RESEARCH PAPER
Contrib. Sci. & Tech Eng, 2024, 1(2)
Homepage: https://cste.journals.umz.ac.ir/
DOI: 10.22080/cste.2024.5095

Application of Additive Manufacturing Methods in the Fabrication of Cutting Tools

Abdolvahed Kami [1]*, Vahid Abedini [1], Ali Jadali [1]

[1] *Faculty of Mechanical Engineering, Semnan University, Semnan, Iran.*

Article Info
Received 18 May 2024
Accepted 30 May 2024
Available online 1 June 2024

Keywords:
Additive Manufacturing;
3D Printing;
Subtractive Manufacturing;
Cutting Tools;
Machining.

Abstract:
Additive manufacturing comprises a set of methods enabling layer-by-layer fabrication of components using a three-dimensional model. Conversely, in subtractive manufacturing, the process begins with a large volume of material and results in the final piece through material removal. One point of convergence between these two processes is the fabrication of machining tools (subtractive manufacturing), such as milling cutters, turning inserts, and boring tools, through additive manufacturing, which can potentially catalyze significant advancements in various machining processes. This article explores several machining tool prototypes fabricated via additive manufacturing and discusses their advantages and capabilities. Additionally, some tools whose properties have been enhanced through additive manufacturing by altering their chemical composition are introduced, and the prospect of multi-material tool fabrication with varying hardnesses is deliberated. Investigations indicate that advancements in additive manufacturing processes can lead to the development of advanced tools capable of producing components with higher hardness and more complex geometries.

***Corresponding Author:** akami@semnan.ac.ir

Supplementary information: Supplementary information for this article is available at https://cste.journals.umz.ac.ir/

Please cite this paper as: Kami, A., Abedini, V., & Jadali, A. (2024). Application of Additive Manufacturing Methods in the Fabrication of Cutting Tools. Contributions of Science and Technology for Engineering, 1(2), 44-47. doi: 10.22080/cste.2024.5095.

1. Introduction

Additive Manufacturing (AM) has emerged as a transformative technology in the realm of manufacturing, offering innovative solutions to enhance the performance and capabilities of cutting tools in machining operations. As the cornerstone of machining processes, cutting tools play a pivotal role in determining the quality and efficiency of machining operations, with key factors such as cooling channels, geometry, weight, and hardness significantly influencing their performance [1]. Employing various AM techniques can enhance the specified characteristics. The study conducted by Yang et al. [2] highlighted the significance of WC-Co hard metals in various applications and discussed the limitations of traditional manufacturing methods. They noted the growing interest in AM for fabricating WC-Co parts due to its ability to produce complex geometries and reduce post-processing. They covered different AM processes, their advantages, disadvantages, microstructures, defects, and mechanical properties and identified future research directions.

Regarding further benefits of AM, the following might be listed [3]: The complexity of the part could be increased using AM, which allows for the manufacture of parts with geometries that are unachievable using conventional methods. The utilization of AM does not compromise its manufacturability, resulting in greater freedom in design. Virtually every concept conceived by a designer may be manufactured. Weight reduction using topology optimization, minimizing the amount of material in a cutting tool while ensuring that its mechanical properties remain sufficient. The process entails doing finite element analysis and subsequently eliminating superfluous materials using an iterative approach.

This article covers several machining process tools developed with the AM and explores their advantages and capabilities. By utilizing AM processes, one may get sophisticated tools capable of manufacturing parts with enhanced hardness and shape complexity.

2. Cutting Tools Made by AM

2.1. End Mill Tool

The tool body is built from H13 tool steel, which is manufactured utilizing the Fused Filament Fabrication (FFF) process and a polymer filament filled with metal powder. The Metal X 3D printer, produced by the Markforged company, was utilized. The process of manufacturing involves initially printing the body of the tool using a 3D printer, with dimensions that are 20% larger than the actual size. This manufactured component is referred to as a "green part" (see Figure 1-a).

ISSN ***3060-6578***

Subsequently, the wax or main binders of the metal powder are removed by a washing and drying procedure. Ultimately, the sintering process is completed, resulting in the tool attaining its ultimate size while considering the shrinkage factor. Afterward, the inserts are positioned and trimmed using a wire cut process. Finally, the tool shank is ground (see Figure 1-b) [4].

