SolidCAM iMachining technology positive effects on cutting tool life during machining AISI 304 steel

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Abstract – *In this paper, the effect of the use of SolidCAM iMachining technology on tool wear during machining of the stainless steel AISI 304 is analyzed. Detection of the tool wear is done indirectly through the measuring appropriate dimensions of the machined parts after machining each of the last 20 items in a raw of 50 items with same machining settings. G-code generated by iMachining technology run on a five-axis milling machine DMU60 MonoBLOCK. Cutting tools used in the operations were 16mm and 4 mm endmills, produced by SARTORIUS and designated as SARA, VHM 35/38, with AlTiN+ coating system. Expected tool life for these tools are about 200-300 min. By performing simple measuring of three characteristic linear dimensions (k1, k2 and k3) there have not been detected significant deviation in measure not even after approximately 1000 min of the machining time. Cutting process flows smoothly and without noise increase. Measuring's were performed by TS642 Heidenhain IR Touch probe and standard caliper tools. MahrSurf TS50 non-contact surface microscope was used to check cutting edge conditions. Dimensional variation is presented in MS Excel using graphs. Also, snapshots of tool wear are presented at the end of the paper.*

Key Words*: *iMachining, Milling, Measuring, Stainless-steel, Cutting edge, Tool wear

1. INTRODUCTION

The production of various products of a certain quality in the metal processing industry is influenced by various factors. These influences can be identified in different ways. Machining technology, cutting tool, jigs and fixtures as well as the machine properties itself have great influence on the production of the workpiece. The main goal of modern methods is to optimize the influencing factors and find their relationship. Also, the basic goal is modern manufacturing metal parts finding reliable tools and methodologies that could consider both individual and mutual influences of all production parameters on quality final workpieces [1]. It is not possible to produce a quality product without a quality tool. However, what is perhaps even more important is to find the appropriate processing modes or cutting conditions for a given tool in order to get the maximum level of productivity. All these production requirements can be achieved by applying iMachining technology. On the official website of SolidCAM it can be find that it is possible to reduce machining time by up to 70% while extending the life of the tool by applying iMachining technology [2]. One such saving has just been described in this paper. Namely, the tool with an estimated lifespan of up to 300 working minutes, using iMachining technology lasted almost 1000 minutes. The aim of this paper is to determine whether this increase in tool life affected the dimensions of the final piece, i.e. whether the dimensions of the workpiece remained within the tolerance limits provided by the drawing.

2. EXPERIMENTAL SET-UP

The workpiece material is 1.4301 - stainless steel. Workpiece which is analyzed is shown in Fig. 1.

Fig -1: Appearance of analyzed work piece

AISI 304 (1.4301) is a widely-used austenitic chromium-nickel stainless steel. It has excellent drawing properties and very good formability, while it is also highly corrosion-resistant. Typical uses of 304 stainless steel include sinks, kitchen equipment such as pans, tubing and much more. Type 304 is sometimes also referred to as 18/8, a moniker that comes from its typical composition of 18% chromium and 8% nickel. Other elements in the alloy include manganese, silicon, nitrogen, carbon, phosphorus, and sulphur [3].

Machinability of this steel is related to very narrow region of cutting conditions. It is unique and is different from other metals, and carbon or alloy steels [4]. Stainless steel possesses a significant challenge for micro-manufacturing technologies, primarily due to its low machinability [5]. Thermal properties of the material results in intensive heat generation. This heat affecting significantly cutting tool, decreasing its tool life. Hence the tool is being damaged very quickly if the cutting conditions are not appropriate. Any deviation from optimal cutting conditions lead into a tool deterioration. Stainless steel possesses some properties, such as low thermal conductivity and high ductility that make them be classified under materials of poor machinability that exhibit a lot of difficulties during cutting [6]. It has long been recognized that conditions during cutting, such as feed rate (mm/rev), cutting speed (m/min) and depth of cut (mm), should be selected carefully to optimize the economics of machining operations and to improve productivity [7]. In this paper, iMachining technology (constant chip thickness methodology) is used in G-code generation process.

