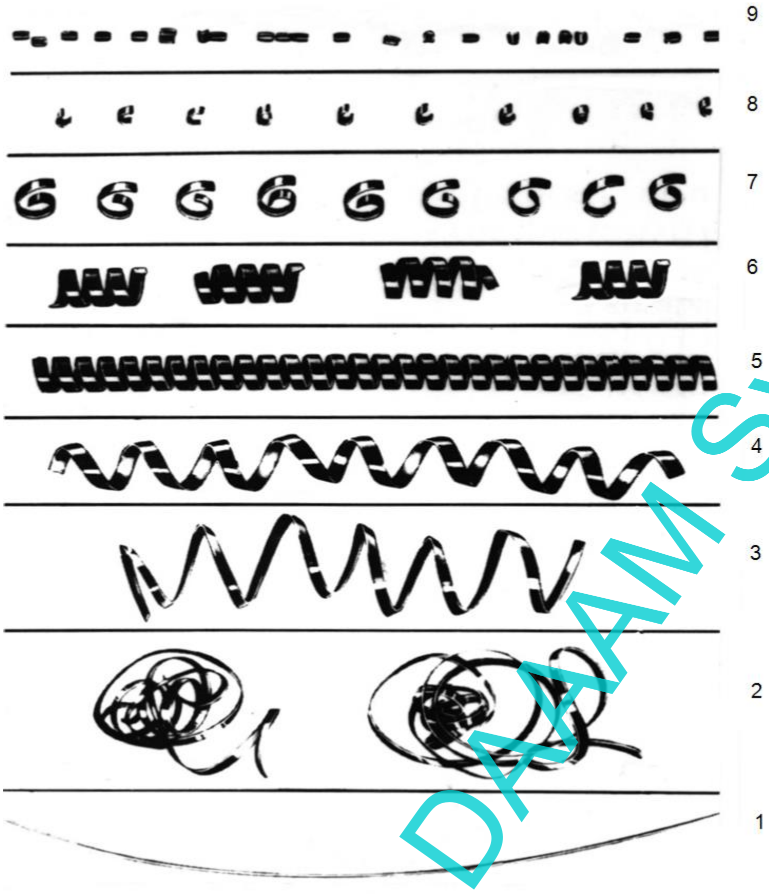

Fig. 1. Chip shape evaluated according to the Seco grading system

4. Preparation of the experiment

4.1. The machine

The experiments were carried out on a DMG CTX BETA 1250 TC A4 machine equipped with controls for precise control of depth of cut and feed during machining. It is a multi-axis machining center that has two spindles as well as a tool spindle and a turret head. The machine provided a stable platform for consistent and controlled experimentation.

The specific parameters are shown in Table 1.

Max. workpiece diameter	340 mm
Max. workpiece length	1 185 mm
Max. bar capacity diameter	102 mm
Max. X-axis stroke	490 mm
Max. Y-axis stroke	200 mm
Max. Z-axis stroke	1 200 mm

Table. 1 Parameters of the machine DMG CTX BETA 1250 TC A4

4.2. Cutting tools:

The cutting tools used for the experiments were CNMG 120408-PF interchangeable insert cutting tools from Kennametal, Coromant, Sumitomo, Korloy, Mitsubishi, Cerazizit, and Pramet, which were selected based on their suitability for the workpiece material and their ability to maintain performance throughout the testing period. Such a diverse group of tools was chosen because of the differences, particularly in chip formers, so that differences could be seen.

4.3. Workpiece material:

The workpiece material selected for this study was C45+QT carbon steel due to its importance in industrial applications and its machinability characteristics, which provides a suitable substrate for investigating chip formation. The advantage of this material is its abundant use for testing as well as its well-known mechanical properties.

4.4. *Measuring tools:*

A suite of precision measurement tools, including a KEYECNE microscope and micrometer, were used to accurately capture and record critical parameters such as chip thickness, chip shape and dimensions.

4.5. Experimental parameters:

4.5.1. Depth of cut:

The depth of cut was varied in the range of 0.3 -2.5 mm to cover the spectrum of machining conditions for both roughing and finishing operations. The chosen depths of cut allowed to observe both the increase in cutting forces and the associated differential effects on chip formation.

