Cutting-Tool Technology: Advanced Manufacturing Methods

Mr. Ahamed Sharif
Assistant Professor, Department of Civil Engineering, Presidency University, Bangalore, India,
Email Id-ahamedsharif@presidencyuniversity.in

ABSTRACT:
Cutting-tool technology is a crucial component of the manufacturing sector because it has a direct impact on the efficacy, precision, and affordability of machining processes. This chapter offers a succinct review of cutting-edge technology, emphasizing its importance, essential elements, and most recent developments. The introduction of the abstract highlights the significance of cutting tools in a variety of machining operations, including turning, milling, drilling, and grinding. Cutting tools are in charge of actually removing material and reshaping the workpiece to the required standards. Cutting speed, surface quality, tool life, and overall productivity are all directly impacted by how well they work. The chapter then goes over the essential features and traits of cutting instruments. It examines the components used to make tools, such as polycrystalline diamond PCD, high-speed steel, carbide, and ceramic. Each material has distinct qualities including toughness, wear resistance, and hardness that make them ideal for particular workpiece materials and applications. The chapter also emphasizes the significance of tool geometry. Rake angle, clearance angle, cutting edge shape, and tool coatings are only a few examples of the geometric features of cutting tools. Cutting pressures, chip control, heat generation, and tool life are all impacted by these aspects. For effective and precise machining, choosing the right tool shape and designing it properly is essential. The chapter also discusses current developments in the field of cutting-tool technology. It mentions the development of cutting-edge coatings that lengthen tool life, lower friction, and increase wear resistance. Examples include titanium nitride TiN, titanium carbonitride TiCN, and diamond-like carbon DLC.

KEYWORDS:

Edge, High, Life, Materials, Resistance, Tool, Wear.

I. INTRODUCTION

Cutting-tool technology is a vital component of the manufacturing sector that focuses on the creation, application, and usage of tools for the removal of materials from processes. These devices, sometimes known as cutting tools, are used in a variety of machining processes, including turning, milling, drilling, and grinding. The choice and use of the proper cutting tools have a significant impact on the efficacy and efficiency of these activities. Cutting-tool technology is a broad discipline that includes a variety of topics such as tool materials, tool shape, coatings, cutting mechanics, and tool life optimization. It seeks to increase tool life, surface finish quality, dimensional accuracy, and chip control to improve the performance, productivity, and cost-effectiveness of machining operations [1], [2]. Cutting tools are often constructed from a range of materials, including polycrystalline diamond PCD, high-speed steel HSS, carbide, and ceramics. Each material has distinctive qualities that make them suitable for particular machining applications, such as hardness, toughness, wear resistance, and heat resistance. Chip formation, cutting pressures, surface polish, and tool life are all significantly influenced by the geometry of cutting tools, which includes the cutting edge's shape, rake angle, clearance angle, and preparation. To minimize tool wear and achieve desired machining results, an optimal tool shape is essential.

Coatings: A lot of cutting tools have thin layers of cutting-edge coatings like diamond-like carbon DLC, titanium nitride TiN, or titanium carbonitride TiCN. These coatings improve wear resistance, lower friction, dissipate heat, and stop built-up edge development, all of which improve tool performance. Developing effective cutting tools requires an understanding of the basic concepts behind cutting, chip generation, and material deformation. Cutting mechanisms used in various machining operations include chip breaking, plowing, and shear cutting. For better rates of material removal and surface quality, cutting-tool technology tries to optimize these processes [3], [4].

Tool life optimization: In cutting-edge technology, extending tool life is a top priority. Optimizing cutting parameters cutting speed, feed rate, and depth of cut, enhancing cooling and lubrication systems, and implementing efficient tool management procedures like tool wear monitoring and tool reconditioning are all examples of strategies for maximizing tool life. cutting-tool technology is essential to the industrial sector because it provides the equipment required for material removal procedures. It includes the choice of suitable tool materials, enhancement of tool geometry, application of cutting-edge coatings, comprehension of cutting mechanics, and extension of tool life. Manufacturing companies are now able to operate with more efficiency, precision, and quality thanks to improvements in cutting-tool technology. Cutting-tool technology is a crucial component of the manufacturing sector because it has a direct impact on the efficacy, precision, and affordability of machining processes. This chapter offers a succinct review of cutting-edge technology, emphasizing its importance, essential elements, and most recent developments.