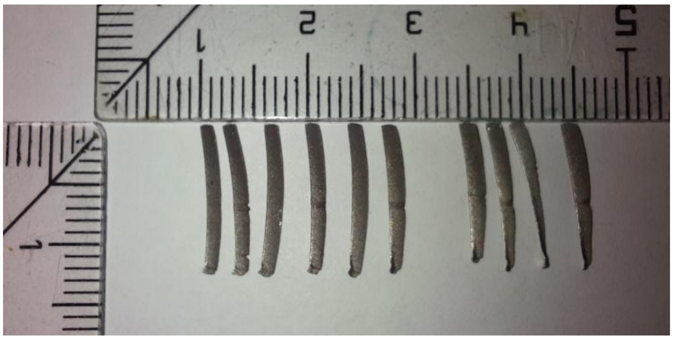


Fig -2: Chip dimensions preview

From Figure 2 it can be seen that the chip thickness (1 mm) is constant and almost with same length (approximately 12 mm). It In general, there are two main types of improvements using iMachining technology: decreasing in Machining Time and increasing in Tool Life. Machining Time can be shortened by increasing the average Material Removal Rate (MRR). Retracts can be kept to a minimum by carefully analyzing the geometry and topology of the remaining material, finding the shortest, relatively smooth relocating detour path to the endpoint, at the current z level of the tool, comparing it to the total length of the alternative retract path, and choosing the shorter of the two. MRR can be further increased by increasing the chip volume. The chip volume is the product of the axial depth of cut, the chip thickness and the chip length. The chip length is determined by the tool radius, the tool engagement angle, the feed and the spindle speed. General role is that the higher the feed the longer the chip and the lower the spindle speed, the longer the chip. Tool life can be increased by ensuring a stable mechanical and thermal load on the tool. The main factor influencing tool wear is vibration. Using appropriate cutting conditions generated tool path results in minimizing dangerous vibrations. To increase tool life, care should be taken to avoid unexpected changes in chip thickness and feed, to keep the tool cutting constantly most of the time, and keeping to a minimum the frequency of repositioning. Tools break and wear out when disproportionately heated, and when vibrations set in. With the high cutting speeds of iMachining, a significant portion of the heat produced by the cut is removed from the cutting zone by the chips flying out. Also, a significant part of the heat is dissipated by using the emulsion. By using forced air cooling, preferably from 2-4 different directions, tool heating may be further reduced. Even if appropriate cutting conditions are used, vibrations may set in, if the workpiece is not clamped appropriately, or if the tool is not (enough) securely fastened. The rigidity of all motion related elements of the machine tool (guide ways, ball screws, bearings, etc.) is critical in the efforts to reduce vibrations and chatter. So, when using a less rigid machine, selecting a less aggressive level of cutting conditions will help to reduce vibrations. In the Technology Wizard window, there is a special slider to select the desired Milling Aggressiveness Level. Changing the level of aggressiveness by simply moving the slider, results in the calculation of a new set of matching values for the cutting conditions parameters [7].

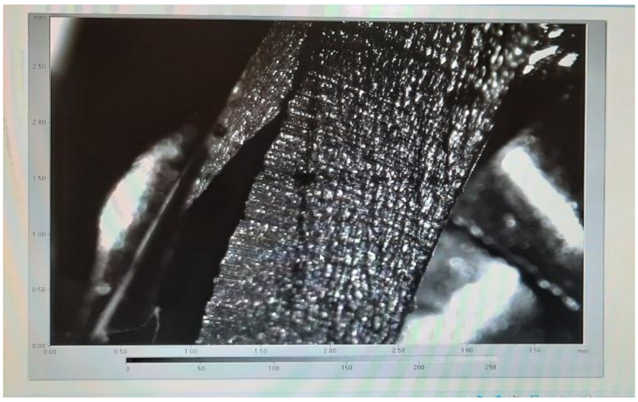


Fig -3: Chip surface preview with MahrSurf TS50 non-contact surface microscope

2.1 Workpiece dimensions

After machining is complete, the machined parts were measured, during which certain dimensional changes caused by tool wear were observed. The Fig. 4 shows the characteristic measures (k1, k2 and k3) for the analysis of changes in the dimensions of the workpiece.

