ADITIVE MANUFACTURING OF M300 STEEL CUTTING TOOLS BY SELECTIVE LASER MELTING

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The article presents preliminary research on the application of additive manufacturing in the production of monolithic cutting tools for various machining operations as a new way of producing cutting tools with innovative potential. The necessary steps to produce functional cutting tools via Selective Laser Melting have been investigated. Two sets if samples were printed via SLM machine ReniShaw AM 400 from maraging steel M300 in collaboration with VSB-TU Ostrava. First set of samples were semi-finished rods and second set were cutting tools with printed geometry. Machine operations such as turning and grinding were used to achieve functionality of cutting tools so that can be used in the machining process. Experimental part of article is focused on investigating of machining capabilities of printed cutting tools.

KEYWORDS

Additive manufacturing, selective laser melting, cutting tools, maraging steel, machining

1 INTRODUCTION

Additive Manufacturing is the formalized term for what used to be called Rapid Prototyping and what is popularly called 3D Printing. The basic principle of this technology is that a model, initially generated using a three-dimensional Computer Aided design (3D CAD) system, can be fabricated directly without need for process planning. Although this is not in reality as simple as it first sounds, AM technology significantly simplifies the process of producing complex 3D objects directly from CAD data. Other manufacturing process requires a careful and detailed analysis of the part geometry to determine things like the order in which different features can be fabricated, what tools and processes must be used, and what additional fixtures may be required to complete the part [Gibson 2021].

Tooling encompasses AM applications based on fabrication cores, cavities, inserts for tools, dies and molds etc. A key point to be made clear is that the complete tool is not obtained but only its important parts are created. The tool is obtained via conventional manufacturing route here, also by utilizing its parts like cavities, cores, etc. [Sristava 2019].

The technology of sintering powder layers (Powder Bed Fusion) is process of rating individual layers of metal powder on the basic table with same chemical composition as metal powder. This technology (according to producer SLM – Selective Laser Melting) works on the principle high power laser, when the basic material is melted – metal powder, which is coated on the platform in very thin layer and by scanning of laser beam is created 3D object in axis Z. Primarily, profile is harden after application of the metal powder and then the building is finished. The building chamber is filled up by inert gas – argon (some machine uses nitrogen. The production process of SLM is influenced by process parameters such as powder, laser, temperature and production strategy which are dependent on each other [Pagac, 2017].

The objective of article is to investigates application of additive manufacturing in the process of tool making of cutting tools and determine necessary steps to achieve required parameters of cutting tools with conventional manufacturing to achieve functional cutting tools for use in machining process. Several authors and companies in their research used additive manufacturing to produce various cutting tools.

Schwanekamp and Reuber in their jointed research project with PraeziGen studied how to overcome tool making by applying additive manufacturing, respectively SLM, to fabricate optimized carbide precision tools with complex inner and outer shape. Developed process chain for AM of near-net shape cutting tools and the qualified tungsten carbide for the SLM process [Schwanekamp 2016]. Conventional process chain for cutting tools is on Fig. 1 and process chain for AM of cutting tools is on Fig. 2.

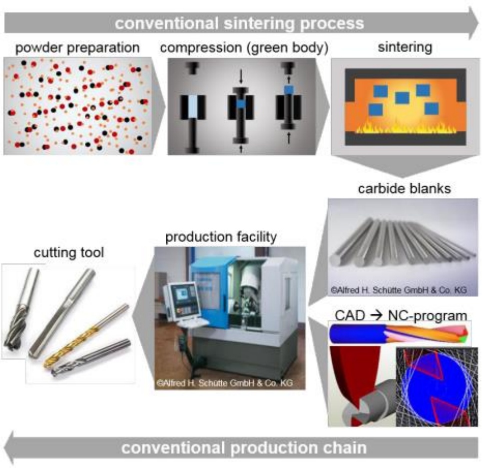

Figure 1. Conventional process of cutting tools [Schwanekamp 2016]

