EXPERIMENTAL OF EFFECTED ON THE RESIDUE STRESS FOR THINNER Al_2O_3 -TiC IN GRINDING AND CUTTING PROCESSES

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ABSTRACT

One of the residual stress is imported the bending on thin material in the machining processes. In this work, to study the surface residual stress on the Al_2O_3 -TiC component used as a substrate for a read-write head in the hard disk drive. In manufacture, both sides on thin material are machined by grinding and cutting process, a cutting tool is used the thinner diamond blade of fine grain size and grinding wheel of fine grain size, the high precision machine is carried out according to the method of experiments. The results are experimented by bar bending, bar parallelism, the surface roughness of grinding size and surface roughness of cutting side, and compared the results by analysis of variance (ANOVA). The results revealed that the blade type and grinding level affected the bar bending, the bar parallelism is not significantly affected, and surface roughness of the grinding side is improved by the grinding level, while the surface roughness of cutting side is main affected by blade type. The optimization show percentage error of experimental and prediction lower than 1.5% by each responds.

Key words: Ceramic Al_2O_3 -TiC, Cutting and grinding process, Slider bar, Bar bending, Surface Roughness.

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1. INTRODUCTION

The grinding and cutting process is machining worked by remove material of the surface of part or workpiece to chip [1] [2]. The mechanical performance is many inside factors such as heat generation, wear, creep life, and fatigue strength [3], as the input factors such as cutting tool type, tool construction, feed rate, spindle speed, depth of cut, coolant, vibration, etc. While the provided are under essential relationships such as tool type and cutting conditions, workpiece and geometrical parameters, and tool material properties, which is the complexity and difficultly of the machining process [4]. The slider bar bending is not directly affected by blade thickness [5]. The cutting surface give affected by the diamond blade size on dicing speeds and abrasive grains size [6]. The additional quality of the machining process is the material removal rate (MRR) [7]. The more important quality of the grinding process is surface roughness and process accuracy [8]. As the combination of cutting parameters is affected the surface roughness [9]. The critical parameter of grinding depth is improved the surface finish by increased and the CBN wheel type is the better grinding wheel, benefice is the high grinding depth and good thermal properties [10], while the depth of cut affected to cutting force [2]. The effect study on surface roughness showed that cutting speed higher than the feed rate, while the residual stress is reduced by the feed rate decreased [11]. The mechanical affected on the surface is influenced by residual stresses, it's plastic deformations phrase and is effected by cutting angle in grinding process on the surface, the compression of material on the surface is affected by grinding or cutting process. During the cutting process is absorbed from cutting force and released into the surface layer. The bending distortion is produced as a result of the residual stresses generated by the scribing operation. [12] Developed the residual stresses by line force dipoles with bending effect model analysis. [13] Study the interrelation between subsurface damage and residual stress by grinding and diamond polishing, the high dislocation density is shown near the layer of the surface. The depth of the hardened layer is destroyed by the impact of the depth of grinding and feed rate [14]. The higher residual stress and deep of residual stress are affected by coarse diamond grains of the grinding process, assumed the compressive stresses on the surface to be results of higher tensile stresses near grain boundaries beneath the compressive stress layer and this will encourage the development of a crack along grain boundaries [15], the compression affected to the residual stressed and hence beneficial to the strength, the abrasive of grinding is influenced the strength and introduced residual stresses on the surface region of archived ceramics. The improvement of the large cracks of the surface region can be using abrasive grinding for removed it [16]. The optimal of the cutting condition can reduced costs or production time and enhance surface [17]. The minimization of the surface roughness studied and reduced the vibration during the machining process [18]. The cutting force magnitude can be improved by reducing ultrasonic vibration [19]. These are presented the prediction of multiple degrees of freedom model, they investigated the relationship between the cutting tool and workpiece in the turning process, the tool overhang and work cross-section is influenced by orthogonal turning process operation [20], the improvement of the surface finish is vibrated damping by a passive process [21]. The dynamic adjustment of position tool during the turning process is accuracy control [22]. The analysis of variance (ANOVA) is a statistic tool for analyzing more the parametric combined, it can find the relationship of two group or more groups of data [1] [2], the better of surface finish is affected by low depth of cut and feed rate the investigated by [23] [24], [25] used the ANOVA for operated the process, [26] showed the surface roughness is affected by feed rate more than cutting speed with using Taguchi method [27] [28].