4.5.2. Feed rate:

The feed rate was set in the range of 0.1 - 0.4 mm/rot to analyze its effect on chip morphology. Multiple feed rates were chosen to allow a comprehensive investigation of the correlation between feed rate and chip shape.

5. Experiment

The main objective of this experiment is to analyze the effect of variation of feed rate and depth of cut on chip formation during turning. The aim of this study is to provide insights into the relationship between these cutting parameters and chip morphology for a selected group of tools and to compare them with each other.

The course of the experiment was as follows setting the initial feed and depth of cut values, a certain distance (L = 50 mm) was always machined. Based on this, chips were taken, and these were then further analyzed. The machine was always cleaned after each test to avoid cross-contamination.

The feed rate was systematically varied within a predetermined range while keeping the depth of cut constant. This procedure was repeated, this time with a different depth of cut, for each insert.

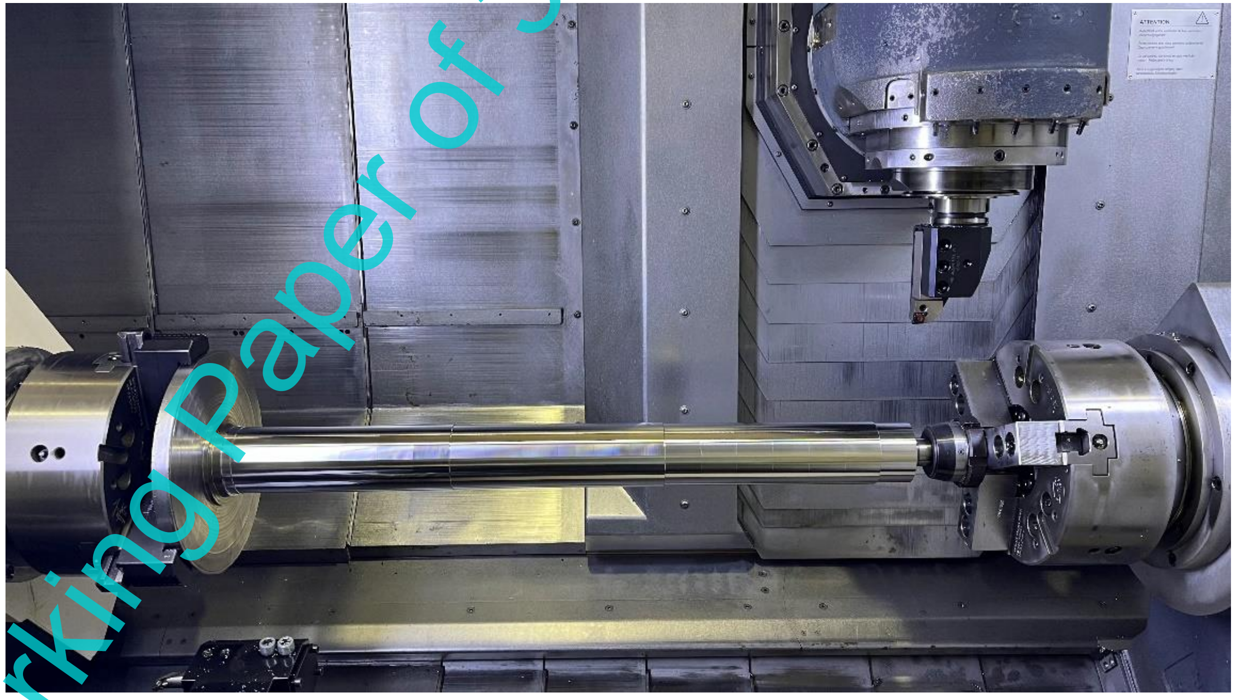

Fig. 2. The course of the experiment on the machine DMG CTX BETA 1250 TC A4

The insert was continuously inspected on an optical microscope to prevent wear and thus affecting the experiment.

6. Results and analysis

The result of each experiment is the table shown in Figure 3. In this table, it is quite clear that the effect of depth of cut is clearly visible, especially on the chip area. Here it can be seen that a small depth of cut results in the formation of very thin chips which cannot be broken even by increasing the feed. These chips are not very suitable, particularly in view of their negative effect on the quality of the finished surface. As the depth of cut increases, the primary plastic deformation increases, which increases the tamping, and the chip starts to split more and more. This phenomenon, combined with the increase in feed rate, is clearly visible and it is possible to observe how the combination of feed rate and depth of cut clearly changes both the cross-section of the chip and its shape.