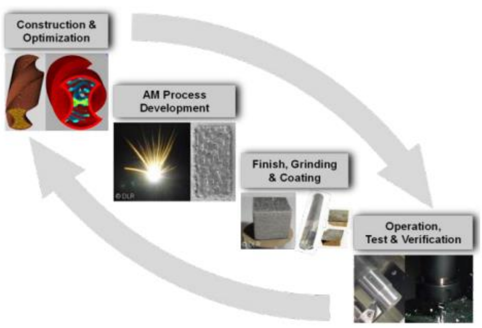

Figure 2. Process chain for AM of cutting tools [Schwanekamp 2016]

Potential benefits of SLM for cutting tools have been also identified in the areas of mechanical properties, chip flow, coolant supply and productivity. In the terms of industrial application of SLM printed tools and exploiting benefits of this tools were published by tool manufactures. One example is printed indexable insert drill body with integrated optimized cooling channels with a flow rate increased by 30% [Schwanekamp 2016]. Indexable insert drill is shown on Fig. 3.

Figure 3. Indexable insert drill manufactured by SLM [Schwanekamp 2016]

KOMET® GROUP and Renishaw developed new range of PCD (Polycrystalline Diamond) screw-in milling cutters. The main bodies of cutters were manufactured via ReniShaw metal additive manufacturing system [Klingauf 2017]. Printed bodies are on Fig. 4

Figure 4. Printed bodies of milling tools [Klingauf 2017]

With change of arrangement of the blades substantially greater axis angle was achieved. In comparison with conventional milling tools, the grooves were greatly shortened. These changes increased productivity of tools for user. For example, 32 mm screw-in head with increased grooves and blades from six to ten can achieve a feed rate that can be up to 50% higher [Klingauf 2017].

Lakner et al. manufactured milling tool conventionally and additively from same tool steel whereas additively manufactured milling tool had an improved design of cooling channels with complex nozzle design what significantly improves flow conditions of cutting fluid in the channels [Lakner 2019]. Comparison of tools is shown on Fig. 5.

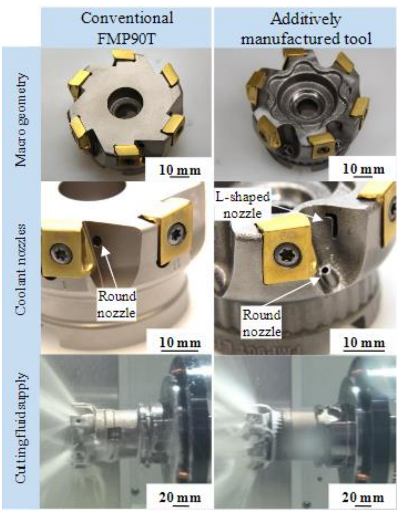

Figure 5. Comparison of manufactured milling tools [Lakner 2019]

From experiments, additively manufactured tool showed less tool wear and reached 67% longer feed travel path (l_f) compared to the conventional tool when taking the best performing cutting insert into account. The L-shaped coolant nozzles of the additively manufactured tool ensured a good lubrication of the tool-chip interface. No major differences in the chip morphology and chip size were found in reliance to the manufacturing process of the cutting tools [Lakner 2019].

Zumofen et al. successfully printed samples of drill bits with internal cooling channels from high-speed steel M2 using SLM [Zumofen 2017]. Printed drill bits are shown on Fig. 6.

Figure 6. Printed drill bits with internal coolant channels [Zumofen 2017]

2 MATERIALS AND METHODS

2.1 Selective laser melting

Metal 3D printing, which is growing in the market, enables the direct production of complex and complex parts. This article uses Selective laser melting (SLM) technology to produce cutting tools. The preparation of tools manufactured by additive technology, which can be used in the machining process, consisted of five steps: design geometry of the tool, additive technology Selective laser melting (SLM), heat treatment, the tool shank turning, and cutting tool geometry grinding.

2.2 Design of cutting geometry

Software NUMROTOplus was used to create a 3D model of cutting tools. NUMROTOplus is used for the design of cutting tools and for creating NC code for grinding machines. This software provides a complete simulation of the grinding operations [Peterka 2020]. The software is equipped with integrated collision control and is able to export a 3D model in STL Format. These models were used for printing cutting tools. Fig. 7 shows the geometry of cutting tools. The dimensions of the cutting tools were increased in order to sharpen the geometry of the tools.

