GEOMETRIC DIMENSIONING AND TOLERANCING (GD&T) OF CONCAVE AND CONVEX FORMS IN THE MILLING OF POLYMERS

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ABSTRACT

Milling polymers have particular complications, especially for their low machining temperatures, so it is important to have the optimal variables to obtain the best nominal value for the final manufactured product. This article compares the engineering tolerance for two different milling strategies, parallel "Raster" and spiral trajectories, to machining concave and convex forms.

This investigation concludes, for machining concave forms either Raster or spiral trajectories have good shape tolerance. On the other hand, for machining convex forms spiral trajectory showed the best engineering tolerance, getting a nominal radius closer to the theoretical radius than the Raster trajectory.

KEYWORDS: Machining Strategy, Raster, Spiral, Tolerance & Trajectory

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1. INTRODUCTION

The actual society has progressed so fast that its need for products has increased in the last years. For this reason, manufacturing techniques need to advance, and they need to be more precise to avoid mistakes during the manufacturing process, faults that result in monetary costs, more time in the manufacturing process, or having a not well-done final product. Some of these errors can be avoided by controlling the machining variables, like cutting speed, cutting direction, or tool trajectory.

Mechanical products before becoming a real product have ideal shape parameters, if everything is done in the best way possible, the final result will have all the characteristics desired. But in the manufacturing process, some manufacturing errors cost accuracy in the ending product especially on the geometrical features [1].

Manufacture process can't produce components that have exactly the nominal value assigned, for this reason, it is important to select the best manufacturing strategies, cutting speed, tool, or trajectory [2], [3]. Additionally, machining parameters, like the radius or shape can be affected by the cutting forces, that can be stabilized by the machining strategy [4].

Milling has two main machining strategies, Raster and Spiral. These are going to be the parameter that leaves the mark on the surface of the product, influencing in the final shape and nominal value [5], [6].

Raster strategy is made doing parallel movements of predefined lines. This strategy is mostly used due to the good operation time that presents, is a "simple" strategy and is fast to calculate for the computer; On the other hand, this strategy presents a significant variation of the contact arc, particularly in the corners and in segments with

a change of direction [7].

The spiral strategy consists in doing spiral movements with the tool in the cutting process. This technique allows better machining in the corners of the working piece, and it is efficient for 2D pockets; Also, it has some advantages, such as a smooth trajectory and a constant cutting direction [8].

Milling polymers have some difficulties, the material can melt during the milling process; furthermore, the polymers can reach their glass transition temperature, resulting in different mechanical properties of what was expected for the final product. If the element melts during the process, it will affect directly in the final shape of the product, causing subsequent problems in the manufacturing process. These are the main reason why adequate manufacturing variables must be chosen [2], [9], [10].

2. TECHNIQUES

The measurement was made using the Video Standard Gage system VISUAL 250®. This is LASER equipment, with a coordinate dimension table, x and y; moving lens, z-direction movement, and optical zoom from 0.7X to 4.5X. The measure and result was analyzed using TESA-VISTA® software. This software allows a quick evaluation of the geometry of the piece [11].

The material used for the analysis was PEEK KETRON 1000® [10], poly-ether-ether-kethone, a polymer made and distributed by Quadrant Company. This is a thermoplastic with no reinforcement, high chemical resistance, hydrolysis similar to PPS6 [12]. All the measurands were made from the same batch [13]. The material characteristics are shown in **Error! Reference source not found..**

Table 1: Mechanical Properties [13]

Property	Value
Fracture Strain	40 %
Tensile modulus	4,34 GPa
Compressive strength	138 MPa
Yield strength	110 GPa

Measures were made using five test replicas for each testing form. The geometrical forms used for testing were concave and convex.

All the tested pieces were manufactured using a KDMB06M0ERLDK115M insert, sold by Kennametal company [14]. This is a carbide insert of *premium* quality, with high resistance to damage to non-ferrous materials, can be used, also, in polymers. The carbide insert is shown in **Error! Reference source not found.** and its characteristics in **Error! Reference source not found..**

Table 2: Insert Characteristics [14]

Insert Reference	W(mm)	S(mm)	RC(mm)
KDMB06M0ERLDK115M	6.00	1.60	3.0

Figure 1: Insert Shape [14].

The mounting insert was an HSS, it is shown in **Error! Reference source not found.**, this gave stability and precision to the machining process. All measurands were machined in a CNN milling machine Leadwell V-20i, with 3-dimensional moving coordinates [15].

Figure 2: HSS Mounting Insert [14].

The statistical technique used in this investigation was mean difference, using the data obtained from the radios tested for each technique through optical analysis. The statistical analysis was made using R statistics®, 3.1.3 version.