This present paper is studying the systematic investigation on cutting machine of ceramic using diamond blade thickness 45, 48, and 71 μm and blade type SD1000, SD1200 and

SD1500, with grinding wheel types, is SD3000, and grinding level is 0, 12.7, and 23.5 mm refer center of grinding wheel. The experiments are assessed in terms of bar bending changes that were investigated and characterized in measure bar bending, bar parallelism, the surface roughness of the grinding side, and cutting side with comparison results by analysis of variance (ANOVA). The minimum of the bar bending, bar parallelism, the surface roughness of both sides is purposed. Finally, the results of experimental and optimization are confirmed by linear regression.

2. METHODS

2.1. Machine and Equipment

This high precision cutting machine was a maximum power of 10kW by study and the Dover precision machine was a maximum spindle speed of 20,000 rpm. The SD1000, SD1200, SD1500 grit side of special diamond blade type, the outside's diameter of 114 mm with thickness dimension of 45, 48, 71 μm , used by the cutting process, the rotating of blade wheel is 9,000 rpm and the feed rate is 180 mm/min see in Table 1.

Table 1 Parameters of experiment

Parameters	Level		
	1	2	3
Blade type (BT, SD)	SD1000	SD1200	SD1500
Blade thickness (BTh, μm)	45T	48T	71T
Grinding level (GL, mm)	0	12.7	23.5

2.2. Material and Preparation

This ceramic type $\text{Al}_2\text{O}_3\text{-TiC}$ used by experimented, they are the percentage mixed by volumes as 65 % and 35 % of Al_2O_3 and TiC, and the 1 μm of grain size particle of polycrystalline microstructure. The physical properties are density 4,300 kg/m^3 , Young's modulus 390 GPa, Poisson's ratio 0.22, specific heat 880 J/kg $^\circ\text{C}$, thermal conductivity 6,302 W/m $^\circ\text{C}$, and Resistivity 20,000 $\Omega\text{-m}$. The specimen size is 15.24 (w) x 46.07 (L) x 1.25 (T) mm for mini section of experiment. It bonded to the fixture by thermal adhesive wax, the holding mini section of wafer fixed to the chuck table by vacuum and the location overhang fixed with at 2.54 mm of distance level.

3. EXPERIMENTAL PROCEDURE

3.1. Experimental Setup

The special grinding wheel type is a SD3000 of grit size, the dimension is a diameter 69 mm and 2 mm Thickness, the rotation of grinding wheel is 9,000 rpm and the feed rate is 250 mm/min. In the experiments were performed under wet conditions, with 7.571 liters/minute of constant coolant flow rate at 2% solution of rustic water-based, and cut depth of cutting process used 1.5 mm see in Figure 1 (a).

Figure 1 Illustration of experiment setting of (a) Grinding and cutting process and (b) 2D and 3D Surface roughness measurements.

3.2. Bar Bending Measurement

The bar bending measurements are performed using a high accuracy machine (Machine design, 1/1,000,000 inch accuracy). A non-contact photography technique is used to capture cross marks on the deposition side of slider no. 2 and 52, then the machine will create the reference line. The machine will move to slider no. 9, 19, 27, 35, and 45, representing the distance of each point to the reference line and report to the display. The positive bar bending is more extended on the grinding side from the cutting side, the equal of extending both sides is zero bending, and the negative bar bending is lower extended on the grinding side from the cutting side.

3.3. Bar Parallelism Measurement

The bar parallelism is calculated by the difference of the thickness value of the top and bottom side. The bar thickness is measured by a z-scope machine, the top side, and bottom side of the slider bar are measured, and each side is separated into 3 zones such as inlet cutting zone, middle zone, and exit zone.

3.4. Surface Roughness Measurement

The surface roughness is measured on both sides for the grinding side and cutting side by Atomic Force Measurement (AFM) machine model AFM5300E. The measured surface roughness (2D and 3D) as shown in Figure 1 (b), with a sample square length of $10 \times 10 \mu\text{m}$, calculated the surface roughness (R_a) by averaging ten roughness values obtained 512 per point on both sides.

4. RESULTS AND DISCUSSIONS

4.1. Bar Bending

Figure 2 shows experimental results of the bar bending trend. The 45T thickness blade increased the blade type SD1000 to SD1500, while the 48T and 71T are irregular trends. The grinding level of 0 mm shows the blade type SD1000 to SD1500 is increased bent, while 12.7 mm and 23.5 mm of grinding level show irregular.

Figure 2 Results of the bar bending with, (a) Blade types vs blade thicknesses and (b) Blade type vs grinding level.

