International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-05, Issue-03, June 2019

Minimization of warpage on slender prismatic parts while milling of Aluminum 2014-T651 by experimental study of aging and stress relieving processes

[1]N.Vinaya Kumar, Research Scholar, JNTUCEH, Hyderabad & India, vnkmrnalla@gmail.com
[2]Dr M.Indira Rani, Professor, JNTUCEH, Hyderabad & India, marpuindira@gmail.com

Abstract **Minimization of warpage on slender prismatic parts while milling of Aluminum 2014-T651 by experimental study of aging and stress relieving processes is new approach. In this study, rough milling on the sized blocks associated heat treatment through stress relieving or aging, then final milling operations were carried out and responses measured. In this experiment, Taguchi L9 (3_4) orthogonal array for experimental selection and ANOVA method for analysis of results were used. Each experiment contains four control parameters namely final wall thickness, rough machining allowance, heat treatment temperature and soaking duration. Nine experiments were performed by taking three levels against each control parameter and values of responses viz. warpage, surface roughness and hardness measured. In this approach, optimum values for main parameters were found, which have influence on warpage, surface roughness and hardness. Experimental results under optimal parametric conditions were validated towards improvement of quality characteristics of the process.**

Keywords — warpage , redistribution of stresses, residual stresses, slender prismatic part, aging, stress relieving, milling.

I. INTRODUCTION

Slender prismatic parts made up of AA2014-T651 are used for structural applications for Avionic systems in Aeronautical industry.

Most of the research have been done on 7000 series aluminum alloys thin wall parts, redistribution of initial residual stresses are main cause to warp [2], [7], [15], [24], [28], [31], curving or bending distortion, in slender prismatic parts are produced by removing maximum amount of material from wrought blocks to minimize the weight resulting in increased fuel efficiency during flight. However, warpage causes reworks and rejections, which effects productivity. More than half material removed from the blanks causes redistribution of stresses [3], [30], [32] in the slender (thin wall) parts, residual stresses at lateral length is lower than the longitudinal length [25], initial residual stresses causes 90% of distortion and induced stresses causes 10% of distortion [38], Induced stresses are more in direction of feed compared with direction of cutting [18], tangential residual stresses directly proportional to the feed [35]. Residual stresses are directly proportional to flank wear and machining asymmetry [29], [10] and its effect is more if the thickness of part is below 1.25 mm [5]. Initial residual stresses is minimized by using polymer quench while solution treating of wrought products [16], followed by stretching [34]. Residual stresses decreases as depth of cut decreases from roughing to finishing [33]. Distortion minimize with polycrystalline diamond tooling [9], helix anlge 40-45° [37], cutter diameter 12 mm [36], quasi symmetric machining [11] and distortion nullify at cutter radius 5.0 mm [20]. Dimensional stability increases with vibration stress relief [23]. Distinctive initial residual stresses are present regardless of whether a similar composition is present [1], [17].

Remaining researches have been done on other aluminum alloys for the study of distortion, maximum residual stresses effected by feed rate rather than speed & depth of cut in Al3Mg [27], distortion is directly proportional to the cutter size, number of flutes on cutter & indirectly proportional to the depth of cut, but volume of material removal does not show any effect in distortion in AA2014-T651 [8], [4], [22], [42]. Distortion reduces by using diamond like carbon (DLC) coated cutters and stress range is indirectly proportional to the helix angle and radial rake angle in AA2014-T651 [40], [41]. Machining induced stresses distortion is more if thickness is 5-6 mm and initial residual stresses distortion is more if thickness more than 10 mm in 2A70 material [14]. Residual stresses are reduced by stretching in A357 [26]. Deformation due to thermal is more than cutting force in thin wall parts [39],

Distortion is minimized by reheating at temperature 290°C for an hour for AA6061 [12], and uphill quench is able to reduce the residual stresses with stable dimensions in AA6061 [19], generally aluminum alloy heat treatment temperature is 260 - 440°C and aging & stress relieving temperature is 175-205°C for 1-2 hours after rough machining to increase precision in machining and stability in aluminum alloys [6]. Minimum rough machining allowance

 DOI : 10.35291/2454-9150.2019.0218

0.8128 mm is suggested upto 25.4 mm for steel forgings and bar [43]. Shop personnel machined the parts by flipping two sides for balancing initial residual stresses [44], this non standardized method effects the productivity.