3. METHOD

Measurands were machined with a 25,4 mm of diameter, a convex and concave form, each of these forms had a theoretical radio of 6.36 mm, as shown in **Error! Reference source not found.**

Figure 3: Measurand's Geometrical Characteristics.

Measurands were manufactured using two different trajectories, *Raster* (parallel trajectory), and *spiral*, these trajectories are shown in figure 4.

Figure 4: a) Parallel Trajectory “Raster”, b) Spiral Trajectory.

4. RESULTS

To determine which trajectory has the best engineering-tolerance, a statistical mean comparison was made using the results obtained through optical measurements.

Results obtained from the measurements taken are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 3: Results of each Technique for Convex Shapes

Technique	Raster				
Radius (mm)	6,321	6,302	6,304	6,249	6,278
Technique	Spiral				
Radius (mm)	6,328	6,339	6,357	6,348	6,336

Table 4: Results of each Technique for Concave Shapes

Technique	Raster				
Radius (mm)	6,382	6,372	6,360	6,370	6,380
Technique	Spiral				
Radius (mm)	6,382	6,386	6,371	6,362	6,370

The radius obtained from convex shape was called radius A, and, in the same way, the radius obtained from concave was radius B for the forehead analysis. This notation is shown in **Error! Reference source not found.**.

Figure 5: Notation for Radius.

For the analysis, a Tukey's range test with a confidence coefficient of 95% was done. Results ANOVA [16], [17] are shown in **Error! Reference source not found.** and **Error! Reference source not found.**

One-way ANOVA: Radius versus Technique

Source	DF	SS	MS	F	P
Techniq	1	0,006452	0,006452	14,24	0,005
Error	8	0,003624	0,000453		
Total	9	0,010076			

S = 0,02128 R-Sq = 64,03% R-Sq(adj) = 59,54%

				Individual 99% CIs For Mean Based on Pooled StDev	
Level	N	Mean	StDev	-----+-----+-----+-----+-----	
1	5	6,2908	0,0279	(------*-----)	
2	5	6,3416	0,0112	(-----*-----)	
				-----+-----+-----+-----+-----	
				6,270	6,300 6,330 6,360

Pooled StDev = 0,0213

Grouping Information Using Tukey Method

Technique	N	Mean	Grouping
2	5	6,34160	A
1	5	6,29080	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Técnica

Figure 6: ANOVA Tukey's Range Test for the Convex Shape.

One-way ANOVA: Radius versus Technique

Source	DF	SS	MS	F	P
Techniq	1	0,0000049	0,0000049	0,06	0,817
Error	8	0,0006856	0,0000857		
Total	9	0,0006905			

S = 0,009257 R-Sq = 0,71% R-Sq(adj) = 0,00%

Level	N	Mean	StDev	Individual 99% CIs For Mean Based on Pooled StDev
1	5	6,37280	0,00879	(-----*-----)
2	5	6,37420	0,00971	(-----*-----)

-----+-----+-----+-----+-----
 6,3600 6,3680 6,3760 6,3840

Pooled StDev = 0,00926

Grouping Information Using Tukey Method

Techniq	N	Mean	Grouping
2	5	6,374200	A
1	5	6,372800	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
 All Pairwise Comparisons among Levels of Técnica

Figure 7: ANOVA Tukey's Range Test for the Concave Shape.

The analysis shows, for machining convex shapes, the spiral technique has the biggest engineering tolerance, compared to the raster technique. For concave forms, there weren't significant differences found between techniques. Both trajectories provide values close to the nominal radius value.

5. CONCLUSIONS

For the machining of the polymer material PEEK, this study concludes:

For machining convex form, the spiral trajectory offers the best engineering tolerance. The Raster trajectory presented a bigger standard deviation, and its average measurement was 6.29mm compared to the average measurement of the spiral technique 6.34 mm.

For concave shapes, either Raster or Spiral trajectories provide an acceptable engineering tolerance, there's not enough evidence to confirm that one trajectory is better than the other. This can be concluded, due to similar results obtained. The average radius obtained for the Raster technique was 6.37 mm, which was the same value obtained for the Spiral technique, with a standard deviation of 0,0198.