Table 2 Experimental results of grinding

Blade Type (Synthetic Diamond)	Blade Thickness (μm)	Grinding Level (mm)	Bar Bending (μm)	Bar Parallelism (μm)	Ra of Grinding (nm)	Ra of Cutting (nm)
SD1000	45T	0	-11.304	3.249	5.320	19.365
SD1000	48T	12.7	-14.145	3.067	3.242	15.120
SD1000	71T	23.5	-4.106	2.786	1.732	13.582
SD1200	45T	12.7	-16.179	3.285	3.982	12.651
SD1200	48T	23.5	-7.601	3.247	1.789	10.263
SD1200	71T	0	-19.659	3.545	5.903	10.741
SD1500	45T	23.5	-20.740	3.132	1.715	9.896
SD1500	48T	0	-29.860	3.741	4.570	7.039
SD1500	71T	12.7	-31.511	3.676	2.464	8.533

As Table 2 of the average of the bar, bending is analyzed by ANOVA statistical technical. The technique is based on partitioning the variable of data by as assumed, however suitable, statistical model. Considering the absolute of evaluation data reading as the response variable, the contributing linear statistical model is used to explain the data for bar bending:

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \quad \left\{ \begin{array}{l} i = 1, 2, 3, \dots, a \\ j = 1, 2, 3, \dots, n \end{array} \right. \quad (1)$$

When y_{ij} is the ij^{th} observation, μ is the mean of the i^{th} factor level or treatment, τ_i is a parameter unique to the i^{th} treatment, ε_{ij} is a random error component. The P-value approach is the probability of a test statistic. A confidence level of 95% is performed analysis. Accordingly, the P-value for parameters is indicated the significance of bigger of $\alpha = 0.05$ [29].

$$SS_T = \sum_{i=1}^a \sum_{j=1}^n (y_{ij} - \bar{y}_{..})^2 \quad (2)$$

$$SS_E = \sum_{i=1}^a \sum_{j=1}^n (y_{ij} - \bar{y}_{i.})^2 \quad (3)$$

$$MS_T = \frac{SS_T}{a-1} \quad (4)$$

$$MS_E = \frac{SS_E}{N-a} \quad (5)$$

$$F - \text{ratio} = \frac{MS_T}{MS_E} \quad (6)$$

$$\% \text{cont.} = \frac{F - \text{ratio}}{\text{total of } F - \text{ratio}} \quad (7)$$

$$R^2 = \frac{SS_M}{SS_T} \quad (8)$$

SS_T is the total sum of squares, SS_E is the sum square error, MS is mean squares, MS_E is mean square error. F-ratio and p-value are the statistical numbers, % contribution is the percent of effected, R² is the coefficient of determination [29].

Table 3 ANOVA of bar bending analysis.

Source	Degree of Freedom	Sum of Square	Mean of Square	F-ratio	P-value	% contribution
Blade Type	2	494.33	247.17	121.77	0.008	71.83
Blade Thickness	2	8.30	4.15	2.05	0.328	1.21
Grinding Level	2	185.54	92.77	45.71	0.021	26.96
Error	2	4.06	4.03			
Total	8	692.24				100

The average of bending results is used the ANOVA by Minitab 14 software, the output shows in Table 3 is obtained. The % contribution shows 71.83% and 26.96% for Blade type and grinding level, respect, at the R² value is 99.41% for average bending, the R² value represents the percentage of data variability accounted by the model. It can be concluded that the effects of blade type and grinding level factors on bending are significant.

4.2. Bar Parallelism

Table 4 ANOVA of bar parallelism analysis.

Source	Degree of Freedom	Sum of Square	Mean of Square	F-ratio	P-value	% contribution
Blade Type	2	0.3642	0.1821	9.83	0.092	51.28
Blade Thickness	2	0.0310	0.0155	0.84	0.545	4.38
Grinding Level	2	0.3149	0.1575	8.50	0.105	44.34
Error	2	0.0370	0.0185			
Total	8	0.7471				100

Fig 3 showed the variation of bar parallelism results on blade type vs blade thickness and blade type vs grinding level. It can see be, at 45T, 48T, and 71T of blade thickness shown the irregular tendency, while at 0 mm of the grinding level show regular, the blade type of SD1000 to SD1500 is the bar parallelism increased.

The calculated bar parallelism for ANOVA shows that the blade type, blade thickness, and grinding level are not significant at the R^2 is 95.04% by Minitab software shown in Table 4.

Figure 3 Results of the bar parallelism with, (a) Bar types vs blade thicknesses and (b) Blade types of vs grinding level

4.3. Surface Roughness of Grinding Side

The trend of the graph shows the surface roughness decreased the grinding level increased see in Fig 4 (a). The surface roughness results of the grinding side are significant by the ANOVA graph with Minitab, it shows p-value < 0.05 of grinding level at 98.67% of % contribution, while blade type and blade thickness are showed not significant on p-value is 0.290 and 0.478, respect. The R^2 value is 98.67% in Fig 5 (b).

Figure 4 Analysis of the surface roughness of the grinding process with (a) Ra of grinding level, (b) Ra of ANOVA.