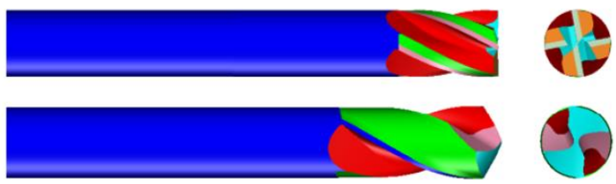

Figure 7. The geometry of cutting tools in software NUMROTOplus

2.3 Printing of samples

Selective laser melting (SLM), in which a laser beam is used, gradually melts individual layers of metal powder, which, after solidification, are combined to form the desired shape. After printing one layer, it is necessary to lower the platform by the height of that layer. The layer thickness was set to 40 µm. This process is then repeated until the entire part is successfully printed. Maraging material M300 was used to produce cutting tools. Maraging steels form a class of iron alloys. This group of materials has a martensitic crystal structure and is strengthened via aging at approximately 500 °C, hence the name 'maraging'. These ultra-low carbon alloys have very high strength and hardness properties. The main alloying element of these alloys is nickel. LPW M300 Tool Steel is used for a range of applications where exceptional tensile strength and hardness are required and therefore lends itself to tooling applications. Tab. 1 shows Maraging steel M300 – chemical composition.

Element	Fe	Ni	Co	Mo	Ti
[%]	Balance	17 - 19	7 - 10	4.5 – 5.2	0.3 – 1.2
Element	Si	Mn	C	P	S
[%]	≤ 0.10	≤ 0.15	≤ 0.03	≤ 0.03	≤ 0.01

Table 1. Maraging steel M300 - chemical composition [Addimen, 2023]

2.4 Heat treatment

A chamber furnace LH 120/12 from Nabertherm GmbH was used for heat treatment of the tested samples. This furnace has a power of 12 kW and reaches temperatures of up to 1200 °C. Printing of the sample and heat treatment of the printed samples was carried out in cooperation with ProtoLab at VSB-TU in Ostrava. Heat treatment of the samples takes place at a temperature of 600 °C for 6 hours.

2.5 Machining of samples

The tool shank was turned on CTX Alpha 500 turning center. The CTX Alpha 500 turning center is equipped with a high-precision tool head for maximum precision with 5000 rpm, 5.4 kW power, and torque. The shank of the tool was turned to a diameter of 10xh6 in order to clamp the tool in the tool grinder. A WZS Reinecker by company ULMER WERKZEUGSCHLEIFTECHNIK tool grinder was used for sharpening the cutting tools. The grinding wheels made of cubic boron nitride by the producer URDIAMANT Slovakia s.r.o. were used for sharpening the cutting tools. Fig. 8 shows preparation of the tool step by step.

Figure 8. Preparation of tool step by step

3 EXPERIMENTAL SETUP AND PROCEDURE

3.1 Workpiece material

Whereas maraging steel is not conventional material used in manufacturing of cutting tools such as high-speed steel or tungsten carbide, it was necessary to determine a suitable material for workpiece. Two potential materials were determined which were aluminium alloy and C45 steel. First manufactured drill bits were used to investigate whether are capable of drilling into these materials. In the case of C45 steel, the drill bit was not capable of drilling. After few seconds of drilling the drill bit was destroyed. The result wear after few seconds of drilling into C45 steel is shown on Fig. 9.

Figure 9. Wear of drill bit after drilling into C45 steel

In the case of aluminium alloy, the drill bit was capable to drill into material. The problem during first drilling was use of inappropriate drilling parameters which were chosen and adjusted based on drilling parameters of tungsten carbide drill bits. The result wear of drill bit is shown on Fig. 10. After second adjust of drilling parameters, the drill bit was capable of drilling into aluminium alloy without any problem. Based on these results, aluminium alloy was determined as workpiece material.