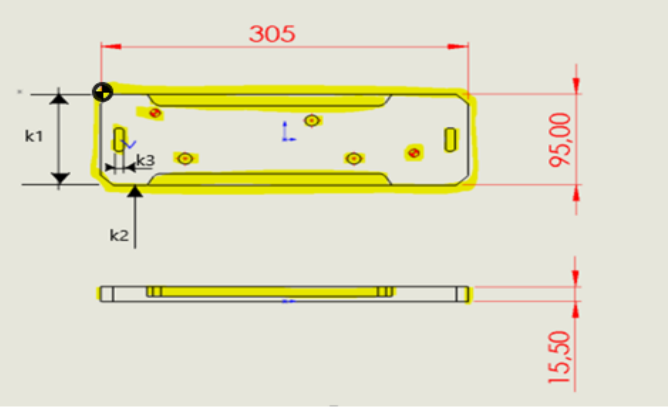


Fig -4: Characteristic measures for the analysis of changes in dimensions

Dimension k1 represents the width of the workpiece, i.e. external measure from side to side; k2 represents the distance from zero of the machine; while k3 represents the width of the pocket, i.e. internal measure. In theory, k1 and k2 should be equally, yet due to clearance 8H7/h6 during positioning the workpiece on the table (through the pin and pin/hole system) there are difference in measure that should not be higher than tolerance of the pin/hole system (0,05 mm). For the analysis, last 20 pieces of the 50 items machined in a raw were taken. Dimensions k1 and k2 were measured with IR touch probe on a milling machine (Fig. 5), and k3 with a caliper tool. Last item (no.20) is machined with new (fresh) tool.

Fig -5: Measuring with IR touch probe on milling machine

Measured dimensions are shown in Table 1.

Table -1: Measured dimensions for 20 parts

No. of part	k1 [mm]	k2 [mm]	k1-k2 [mm]
1.	94,9511	94,9586	-0,0075
2.	94,955	94,9422	0,0128
3.	94,9636	94,9644	-0,0008
4.	94,9546	94,9646	-0,01
5.	94,9502	94,9363	0,0139
6.	94,9508	94,952	-0,0012
7.	94,9655	94,9688	-0,0033
8.	94,9549	94,934	0,0209
9.	94,9567	94,9518	0,0049
10.	94,9632	94,9671	-0,0039
11.	94,9541	94,9613	-0,0072
12.	94,9503	94,9568	-0,0065
13.	94,9536	94,9383	0,0153
14.	94,9576	94,9707	-0,0131
15.	94,9577	94,9692	-0,0115
16.	94,966	94,944	0,022
17.	94,9553	94,9213	0,034
18.	94,9579	94,9576	0,0003
19.	94,9579	94,9445	0,0134
New tool- 20.	94,9868	94,9655	0,0213

The obtained values were analyzed, entered in Excel and their change and dependence is shown in Chart 1.

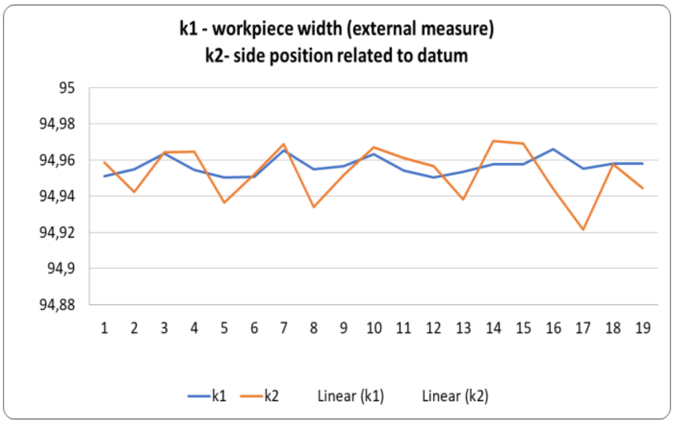


Chart -1: The change of obtained k1 and k2 values

On Chart 1 the k1 and k2 measures from the first to the last piece can be clearly seen. Also it can be concluded that the wear of the tool, after each machining, lead to the increasing in k1 and k2 dimension differences. That is shown in Chart 2, i.e. the graphical representation of the difference between the dimensions k1 and k2.

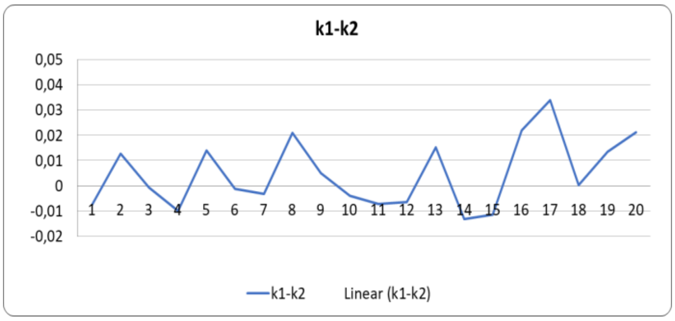


Chart -2: The difference between the obtained k1 and k2 values

Dimension k3 is related to the pocket machining with second tool, 4mm endmill. It was measured manually, using caliper tool. The measured data are shown in Table 2. From the diagram of the change in the dimension of the pocket, it can be seen that there have been small changes, but due to the inaccuracy of measurements with a caliper tool, they are considered acceptable and can be classified within the allowed tolerance read from the drawing 8 ± 0.05. Besides, the fixturing of the workpiece is done by pin/hole system with same tolerance of 0,05 mm.

