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Understanding of Redistribution of Stresses and Controlling of Distortion While Machining of Aluminum Thin Wall Parts

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Abstract

In modern aeronautical industry, machined thin wall parts usage is more to reduce the weight of air craft and increase the fuel efficiency, but distortion will be occurred due to redistribution of residual stresses in thin wall parts while machining on wrought blocks of Aluminum. This paper presents an overview on redistribution of stresses and controlling of distortion while machining of Aluminum of thin wall parts.

Keywords: *Aluminum, redistribution, distortion, machining, thin wall, residual stresses.*

INTRODUCTION

In the modern aircrafts, Monolithic thin wall parts usage is more to minimize the weight to increase the efficiency and to minimize the fuel. More than 90% of the material removed from the wrought blocks to make slender parts which are complex in geometry and high machining tolerances. Distortion will be occurred while removing of lot of material removal due to redistribution of residual stresses.

Residual stresses are of two types which are inbuilt residual stresses and induced residual stresses. In heat treatable Aluminum wrought blocks, inbuilt residual stresses are raised due to thermal gradient difference while quenching after solution treatment. Induced stresses are raised due to cutting forces, heat generation, etc., while machining.

These residual stresses and redistribution of stresses cause a lot of rejection and wastage of production time in aeronautical industry. Hence, these stresses and its effects have to be understood.

Aim of this paper is to understand about redistribution of stresses and methods to control distortion.

LITERATURE REVIEW

Distortion

Distortion is occurred, during the removal of material while machining, due to redistribution of residual stresses. Lot of research have been going on redistribution stresses and induced stresses to minimize distortion of thin wall parts during machining.

Aluminum wrought products are solution treated and quenching operation is carried out in quenchants like water, glycol etc., to improve the mechanical properties. However, sudden cooling process cause thermal gradient is developed and thus residual stresses are generated in the wrought products, and it will be balanced by compression stresses at external surface and tensile stresses at internal surface. These wrought products to be machined to make thin wall parts. However, thin parts will be distorted due to the redistribution of residual stresses.

Most of the research has been gone on 7000 series Aluminum alloys to study of distortion and residual stresses on thin wall parts, which are mentioned in Table 1.

Table 1: List of researches on Distortion of thin wall parts

Reference	Material	Conclusion/Remarks
Gao, Hanjun & Zhang, Yidu et al [2] (2017)	Aluminum	Initial stresses directly affected the workpiece distortion.
J-F. CHATELAIN, J-F. LALONDE, et al [7] (2014)	AA7475-T7351	Initial stresses fixed in raw material effects on final part deformation.
Nervi, Sebastian & Szabó, Barna, et al [31] (2009)	Aluminum	Induced stresses during machining are the main cause distort for thin wall machined parts.
Q.C. Wang et al. [28] (2006)	AA7075-T375	Original residual stresses are the main cause for machining distortion
Yang, Y & Li, M & R. Li, K. [24] (2014)	AA7075	Initial residual stresses in the blank plays an important role in machining distortion for monolithic parts.
Schulze, V & Arrazola, et al [15] (2013)	AA7075 -T6	Increase in distortion is directly proportional to induced

Reference	Material	Conclusion/Remarks
		residual stresses
Liu, Liangbao & Sun, Jianfei, et al[32] (2015)	AA7085-T7452	Stresses redistributed after removal of half of the material removal and deformation is stable after material removing of 60%.
Bankole I. Oladapo et al [1] (2017)	AA7050- T651	-Heat treatment of different materials showed different stresses and strains despite of having same composition. -The values of tensions are different with different curvatures.
Robinson, J. S., Tanner, et al [13] (2011)	AA7449	Residual stresses are highly compressive and tensile stresses are in subsurfaces and balanced by tensile stresses
Wei, Y. & Wang, X.W [25] (2017)	AA7050-T7451	Effect of lateral residual stresses will be lesser than the longitudinal stress if the length is more than width.
Robinson, J. S., Tanner, D. A, et al [30] (2011)	AA7449	After quenching process, induce compressive stresses on subsurface and induce tensile stresses in surface and after machining half away the blocks, tensile stresses are redistributed.
Iñigo Llanos, Jose L. Lanzagorta, et al [17] (2017)	AA7050-T651	-Different stocks show different residual stresses. -Even though the magnitudes of residual stresses are different, profile of the residual stresses is same.
Liu, Liangbao & Sun, Jianfei, et al [21] (2015)	AA7085-T7452	Deformation is stable after 60% of material removal.
Huang, X., Sun, J. & Li, J [38] (2015)	Aluminum alloy	90% deformation is due to the initial residual stress and and 10 % of the deformation is due to induced machining stresses.
B. Denkena, C. Schmidt, M. Krüger [39] (2010)	Aluminum alloy	Thermal induced deformation is more than cutting force deflection
Zhao-jun WANG, Wu-yi CHEN et al[3] (2005)	AA7050-T7351	-Distortion increased to uneven concentration of stresses when first few layers are removed -Distortion reduces gradually when half of the material is cut
Garimella Sridhar, Ramesh Babu Poosa, et al[4] (2015)	AA2014-T651	-Distortion do not depend upon the volume of material removed -Work pieces significantly distorts less than 3mm thickness
Huang, Xiaoming & Sun, Jie et al[5] (2014)	AA7050-T7451	-Work pieces distort with more effect when thickness is below 1.25mm
Sridhar, Garimella & Babu.P [8] (2015)	AA 2014-T651	-Distortion increases with increase in cutter size
Masoudi, Soroush & Amini et al [9](2015)	AA7075-T6	-PCD (Polycrystalline Diamond tooling) cutters are better than carbide tools to minimize distortion due to lower temperature and lower machining and distortion potential in the parts can be reduced by an increase in parts thickness.
Zhang, Zheng & Li, Liang [10] (2014)	AA7050-T7451	-Distortion increases with increase in machining asymmetry. -Partition wall will be minimise the distortion.
Wu, Q.; Li, D.-P.; Zhang, Y.-D [11] (2016)	AA7075	Deformation reduces upto 20% by quasi symmetric machining method compared to one side machining method
Rafey Khan, A & Nisar, Salman, et al [12] (2016)	AA6061	Optimum temperature is 290°C for 1 hr to reduce the distortion upto 60% compared with normal method.
Mei Zhongyi, and et. al [14] (2011)	2A70 casting	If the thickness of workpiece is less than 5-6 mm ,then machining induced surface residual stresses causes distortion and if thickness is above10mm then

