Engineering and Scientific International Journal (ESIJ)
Volume 3, Issue 1, January – March 2016
ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

Residual Stresses in Machining: A Review

S.V.Prasad [#1], Dr.P.LaxmiNarayana*[2], Dr.P.Ravinder Reddy*[3]
[1] *Senior Manager,Designs,HAL,Hyd,India*
prasad.sv@hal-india.com
[2]*Professor,Dept of ME,Osmania University,Hyd,India,*
laxp@osmania .ac. in
[3]*Professor,Dept of ME,CBIT,Affliated to JNTU ,Hyd,India*
hod_me@chit.ac.in

Abstract— The most challenge is considered in Aviation industries is milling part features from prismatic blocks to part features by means of floor and wall thicknesses is very comparable to sheet metal assemblies. The distortion of machined components is a major factor in the industry of structural aerospace component manufacturing. The distribution of machining-induced stresses can affect the ability of the component's to endure rigorous and harsh loading conditions, as well as causing dimensional and geometrical deviations. It also directs to the high refusal rate and problems of quality association throughout component assembly. It is so essential to understand the mechanism that is at the root of parts distortion. This might result both from available residual stresses in work pieces or induced by the machining process.

Keywords— Residual stresses, FEM, analytical method, experimental method, machining, and part distortion.
.

1. Introduction

Residual stresses (RS) are considered as the inherent internal stresses associated to the materials in the lack of outer forces or thermal gradients [Withers, Bhadeshia, 2000]. The residual stress conditions are strongly associated with mechanical and metallurgical history in the part manufacturing process lifecycle.

The most frequently used two materials in aerospace industry are rolled plate and forgings. Both rolled plate and forgings have completely distinct residual stress status. The residual stresses in rolled plate characteristically follow an M profile with compressive residual stresses in the surface of the plate and tensile residual stresses in the plate centre. On the other hand, the residual stress placed in forging usually has a ∩ profile, extremely tensile residual stress in the hub and compressive at the surface[1]. Figure 1 and Figure 2 show the profiles for rolled plate and forging correspondingly.

2. Importance of the Study

The distortion of machined components is always a contributing factor in structural aerospace component manufacturing. The distribution of machining-induced stresses will influence the component's ability to withstand severe loading situation, as well as grounding dimensional and geometrical divergence. It also leads to the high rejection rates and quality-related problems during constituents' assembly. It is consequently essential to recognize the mechanism that is at the root of component deformation; this could result both from existing residual stresses in work pieces or induced by the machining process. Residual stresses shows significant place in the machined components performance. Component characteristics that are influenced by residual stress includes the variables like fatigue life, resistance of corrosion, and part distortion. The functional behavior of machined components may be improved or impaired by the residual stresses. Due to this, understanding the residual stress imparted by machining is an essential aspect of learning machining and taken as a whole part quality.

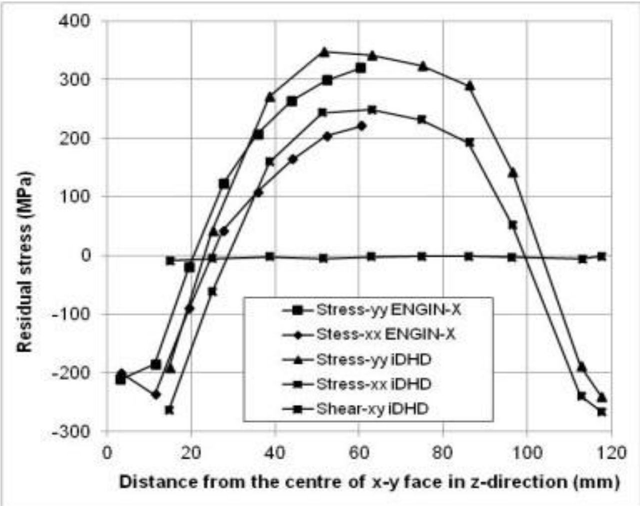

Fig. 1: RS profile in AA 2014 rolled sheet

The life of a structural part for aerospace use is typically a task of the contacts between the existing component defects, the loading conditions in service like existing residual stress which considered within the parts. Depending on their type, distribution or magnitude, the residual stresses may be valuable or disparaging for the component. Each of the many processes used in the manufacturing components is constantly adds to the residual stresses, ensuing in a final distribution affecting the mechanical properties and construct geometrical and dimensional divergence for the part features. Another important source of residual stresses in parts is the machining process.