The introduction of the chapter highlights the significance of cutting tools in a variety of machining operations, including turning, milling, drilling, and grinding. Cutting tools are in charge of actually removing material and reshaping the workpiece to the required standards. Cutting speed, surface quality, tool life, and overall productivity are all directly impacted by how well they work. The chapter then goes over the essential features and traits of cutting instruments. It examines the components used to make tools, such as polycrystalline diamond PCD, high-speed steel, carbide, and ceramic. Each material has distinct qualities including toughness, wear resistance, and hardness that make them ideal for particular workpiece materials and applications [5], [6].

The chapter also emphasizes the significance of tool geometry. Rake angle, clearance angle, cutting edge shape, and tool coatings are only a few examples of the geometric features of cutting tools. Cutting pressures, chip control, heat generation, and tool life are all impacted by these aspects. For effective and precise machining, choosing the right tool shape and designing it properly is essential. The chapter also discusses current developments in the field of cutting-tool technology. It mentions the development of cutting-edge coatings that lengthen tool life, lower friction, and increase wear resistance. Examples include titanium nitride TiN, titanium carbonitride TiCN, and diamond-like carbon DLC. The incorporation of computer-aided design CAD and computer-aided manufacturing CAM in tool design and simulation is also acknowledged, allowing for the creation of more precise and personalized tool geometries an essential component of machining processes is cutting-tool technology. The relevance of cutting tools, their components, geometry, and current developments are highlighted in the chapter. Manufacturers may enhance productivity, precision, and cost-effectiveness in their machining operations by comprehending and improving cutting-tool technology [7], [8].

II. DISCUSSION

Tool Life

In machining, a cutting tool may malfunction in one of three ways, as our introductory paragraph suggested:

1. Failure due to fracture when the tool point experiences an excessive cutting force, which leads to an abrupt failure through the brittle fracture.
2. A temperature failure. This failure happens when the cutting temperature is too high for the material of the tool, causing the material at the tooltip to soften, which causes plastic deformation and loss of the sharp edge.
3. Gradual degradation. Gradual cutting-edge wear results in loss of tool form, a decrease in cutting effectiveness, an acceleration of wear as the tool becomes extensively worn, and eventually tool failure in a way akin to a thermal failure.

The cutting tool is lost too soon as a result of fractures and thermal problems. Therefore, these two kinds of failure shouldn't exist. The longest feasible usage of the tool, with the corresponding economic benefit of that prolonged use, is achieved through gradual wear, which is preferable among the three potential tool failures. When trying to manage the mechanism of tool failure, product quality must also be taken into account. Worksurface damage frequently results from unexpected tool point failures during cuts. This damage necessitates either reworking the surface or maybe scrapping the component. By choosing cutting settings that favor slow tool wear over fracture or thermal failure, and by switching out the tool before the ultimate catastrophic loss of the cutting edge occurs, the damage can be prevented.

Tool Wear

Tool wear is the slow degradation of a cutting tool's surface that occurs during machining operations as a result of contact with the material of the workpiece. The performance of the tool, dimensional accuracy, surface finish quality, and overall productivity can all be affected by this unavoidable occurrence in machining operations. For machining processes to remain effective and efficient, tool wear must be understood and managed. During machining, a variety of tool wear can happen, including:

Flanker Wear: The most frequent kind of tool wear, known as flank wear, takes place on the cutting tool's flank face. Due to the repetitive contact with the workpiece material, there seems to be progressive wear or abrasion along the cutting edge of the tool. Increased cutting pressures, poor surface quality, dimensional errors, and shortened tool life can all be caused by flank wear.

Ratchet Wear: The development of a depression or pit on the tool's rake face is indicative of crater wear. It mostly happens as a result of chemical interactions between the materials of the workpiece and the tool that are brought on by the high temperatures produced during the cutting process. Reduced cutting tool life, greater cutting pressures and decreased surface finish quality can all be caused by crater wear.

Developed Edge BUE

A chip will attach to the tool surface when there is a built-up edge, which is an accumulation of workpiece material on the cutting edge of the tool. BUE can cause concerns with surface quality, higher cutting forces, and inadequate chip evacuation. It is frequently noticed while working with materials like soft or sticky materials that have the propensity to cling to the cutting instrument.

Temperature Cracking

When a cutting tool is subjected to high temperatures, thermal cracking happens, which results in fissures appearing on the tool's surface. Rapid heating and cooling cycles or excessive heat produced during milling can also lead to thermal cracking. It can cause catastrophic tool failure and substantially shorten tool life.