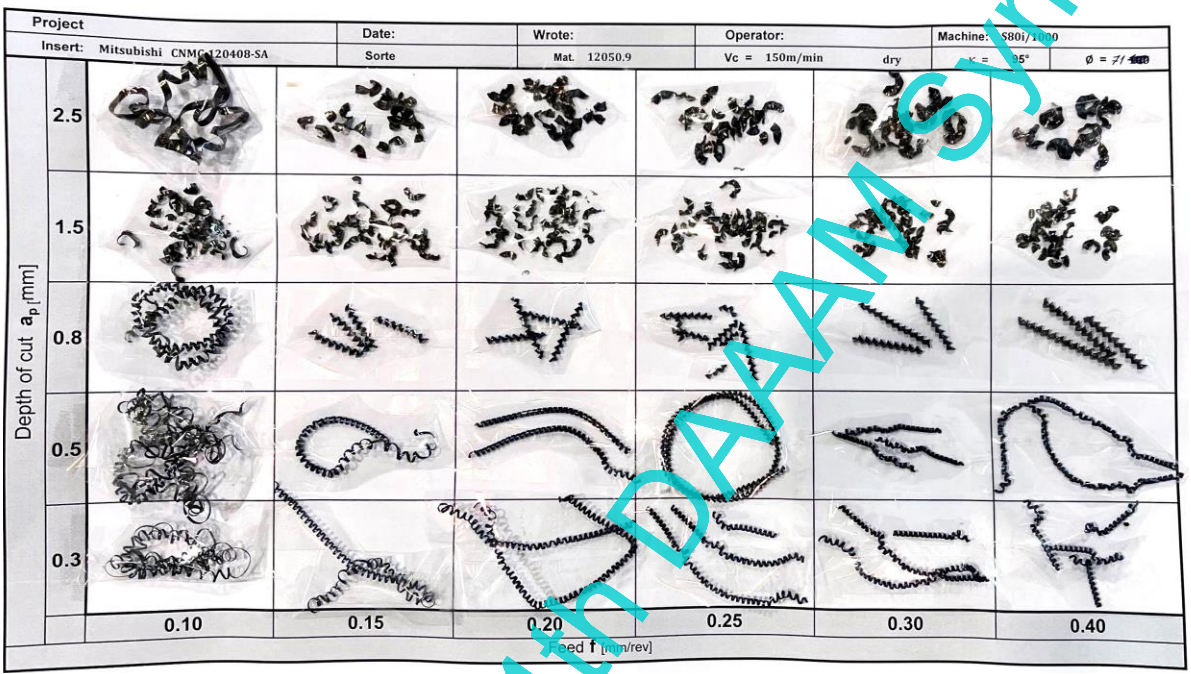

Fig. 3. Snapshot of the effect of feed and depth of cut on chip shape

The separate effect of the displacement is also apparent from the figure, most notably at higher depths of cut. Here it is possible to observe how the chip is gradually packed and thus again the primary plastic deformation ratio increases. As a result, a gradual increase in chip area can be observed.

The result of these tests is the detection of problematic chip formation, mainly due to low feed and depth of cut values. It can be seen here that the depth of cut is problematic below ap = 0.8 mm, inclusive. Above this value a more suitable chip formation already occurs, which is however very dependent on the use of the insert.

The evaluation of this part is dealt with in Figure 4. where the evaluation of the individual chip shape for the used values and feed rate can be observed. The evaluation was carried out based on the normative of figure 1. Here it can be seen that with increasing depth of cut almost all the insert types are achieving suitable VBD shape. The different geometries of the chip formers are then significant especially at lower depths and with decreasing feed values.