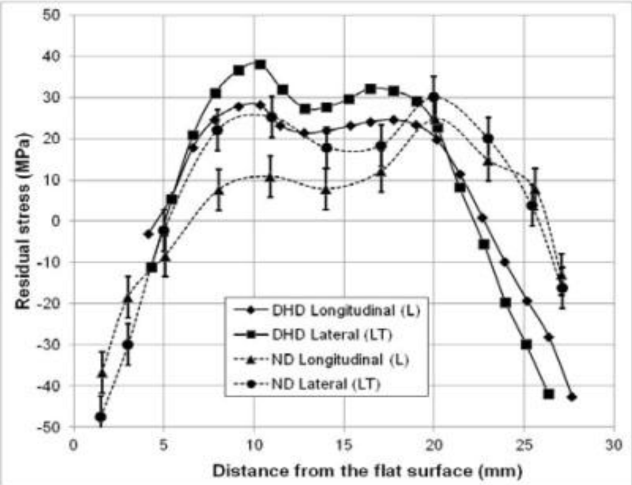

Fig. 2: RS profile in AA7449 forging

The approach and the methodologies usually followed in measuring /modeling /calculating the residual stress are

1) Experimental Methods
2) Analytical and Statistical Modeling
3) Residual Stress Modeling with FEM

This paper details about the methodologies in measuring the residual stresses and the previous works done in each methodology. It concludes with the advantages and limitations in analytical modeling method and FEM modeling method. It also concludes with the probable future scope of work in measuring the residual stress.

3. Experimental Efforts in Residual Stress

Totten and Mackenzie [2] postulate that residual stresses result from a combination of three mechanisms: uneven deformation of plastic due to mechanical forces, thermal effect and change of material volume. It happens because of solid phase transformation. This mechanism is associated with high temperature transmission, which is from the cutting tool to the part substances during machining. The phase conversion causes a gradual raise in grain size that result in compressive stresses followed the cooling of the material. According to the researchers' suggestion, this transformation is a major factor, and in some cases, may be the dominant part distortion source. The magnitude and distribution of the stress from side to side the depth is known to be a function of the machining conditions for a given material, e.g., cutting tool geometry, tool path strategies, speed, depth of cut, feed and etc. thorough research is being pursued in this area [3,4,5,6].

Most of the early efforts at determining the effect of machining on residual stress are measured as the experimental in nature. Considerably the pioneering efforts at assessing the residual stress due to machining were undertaken by Henriksen [7]. He experimented on low-carbon steel orthogonally machined. The work concluded that mechanical and thermal effects show a major role in residual stress development, but mechanical influence dominated.

Liu and Barash attempted to recognize the outcome of machining constraints on the residual stress in a machined surface [8]. They found that for orthogonal cutting, four parameters exclusively gritty the pattern of residual stress on a machined surface. The parameters incorporated the length of the shear plane, tool flank wear, shape of the cutting edge, and the depth of cut.

- The figure of the cutting edge strong-minded the residual stress pattern near the machined surface.
- The researchers identified that the tool flank wear augmented cutting temperature.
- They also found that smaller depths of cut did not necessarily produce low subsurface stresses.
- They concluded that a lower degree of constraint in the deformation process constructs a lower stage of residual stress.

Xie and Bayoumi [9] also investigated the effect of tool wear on the residual stress in machining. It found that tool wear impacted residual stress.

Sadat and Bailey [10] performed orthogonal cutting trials on AISI 4340 to establish the effects of cutting speed, feed rate, and depth of cut on residual stress profiles.
They found that:

- The absolute value of the residual stresses increased with an increase in depth beneath the machined surface.
- Peak residual stresses at low speeds were tensile but became increasingly compressive at high feed rates.

Sadat [11] also experimented with machining on Inconel-718. That research was an effort to resolve the outcome of cutting speed and tool-chip contact length on the surface integrity produced by machining. They accomplished that both mechanical and thermal effects results the residual stress distribution and the plastically deformed layer. It demonstrates that the depth of the residual stresses extend beneath the machined surface increases with a decrease in cutting speed.