Chipping or Notching

The term notching or chipping describes the development of minute fissures or chips along the tool's cutting edge. Excessive cutting pressures, material fatigue, or insufficient tool material toughness can all contribute to it. The cutting edge's sharpness and integrity are compromised by notching or chipping, which results in worse cutting performance and shorter tool life. To maintain machining effectiveness and quality, tool wear management is essential. To reduce tool wear and increase tool life, a number of steps can be done, including choosing the best tool materials with a high level of toughness and wear resistance for a certain machining application. reducing tool wear by carefully controlling cutting parameters such as cutting speed, feed rate, and depth of cut. putting in place efficient lubrication and cooling systems to manage heat generation and lessen friction. using cutting-edge tool coatings, such as DLC, TiN, or TiCN, to improve wear resistance. Regular monitoring and examination of tool wear are necessary to spot wear indicators and act quickly to prevent further damage, such as replacing or reconditioning the tool. putting into effect appropriate maintenance procedures for tools, such as sharpening or regrinding, to maintain the cutting edge and prolong tool life. Manufacturers may successfully control tool wear, improve tool life, and guarantee consistent and high-quality machining outputs by understanding the causes and characteristics of tool wear and putting relevant techniques into practice.

Tool Life and The Taylor Tool Life Equation

The term tool life describes how long a cutting tool may be used before it wears out, is damaged, or needs to be replaced. Increased productivity, lower tooling costs, and consistent machining performance all depend on maximizing tool life. Cutting speed, feed rate, and tool life are related to the Taylor Tool Life Equation, which was created by F.W. Taylor. You may find the Taylor Tool Life Equation by using:

$$V * T^n = C$$

where: n is a constant relating to the material of the tool and workpiece; V is cutting speed in meters per minute or feet per minute; T is tool life in minutes or number of pieces machined; and C is a constant.

According to the Taylor Tool Life Equation, there is a strong correlation between cutting speed and tool life. According to the equation, tool life reduces as cutting speed increases and vice versa. It suggests that the best cutting speed for maximizing tool life exists. The material of the tool, the composition of the workpiece, and the cutting circumstances all affect the exponent's value, n. It is calculated empirically using cutting experiments and varies depending on the material combinations of the tool and workpiece.

The variables V and C are particular to the machining environment, workpiece, and tool. They are created by tool makers or based on empirical data from cutting experiments. It's vital to remember that the Taylor Tool Life

Equation simply approximates the behavior of tools and only gives a simplified connection. It does not take into consideration several intricate aspects, such as cutting tool shape, cutting pressures, heat production, and tool wear processes, that affect tool wear and tool life. For the initial tool life estimate and the choice of cutting settings, the Taylor Tool Life Equation is a good guideline. By adjusting cutting rates and feeds, producers may increase tool life and productivity. To control tool life in actual machining applications, it should be utilized in conjunction with real-world experience, tool wear monitoring, and other factors.

Tool Life Criteria in Production

When a cutting tool has to be changed or reconditioned during machining processes, precise guidelines or measurements are employed as tool life standards. To maintain effective and dependable production processes and reduce downtime and tooling costs, it is essential to establish acceptable tool life requirements. Based on variables including tool wear, dimensional accuracy, surface smoothness, and productivity demands, several criteria might be taken into account. The following list of production-related tool life requirements includes:

Tool Abuse: One of the main elements taken into account when calculating tool life is tool wear. Visual inspection or automated techniques are used to keep track of crater wear, flank wear, and other types of wear. The tool is replaced or reconditioned after the wear exceeds a certain threshold, which is commonly expressed in terms of a specific wear width or %.

Dimensional Precision: The requirements of the machined items' dimensional correctness may also be used as a basis for tool life standards. A cutting tool may begin to create pieces with dimensions that are beyond the required tolerances as it becomes worn. The tool has reached the end of its useful life when the dimension's deviations are more than the allowable tolerances.

Finished Surface Quality: The standards for surface smoothness are very important in determining tool life. A worn-out cutting tool may result in harsher surface finishes or surface flaws. It is necessary to replace or recondition the tool when the surface roughness or the presence of faults exceeds the permitted limitations.

