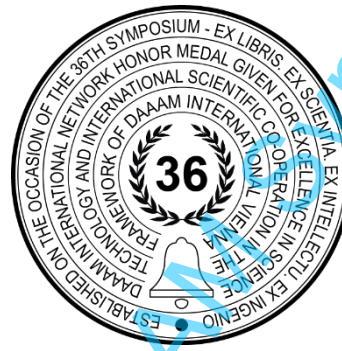


EXPERIMENTAL COMPARISON OF ADAPTIVE MILLING STRATEGIES ACROSS COMMERCIAL CAM SOFTWARE

Filip Klatil & Jan Hnatik



This Publication has to be referred as: Klatil, F[ilip] (2026). Experimental Comparison of Adaptive Milling Strategies Across Commercial CAM Software, Proceedings of the 37th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/37th.daaam.proceedings.xxx

Abstract

This paper investigates adaptive milling strategies available in computer-aided manufacturing systems can generate different toolpaths even when the same geometry, tool, and workpiece material are used. This study compares SolidCAM iMachining, Siemens NX 3D Adaptive Roughing, and Autodesk Fusion 360 Adaptive Clearing under workshop conditions. A test component containing an open pocket, an open pocket with an island, and a closed pocket was machined from steels DIN 1.0503 and DIN 1.7225 and stainless steel DIN 1.4404 using an 8 mm four-flute cemented-carbide end mill. Machining time was measured directly on the CNC machine, while tool condition and process behaviour were documented during repeated tests. Fusion 360 produced the shortest total machining time, approximately 15% below SolidCAM and 31% below Siemens NX. However, Fusion 360 showed earlier tool clogging when machining DIN 1.4404, whereas SolidCAM maintained the most stable process during repeated cutting. Siemens NX required the longest machining time and exhibited pronounced tool loading. The results show that CAM strategy selection cannot be based on cycle time alone; toolpath continuity, entry motion, and tool condition must also be considered when selecting an adaptive roughing strategy

Keywords: CAM systems; CNC milling; toolpath strategy; machining time

1. Introduction

Computer-aided manufacturing systems translate product geometry and technological inputs into executable machine-tool motion. In addition to the workpiece model, programming requires information about the machine, tooling, stock, material, postprocessor, and permissible feed and acceleration limits [1]. Cutting-tool definitions also require consistent geometric data such as diameter, cutting-edge length, flute number, corner radius, and helix angle [2]. Although modern systems automate many settings, technological control remains necessary because software environments still generate and transfer machining parameters differently.

Adaptive roughing is intended to maintain a more uniform tool engagement by combining a relatively small radial engagement with a larger axial depth and smooth changes of direction [6]. The practical result depends on how the CAM

algorithm connects cutting passes, enters enclosed regions, and limits engagement in corners. Measurements of conventional milling and iMachining in open and closed pockets have also shown that the claim of constant tool load must be evaluated using the actual cutting-force response [7].

Toolpath geometry and cutting parameters must therefore be assessed together. The definition of the end mill, including its flute and edge geometry, provides an additional basis for interpreting tool engagement and chip evacuation [2]. Process monitoring can provide supporting evidence because vibration and acoustic emission respond to changes in cutting conditions and stability [8]. These considerations support a multi-criterion comparison rather than a ranking based only on simulated cycle time.

The present study compares three commercial adaptive roughing strategies: SolidCAM iMachining, Siemens NX 3D Adaptive Roughing, and Autodesk Fusion 360 Adaptive Clearing. The research question is whether the three systems, when applied to the same test features and tool specification, produce meaningful differences in measured machining time, toolpath behaviour, and observed tool condition. The primary criterion is machine time measured on the CNC machine; qualitative tool-condition observations are used to interpret whether the shortest cycle also provides a stable cutting process.

2. Materials and Methods

2.1. Workpiece materials and test component

The experiment used non-alloy steel DIN 1.0503, Cr-Mo steel DIN 1.7225, and austenitic stainless steel DIN 1.4404. DIN 1.0503 is commonly used for moderately loaded machine components [3]. DIN 1.7225 is characterised by higher hardenability and wear resistance [4], while DIN 1.4404 represented the most difficult material in the test group because of its tendency to work harden and adhere to the cutting edge [5]. The tests involving DIN 1.7225 and DIN 1.4404 were each repeated on three separate blanks, whereas DIN 1.0503 was tested only once because the initial run did not reveal differences large enough to justify further repetitions within the preliminary experiment. Consequently, the present dataset is not balanced across the material groups and does not provide a sufficient basis for reliable statistical testing. Future experiments will therefore employ an equal number of repetitions for all three materials to enable statistically robust comparisons of the effects of workpiece material and CAM strategy.