Stress relieving and uphill quenching techniques are necessary to reduce initial residual stresses and thus it reduces distortion. However, uphill quenching process requires extensive fixtures [13], [21], skilled personnel and also expensive. Hence, it is infeasible for small scale sectors. Moreover literature is not available for stress relieving and rough machining allowance for AA2014 to minimize distortion. Therefore, this research has been performed to minimize warpage by providing rough machining allowance and stress relieving on slender prismatic parts of AA2014.

The aim of this work is to minimize warpage on slender prismatic parts of AA2014-T651 while milling and by considering with optimum surface roughness and hardness values by taking final wall thickness, rough machining allowance, heat treatment temperature and soaking duration as control parameters at three different levels and using Taguchi's orthogonal table, S/N ratios and ANOVA fit general linear model for analysis.

II. PLAN OF EXPERIMENTS

In the following experiment, responses viz., warpage, surface roughness and hardness studied by taking raw material thickness is as constant. Four sides milling is done to maintain size and then rough milling followed by aging or stress relieving operations are carried out then final milling operations are performed to maintain final thickness as per experimental design. Taguchi L9 is used for optimum set of experiments for investigation of four controlling factors namely final wall thickness, rough machining allowance, heat treatment temperature and soaking duration against three different levels of parameters. Cutting parameters namely feed, speed and depth of cut are taken as constant in the experiment.

Step by step of experiment plan is mentioned below

1) Selected 20.0 mm thickness raw material of Aluminum 2014-T651.
2) Band saw is used for sizing operation. With the help of vertical milling machine, length and width 65.0 x 120.0 mm maintained.
3) Flatness maintained through 0.25 mm skin cut on each side.
4) Cutting parameters, cutting speed 3000 RPM, feed 1000 mm/min and depth of cut 0.5 mm are kept constant. A Solid carbide end mill with Ø10 mm is used for making samples. Samples are clamped on the vacuum fixture
5) Rough milling done on MITSUI SEIKI VR3A CNC vertical milling machine for different wall thickness by considering milling allowance as per experiment table and model & dimensions of rough milling are shown respectively at figure 1 & 2.
6) Aging and stress relieving carried out in 24KW power rating of forced air circulated furnace at indicated temperature and time duration based on experimental design.
7) Performed finish milling operation on vertical CNC milling machine, maintaining final wall thickness based on experimental design. Model & dimensions shown respectively at figure 3 & 4.
8) Warpage is measured with vertex multi sensor measurement systems (Micro-Vu Vertex 311HC).
9) Hardness measured with the help of FIE RASNE Hardness tester in terms of HRB scale.
10) Surface roughness Ra measured using surface tester MITUTOYO SJ210P.

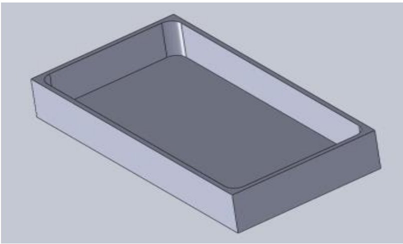

Figure 1. Model for rough machining sample

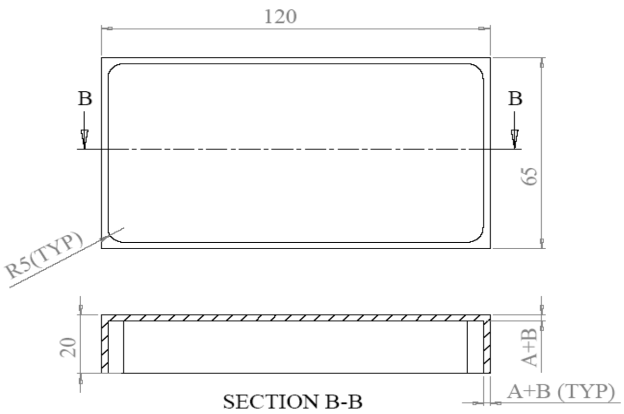

Figure 2. Dimensions for rough machining sample, Dimensions:mm, A is the final wall thickness and B is rough machining allowance.