Productivity and Tool Switching: Tool life requirements may also be influenced by the intended degree of output. Longer tool life may be desirable if frequent tool replacements severely interrupt production flow or increase downtime. In these situations, the parameters for tool life are established to provide longer production runs before tool replacement.

Cost factors to consider

Cost factors, such as the total cost of tooling and machining processes, can also be used as a criterion for tool life. The influence of tool life on total production costs is taken into consideration, along with elements like tool replacement and reconditioning prices. Optimizing tool life aims to reduce the overall cost per component produced. A lot of times, trial runs, data analysis, and real-world experience are used to set tool life standards. They may differ based on the particular machining process, tool and workpiece materials, cutting settings, and quality standards. Manufacturers must set tool life standards that strike a balance between the requirement for reliable quality, productivity, and cost-effectiveness in their manufacturing operations. To provide the best machining outcomes, regular monitoring and assessment of tool performance against the set criteria enable prompt tool replacements or reconditioning.

High-Speed Steel and Its Predecessors

High-speed steel HSS is a kind of tool steel renowned for its superior fusion of toughness, heat resistance, and hardness. It is frequently utilized in cutting tool applications that include high-speed machining processes including milling, drilling, and turning. Building on its predecessors, HSS represented a substantial leap in tool steel technology. Before the invention of HSS, alloys, and carbon steels were often utilized as tool materials. These materials have limits in terms of cutting speed, tool life, and heat resistance but offered sufficient performance for many machining processes. The desire for better tool materials increased as machining operations grew more demanding. There are two broad groups in which the HSS's predecessors may be placed:

Stainless Steels: The first materials utilized to make tools for machining processes were carbon steels. With a carbon concentration ranging from 0.6% to 1.5%, their main components are iron and carbon. Although carbon steels have high toughness and hardness, they have poor heat and wear resistance. Due to quick tool wear, they are suited for low-speed machining applications but not for high-speed machining.

Steel alloys: By including certain alloying elements like chromium, tungsten, molybdenum, and vanadium, alloy steels were created as an enhancement over carbon steels. These alloying components gave the tool steel more hardness, toughness, and wear resistance. Alloy steels outperformed carbon steels in terms of performance, enabling faster cutting rates and longer tool lives. They were still constrained when it came to milling at even greater rates, though. Early in the 20th century, high-speed steel HSS was developed, and this led to the breakthrough. In the United States in 1900, Frederick Winslow Taylor and Maunsel White created the first HSS. In comparison to its forerunners, it created a new class of tool steel with much better characteristics. Iron makes up the majority of HSS, with alloying materials including tungsten, molybdenum, chromium, vanadium, and cobalt. These alloying components improve the steel's toughness, wear resistance, red hardness the capacity to sustain hardness at high temperatures, and hardness.

HSS revolutionized machining technology by providing faster cutting rates and increased tool longevity. Due to its better heat resistance, it was possible to efficiently process a larger variety of materials and boost production. Despite the popularity of more modern tool materials like carbide and ceramic for some types of machining, HSS is still commonly employed in many cutting tool applications today. high-speed steel HSS, which was built on the usage of carbon steel and alloy steels as tool materials, emerged as a key development in tool steel technology. High-speed machining and longer tool life were made possible by the superior hardness, toughness, wear resistance, and heat resistance that HSS provided. Its invention transformed the machining sector and paved the way for subsequent improvements in cutting tool materials.

Cast Cobalt Alloys

Cobalt-based superalloys, commonly referred to as cast cobalt alloys, are a class of alloys having cobalt as their main base metal and several other alloying elements. These alloys are ideal for demanding applications in sectors including aerospace, energy, and medicine because of their high strength, heat resistance, corrosion resistance, and wear resistance.

Cast cobalt alloys' essential features include:

Strength at High Temperatures: Cast cobalt alloys are perfect for applications requiring high working temperatures because they maintain their strength and integrity even at high temperatures. At temperatures as high as 1,200 °C 2,192 °F, they can resist intense thermal cycling and yet maintain their mechanical characteristics.

Corrosion and Wear Resistance: Cast cobalt alloys are ideally suited for locations where abrasion or chemical exposure is common because of their outstanding resistance to wear, erosion, and corrosion. These alloys can withstand extreme circumstances such as hot gases, corrosive media, and high-temperature oxidation.

Strength and Fortitude: Cast cobalt alloys have a high strength-to-toughness ratio that enables them to withstand impacts and mechanical loads. This qualifies them for applications that call for load-bearing or dynamically-exposed elements.