Material	Material group	Test repetitions
DIN 1.0503	Non-alloy steel	1
DIN 1.7225	Cr-Mo steel	3
DIN 1.4404	Austenitic stainless steel	3

Table 1. Workpiece materials and experimental repetitions

The test component contained three representative features: an open pocket, an open pocket with an island, and a closed pocket. Two pockets included slightly inclined walls. The closed pocket was particularly important because the software had to generate an entry motion and then maintain adaptive engagement inside a confined region.

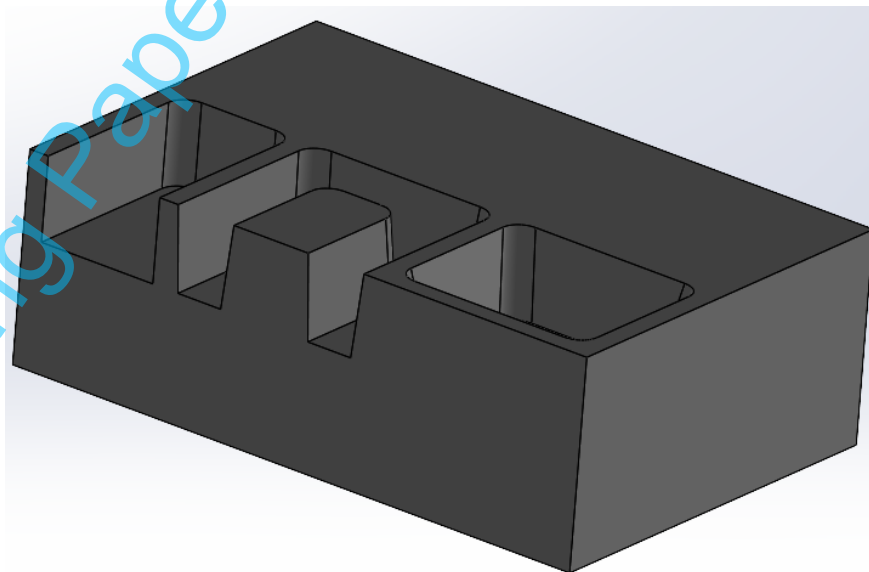


Fig. 1. Test component with three pocket geometries

2.2. Cutting tool and compared strategies

All tests used a four-flute, 8 mm solid cemented-carbide end mill supplied by Hofmeister; the main geometric parameters follow standard end-mill terminology [2]. The tool was selected as a general-purpose cutter rather than a geometry optimized for one specific material. This choice made it possible to observe the combined influence of workpiece material and generated toolpath without introducing a material-specific tool design

Parameter	Value	Parameter	Value
Diameter	8 mm	Cutting-edge length	19 mm
Number of flutes	4	Overall length	63 mm
Corner radius	0.1 mm	Helix angle	30 degrees

Table 2. Main dimensions of the cemented-carbide end mill

The compared operations were iMachining in SolidCAM, 3D Adaptive Roughing in Siemens NX, and Adaptive Clearing in Fusion 360. The same part geometry and tool definition were used as the comparison basis. For each material, the target technological conditions were kept comparable, while each CAM system generated its own motion sequence, entry strategy, links, and local engagement control.

2.3. Experimental procedure and evaluation

Each pocket was prepared as a separate numerical-control program so that its machining time could be recorded independently. Time was measured directly during machining rather than taken only from CAM simulation. The tool was documented before testing and inspected during the experiment. Observations included sparks during entry, vibration, edge chipping, and material adhesion or clogging the tool face.

Machining time was the primary response. Tool condition was treated as a supporting qualitative response because the experiment did not measure flank-wear width, cutting forces, spindle load, or acoustic emission. This distinction is important: the study compares process behaviour and visible tool condition, but it does not establish statistically validated tool life for any CAM system.

3. Results and Discussion

3.1. Machining time

Fusion 360 produced the shortest total time for every tested material, while Siemens NX produced the longest. Summed over all three materials, the recorded totals were 40.39 minutes for Fusion 360, 47.60 minutes for SolidCAM, and 58.98 minutes for Siemens NX. Fusion 360 was therefore approximately 15.1% faster than SolidCAM and 31.5% faster than Siemens NX. The largest separation between systems occurred in the closed pocket, where entry and the organisation of successive levels contributed more non-cutting or less direct motion.