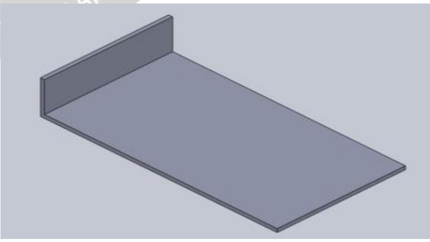

Figure 3. Model of finishing sample

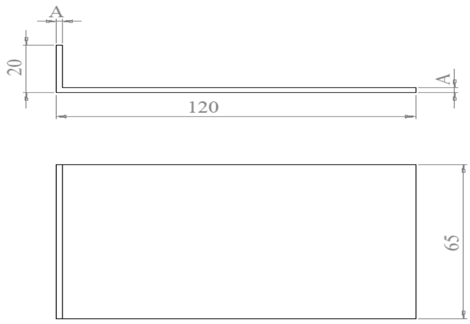

Figure 4.Dimensions for finishing sample,

 DOI : 10.35291/2454-9150.2019.0218

Dimensions:mm, A is the final wall thickness

III. DESIGN OF EXPERIMENTS

Warpage depends on final wall thickness as induced stresses, cutting forces and thermal forces predominant on thin wall parts. Redistribution of initial stresses will act subsequent to partial material removal. Hence, rough machining allowance is also taken as controlling parameter. In addition, heat treatment temperature and soaking duration are important parameters in stress relieving or aging in order to reduce initial residual stresses. Stress relieving and aging process is differentiated with heat treatment temperature in the experiment, aging temperature is upto 205°C [6], and stress relieving temperature is above 205°C.

A. Selection of Control factors and Levels

Selection of control factors finalized based on above study. Finally, four control parameters viz., final wall thickness, rough machining allowance, heat treatment temperature and soaking duration are chosen and its levels are chosen as three based on experience and literature. Milling operations are carried out on AA2014-T651 by providing rough machining allowance followed by heat treatment operation and final wall thickness based on experimental designs which is shown in table 1.

Table 1. Control factors and levels for ageing & stress relieving

Factors /Levels	Final wall thickness mm (A)	Rough machining allowance mm (B)	Heat treatment Temperature °C (C)	Soaking duration hours (D)
1	1	1	180	1
2	2	2	260	2
3	3	3	300	3

B. Experimental Designs

Total 81 combinations of experiments are required to cover the four process parameters and three levels in full factorial design, but nine experiments are enough according to Taguchi design of experiments. Hence, statistical software Minitab-17 is used to generate Taguchi orthogonal array L9(3_4) for four control factors and its three levels. Experimental design table shown in table 2 and allotted experiment numbers shown in figure 5 & 6.

Table 2. L9 (3_4) Orthogonal Array with control factors

Exp. no	Column			
	A	B	C	D
1	1	1	180	1
2	1	2	260	2
3	1	3	300	3
4	2	1	260	3
5	2	2	300	1
6	2	3	180	2
7	3	1	300	2
8	3	2	180	3
9	3	3	260	1

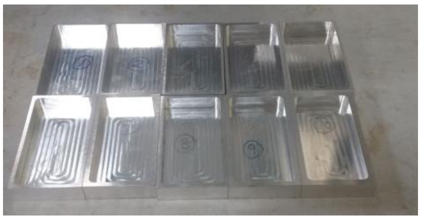

Figure 5. Allotted experiment no's on rough machined samples

Figure 6. Allotted experiment no's on finished machined samples

IV. RESULTS AND DISCUSSIONS

Response values and S/N ratios of warpage, surface roughness and hardness are measured and shown in table 3 & 4. For the process, S/N ratio performance characteristic for warpage and surface roughness parameters is selected as "smaller is better" and for hardness as "larger is better".