4.4. Surface Roughness of Cutting Side

Figure 5 (a) shows the graph of surface roughness for the cutting side, the blade type SD1000 is highest of surface roughness value all of the blade thickness, while the blade type SD1500 is lowest of surface roughness value all of blade thickness. Similarly, the ANOVA shows significant for blade type, a p-value is 0.044 at 80.40% of % contribution, and the R^2 value is 96.46%, with 95% confidential shown in Figure 5 (b).

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Figure 5 Show the surface roughness of cutting side with (a) Ra value of blade type with blade thickness, (b) Surface roughness analysis by ANOVA

4.5. Optimization and Confirmations

The optimized conditions of a linear model are determined by the direction indicated by the bar bending (Bb), bar parallelism (Bp), the surface roughness of grinding level (Rag), and Ra of cutting side (Rac). The regression analysis is calculated to establish the relationship number of the independent and dependent variables for prediction purposes. In this study, using the first-order regression model (9) is the developing relationship for the main effects and depending on the number of independent variables (x), levels, and experimental trials. The equation (9), β is denoted as regression coefficients, x is denoted as independent variables, y is denoted as a dependent variable, and ϵ is denoted as a random error [27].

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \epsilon \quad (9)$$

$$Bb = 26.22 - (0.035663 * BT) - (0.0763 * BTh) + (0.39 * GL) \quad (10)$$

$$Bp = 2.2581 + (0.000929 * BT) + (0.00239 * BTh) - (0.019117 * GL) \quad (11)$$

$$Rag = 6.96 - (0.0012056 * BT) - (0.00457 * BTh) - (0.15005 * GL) \quad (12)$$

$$Rac = 34.295 - (0.014595 * BT) - (0.06973 * BTh) - (0.04752 * GL) \quad (13)$$

When Bb is bar bending, BT is blade type, BTh is blade thickness, GL is grinding level, Bp is bar parallelism, Rag is surface roughness average of grinding side, and Rac is the surface roughness of cutting side.

Equations (10)-(13), represent the first-order regression equation generated by Minitab software according to the experimental data. Tables 5-6 show the comparison of prediction and experimental results for responses to evaluate. The percentage relative error is calculated to identify the experimental divide of the prediction value. The average of percent errors is 0.11%, 0.26%, 0.36%, and 1.32% of bar bending, bar parallelism, Ra of grinding side, and Ra of cutting side, respect.

Table 5 The experimental and prediction by regression for bar bending, bar parallelism, surface roughness of grinding side, and surface roughness of cutting side.

Run	Bar Bending			Bar parallelism			Ra of Grinding side			Ra of Cutting side		
	Exp.	Pred.	% Err	Exp.	Pred.	% Err	Exp.	Pred.	% Err	Exp.	Pred.	% Err
1	-12.731	-12.877	5.510	5.549	-0.70	16.759	16.562	1.17	-1.14	3.467	3.295	4.95
2	-8.273	-8.152	3.516	3.629	-3.22	15.944	15.749	1.22	1.46	3.109	3.059	1.60
3	-5.786	-5.695	1.871	1.904	-1.75	13.672	13.632	0.29	1.57	2.812	2.908	-3.40
4	-15.308	-15.056	3.610	3.402	5.77	13.224	13.040	1.40	1.65	3.266	3.238	0.85
5	-11.233	-11.073	1.771	1.768	0.20	12.571	12.317	2.02	1.43	3.082	3.039	1.40
6	-21.506	-21.993	5.020	5.189	-3.37	11.902	11.830	0.61	-2.26	3.619	3.543	2.10
7	-21.614	-21.543	1.425	1.420	0.39	8.642	8.148	5.71	0.33	3.153	3.310	-4.97
8	-30.260	-30.937	5.055	4.932	2.43	9.727	9.055	6.90	-2.24	3.859	3.767	2.39
9	-27.796	-27.739	2.836	2.921	-3.01	6.371	6.848	-7.49	0.21	3.489	3.579	-2.56

5. CONCLUSIONS

The grinding and cutting process for the slider bar was controlled by the slider bar defection or bar bending by the machining process. The residue stress induced in the grinding surface contributed force into the angle line direction. The cutting process-induced force into horizontal line direction, both directions of forces were significantly affected by slider bar bending. Three grinding levels and three cutting blades are investigated. This experiment shows as below:

- The bar bending result is affected 71.83% and 26.96% by blade type and grinding level, it shows significantly,
- The bar parallelism result is showed not significant of all parameters.
- The surface roughness trend of the grinding side is improved by grinding level.
- The blade type is affected to surface roughness for the cutting side.
- The optimization show percentage error of experimental and prediction lower than 1.5% by each responds.

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