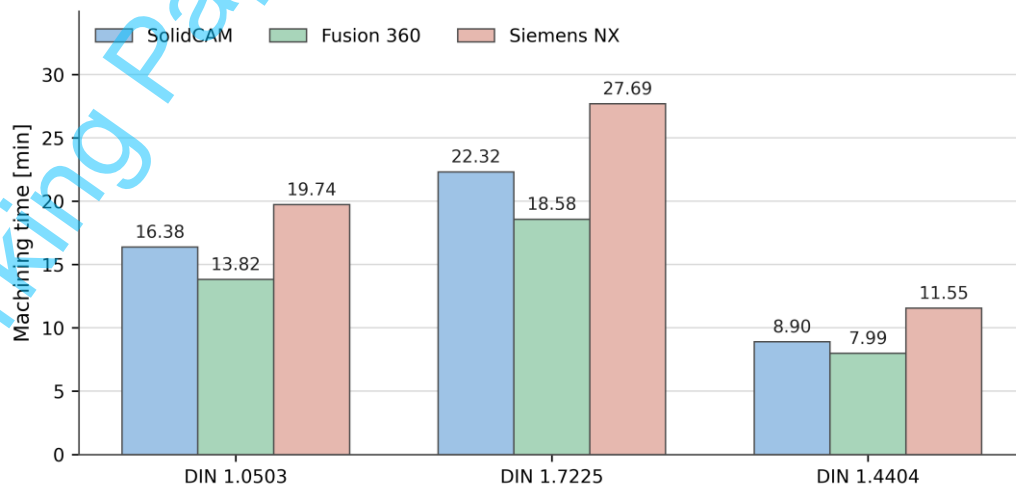


Fig. 2. Total recorded machining time by material and CAM system

Material	Feature	SolidCAM [min]	Fusion 360 [min]	Siemens NX [min]
DIN 1.0503	Open pocket	3.08	2.32	3.38
DIN 1.0503	Open pocket with island	9.14	7.40	10.28
DIN 1.0503	Closed pocket	4.16	4.10	6.08
DIN 1.0503	Total	16.38	13.82	19.74
DIN 1.7225	Open pocket	4.39	3.30	5.07
DIN 1.7225	Open pocket with island	12.58	10.08	14.32
DIN 1.7225	Closed pocket	5.35	5.20	8.30
DIN 1.7225	Total	22.32	18.58	27.69
DIN 1.4404	Open pocket	1.25	1.18	1.45
DIN 1.4404	Open pocket with island	5.10	4.38	6.10
DIN 1.4404	Closed pocket	2.55	2.43	4.00
DIN 1.4404	Total	8.90	7.99	11.55

Table 3. Recorded machining times for the three pocket features

3.2. Generated toolpaths

The time differences were consistent with the observed motion patterns. In the closed pocket, Siemens NX first roughed the corner radius and then completed the remaining perimeter by separate levels. The sequence was systematic but divided the operation into more distinct segments and transitions. Fusion 360 generated the most continuous motion: it pre-roughed the radius and completed the remaining material on the same level with fewer interruptions. SolidCAM behaved between these two approaches, alternating more frequently between regions of the pocket and then returning to complete other corners or perimeter sections.

The observed motion patterns show that toolpath selection can influence machining time even when the removed geometry is unchanged. Studies reported related evidence when comparing cutting-force behaviour for conventional milling and iMachining in open and closed pockets [7].

3.3. Observed process behaviour and tool condition

The fastest strategy did not provide the most stable tool condition in the difficult materials. During machining of DIN 1.7225, Fusion 360 showed sparking during entry in the second test and a stronger occurrence in the third. Siemens NX showed still more pronounced sparking in the second test and repeated it in the third. SolidCAM completed the repeated tests without a comparable failure; only mild sparking was observed during entry in the third test.

The distinction became clearer in DIN 1.4404. The Fusion 360 tool clogged during entry into the final pocket in the second test and could not be reused. The Siemens NX tool completed the second test with light sparking but clogged in a similar entry region during the third test. SolidCAM completed the third test with light vibration and without the severe clogging observed for the other two strategies. Figure 3 documents the tool faces after the reported tests.