Table 3. Experimental responses values of warpage, surface roughness and hardness

Exp. no	Warpage (X) mm	Surface roughness (Ra) µm	Hardness HRB
1	0.46	0.462	80.7
2	0.44	0.345	72.9
3	0.51	0.743	45.1
4	0.0979	0.538	70.3
5	0.0532	0.684	64.4
6	0.0597	0.38	79.1
7	0.099	0.953	55
8	0.0218	0.443	76.9
9	0.0075	0.654	77.1

Table 4. Experimental data S/N ratios of warpage, surface roughness and hardness

Exp.no	S/N X	S/N Ra	S/N HRB
1	6.744843	6.70716	38.13747
2	7.130946	9.243618	37.25455
3	5.848596	2.580224	33.08353
4	20.18435	5.384354	36.93911
5	25.48177	3.298878	36.17772
6	24.48051	8.404328	37.96353
7	20.0873	0.418142	34.80725
8	33.23087	7.071925	37.71853
9	42.49877	3.688445	37.74109

 DOI : 10.35291/2454-9150.2019.0218

ISSN : 2454-9150 Vol-05, Issue-03, June 2019

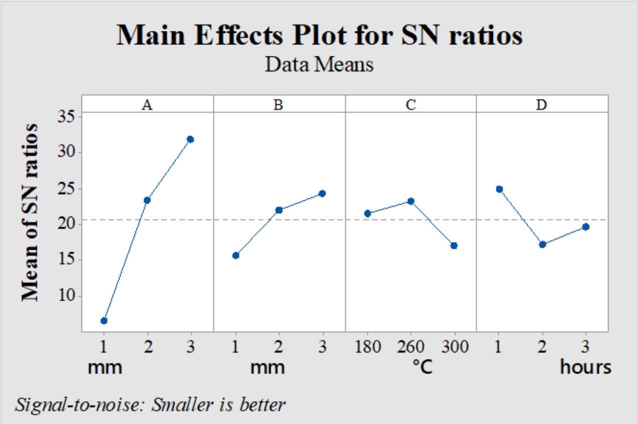

Figure 7. S/N ratio plot for Warpage vs. A, B, C, D

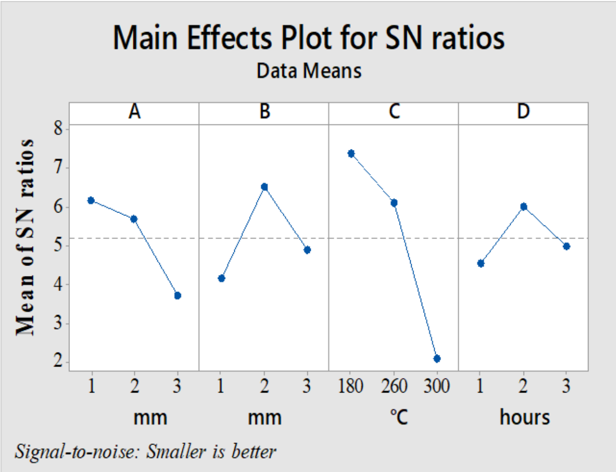

Figure 8. S/N ratio plot for Roughness vs A, B, C, D

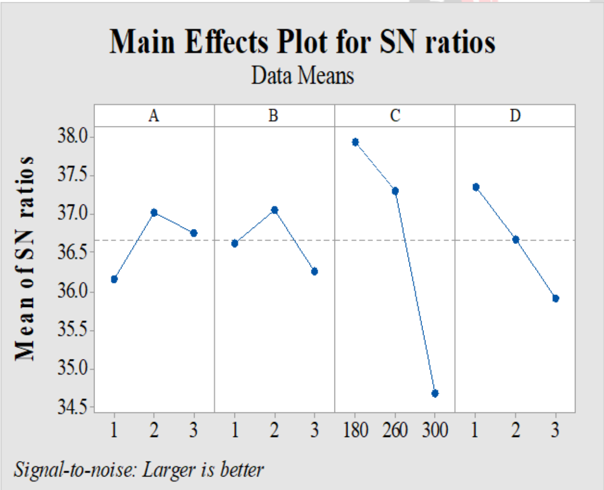

Figure 9. S/N ratio plot for Hardness (HRB) vs A, B, C, D

S/N ratios are shown for individual responses for warpage, surface roughness and hardness at figure 7, figure 8 and figure 9 respectively. ANOVA are given in table 5 (warpage), table 6 (surface roughness) & table 7 (hardness). Minitab-17 statistical software is extensively used for Design of experiments (DOE), plots and analysis, in the present study.