Cutting depth ap [mm]	2,5	Ceratizit F50		7	8	8	8	8	8
		Korloy LP		2	8	8	8	8	8
		Mitsubishi SA		3	8	8	8	7	7
		Sumitomo LU		7	8	8	8	8	8
		Kennametal FN		2	7	8	8	8	8
		Coromant PF		2	8	8	8	8	8
	1,5	Ceratizit F50		4	8	8	8	9	9
		Korloy LP		7	8	8	9	9	9
		Mitsubishi SA		7	8	8	8	8	8
		Sumitomo LU		7	8	8	8	8	7
		Kennametal FN		2	6	8	8	8	9
		Coromant PF		2	8	8	8	8	8
	0,8	Ceratizit F50		5	5	5	5	5	5
		Korloy LP		5	6	6	8	8	8
		Mitsubishi SA		4	6	6	6	6	6
		Sumitomo LU		2	6	6	6	6	6
		Kennametal FN		3	5	5	6	6	5
		Coromant PF		5	6	6	6	6	6
	0,5	Ceratizit F50		4	4	5	5	6	6
		Korloy LP		4	4	5	5	5	6
		Mitsubishi SA		4	5	5	5	6	5
		Sumitomo LU		4	5	5	5	5	4
		Kennametal FN		2	3	4	4	5	5
		Coromant PF		4	5	5	5	4	4
	0,3	Ceratizit F50		4	4	5	5	5	5
		Korloy LP		3	3	3	4	4	5
		Mitsubishi SA		4	5	5	5	5	6
		Sumitomo LU		2	4	4	4	4	4
		Kennametal FN		2	2	4	4	5	5
		Coromant PF		3	5	5	5	4	4
	HB		0,040	0,100	0,150	0,200	0,250	0,300	0,400
			4%	20%	30%	40%	50%	60%	80%
			Feed f [mm/rev]						

Fig. 4. Table for the evaluation of the dependence of the geometry of the formers on the shape of the chip

The result of these experiments is a comprehensive table that gives clear recommendations for the choice of the selected types of variables per material type used. The overall contribution of this experiment is to determine the effect of the geometry of the chip formers on the shape of the chip. This result is transferable to other material types.

7. Conclusion:

In the pursuit of enhancing machining efficiency, achieving optimal chip formation in turning technology is a critical endeavor. This study has sought to investigate the intricate relationship between feed rate, depth of cut, and chip morphology, with the overarching aim of shedding light on the factors that influence this essential aspect of the machining process.

Our research has led to several key findings and insights:

Impact of Feed Rate: Through systematic experimentation, it is evident that variations in feed rate play a substantial role in influencing chip thickness, shape, and overall chip morphology. Higher feed rates tend to produce thinner, more continuous chips, while lower feed rates result in thicker, segmented chips. This observation aligns with the existing body of knowledge, emphasizing the importance of feed rate in chip formation.

Influence of Depth of Cut: The depth of cut, a parameter often overshadowed by cutting speed and feed rate, has been shown to be a crucial determinant of chip morphology. Our experiments have demonstrated that varying the depth of cut significantly affects chip thickness and shape. Lower depths of cut lead to thinner and more continuous chips, while higher depths of cut result in thicker, segmented chips. This underlines the importance of considering depth of cut as a fundamental parameter in optimizing chip formation.

Combined Effects: The interaction between feed rate and depth of cut is a key aspect of our research. It has been revealed that the combined effect of these parameters plays a pivotal role in shaping the chip. Identifying the optimal combination of feed rate and depth of cut is essential for achieving the desired chip morphology, machining efficiency, and tool longevity.

Practical Application: The study has practical implications for the field of turning technology. It provides valuable insights into tool selection and machining strategy by optimizing feed rate and depth of cut. The understanding of these parameters can contribute to improved tool performance, reduced tool wear, enhanced surface quality, and greater dimensional accuracy in machining operations.

Research Gaps: While this research has contributed to our understanding of chip formation in turning technology, there remain significant gaps in the current knowledge. Further exploration is warranted to encompass diverse tool geometries, workpiece materials, and lubrication techniques, particularly in the context of modern cutting tools and coatings.

In conclusion, this study underscores the importance of feed rate and depth of cut in shaping chip formation during turning technology. By conducting systematic experiments, we have revealed the intricate relationships between these parameters and chip morphology. The results of this research can serve as a foundation for optimizing machining processes and tool selection, ultimately leading to increased productivity and improved tool performance.

As the field of turning technology continues to evolve, ongoing research and exploration are essential to address the remaining gaps and refine our understanding of chip formation for enhanced efficiency and precision in machining operations.

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