Table 2: Measured k3 values

No. of part	k3
1.	7,94
2.	7,93
3.	7,93
4.	7,92
5.	7,91
6.	7,9
7.	7,91
8.	7,92
9.	7,92
10.	7,94
11.	7,97
12.	7,98
13.	7,96
14.	7,95
15.	7,95
16.	7,96
17.	7,94
18.	7,97
19.	7,96
New tool- 20.	7,95

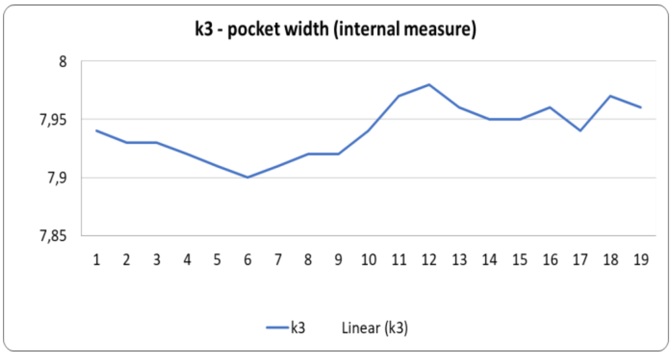


Chart -2: The change of obtained k3 values

3. TOOL WEAR

Tool wear resulting from iMachining operations shown in Fig. 5, will be considered and presented in next few pictures.

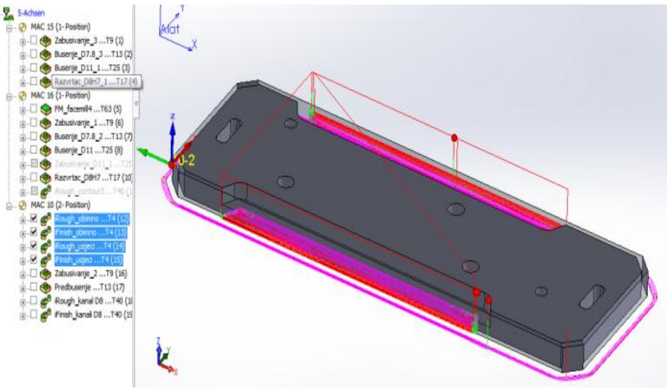
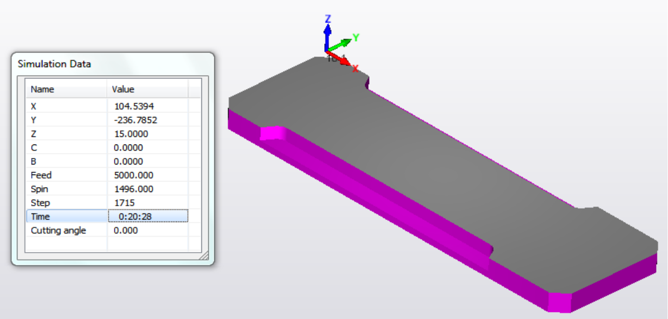


Fig -7: iMachining operations

Occurrence of weak adhesion between the tool and the workpiece causes adhesive wear by the mechanical removal of tool material when the adhesive junctions are broken as the chip flows over the tool [8]. Machining was performed on a five-axis milling machine, the processing tool used in this case is a 16 mm endmill, SARTORIUS-SARA, VHM 35/38,with AlTiN + coating.

Fig. -8: EndMill SARTORIUS-SARA, VHM 35/38, AlTiN + coating

Endmill characteristics: solid carbide tool cutting material, with 4 cutting edges for wet and dry machining, extremely high material removal rates and tool life. The tool worked for approximately 1000 minutes (20 min x 50 pcs, Fig. 9).