Figure 10. Wear of drill bit after drilling into Aluminium alloy

3.2 Machining conditions

Machining experiments were conducted on a DMG Ultrasonic 20 Linear. Cutting tool used in machining was an uncoated four flute end mill with 11 mm diameter. The used cutting speed (v_c) was 260 m.min^{-1}, feed per tooth (f_z) was 0.05 m, axial depth of cut (a_p) was 12 mm and radial depth of cut (a_e) was 0.5 mm. Experiment was meant to constitute side milling operation. Setup for the experiment is shown on Fig. 11.

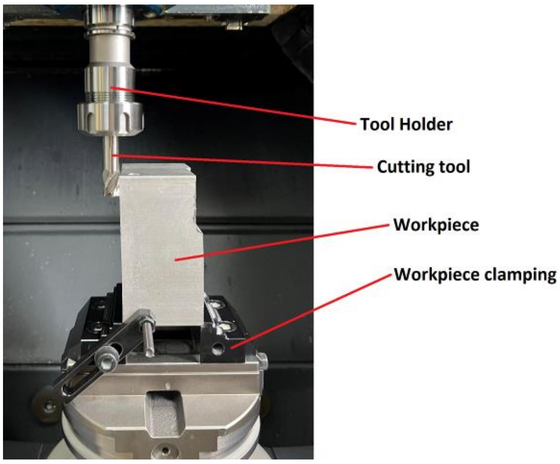

Figure 11. Machining experiment setup

3.3 Tool wear measurement

Digital optical microscope Dino-Lite was used to observe tool wear and measure the tool wear indicator average flank wear (VB) on the side cutting edge. The measurement has been taken every 1000 mm of travelled cutting length. The example of measurement is shown on Fig. 12.

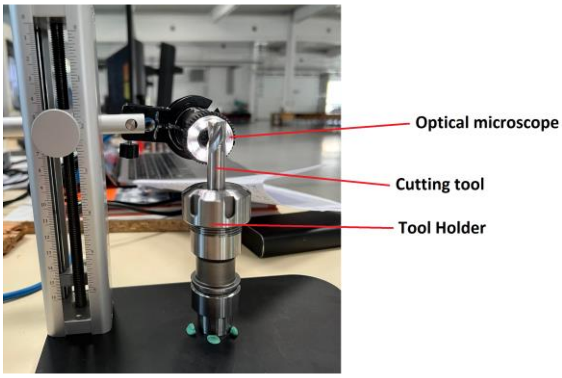

Figure 12. Example of measurement setup for tool wear measurement

3.4 Measurement of machined surface roughness

Measurement of machined surface roughness was carried out using portable surface roughness tester Mitutoyo SJ-210. Machined surface area was measured six times at different places and three parameters Ra, Rq and Rz were recorded. The measurement setup is shown on Fig. 13.

Figure 13. Measurement of machined surface

4 RESULTS

4.1 Tool wear

Tool wear was initiated after first 1000 mm of travelled cutting length. Average Flank wear (VB) reached value 0.140 mm and was evenly distributed. The wear of cutting tool after first 1000 mm of travelled cutting lengths is shown on Fig. 14.

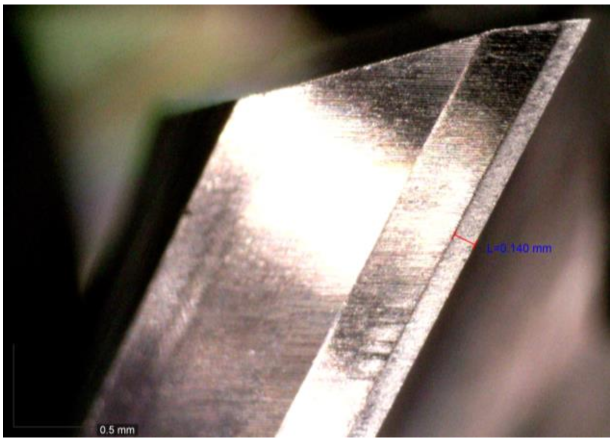

Figure 14. Value of average flank wear (VB) after first 1000 mm of traveled cutting lengths.