Jang used turning experiments on AISI 304 stainless steel to determine the effect of machining parameters [12]. Residual stresses were measured using X-ray diffraction. The work showed so as to the tool sharpness has a strong sway on the surface residual stress.

It was also determined from experimental data that depth of cut and feed rate didn't extensively influence the residual

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

stresses in the subsurface of the material. However, the tool edge geometry have an overriding character in the subsurface residual stress profile.

Jacobson analyzed hard turning trials on hardened M50 steel HRc 61 [13]. It was found that M50 consistently showed compressive residual stress at the surface. The effective rake angle and nose radius of the tool affect the amount of residual stress generated. High inverse rake angle and minor nose radius generates more compressive residual stress profile. The experimental results illustrates that depth of cut does not influence the amount of residual stress generated in hard turning. A motivating outcome is that depth of cut does not affect the amount of residual stress. The research also showed that the effective tool nose and rake angle radius are affected the residual stresses.

The experimental research has provided a qualitative accepting of the property of cutting variables on machining-induced residual stress. The general findings have indicated that in the nonappearance of chemical transformation, the residual stress profile is dependent on a combination of loadings. For cases where mechanical loads dominate, compressive residual stress profiles are more probable. While thermal loads govern, the residual stress summary showing much more tensile characters.

4. Analytical and Statistical Modeling of Residual Stress

The analytical and statistical modeling methods of residual stresses will quantify and explain the mechanisms that produce residual stress from machining and aim to correlate the influence of machining factors to residual stress. Tsuchida [14] experimented on the effect of cutting conditions on the residual stress allocation. That carries out tests in which speeds, feeds, and depths of cut were varied.

- They accomplished that the reduction in cutting speed reduce the tensile residual stress which is closer to the surface, and raised depth of the residually stressed layer.
- Also, the raised feed transferred the surface residual stress towards tension whereas growing the residually stressed layer. It also proved that an increase in the depth of cut never affect the residual stress distributions.
- Most significantly, they exposed that the crest residual stresses may exist beneath the surface of machined components.

An empirical method for the surface residual stress was shaped from their testing. In another work, Liu and Barash [15] aimed to characterize the state of the bulk of the material because of the chip removal progression. Three quantities were established as pertinent to quantify the mechanical status of the work piece. They included apparent strain energy density, strain hardening index and residual stress allocation. The investigations show that the length of the shear plane uniquely determined the plastic deformation of the subsurface sheet for a known depth of cut. The three parameters mentioned previously all augmented with the extent of the shear plane. That also found that a size effect influenced the state of the machined sub-layer. These identifications were related in that they established an overall material state rather than just residual stress.

Subsequently Liu and Barash [16], they added flank wear to the list of input parameters. They found that the flank wear length altered the residual stress model by dropping the shear plane length. They concluded that the origins of residual stress are principally mechanical though thermal sway is apparent.

Matsumoto, Barash, and Liu [17] studied the cause of hardness on surface reliability of AISI 4340 steel. They analyzed the effects based on the chip formation type. The Machined parts with hardness below HRC 49 produced continuous chips. Increasing hardness led to segmented chip construction. Here, the concept of rolling contact loading is utilized to explain the cyclic loading practiced by the work piece during machining. That effort was significant in that it was an early application of theory in an endeavor to elucidate machining-persuaded residual stresses. For hardened steel, the surface layer affected by the deformation is shallow; the burnishing is the overriding stress generating mechanism resulting in compressive residual stress. When cut soft steel, the deformation arrived at a deeper layer and the surface layer is compressed resulting in tensile residual stress.

Wu and Matsumoto [18] employed the idea of a passing load over a point in the work piece. The rationale is that all positions in the work piece experience having the similar stress history. This stress history subsequently influences the residual stress. In case of loading conditions that are constructively predominant in compressive, the resulting residual stress will be tensile while strains are go back to zero. Loads that are primarily tensile, the resulting residual stress is compressive when strains returned to zero. They invoke an incorporation of the Boussinesq equation to forecast the stresses that felt in the subsurface due to the passing load.