Table 5. ANOVA for Warpage

Factor (F)	DF	ADJ SS	ADJ MS	SS'	P%(contribution)
A	2	0.343071	0.17153	0.343071	97.551
B	2	0.003373	0.00168	0.003373	0.95
C	2	0.003136	0.00156	0.003136	0.89
D	2	0.002103	0.00105	0.002103	0.59
Error	0				
Total	8	0.351683			

Table 6. ANOVA for Roughness

F	DF	ADJ SS =SS'	ADJ MS	P%
A	2	0.050379	0.0251	16.16
B	2	0.039485	0.0197	12.67
C	2	0.219242	0.1096	70.35
D	2	0.002531	0.0012	0.812
Err	0			
Tot	8	0.311636		

Table 7. ANOVA for Hardness (HRB)

F	DF	ADJSS =SS'	ADJ MS	P%
A	2	130.6	65.33	8.37
B	2	24.67	12.33	1.58
C	2	1138.6	569.3	72.99
D	2	266	133	17.05
Err	0			
Tot	8	1560		

A. Effect of Parameters

Effects of control parameters and associated responses discussed through figures of S/N ratios and tables of ANOVA:

1) From table 5, warpage is mainly depends upon final wall thickness and its contribution is 97.55%, because initial residual stresses are redistributed due to lot of material removal in machining and cutting induced stresses predominantly effect for lower wall thickness.
2) From table 6, surface roughness is mainly depends upon heat treatment temperature about 70.35% and then 16.16% of final wall thickness, because BUE (Built up edge) forms on cutter due to AA2014 ductility increases as temperature increases, so that surface roughness increases.
3) From table 7, hardness is mainly depends upon heat treatment temperature about 72.99% and then 17% of soaking duration, because temperature is more impact will create compared with soaking duration in Aluminum alloy heat treatment.
4) From figure 7, Minimum warpage is observed at 260°C for one hour soaking duration and 3 mm rough machining allowance, because stress relieved the parts at this temperature.
5) From figure 8, Minimum surface roughness is observed at 2.0 mm rough machining allowance and at 180°C

 DOI : 10.35291/2454-9150.2019.0218

temperatures and soaking duration of 2 hours, because intermetallic alloy (Cu) precipitate at this temperature.

6) From figure 9, hardness is decreased with increasing heat treatment temperature and soaking duration, because overaging is carried out at higher temperatures.

B. Confirmation Test

The impact of control parameters studied on responses viz., warpage, surface roughness and hardness using S/N ratios and ANOVA. The control parameters corresponding to combination set "A3B3C2D1" is found for optimum response parameters.

Before the experiment starting, Warpage 0.95 mm is measured on trail sample for final thickness 1.0 mm without heat treatment i.e normal machining procedure.

Confirmation test conducted on 1 mm finishing wall thickness sample so combination set A1B3C2D1 i.e. 1 mm finish wall thickness, 3.0 mm rough machining allowance, heat treatment temperatures of 260°C for duration of one hour soaking and results are mentioned in the table 8.

Table 8.Table showing results of Confirmation Test

	Trail experiment E_t	Optimal condition	
		Prediction	Experiment
Factor combinations	-	A1B3C2D1	A1B3C2D1
Warpage, mm	0.95	0.38	0.15
Hardness, HRB	80	69.11	77.1
Surface roughness, Ra	0.177	0.514	0.27

Here,
E_T- Trail experiment by normal procedure to maintain 1.0 mm final wall thickness

Regression equations for responses with respect to the controlling parameters:

$x = 0.540 - 0.2136\ A - 0.0133\ B + 0.000290\ C + 0.0182\ D$

$HRB = 122.0 + 1.72\ A - 0.78\ B - 0.1817\ C - 4.98\ D$

$Ra = -0.185 + 0.0833\ A - 0.0293\ B + 0.00276\ C - 0.0127\ D$

Warpage is reduced in the optimal experiment to 6.33 times of normal machining procedure with minor variations of hardness and surface roughness. Experimental optimal results got better than the predicted results.