Biocompatibility: Because some cobalt alloys are biocompatible, they can be utilized in surgical equipment, dental prosthesis, and orthopedic implants, among other medical and dental products. The biocompatible cobalt alloys are compatible with human tissues and have good bodily fluid corrosion resistance.

Accuracies In Casting

Several casting processes, including investment casting and precision investment casting also known as the lost-wax method, can be used to create cast cobalt alloys. This makes it possible to produce delicate and complex components with superb dimensional accuracy and surface polish. The following are some uses for cast cobalt alloys:

Components of a Gas Turbine

In the aerospace sector, cast cobalt alloys are widely utilized to make gas turbine engine parts such as turbine blades, combustion chambers, and nozzle guide vanes. These alloys are capable of withstanding the high temperatures, heavy loads, and corrosive conditions that are present during gas turbine operation.

Equipment for Chemical Processing

Cast cobalt alloys are ideal for chemical processing applications because of their superior corrosion resistance. They are utilized in equipment handling corrosive chemicals and aggressive fluids, including valves, pumps, impellers, and other equipment.

Oil and Gas Sector

Cast cobalt alloys are used in the oil and gas sector for components that must withstand high temperatures and pressures. They are utilized in equipment such as wellhead equipment, downhole tools, and valves that must have excellent resistance to wear, erosion, and corrosion.

Dental implants and biomedicine

Dental prostheses and orthopedic implants like hip and knee replacements are both made of biocompatible cobalt alloys. The mechanical strength, corrosion resistance, and superior biocompatibility of these alloys make them ideal for implanted medical devices. Advanced materials with outstanding strength, heat resistance, corrosion resistance, and wear resistance are cast cobalt alloys. They are widely used in sectors of the economy that need high-performance materials that can tolerate abrasive conditions, extreme heat, and mechanical pressures.

III. CONCLUSION

Modern industrial processes rely heavily on cutting-tool technology to efficiently shape, machine, and fabricate a variety of materials. The industry has undergone a revolution thanks to the ongoing developments in cutting-tool technology, which have increased machining operations' productivity, accuracy, and quality. Cutting-tool materials have drastically changed throughout time, progressing from conventional carbon steels and alloy steels to the creation of high-speed steel HSS, carbide, ceramic, and other cutting-edge tool materials. For certain machining applications, each material has special qualities and traits that are appropriate to them, such as chemical stability, wear resistance, wear resistance to heat, and hardness. The development of tool geometries and designs has also improved cutting performance. To increase cutting effectiveness, chip control, and surface finish quality, various cutting-tool geometries, such as single-point tools, multi-point tools, inserts, and coatings, are used. Tool life and machining capabilities have been further improved by the design and development of tool holders, tool inserts, and cutting-edge preparations.

REFERENCES

[1] W. Fan, W. Ji, L. Wang, L. Zheng, en Y. Wang, A review on cutting tool technology in machining of Ni-based superalloys, Int. J. Adv. Manuf. Technol., 2020, doi: 10.1007/s00170-020-06052-9.

[2] A. Saini, B. S. Pabla, en S. S. Dhami, Developments in cutting tool technology in improving machinability of Ti6Al4V alloy: A review, Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., 2016, doi: 10.1177/0954405416640176.

[3] Y. Deng, W. Chen, B. Li, C. Wang, T. Kuang, en Y. Li, Physical vapor deposition technology for coated cutting tools: A review, Ceramics International. 2020. doi: 10.1016/j.ceramint.2020.04.168.

[4] S. Graham T., Cutting Tool Technology: Industrial Handbook, Igarss 2014. 2008.

[5] Z. Wu, Y. Yang, C. Su, X. Cai, en C. Luo, Development and prospect of cooling technology for dry cutting tools, Int. J. Adv. Manuf. Technol., 2017, doi: 10.1007/s00170-016-8842-7.

[6] Cutting Tool Technology. 2008. doi: 10.1007/978-1-84800-205-0.

[7] P. Mueller-Hummel, Cutting Tool Technology for Machining Composite Curing Tools, SAE Int. J. Aerosp., 2012, doi: 10.4271/2012-01-1875.

[8] C. Brecher, F. Wellmann, en A. Epple, Quality-predictive CAM Simulation for NC Milling, Procedia Manuf., 2017, doi: 10.1016/j.promfg.2017.07.284.