A COMPARATIVE ANALYSIS OF THE IMPACT OF CNC MILLER PROGRAMMING ON MACHINING EFFECTS

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Abstract: This paper presents a comparison of the impact of the programming methods of a CNC miller on the machining effects. As a part of the study, the test samples were made of the EN AW-2024 aluminium alloy. The CNC machining programs compared were developed with two programming methods: by inputting the CNC machining program directly from the CNC miller's control panel (machine level programming) and in a CAM software environment (CAM programming). The machining effect indicators adopted included: machining time, surface quality, and dimensional deviation of specific geometrical features. A measurement of the machining times revealed than the CAM programming reduced the machining time up to 20% from the machining time of the machine level programming. A conclusion stands valid that CNC machining programs developed in the CAM software environment are more efficient than CNC programming directly with the CNC miller control panel, most likely due to the machining path optimisation in CAM. In addition, given the experimental test results, it was found that smaller machined errors were also obtained for CAM programming. To conclude, the comparative analysis revealed that CAM programming provided better machining results than the machine level programming.

Keywords: programming, CAM, CNC machine tool

1. INTRODUCTION

In recent years, industry has experienced a dynamic development of technical preparation of production which requires support of CIM (Computer Integrated Manufacturing) and a suitable organizational structure (Przybylski and Deja, 2007).

CAM (Computer Aided Manufacturing) is defined as "a system for managing a manufacturing process and its control with a computer workstation". Most CAM software solutions today allow for transferring the workpiece geometry from CAD module or separate software CAD to CAM. CAM software enables selection of machining parameters, include machining tool libraries, and can simulate visualised machining processes (Chlebus, 2000; Czech-Dudek, 2015).

The application of CAD with CAM is currently the foundation of manufacturing engineering preparation and comprises most engineering aspects of product design and manufacturing. However, proper use of CAD/CAM requires a sufficient know-how and advanced software operating skills. Those systems have found a widespread use in engineering industry mainly because they improve manufacturing efficiency and possibility to reduce the time of manufacturing programs correction, product range switchover, and product quality improvement. The most popular of the advanced CAD/CAM systems include software solutions like CATIA and NX. However, they are expensive, which is a major issue. This largely why they are applied mostly by large industrial corporations with a considerable capital

(Chlebus, 2000; Dubovska et al., 2014; Lynn et al., 2017; Masood and Lau, 1998; Niesłony and Grzesik, 2011; Przybylski and Deja, 2007; Zaborski and Tubielewicz, 2004).

The basic elements of the CNC system of a machine tool include (Honczarenko, 2008):

- a programmable logical controller (PLC),
- a numerical control system (NC),
- an adaptive and actuation control system (AAC).

The NC collects the mathematical notation of movements and processing data from a CNC machining program, which is written in a symbolic format. The PLC is an interface between the NC and the AAC, where the latter controls the elements of the CNC machine tool. The most recognizable CNC system brands today include Sinumeric, Heidenhain, Fanuc, and Haas (Honczarenko, 2008; Vichare, 2017).

CNC machine tool programming is defined as "a set of activities the outcome of which is the development of a machine control program, written in a specific language and format" (Habrat and Wdowik, 2010).

The control program development methods are classified as follows (Habrat and Wdowik, 2010; Lynn et al., 2017; Minquiz, 2014; Wang and Zhou, 2018):

- manual programming, by which a control program is developed directly with the control panel interface of the machine (i.e. the machine level programming),
- automatic programming, which is an advanced program development process guided with aiding tools, i.e. CAD/CAM software or a programming microchip integrated with the CNC system (i.e. the CAM programming).

2. METHODOLOGY

The aim of the presented study was to compare the obtained machining effects during the machine level programming and with application of the CAM programming.

As a part of this work, a test sample was manufactured. The geometrical features of which are shown in Fig. 1. The overall dimensions were: 100 x 60 x 60 mm.