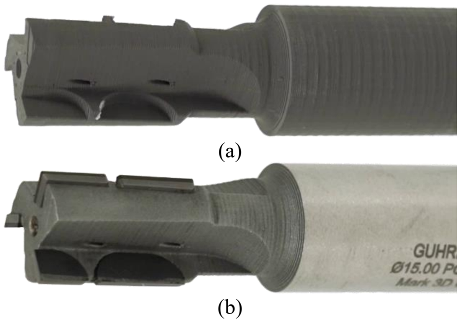

Figure 1. **a) The printed part (green part). b) the 3D-printed part after the sintering process and the positioning of inserts (final part) [4]**

The main advantage of this tool, in contrast to tools produced using conventional methods, is the creation of cooling channels. Cooling channels are formed via the drilling process in tools manufactured using conventional methods. A central hole evolves along the tool's axis to allow fluid entry, while lateral holes are formed along the tool's radial direction to disperse fluid onto the tool inserts.

AM offers designers significant design flexibility, allowing them to create coolant channels in any form that optimizes coolant spray conditions. Optimizing the coolant channels enhances heat removal from the tool and workpiece, while also facilitating the material removal through enabling direct contact between the coolant and inserts. These specified features enhance the conditions for machining. Figure 2, displays one of the several designs that might be employed as the cooling channels for this equipment.

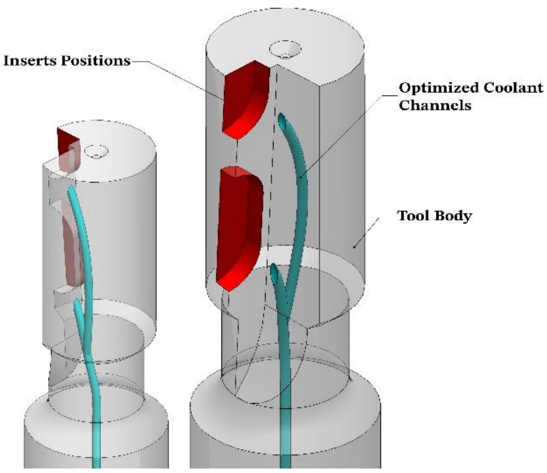

Figure 2. **One of the viable options for cooling channel design [4]**

The second primary benefit of this end mill is its reduced weight in comparison to tools manufactured using conventional methods. AM has enabled the tool body to be filled with a honeycomb structure, causing a 30% reduction in weight. This weight reduction will be beneficial for the machining process. The shell thickness applied to the honeycomb structures for this tool ranges from 0.001 to 0.002 inches, which is the maximum allowable thickness for this tool.

2.2. Electric Vehicle Stator Boring Tool

To achieve large-scale production of electric vehicle motor stators, it is important to machine their holes in one step. Using conventional methods to manufacture the tool will result in a significant increase in its weight due to its large diameter. The utilization of AM to fabricate this tool has considerably decreased its weight. This tool is created using topology optimization, a two-material construction, and a honeycomb-filling pattern. Therefore, the weight of the tool is significantly reduced. Furthermore, the tool takes into account efficient cooling pathways [5], as seen in Figure 3.

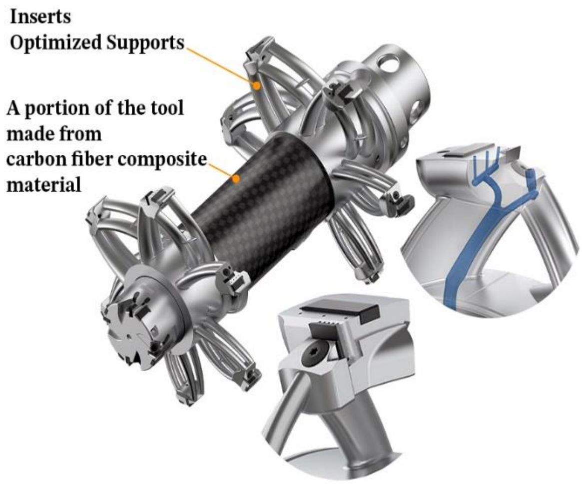

Figure 3. **Electric vehicle stator boring tool [5]**

2.3. Bell Tool for External Machining

As mentioned, AM offers the potential for freedom in designing and filling the honeycomb pattern throughout the production process. The tool maker has utilized two benefits of AM to develop a tool with an internal honeycomb structure and improved coolant channels. This tool is specifically designed for machining the outside surface of hose joints, such as turbocharger hose joints. As a result of these design features, the tool weight has been reduced by 30% [6]. The tool shown in Figure 4 illustrates the Bell Tool.