Simulation Data

Name	Value
X	104.5394
Y	-236.7852
Z	15.0000
C	0.0000
B	0.0000
Feed	5000.000
Spin	1496.000
Step	1715
Time	0:20:28
Cutting angle	0.000

Fig -9: Machining time for endmill ϕ16 mm per one work piece

The tool worked evenly at depths of 8 mm and 16 mm.

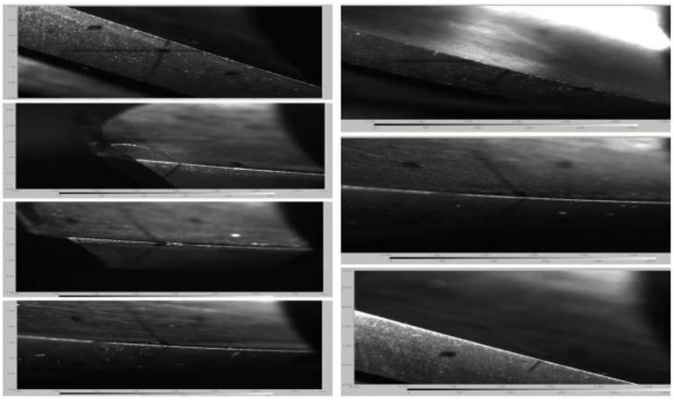


Fig. -10: Preview of gradual tool wear using MahrSurf TS50 non-contact surface microscope

The analysis of the tool wear shows that there are some chipping of the cutting edge, probably generated during first cut in stock material that is prepared by laser cutting. Heat affected layer might be considered as cause of this chipping (Fig. 11). On the other hand, Fig. 10 reveals that the rest of the engaged cutting edge shows no significant (distinctive) tool wear feature. Yet, the wearing is, of course, existing and that is confirmed by increasing values of k1, k2. The possible reason for well tool performance might be appropriate tool coating selection. Generally, AlTiN and TiAlN coatings are used in dry or wet machining (milling or turning) of SS 304 steel because of their high oxidation [9], and good wear resistance [10]. With increasing aluminum content in the TiAlN coatings, phase changes occur, resulting in TiN=TiAlN. This change from single layer to multilayer eventually improves the surface properties of the coating [11].

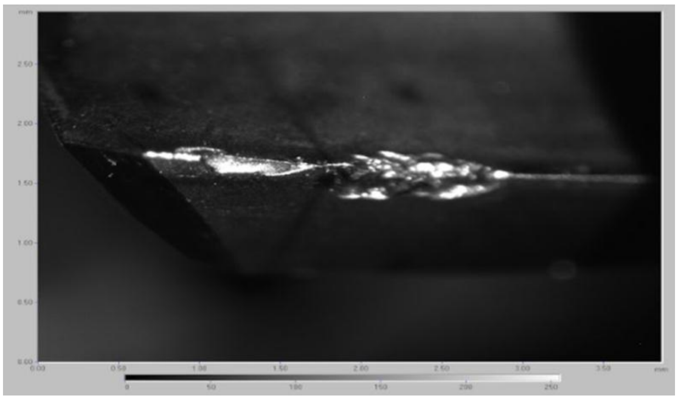


Fig. -11: The tool cutting edge chipping preview using MahrSurf TS50 non-contact surface microscope

3. CONCLUSIONS

The conclusion that can be draw based on the analysis of the performed measurement is that tool wear has an impact on smaller deviations of dimensions k1, k2 and k3, and that these deviations increase with the number of processed pieces. The tolerance of the measures given in the drawing is 0.05 mm for all three dimensions k1, k2, k3. Only dimension k3 has deviations of measured values that exceed the allowed tolerance. Out of a total of 20 pieces, for 11 pieces, the measure k3 exceeds the value of the allowed tolerance, and that slightly. This can be attributed to measurement errors, since the measurement was performed with a caliper tool, so the error of the measuring instrument as well as the measuring performer is possible. In addition to measurement errors, significant tool wear was observed, which can also affect the final values of the dimensions. Figures 6 and 7 clearly show the tool wear recorded on a microscope. Crater-shaped tool wear can be seen on the cutting edges (less than 2 mm). These craters can be caused by tools coming across hardened parts or inclusions in the material that are unpredictable. When the tool encounters such hardened inclusions, the tool material is carried away on the cutting edge.

The advantages of using iMachining technology are certainly visible in terms of tool life. Namely, the endmill tool lasted about 1000 minutes in the machining. This work proves that iMachining technology extends tool life by 70% and more.

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