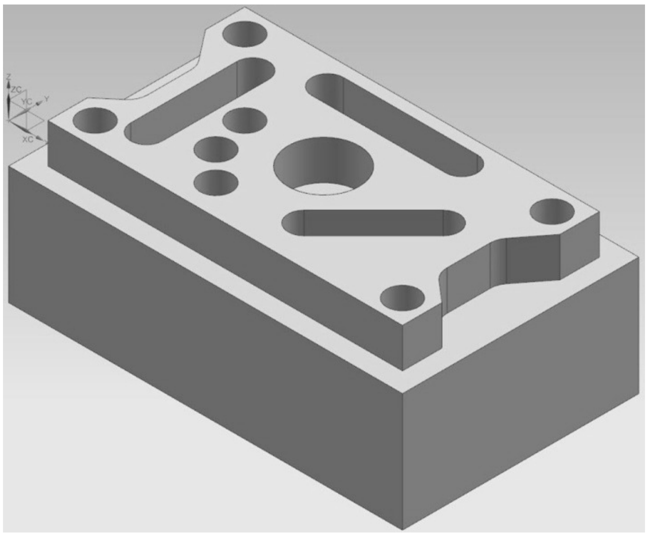


Fig. 1. Model of the test sample

The test samples were made of EN AW-2024 T351 aluminium alloy. The chemical composition and the selected mechanical properties of the alloy are presented in Table 1. The semi-finished product was cuboid with dimensions: 100 x 60 x 60 mm.

Table 1
Chemical composition and selected mechanical properties of EN AW-2024 aluminium alloy

Chemical composition [%]	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
	0.5	0.5	3.8 - 4.9	0.3 - 0.9	1.2 - 1.8	0.1	0.25	0.15
Mechanical properties	**Density, ρ**	**Young's modulus, E**	**Tensile strength, R_m**	**Yield strength, $R_p0,2$**	**Brinell hardness**			
	2.78 g/cm^3	73 GPa	430 MPa	290 MPa	122 HB			

Source: (PN-EN 573-3:2014-02 and PN-EN 485-2:2016-10).

The 3D model of the test sample and the design of the manufacturing process, which included the machining process simulation and the generation of the CNC control code, were developed in the NX10 software environment. The test samples were machined with an Avia VMC 800HS machining centre with a Heidenhain iTNC 530 control system.
The manufacturing process of the test sample machining included:
- contour milling,
- grooves and central hole milling,
- spot drilling and drilling of remaining holes.

The test samples were fabricated with four different tools:
- a milling cutter (SGS 44305), diameter: ø8 mm – roughing contour milling,
- a milling cutter (SGS 44701), diameter: ø6 mm – finishing contour milling, grooves and central hole milling,
- a spotter (NWRc 2.0 A DIN 333-A), diameter: ø2 mm – spot drilling,
- a twist drill (NWKa DIN 338 HSS), diameter: ø8.5 mm – drilling of remaining holes.

Due to the use of high-performance machining technologies from the High Speed Machining group, the milling cutters, held in heat-shrink holders, were balanced on a CIMAT-RT 610 balancing machine.
Table 2 shows the technological parameters used in the machining process.

Table 2
Technological parameters used in the machining process

Machining operations	Technological parameters		
	v_C [m/min]	f_Z [mm]	n [rpm]
Roughing contour milling	402	0.06	16,000
Finishing contour milling	414	0.06	22,000
Grooves and central hole milling	301	0.06	16,000
Spot drilling	30	0.05	4,775
Drilling	30	0.05	1,194

The machining effect indicators by which the machining results could be compared between the machine level programming and CAM programming were:
- machining time,
- surface quality,
- dimensional deviation of selected geometric features.

Fig. 2 presents a simplified plan of the experiment. The programming method (either the machine level programming or the CAM programming) was an independent variable. Dependent variables included machining time, surface quality, and dimensional deviation. The fixed factors were the material of semi-finished product (EN-AW 2024), and the test sample geometry.

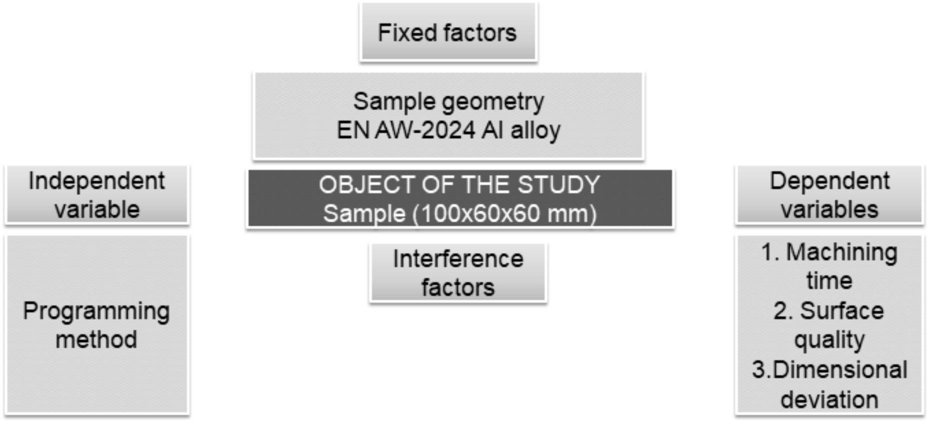


Fig. 2. Simplified plan of the experiment

The machining time was defined by the readings of the CNC control panel and verified with a digital stopwatch. The surface quality was inspected by visual examination. The dimensional deviation was determined by measuring the geometric features of the test samples with a Zeiss Vista coordinate-measuring machines.
The tool paths were optimised after the first test, therefore, two test samples were fabricated for each of the two programming methods.