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REFERENCES

1. Shao, N., Ding, X., & Liu, J. (2020). Tolerance analysis of spur gears based on skin model shapes and a boundary element method. *Mechanism and Machine Theory*, 144, 103658. <https://doi.org/10.1016/j.mechmachtheory.2019.103658>
2. Wang, B., Wei, S., Wang, Y., Liang, Y., Guo, L., Xue, J., ... Xu, B. (2018). Effect of milling time on microstructure and properties of Nano-titanium polymer by high-energy ball milling. *Applied Surface Science*, 434, 1248–1256. <https://doi.org/10.1016/j.apsusc.2017.11.265>
3. Napolitano, Salvatore, and Antonio Ascione. "Performance Posture Correlation: A Study in the Women's Water Polo." *International Journal of Humanities and Social Sciences (IJHSS)* 6.6 (2017): 53-62.
4. Wang, Y., Calhoun, S., Bosman, L., & Sutherland, J. W. (2019). Tolerance allocations on products: A life cycle engineering perspective. *Procedia CIRP*, 80, 174–179. <https://doi.org/10.1016/j.procir.2019.01.089>
5. Plaza, M., Zębala, W., & Matras, A. (2019). Decision system supporting optimization of machining strategy. *Computers and Industrial Engineering*, 127, 21–38. <https://doi.org/10.1016/j.cie.2018.11.034>
6. Lasemi, A., Xue, D., & Gu, P. (2010). Recent development in CNC machining of freeform surfaces: A state-of-the-art review. *CAD Computer Aided Design*. <https://doi.org/10.1016/j.cad.2010.04.002>
7. Krishnan, Karthika. "A Hypsometric Perspective in Comprehending the Geomorphic Development of Tambraparni River Basin, Western Flank, South Western Ghats." *International Journal of Humanities and Social Sciences (IJHSS)* 4.5 (2015).
8. Nicolais, L., Sheikh-Ahmad, J. Y., & Davim, J. P. (2012). Cutting and Machining of Polymer Composites. In *Wiley Encyclopedia of Composites*. <https://doi.org/10.1002/9781118097298.weoc061>
9. Amaro, P., Ferreira, P., & Simões, F. (2020). Comparative analysis of different cutting milling strategies applied in duplex stainless steel. *Procedia Manufacturing*, 47, 517–524. <https://doi.org/10.1016/j.promfg.2020.04.132>
10. Huang, N., Jin, Y., Lu, Y., Yi, B., Li, X., & Wu, S. (2020). Spiral toolpath generation method for pocket machining. *Computers and Industrial Engineering*, 139. <https://doi.org/10.1016/j.cie.2019.106142>
11. Brillhart, M., & Botsis, J. (1992). Fatigue fracture behaviour of PEEK: 2. Effects of thickness and temperature. *Polymer*. [https://doi.org/10.1016/0032-3861\(92\)90805-7](https://doi.org/10.1016/0032-3861(92)90805-7)
12. Zhao, H., & Li, R. K. Y. (2006). Fracture behaviour of poly(ether ether ketone) films with different thicknesses. *Mechanics of Materials*. <https://doi.org/10.1016/j.mechmat.2005.05.013>
13. Standard Gage - Visual 250 - EuroPac Precision. (2020). Retrieved August 7, 2020, from <http://www.europacprecision.com/products/optical-measurement/vision-systems/standard-gage-visual-250.htm>
14. Roseline, S. SAGAYA, and EC HENRY Amirtharaj. "A new ranking of intuitionistic fuzzy numbers with distance method based on the circumcenter of centroids." *International Journal of Applied Mathematics & Statistical Sciences (IJAMSS)* 2.4 (2013): 37-44.
15. Rae, P. J., Brown, E. N., & Orlor, E. B. (2007). The mechanical properties of poly(ether-ether-ketone) (PEEK) with emphasis on the large compressive strain response. *Polymer*. <https://doi.org/10.1016/j.polymer.2006.11.032>
16. Ketron® PEEK. (n.d.). Retrieved August 12, 2020, from <https://www.mcam.com/na-es/productos/plasticos-maquinales/avanzados-325-425-f/ketronr-peek/>

17. Carbide Compacts. (n.d.). Retrieved August 11, 2020, from <https://www.kennametal.com/es/es/products/engineered-wear-solutions/engineered-components/carbide-compacts-and-substrates.html>
18. Singh, S. S., et al. "Experimental Investigation of Thermal Efficiency of Boiling Pot with Modified Surface Geometry." *International Journal of Mechanical and Production Engineering Research and Development* 8: 479-486.
19. TREE VMC-760/20 Centros de Maquinado Verticales - MachineTools.com. (n.d.). Retrieved August 12, 2020, from <https://www.machinetools.com/es/models/leadwell-v-20i>
20. Singh, V., Zutshi, S. Goel, U & Murtaza, Q. (2020). Effect of process variables using square type cutting tool on surface roughness and residual stress of EN24 in an end-milling process. *International Journal of Mechanical and Production Engineering Research and Development*. 10(3), 147-158. <https://doi.org/10.24247/ijmperdjun202014>
21. Bhattacharya, A., Das, S., Majumder, P. & Batish, A. (2009). Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI1045 steel using Taguchi design and ANOVA. *Production Engineering Research and Development*. 3, 31-40. <https://doi.org/10.1007/s11740-008-0132-2>