In other machining processes, Fuh [19] developed an empirical model to predict the residual stresses produced by milling of 2014-T6 aluminum. The mathematical model integrated cutting environment like cutting speed, feed, and cutting depth as well as tool geometry characteristics known as flank wear and nose radius. The investigations utilized a response surface methodology (RSM) coupled with a Taguchi method to limit the quantity of the essential experiments. The postulated mathematical model implemented second-order polynomial to produce a relationship between the residual stress and cutting constraints. The curve fitting practices supply little imminent into the physical bond among the cutting parameters and the residual stress.

An analytical model was presented by Jacobus [20] which utilized an incremental plasticity representation,

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

similar to that implemented by Merwin and Johnson [23]. Rather than presume a stress factor in the work piece, the model implicit a shape for the deformation of the substance beneath the tool. The Residual stress is represented in a synchronize frame in association with the tool. The deformation parameters are considered as the function of edge radius and the depth of cut.

Mittal and Liu continued efforts in modeling residual stress in hard turning [21]. The model understood that the residual stress profiles well to a polynomial profile that was a task of depth into the work piece. Coefficients of the polynomial were the independent tasks of the machining parameters.

5. Residual Stress Modeling with FEM

One of the earliest efforts at modeling residual stress using FEM was undertaken by Okushima and Kakino [22]. They were They were one of the first to implement related analysis to residual stress forecast from the machining method. The plowing effect of the tool edge and the thermal consequence of temperature allotment formed in metal cutting are modeled. The modeling results were evaluated with investigational data calculated by X-ray diffraction. The Residual stresses are also calculated in the cutting direction and across the cutting direction. It concludes that the mild cutting conditions are necessary to minimize tensile residual stresses.

Mishra [23] developed an investigative model on the basis of FEM to establish residual stresses due to a moving heat source. The author discussed the effect of the mechanical force magnitude, rate of the heat input, and the speed of movement of the work piece on the residual stresses

Lin [24] used a finite element method to determine the strain field in the work piece. The modeling procedure established by Merwin and Johnson [23] was employed to predict the residual stresses produced by machining. Lin incorporated both thermal and mechanical loads in the model. Trends from the model were evaluated with experimental facts. Model boundary conditions like shear angle are considered to be known.

Another work by Lin and Lee [25] used the same modeling attitude but it integrated the effect of flank wear. Similar researches aimed at determining the interaction between thermal and mechanical loading, Wiesner [26] used a finite element method to determine the residual stresses from orthogonal machining of AISI 304. The work piece temperature of the stationary is calculated using a finite difference method. The result of the model demonstrates the mechanical and thermal impact of the orthogonal cutting process caused tensile residual stress. This model is authenticated by X-ray diffraction analysis of machined trials. Low shear angles and working angles are found to be parameters that are utilized to augmented tensile residual stress.

Shih [27] developed a plane-strain finite element simulation of orthogonal metal cutting. The studies integrated detailed material modeling including effects of elasticity, viscoplasticity, large strain, high strain-rate and temperature. The model was validated and compared with experimental results.

Hua [28, 29] used a commercial FEA package DEFORM 2D, which is a Lagrangian implicit code designed for metal forming practices to simulate orthogonal cutting of AISI 52100. The work focused on analyzing the effect of feed rate, hardness, work piece and cutting rim on the subsurface residual stress formation in hard turning.

Liu and Guo [30, 31] used the commercial FEM code Abaqus / Explicit to examine the result of sequential cuts and tool-chip friction on residual stresses in AISI 304 stainless steel machined layer. The exaggerated layer from the first cut was found to change the residual stress allotment generated from the second cut. In addition to that, residual stress is sensitive to the friction condition at the tool-chip interface.

6. Advantages and limitations of FEM Method

FEM methods have been able to produce sufficiently useful results in forecasting residual stress because of cutting [32]. However, the FEM models have made little effort to illuminate the mechanisms that gave rise to the machining induced residual stresses. Additionally, FEM still requires important computational supremacy, and can be time exorbitant. Changes in the cutting conditions require re-computing the model. Due to this the application of FEM for production guidance has been restricted. FEM does an adequate job in calculate the residual stresses, but that is not considered as easy to adapt for varying process parameters because they are typically time consuming.