3. RESULTS

In the first stage of the experiment, the obtained machining times during the machine level programming and the CAM programming were analysed for two tests of machining. Fig. 3 shows a comparison of the machining times from the two programming methods. For the trial version (test no. 1) of the CAM programming, machining times was 4 min 13 s, while for the final version (test no. 2) – 3 min 59 s. In case of the machine level programming, during the trial version (test no. 1), machining times was 6 min 11 s, and for the final trial (test no. 2) the time was shortened and amounted to 5 min 24 s. Based on obtained results of machining times, it was observed that the CAM programming can reduce the machining time by about 20% against the machine level programming. It can be argued then that CNC machining programs developed by CAM programming allow for a better machining efficiency than machine level programming, which probably results from better optimization of paths in the CAM software.

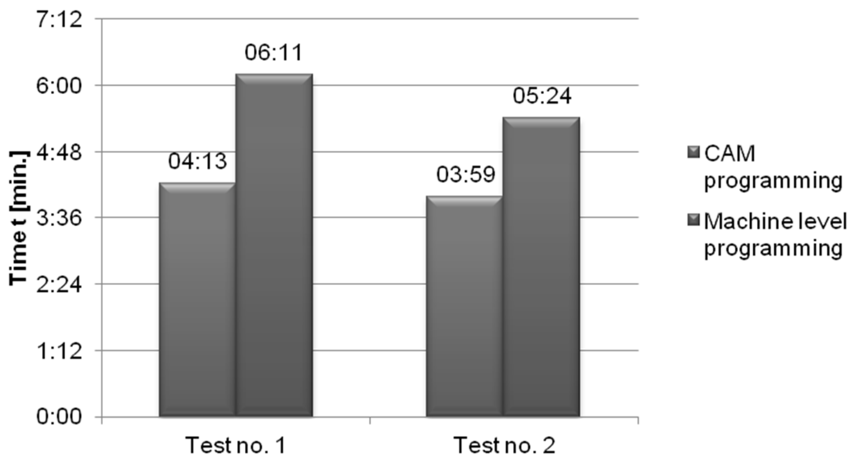
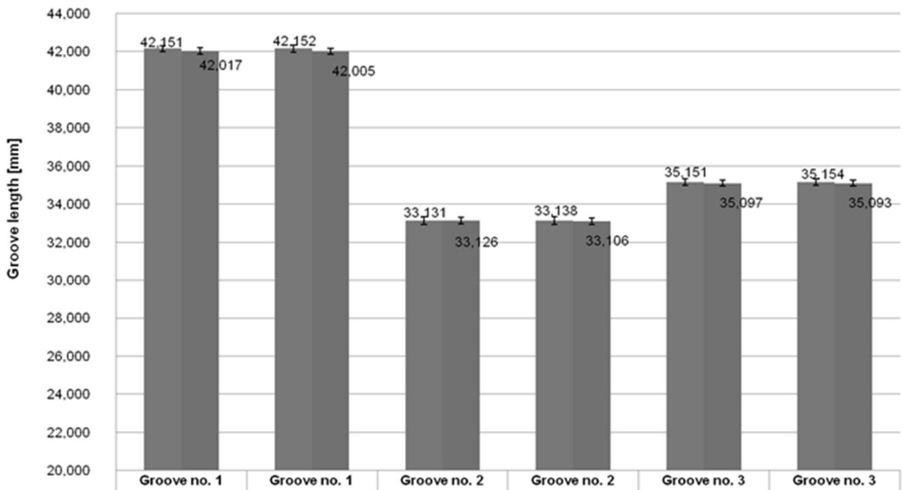