V. Conclusions

Experimental mean values of S/N ratio, analysis by ANOVA and also confirmation test results are analyzed and the following points have been concluded:

1) Warpage can be reduced upto 6.33 times by stress relieving, after rough machining, at a temperature of 260°C and holding for an hour in slender prismatic parts of AA2014-T651.
2) Warpage is minimized by providing rough machining allowance 3.0 mm before stress relieving on AA2014-T651.
3) Warpage is mainly depends upon final wall thickness and its contribution up to 97.55%.
4) Surface roughness can be minimized in AA2014-T651 by providing 2.0 mm rough machining allowance and further ageing at 180°C for 2 hours soaking duration.

References

[1] Bankole I. Oladapo, A.O.M. Adeoye, S.O. Oyegoke, S.O. Afolabi, Analysis for Distortion of Thin-wall Milling on Machine Component and its Effect on Global Warming, Procedia Manufacturing, Volume 7, 2017, Pages 529-536,ISSN 2351-9789.

[2] Gao, Hanjun & Zhang, Yidu & Wu, Qiong & Liu, Chang. (2017). Influence of initial residual stress distribution on machining deformation of plate blank. AIP Conference Proceedings. 1829. 020032. 10.1063/1.4979764.5

[3] Zhao-jun WANG, Wu-yi CHEN, Yi-du ZHANG, Zhi-tong CHEN, Qiang LIU,Study on the Machining Distortion of Thin-walled Part Caused by Redistribution of Residual Stress, Chinese Journal of Aeronautics, Volume 18, Issue 2,2005, Pages 175-179, ISSN 1000-9361.

[4] Garimella Sridhar, Ramesh Babu Poosa, Volume of Material Removal on Distortion in Machining Thin Wall Thin Floor Components, International Journal of Mechanical Engineering and Applications. Vol. 3, No. 5, 2015, pp. 86-93. doi: 10.11648/j.ijmea.20150305.1

[5] Huang, Xiaoming & Sun, Jie & Li, Jianfeng. (2015). Effect of Initial Residual Stress and Machining-Induced Residual Stress on the Deformation of Aluminium Alloy Plate. Strojniski Vestnik. 61. 131-137. 10.5545/sv-jme.2014.1897.

[6] ASM handbook, Heat treating of Aluminum alloys, Volume 4, 1998.

[7] Chatelain, Jean-François & Lalonde, J.-F & Tahan, Antoine. (2011). A comparison of the distortion of machined parts resulting from residual stresses within workpieces. International Conference on Manufacturing Engineering, Quality and Production Systems, MEQAPS - Proceedings. 79-84.

[8] Sridhar, Garimella & Babu, P. (2015). Effect of a milling cutter diameter on distortion due to the machining of thin wall thin floor components. Advances in Production Engineering & Management. 10. 140-152. 10.14743/apem2015.3.198.

[9] Masoudi, Soroush & Amini, S & Saeidi, Ehsan & Eslami-Chalander, Hamdollah. (2015). Effect of machining-induced residual stress on the distortion of thin-walled parts. International Journal of Advanced Manufacturing Technology. 10.1007/s00170-014-6281-x.

[10] Zhang, Zheng & Li, Liang & Yang, Yinfei & He, Ning & Zhao, Wei. (2014). Machining distortion minimization for the manufacturing of aeronautical structure. The International Journal of Advanced Manufacturing Technology. 73. 1765-1773. 10.1007/s00170-014-5994-1.

[11] Wu, Q.; Li, D.-P.; Zhang, Y.-D. Detecting Milling Deformation in 7075 Aluminum Alloy Aeronautical Monolithic Components Using the Quasi-Symmetric Machining Method. Metals 2016, 6, 80.

[12] Rafey Khan, A & Nisar, Salman & Shah, A & A. Khan, M & Khan, Sohaib & Sheikh, Mohammed. (2016). Reducing machining distortion in AA 6061 alloy through re-heating technique. Materials Science and Technology. 1-7. 10.1080/02670836.2016.1243335.

[13] E C A Simencio, L C F Canale & G E Totten (2011) Uphill quenching of aluminium: a process overview, International Heat Treatment and Surface Engineering, 5:1, 26-30, DOI: 10.1179/174951410X12851626813177

[14] Mei Zhongyi, and et. al [2011] c., "Distortion Anal ysis of Shaped Workpiece in NC Machining", Proceedings of World Congress on Engineering 2011,

 DOI : 10.35291/2454-9150.2019.0218

vol. III, London, UK, on line.