7. Advantages and limitations of Analytical Method

The current state of analytical modeling of the tool state on the residual stress falls short in terms of application to industrial environments. Models like that developed require extensive model calibration based on cutting tests. Other models that have been used to predict residual stress is also requisites a great deal of experimental data which was used to fit the residual stress data in a curve fitting model.

The analytical models cover various aspects of sources of residual stress and mechanisms that have an effect on the profiles. On the other hand, a thorough model for predicting residual stress with consideration of tool edge forms is presently unavailable.

8. Future Scope of the Study

Although impact of various tool parameters and process parameters on residual stress and induced machining stress are studied, influence of some of the parameters like tool vibrations, machine vibrations, coolant effects during machining process etc are yet in initial phase of progress. The current techniques for measuring residual stresses are a cumbersome and time consuming process and hence a reliable, robust and faster way of measuring residual stress is the need of the day.

References

[1] Wei-Ming Sim., Residual stress Engineering in manufacture of Aerospace structural parts, 2000.

[2] Totten, G. E., Scott Mackenzie D., Handbook of aluminum. New York, Marcel Dekker Inc., 2003.

[3] Nowag L., Solter J., Walter A., Brinksmeier E., Effect of machining parameters and clamping technique on residual stresses and distortion of bearing rings, Materialwissenschaft und Werkstofftechnik, vol. 37, no 1, pp. 45-51, 2006.

[4] Zhang, Yi-Liang, Hui-Ru Huang and Xiang Li. Research on distribution of turning residual stress, J of Beijing University of Technology, vol. 32, no 7, pp. 582-586, 2006

[5] Salio, M., Berruti T., De Poli G., Prediction of residual stress distribution after turning in turbine disks, Int J of Mechanical Sciences, vol.48, no 9, pp. 976-984, 2006.

[6] Capello E., Residual stresses in turning: Part II. Influence of the machined material, J of Materials Processing Technology, vol. 172, no 3, pp. 319-326, 2006.

[7] Henriksen, E.K., Residual Stresses in Machined Surfaces. American Society of Mechanical Engineers -- Transactions, 1951. 73(1): p. 69-76..

[8] Liu, C.R. and M.M. Barash, Variables Governing Patterns of Mechanical Residual Stress in a Machined Surface. Journal of Engineering for Industry,Transactions ASME, 1982. 104(3): p. 257-264.

[9] Xie, Q., et al. A Study on Residual Stresses and Tool Wear Induced by the Machining Process. in NAMRC XVII. 1989: SME.

[10] Sadat, A.B. and J.A. Bailey, Residual Stresses in Turned AISI 4340 Steel Experimental Mechanics, 1987. 27(1): p. 80-85.

[11] Sadat, A.B., Surface Region Damage of Machined Inconel-718 Nickel-Based Superalloy Using Natural and Controlled Contact Length Tools. Wear, 1987. 119(2): p. 225-35.

[12] Jang, D.Y., et al., Surface Residual Stresses in Machined Austenitic Stainless Steel. Wear, 1996. 194(1-2): p. 168-173.

[13] Jacobson, M., Surface Integrity of Hard-Turned M50 Steel. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2002. 216(1): p. 47-54.

[14] Tsuchida, K., Y. Kawada, and S. Kodama, Study on the Residual Stress Distributions by Turning. 1975. 18(116): p. 123-130.

[15] Liu, C.R. and M.M. Barash, Mechanical State of the Sublayer of a Surface Generated by Chip-Removal Process Part 1: Cutting with a Sharp Tool. Journal of Engineering for Industry, Transactions ASME, 1976. 98 Ser B(4): p. 1192-1201.

[16] Liu, C.R. and M.M. Barash, Mechanical State of the Sublayer of a Surface Generated by Chip-Removal Process Part 2: Cutting with a Tool with Flank Wear. Journal of Engineering for Industry, Transactions ASME, 1976. 98 Ser B(4): p. 1202-1208.

[17] Matsumoto, Y., M.M. Barash, and C.R. Liu, Effect of Hardness on the Surface Integrity of AISI 4340 Steel. Journal of Engineering for Industry, Transactions ASME, 1986. 108(3): p. 169-175.

[18] Wu, D.W. and Y. Matsumoto, Effect of Hardness on Residual Stresses in Orthogonal Machining of AISI 4340 Steel. Journal of Engineering for Industry,Transactions of the ASME, 1990. 112(3): p. 245-252.