Fig. 3. Comparison of the machining times from the two programming methods

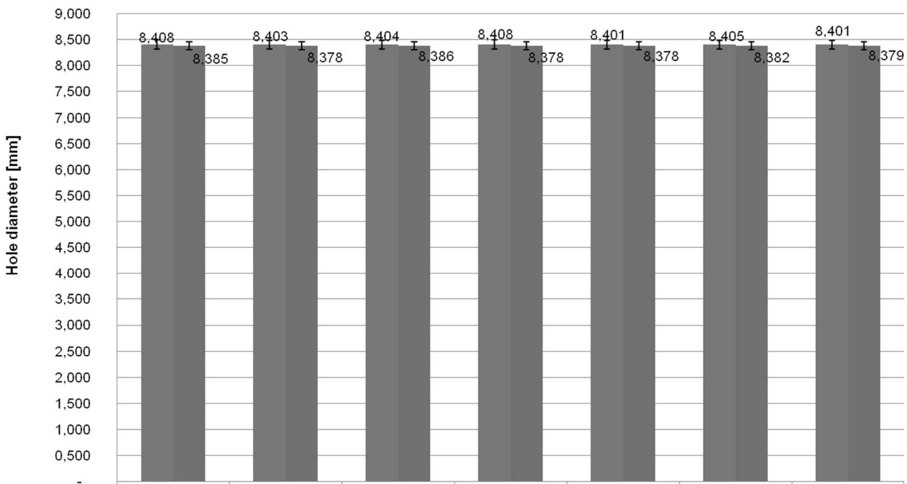
The second stage of the analysis of the machining results was an assessment of the surface quality. A comparison of the surface quality between the test samples machined with the machine level programming and the CAM programming revealed no significant difference. For both programming methods, a notch was visible on an inner wall of groove, but this phenomenon was more prominent in the test samples fabricated with the machine level programming.
The last stage of the analysis included the measurement of specific geometric features. It started with the measurement of the length of three grooves, which the nominal dimensions were, respectively: 42 mm (groove no. 1), 33 mm (groove no. 2) and 35 mm (groove no. 3). Fig. 4 shows the measured groove length for the two programming methods.



	Groove no. 1 Test no. 1	Groove no. 1 Test no. 2	Groove no. 2 Test no. 1	Groove no. 2 Test no. 2	Groove no. 3 Test no. 1	Groove no. 3 Test no. 2
Machine level programming	42,151	42,152	33,131	33,138	35,151	35,154
CAM programming	42,017	42,005	33,126	33,106	35,097	35,093

Fig. 4. Measured groove length for the two programming methods

Fig. 5 presents the measurement results for the hole diameters with a nominal size of 8.5 mm obtained for both programming methods during the final test (test no. 2).



	Hole no. 1	Hole no. 2	Hole no. 3	Hole no. 4	Hole no. 5	Hole no. 6	Hole no. 7
Machine level programming	8,408	8,403	8,404	8,408	8,401	8,405	8,401
CAM programming	8,385	8,378	8,386	8,378	8,378	8,382	8,379

Fig. 5. Measured hole diameters for both programming methods (test no. 2)

The results expressed as the measured length values of the grooves and the hole diameters revealed that they were close the nominal values. The maximum dimensional deviations of all grooves were found in the test samples machined with the machine level programming and they equalled, respectively: groove no. 1 - 0.152 mm (test no. 2), groove no. 2 - 0.138 mm (test no. 2), groove no. 3 - 0.154 mm (test no. 2). For the hole, the highest dimensional deviation also obtained for the machine level programming and it was -0.122 mm (in holes no. 2 and no. 5). Note that the machining effects in the drilling of holes depends mainly on the tool quality and the machining parameters. A logical take of the problem dictated that there should be no significant differences in the dimensional deviations of the hole diameters between the two programming methods. Still, the highest dimensional dimension was found in the machining with the machine level programming. This will require an in-depth analysis. The experiment led to a conclusion that the CAM programming provided lower machining errors.

4. CONCLUSION

- Based on the experimental results, it was found that the CAM programming provided better manufacturing and cost efficiency effects than using the machine level programming.
- The application of the CAM programming reduced the machining time by approx. 20% from the machining time provided by the machine level programming. In cost efficiency terms, a reduction of machining time is crucial, because of the machining industry continues to minimize the manufacturing costs. Time saving by the CAM programming is an effect of multiple contributors, including optimised tool paths and removal of obsolete dead movements.
- The analysis of the selected geometrical features revealed that the machine level programming gave higher dimensional deviations. This means that the CAM programming, in addition to increasing the efficiency, also ensures higher accuracy of elements.
- CAM software does not block the CNC machine tool, when the program is created. However, it requires a PC workstation and a CAM software installation.
- A major aspect of CNC machine tool application is safety. A CAM software allows for simulating models of fixtures, tools and also machine tool. This largely eliminates the risk of tool and workpiece collision and removes costs of damage of the tools, the fixtures, or the machine tool.
- Note that despite the advanced evolution in the design of modern CNC machine tools, machine level programming is encumbered with a risk of programming errors, and consequently the occurrence of a costly collision, also in comparison with programming in the CAM is characterized by much lower efficiency.

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