The printing process of this tool involves the utilization of a selective laser melting (SLM) technique. Subsequently, the item underwent standard post-processing procedures, followed by the soldering and lasering to position the inserts on it.

2.4. Face Milling

2.4.1. Lightweight CoroMill® 390

The Lightweight CoroMill® 390, a tool created by Sandvik, utilizes AM to create an interior honeycomb structure and optimized cooling channels [7]. This results in reduced weight and improved cooling efficiency (see Fig. 5). The body of this tool was 3D-printed using the Powder Bed Fusion (PBF) method and is made from titanium.

Figure 4. External machining tool for hose connections [6]

Figure 5. Lightweight CoroMill® 390 [7]

One distinction between this tool and the conventionally fabricated CoroMill® 390 tool is its lower height, resulting in the machining zone being closer to the damper in the tool shank. Due to the same factor, it is now feasible to use a larger depth of cut for machining operations with this tool in comparison to the CoroMill® 390 tool. Consequently, the level of material removal in machining processes will also increase [7].

2.4.2. KOMET JEL® Face Mill

Similar to other tools developed through AM, 2.4.2. KOMET JEL® Face Mill is a particular tool that includes enhanced coolant channels and a honeycomb construction that has been improved (see Figure 6). This tool was fabricated employing the High-Performance Computing (HPC) technique for optimization [8].

Figure 6. KOMET JEL® Face Mill [8]

This tool can operate at a greater rotation, feed, and cutting speed compared to a conventional tool. As a result, the machining time is reduced. Furthermore, this equipment exhibits lower noise levels even when operating at greater speeds [8]. The manufacturing of this tool is done by the PBF.

2.5. Internal Gear Machining Tool

The internal gear machining tool shown in Figure 7, was fabricated by SLM technology [9]. The tool was created using tungsten carbide-cobalt powder (WC-Co) with the compositions outlined in Table 1. This tool was specifically designed for machining internal gear teeth.

Table 1. Chemical composition of WC-Co powder (%wt) [9]

	C	Co	Fe	W	Remaining
W5C17Co	4.8-5.3	15.5-18	≤ 1	Bal.	0.5≤

This tool has been built with the SISMA MYSINT100 3D printer, MARCAM AutoFab laser scanning software, and LPW company's powder with a grain size range of 15 to 45 micrometers. After completing the printing process, the tool underwent hot isostatic pressing (HIP) during the post-processing stage. Figure 7 depicts the orientation of the print and the tool that has been produced.

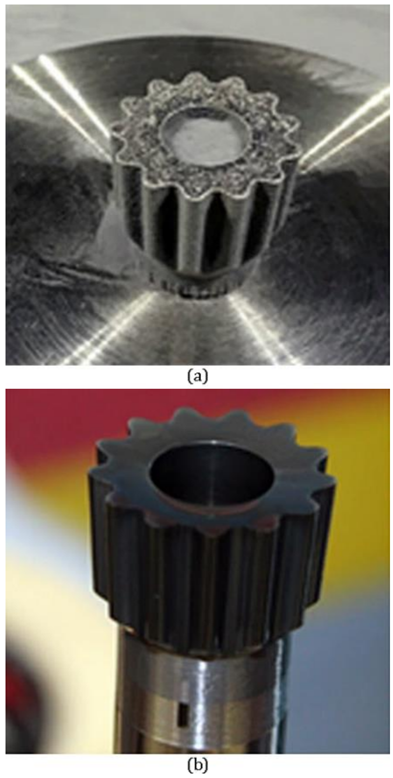

Figure 7. a) Build orientation of internal gear machining tool b) Tool after post-processing [9]

2.6. WC-Co Cutting Tool Reinforced by Diamond

This cutting tool is manufactured with the Directed Energy Deposition (DED) technique as a multi-material. The exterior layers of the tool, which are the areas that come into touch with the workpiece, are reinforced with synthetic diamond. The tests conducted only include a conceptual design, as shown in Figure 8, and a test tool, as depicted in Figure 9. The provided design demonstrates the possibility of creating a tool insert with three distinct levels of hardness, each suitable for machining a certain type of material.