Tool wear gradually spread until catastrophic degradation of the cutting edge occurred what initiated end of life of cutting tool. On Fig. 15 is shown progression of tool wear and on Fig. 16 is shown catastrophic degradation of cutting edge.

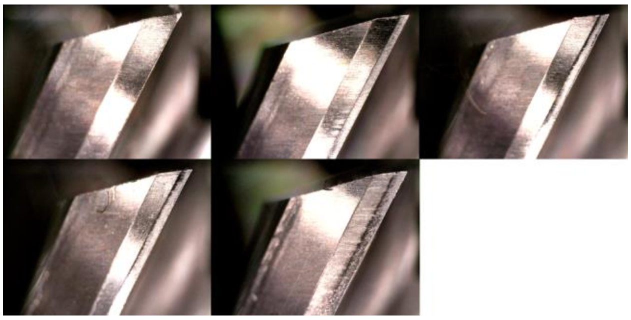

Figure 15. Progression of tool wear

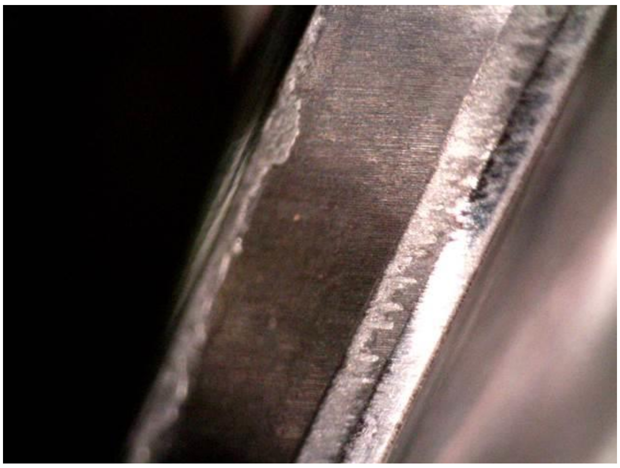

Figure 16. Initiated end of life of cutting tool

4.2 *Machined surface roughness*

The measured values of the surface roughness of the machined surface coincided with the development of the wear of the cutting tool. Until significant wear of the tool and degradation of the cutting edge occurred, the roughness parameter values Ra, Rq and Rz were stable. After high wear was reached, there was a high increase in the values of all three parameters, which showed the reach of tool life. Development of machined surface roughness is shown on Fig. 17.

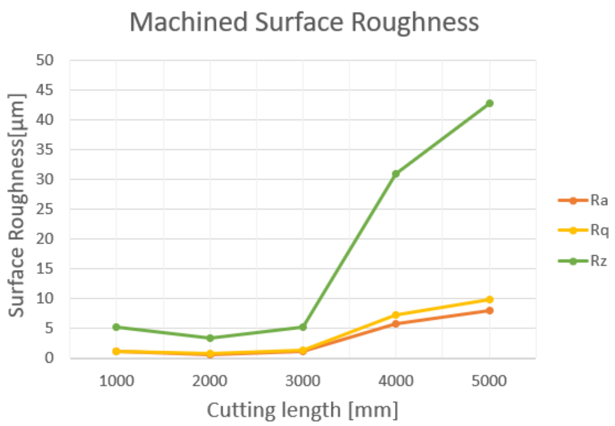

Figure 17. Development of machined surface roughness

5 CONCLUSIONS

In this preliminary research, the cutting tools were successfully manufactured using combination of additive manufacturing and conventional manufacturing technologies. In the experiment was investigated capabilities of cutting tools in machining process. Tool wear and machined surfaces roughness were measured. Results shows that cutting tools manufactured using additive manufacturing are capable of cutting. The obtained information and results will be used in the following research, which will be focused on additive manufacturing of cutting tools made from materials for cutting tools such as tungsten carbide and high-speed steel. Subsequently investigate their capabilities of machining compared to conventionally produced cutting tools and possibilities of application of lattice structures in monolithic cutting tools.

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