[15] Schulze, V & Arrazola, Pedro & Zanger, F & Osterried, J. (2013). Simulation of Distortion Due to Machining of Thin-walled Components. Procedia CIRP. 8. 10.1016/j.procir.2013.06.063.

[16] Masoudi, Soroush & Amirin, Ghasem & Saeedi, Ehsan & Ahmadi, Mohammad. (2015). The Effect of Quench-Induced Residual Stresses on the Distortion of Machined Thin-Walled Parts. Journal of Materials Engineering and Performance. 24. 10.1007/s11665-015-1695-7.

[17] Iñigo Llanos, Jose L. Lanzagorta, Arkaitz Beristain, Part Distortion Modeling on Aluminum Slender Structural Components for Aeronautical Industry, Procedia CIRP, Volume 58, 2017, Pages 158-162, ISSN 2212-8271,

[18] Huang, Xiaoming & Sun, Jie & Li, Jianfeng & Han, Xiong & Xiong, Qingchun. (2013). An Experimental Investigation of Residual Stresses in High-Speed End Milling 7050-T7451 Aluminum Alloy. Advances in Mechanical Engineering. 2013. 10.1155/2013/592659.

[19] Jones, Robert Michael, "Prediction of Residual Stress and Distortion from Residual Stress in Heat Treated and Machined Aluminum Parts"(2014).Master's Theses. 4423. http://scholarworks.sjsu.edu/etd_theses/4423

[20] Denkena, Berend & Boehnke, D & de Leon, Luis. (2008). Machining induced residual stress in structural aluminum parts. Production Engineering. 2. 247-253. 10.1007/s11740-008-0097-1.

[21] Croucher, T. "Minimizing Machining Distortion in Aluminum Alloys through Successful Application of Uphill Quenching" Journal of ASTM International, Vol. 6, No. 7, 2009, pp. 1-14, https://doi.org/10.1520/JAI101770. ISSN 1546-962X

[22] Sridhar, Garimella & Babu, P & Publication, IAEME. (2013). CUTTING PARAMETER OPTIMIZATION FOR MINIMIZING MACHINING DISTORTION OF THIN WALL THIN FLOOR AVIONIC COMPONENTS USING TAGUCHI TECHNIQUE. International Journal of Mechanical Engineering and Technology 0976-6359. 4. 71-78.

[23] G H Xiong , K Liao, X Y Chang, J A Liu, Deformation Control by VSR Technique on Al alloy Thin-Walled Components, 2017 IOP Conf. Ser.: Mater. Sci. Eng.269 012003.

[24] Yang, Y & Li, M & R. Li, K. (2014). Comparison and analysis of main effect elements of machining distortion for aluminum alloy and titanium alloy aircraft monolithic component. The International Journal of Advanced Manufacturing Technology. 70. 10.1007/s00170-013-5431-x.

[25] Wei, Y. & Wang, X.W. Int J Adv Manuf Technol (2007) 33: 260. https://doi.org/10.1007/s00170-006-0470-1

[26] Yang, Xiawei & Zhu, Jingchuan & Nong, Zhisheng & Lai, Zhonghong & He, Dong. (2013). FEM simulation of quenching process in A357 aluminum alloy cylindrical bars and reduction of quench residual stress through cold stretching process. Computational Materials Science. 69. 396–413. 10.1016/j.commatsci.2012.11.024.

[27] Belgasim, O., and M. H. El-Axir, "Modeling of residual stresses induced in machining aluminum magnesium alloy (Al–3Mg)," Proceedings of the world congress on engineering, Vol. 2. 2010

[28] Q.C. Wang et al., "Numerical Simulation of Machining Distortion of Residually Stressed Aircraft Aluminum Components", Key Engineering Materials, Vols. 315-316, pp. 235-238, 2006

[29] Tang, Z & Yu, T & Q. Xu, L & Zhanqiang, Liu. (2013). Machining deformation prediction for frame components considering multifactor coupling effects. The International Journal of Advanced Manufacturing Technology. 68. 10.1007/s00170-012-4718-7.