[19] Fuh, K.-H. and C.-F. Wu, Residual-Stress Model for the Milling of Aluminum Alloy (2014-T6). Journal of Materials Processing Technology, 1995. 51(1-4): p.87-105.

[20] Jacobus, J.K., R.E. DeVor, and S.G. Kapoor, Machining-Induced Residual Stress:Experimentation and Modeling. Journal of Manufacturing Science and Engineering, 2000. 122: p. 20-31.

[21] Mittal, S. and C.R. Liu, Method of Modeling Residual Stresses in Superfinish Hard Turning. Wear, 1998. 218(1): p. 21-33.

[22] Okushima, K. and Y. Kakino, Residual Stress Produced by Metal Cutting. CIRP Annals, 1971. 20(1): p. 13-14.

[23] Mishra, A. and T. Prasad, Residual Stresses Due to a Moving Heat Source.International Journal of Mechanical Sciences, 1985. 27(9): p. 571-581.

[24] Lin, Z.-C., Y.-Y. Lin, and C.R. Liu, Effect of Thermal Load and Mechanical Load on the Residual Stress of a Machined Workpiece. International Journal of Mechanical Sciences, 1991. 33(4): p. 263-278.

[25] Lin, Z.-C. and B.-Y. Lee, An Investigation of the Residual Stress of Machined Workpiece Considering Tool Flank Wear. Journal of Materials Processing Technology, 1995. 51: p. 1-24.

[26] Wiesner, C., Residual Stresses after Orthogonal Machining of AISI 304:Numerical Calculation of the Thermal Component and Comparison with Experimental Results. Metallurgical Transactions A (Physical Metallurgy and Materials Science), 1992. 23A(3): p. 989-96.

[27] Shih, A.J., Finite Element Analysis of the Rake Angle Effects in Orthogonal Metal Cutting. International Journal of Mechanical Sciences, 1996. 38(1): p. 1-17.

[28] Hua, J., et al., Effect of Feed Rate, Workpiece Hardness and Cutting Edge on Subsurface Residual Stress in the Hard Turning of Bearing Steel Using Chamfer + Hone Cutting Edge Geometry. Materials Science and Engineering A, 2005. 394(1-2): p. 238-248

[29] Hua, J., D. Umbrello, and R. Shivpuri, Investigation of Cutting Conditions and Cutting Edge Preparations for Enhanced Compressive Subsurface Residual Stress in the Hard Turning of Bearing Steel. Journal of Materials Processing Technology, 2006. 171(2): p. 180-187.

[30] Liu, C.R. and Y.B. Guo, Finite Element Analysis of the Effect of Sequential Cuts and Tool-Chip Friction on Residual Stresses in a Machined Layer. International Journal of Mechanical Sciences, 2000. 42(6): p. 1069-1086.

[31] Guo, Y.B. and C.R. Liu, Fem Analysis of Mechanical State on Sequentially Machined Surfaces. Machining Science and Technology, 2002. 6(1): p. 21-41.

[32] Gagandeep Kaur and Gagandeep kaur, Optimal sitting and sizing of Distributed Generation, Engineering and Scientific International Journal, Volume 2, Issue 4, October – December 2015, p. 107-109.

Mr S.V.Prasad is a Senior Manager in SLRDC Dept ,of HAL Hyderabad. He areas of work are prototype manufacturing of Avionic mechanical parts. He has 17yrs of Experience in Aviation sector.He has published papers in the areas of materials used and challenges in Aviation industry.

Dr.P.Laxminarayana is a Professor in Dept of Mechanical Engineering at Osmania University.His areas of interest are Production,Engineering,Advanced Manufacturing &Industrial Engg.He has over 25 years of experience & published various papers in International and National Journals .

Dr. P.Ravinder Reddy is Professor in Dept of Mech.Engg at CBIT.He has 25Years of Teaching, Industrial and Research experience in the areas of Design, Geometric and Finite Element Modeling and Analysis, Composites, Fracture and Fatigue, Vibration and Acoustics, PSD analysis, Compressor modeling, Robotics, Nano Technology, Precession Engineering -Published over 175Technical papers in various reputed journals and conferences in National and International level