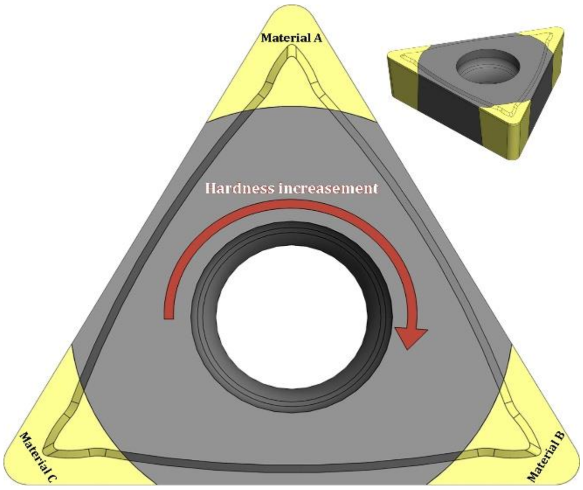

Figure 8. **Conceptual design of the tool [10]**

Figure 9. **A test sample made of a diamond-enhanced WC-Co tool [10]**

3. Conclusion

The integration of additive manufacturing (AM) methods in the fabrication of cutting tools presents a promising path for enhancing various aspects of subtractive manufacturing processes. Through examination of several machining tool prototypes developed via AM, it becomes evident that this approach offers substantial advantages in terms of weight reduction, optimization of cooling channels, enhancement of machining parameters, flexibility in tool material selection, and optimization of tool geometry. The innovative utilization of AM technologies enables the creation of cutting tools with intricate geometries and optimized internal structures, such as honeycomb patterns, which enhance cooling efficiency and reduce tool weight. These advancements not only contribute to improved machining performance but also lead to significant reductions in machining time and energy consumption. Furthermore, the ability to fabricate multi-material tools with tailored properties, such as the integration of synthetic diamond reinforcement in WC-Co cutting tools, demonstrates the potential of AM to push the boundaries of tool functionality and durability.

4. References

[1] Knight, W. A., & Boothroyd, G. (2019). Fundamentals of Metal Machining and Machine Tools. CRC Press, Boca Raton, United States. doi:10.1201/9780429114243.

[2] Yang, Y., Zhang, C., Wang, D., Nie, L., Wellmann, D., & Tian, Y. (2020). Additive manufacturing of WC-Co hardmetals: a review. International Journal of Advanced Manufacturing Technology, 108(5–6), 1653–1673. doi:10.1007/s00170-020-05389-5.

[3] Diegel, O., Nordin, A., & Motte, D. (2020). A practical guide to design for additive manufacturing. Springer, New York, United States. doi:10.1007/978-981-13-8281-9.

[4] Zelinski, P. (2020). 3D Printed Tool for CNC Machining: The Cool Parts Show #17. ADDITIVE MANUFACTURING, Las Vegas, United States. Available online: https://www.additivemanufacturing.media/articles/3d-printed-tool-for-cnc-machining-the-cool-parts-show-s3e1 (accessed on April 2024).

[5] Zelinski, P. (2022). 3D Printed Tool for Machining Electric Vehicle Motors: The Cool Parts Show #39. ADDITIVE MANUFACTURING, Las Vegas, United States. Available online: https://www.additivemanufacturing.media/articles/3d-printed-tool-for-machining-electric-vehicle-motors-the-cool-parts-show-39 (accessed on April 2024).

[6] Mapal. (2020). Available online: https://mapal.com/en-int/a/additiv-manufactured-bell-tool (accessed on April 2024).

[7] Sandvik Coromant. (2019).Lightweight CoroMill® 390 produced using additive manufacturing reduces vibration in long-overhang milling. Available online: https://www.sandvik.coromant.com/en-gb/press/lightweight-coromill-390-additive-manufacturing (accessed on April 2024).

[8] YouTube, San Bruno, United States. Available online: https://www.youtube.com/@kometgroup/playlists (accessed on April 2024).

[9] Fortunato, A., Valli, G., Liverani, E., & Ascari, A. (2019). Additive Manufacturing of WC-Co Cutting Tools for Gear Production. Lasers in Manufacturing and Materials Processing, 6(3), 247–262. doi:10.1007/s40516-019-00092-0.

[10] Traxel, K. D., & Bandyopadhyay, A. (2021). Diamond-reinforced cutting tools using laser-based additive manufacturing. Additive Manufacturing, 37. doi:10.1016/j.addma.2020.101602.