(a) Fusion 360



(b) Siemens NX



(c) SolidCAM

Fig. 3. Tool condition after repeated machining of DIN 1.4404

The qualitative observations indicate a productivity-stability trade-off. Fusion 360 reduced machining time by using more continuous and direct paths, but material adhesion developed sooner in DIN 1.4404. SolidCAM required more time but maintained the most stable cutting behaviour across repeated tests. Siemens NX combined the longest time with marked tool loading, showing that a longer cycle does not automatically imply a gentler process. Cutting-force measurements of iMachining similarly demonstrate that tool-load claims should be verified experimentally under the selected pocket geometry and cutting conditions [7].

3.4. Limitations and further work

The experiment was designed as a practical comparison and has four main limitations. First, the number of repetitions was not balanced because DIN 1.0503 was tested once. Second, tool condition was evaluated visually rather than by a quantitative wear criterion. Third, spindle load, cutting forces, vibration, and energy consumption were not recorded. Fourth, the comparison represents one part geometry, one tool diameter, and one set of target conditions. The results therefore identify system-specific behaviour for this test but do not establish a universal ranking of the software.

Further work should use the same number of repetitions for all materials, extend the cutting time and removed volume, measure flank wear and adhesion after each feature, and record spindle load or cutting force synchronously with the toolpath [9]. Acoustic-emission or vibration sensing would provide an additional stability indicator [8]. Testing modified entry motions in the closed pocket would also help determine whether the observed clogging was caused primarily by entry geometry or by the subsequent adaptive path.

4. Conclusion

The experiment demonstrated that three adaptive roughing strategies generated materially different machining times and tool responses for the same pocket features. Fusion 360 achieved the shortest total time, approximately 15.1% below SolidCAM and 31.5% below Siemens NX. Its advantage came from more continuous paths and fewer interrupted movements, particularly in the closed pocket. However, it produced the earliest tool clogging in DIN 1.4404. SolidCAM did not achieve the shortest cycle but provided the most stable repeated machining, while Siemens NX combined the longest time with pronounced tool loading. CAM-system selection should therefore consider both cycle time and the way in which the generated path loads the cutter. The present findings support direct machine verification of a CAM strategy before it is adopted for difficult materials or repeated production.

5. Acknowledgments

This article was supported by the Ministry of Education, Youth and Sports of the Czech Republic (MŠMT) under the project SGS-2025-025: Research and development for innovation in Machining, additive technology and quality assurance.

6. References

- [1] SolidCAM Ltd. (2025). SolidCAM Documentation, available at: <https://www.solidcam.com/subscription/documentation/> (accessed 01 October 2026)
- [2] Mitsubishi Materials Corporation (n.d.). End Mill Features and Specification, available at: https://www.mitsubishicarbide.net/contents/mhg/de/html/product/technical_information/information/endmill_terminology.html (accessed 01 October 2026)
- [3] Studer-Biennaform (n.d.). 1.0503 – C45 Heat-Treatable Steel Properties and Applications, available at: <https://www.studersa.com/en/materials/10503-c45-10083-2-a830-a830m-1045-g10450;127> (accessed 15 October 2026)
- [4] Siderticino (n.d.). 42CrMo4: Steel Technical Specifications, available at: <https://siderticino.it/en/steel-datasheets/42crmo4/> (accessed 15 October 2026)
- [5] Abrams Industries (n.d.). 1.4404 / 1.4401 Stainless and Acid-Resistant Steel, available at: <https://eu.abrams-industries.com/steel/premium-14404-14401/> (accessed 15 October 2026)
- [6] Canadian Metalworking (n.d.). What Dynamic Milling Can Do for You, available at: <https://www.canadianmetalworking.com/canadianindustrialmachinery/article/automationsoftware/what-dynamic-milling-can-do-for-you> (accessed 01 October 2026)
- [7] Hnatik, J.; Kutlwaser, J. & Sklenicka, J. (2016). iMachining Cutting Force Measurement, Proceedings of the 26th DAAAM International Symposium, pp.0955-0959, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/26th.daaam.proceedings.134
- [8] Povolny, M.; Kroft, L. & Sykora, J. (2022). Vibration Measurement During Milling by Acoustic Emission, Proceedings of the 33rd DAAAM International Symposium, pp.0319-0325, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-36-5, ISSN 1726-9679, Vienna, Austria, DOI: 10.2507/33rd.daaam.proceedings.044
- [9] Sklenicka, J.; Hnatik, J.; Fulemova, J.; Gombar, M.; Vagaska, A. & Jirasko, A. (2024). Experimental Analysis of Effect of Machined Material on Cutting Forces during Drilling, Materials, Vol. 17, No. 11, (June 2024), Article 2775, ISSN 1996-1944, DOI: 10.3390/ma17112775