[30] Robinson, J. S. ; Tanner, D. A. ; Truman, C. E. ; Wimpory, R. C./ Measurement and prediction of machining induced redistribution of residual stress in the aluminium alloy 7449. In: Experimental Mechanics. 2011 ; Vol. 51, No. 6. pp. 981-993b

[31] Nervi, Sebastian & Szabó, Barna & Young, Keith. (2009). Prediction of Distortion of Airframe Components Made from Aluminum Plates. Aiaa Journal - AIAA J. 47. 1635-1641. 10.2514/1.37233.

[32] Liu, Liangbao & Sun, Jianfei & Chen, Wuyi & Sun, Pengfei. (2015). Study on the machining distortion of aluminum alloy parts induced by forging residual stresses. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 231. 10.1177/0954405415583805.

[33] Li, Beizhi & Jiang, Xiaohui & Yang, Jianguo & Y. Liang, Steven. (2015). Effects of depth of cut on the redistribution of residual stress and distortion during the milling of thin-walled part. Journal of Materials Processing Technology. 216. 223–233. 10.1016/j.jmatprotec.2014.09.016.

[34] Koç, Muammer & Culp, John & Altan, Taylan. (2006). Prediction of residual stresses in quenched aluminum blocks and their reduction through cold working processes. Journal of Materials Processing Technology - J MATER PROCESS TECHNOL. 174. 342-354. 10.1016/j.jmatprotec.2006.02.007.

[35] Jiang, Xiaohui & Li, Beizhi & Yang, Jianguo & Yan Zuo, Xiao. (2013). Effects of tool diameters on the residual stress and distortion induced by milling of thin-walled part. The International Journal of Advanced Manufacturing Technology. 68. 10.1007/s00170-012-4717-8.

[36] Jiang, Xiaohui & Li, Beizhi & Yang, Jianguo & Zuo, XiaoYan & Li, Kang. (2012). An approach for analyzing and controlling residual stress generation during high-speed circular milling. The International Journal of Advanced Manufacturing Technology. 66. 10.1007/s00170-012-4421-8.

[37] Izamshah, Raja & Y. Yuhazri, M & Hadzley, M & Md Ali, Mohd Amran & Subramonian, Sivarao. (2013). Effects of End Mill Helix Angle on Accuracy for Machining Thin-Rib Aerospace Component. Applied Mechanics and Materials. 315. 773-777. 10.4028/www.scientific.net/AMM.315.773.

[38] Huang, X., Sun, J. & Li, J. Int J Adv Manuf Technol (2015) 77: 1035. https://doi.org/10.1007/s00170-014-6533-9

[39] B. Denkena, C. Schmidt, M. Krüger, Experimental investigation and modeling of thermal and mechanical influences on shape deviations in machining structural parts, International Journal of Machine Tools and Manufacture ,Volume 50, Issue 11,2010,Pages 1015-1021,ISSN 0890-6955.

[40] S.V.Prasad, Dr.P.Laxmi Narayana, Dr.P.Ravinder Reddy (2017), Influence of Tool Coatings on Distortion of 2014A T651 Aluminum Alloy during Machining, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 6, Issue 10, October 2017, ISSN(Online): 2319-8753, ISSN (Print): 2347-6710, DOI:10.15680/IJIRSET.2017.0610028.

[41] S.V.Prasad, P.Laxmi Narayana, Dr.P.Ravinder Reddy (2017), Influence of Tool angles off Endmill on Distortion of 2014A T651 Aluminium Alloy during Machining, International Journal of Research in Engineering and Technology, Volume: 06 Issue: 06,| June-2017, eISSN: 2319-1163 | pISSN: 2321-7308.

[42] Garimella Sridhar & Poosa Ramesh Babu (2018) Influence of tool parameters on machining distortion of thin wall thin floor components, Advances in Materials and Processing Technologies, 4:1, 61-85, DOI: 10.1080/2374068X.2017.1368002.

[43] P.S.Houghton, Heat treatment of Metals for Manufacturing processes and service, Volume 1, 1960, page 9.

[44] ASM Handbook, Materials Selection and Design, Section Residual stresses caused by various machining processes, Volume 20, 1997.

 DOI : 10.35291/2454-9150.2019.0218