Reference	Material	Conclusion/Remarks
		quenching induced surface residual stresses causes distortion
Masoudi, Soroush, et al [16] (2015)	AA7075	Polymer quenched parts stress levels are lower than water quenched parts, and polymer quench parts are 10% lower hardness than water and uphill quench.
Huang, Xiaoming, et al [18](2013)	AA7050-T7451	Residual stresses are higher in feed direction when compared to cutting direction
Jones, Robert Michael [19] (2014)	AA6061	Uphill quench can able to low residual stresses with stable dimensions.
Denkena, Berend & Boehnke, et al [20] (2008)	AA7449-T7651	Cutter radius 5mm nullify the residual stresses in the workpiece
Sridhar, Garimella & Babu, P [22] (2013)	AA2014A-T651	-Distortion is minimized to 0.05 mm at feed 0.05 mm/tooth, speed 150 m/min, 0.4 mm doc, constant overlap tool path. -Depth of cut is main contributing factor and followed by width of cut.
G H Xiong, K.Liao, et al [23] (2017)	AA7075-T651	VSR improve the dimensional stability of Aluminum thin wall structures
Yang, Xiawei & Zhu, Jingchuan , et al [26] (2012)	A357	Residual stresses can be reduced upto 90% by stretching process
Belgasim, O., and M. H. El-Axir [27] (2010)	Al3Mg	Feed rate affects maximum residual stresses than cutting speed and depth of cut.
Tang, Z & Yu, T & Q. Xu, L [29] (2013)	AA7075-T7451	Tool flank wear effects the residual stresses
Li, Beizhi & Jiang, Xiaohui, et al [33] (2015)	AA2024-T3	Residual stresses decrease as depth of cut decreased from roughing to finishing.
Koç, Muammer & Culp, John, et al [34] (2006)	AA7050 forging block	90% residual stresses reduced by stretching of 2%.
ASM Hand book [6] (1991)	Aluminum	Induced residual stresses will be minimized upto 90% in rolled aluminum blanks by stretching and produced 1 to 3% permanent elongation
Jiang, Xiaohui & Li, Beizhi, et al [35] [36] (2012) (2013)	AA7050-T7451	Residual stress and distortions can be decreased by increasing the tool diameter at Ø12 mm and tangential residual stresses directly proportional to the feed.
Izamshah, Raja & Y. Yuhazri, M & Hadzley, M [37] (2013)	AA7056	Magnitude of wall deflection is indirectly proportional to the helix angle and effective helix angle is 40 -45°.
S.V.Prasad, et al [40][41] (2017)	AA2014-T651	Distortion varies in ascending order of coated end mills is DLC (Diamond like carbon coating)<TiAlN<Uncoated<TiN, and also stated stresses range will be decreased if the helix angle and radial rake angle increases.
Garimella Sridhar & Poosa Ramesh Babu [42] (2018)	AA2014-T651	Distortion will minimized using two flute lower helix angle cutters.

From the above literatures, initial residual stresses is the main cause to distort the thin wall parts, even material is same batch and same composition the values of residual tensile stresses will be different, so controlling of distortion is big challenge for thin wall parts.

Distortion controlling methods

Distortion can be controlled based on mentioned literatures at following phases.

1. Design phase: To minimize distortion following points to be considered while designing,

   a. Part geometry:

   - Wall thickness shall be 3.0 mm and more.

- Part geometry shall be symmetrical.
- Part depth shall be less than half of the depth.
- Partition wall shall be incorporate

b. Condition of the material: Stretched wrought products shall be used.

2. Manufacturing phase: To minimize distortion following points to be considered while manufacturing,

a. Cutter shall be,

- Optimum cutter diameter
- Coated cutters
- Optimum helix angle
- Minimum number of flutes

b. Optimum cutting parameters shall be used viz. feed, speed and depth of cut.

c. Selection of Machining:

- Quasi symmetric method shall be used.
- Ensure tool wear in process of machining.

d. Heat treatment methods:

- Reheating shall be carried out to relieve residual stresses.
- Uphill or Polymer quench shall be followed after rough machining for heat treatable alloys.

CONCLUSION

Various conclusions can be drawn to minimize the distortion in Aluminum alloys from different literatures:

1. Distortion is directly proportional to the internal residual stresses.
2. Distortion can be minimized by heat treatment methods like reheating, stress relieving, uphill quenching etc.
3. Distortion can be reduced by using solid carbide, PCD/DCL cutters, optimum cutter size and optimum of cutter parameters viz feed, speed & depth of cut.

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