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Residual Stress Measurement in the Hard Turned SKD Tool Steel

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Most manufacturing processes such as welding, cutting and molding generate residual stresses on the surface of manufactured parts. Tensile residual stress is harmful to the surface integrity, which results in reduced fatigue life and causes other structural failures when the service stresses are superimposed on the residual stresses. In the research, the residual stresses of the high hardness steel (over $H_{RC}60$) workpiece (SKD11) machined by the hard turning were measured using Hole-drilling Method. Residual stress in the surface of hard turned workpiece was mainly appeared to be compressive stress.

Keywords : Surface Residual Stress, Hard Turning, SKD11, Hole-Drilling Method

1. INTRODUCTION

Surface integrity is a measure of the quality of a machined surface and is interpreted as elements that describe the actual structure of both surface and subsurface. Surface integrity is generally defined by its mechanical, metallurgical, chemical and topological states of surface properties such as surface roughness, hardness variation, structural changes, and residual stress, etc [1-6].

Since hard turning starts getting attention in machining industry recently, it is very important that production engineer is completely informed with the relationship between the characteristics of the machining process and the quality of the product [1-5]. The effect of machining on the mechanical properties of the surface layer must be understood so that remedial machining procedures can be introduced. For this purpose, cutting tests without using coolants were performed using SKD 11 tool steel in the practical ranges of cutting conditions for the hard turning operation. Ceramic tools were used in the experiment because of its better wear resistance in the mid-low cutting speed. The workpiece was heat-treated to increase hardness up to Rc 60. According to the robust design methodology of Taguchi experimental technique, amount of residual stress on/under the surface and the maximum depth of stressed zone in the machined workpieces were measured using hole drilling technique.

2. Experiment

A CNC turning center with Fanuc controller was selected for the cutting tests. Nine SKD 11 tool steel bars of 150 mm in length and 67 mm in diameter were prepared. The chemical composition of the workpiece in weight percent was reported as 69.493 Fe, 0.059 C, 0.3 Mn, 0.3 Si, 12 Cr, 0.8 Mn, 0.8 V, 0.3 Si, and 1.55 C. Each bar was premachined and heat treated to increase the hardness of the workpiece up to 65 Rc. Hard turning tests were conducted using ceramic tools of Al_2O_3 with Tic coating. In the hard turning tests, a robust design methodology developed by Dr. Denichi Taguchi was utilized to study the effect of machining conditions on the residual stress profiles. Cutting conditions of the hard turning tests were listed in Table 1 and the best orthogonal array for the residual stress measurement was L_9. Each cutting parameter has three levels and by applying the standard orthogonal array L_9 utilizing the column-merging technique and dummy level technique, nine tests as listed in Table 1were conducted.

Strain gages, type CEA-0600062UL-120 were used in the residual stress measurement and a computer system (System 5000 of Vishay Inc.) was utilized to calculate the stresses using signals from strain gages. RS-200 air drill was used to make hole on the machined surface. The drill can run at maximum 100,000 rpm. Using the measured strains, stress profiles along the depth of holes were calculated in data analyzing computer. Fig. 4 shows hard turned specimen with attached strain gages, and the hole drilling device with a specimen on the fixture. The cutter was a carbide drill of 1.6 mm in diameter

Table 1 Cutting Condition

Variable Factor	Level 1	Level 2	Level 3
(A) cutting speed [m/min]	50	90	130
(B) feed rate [mm/rev]	0.1	0.15	0.2
(C) depth of cut [mm]	0.05	0.1	0.2

Test \ Factor	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

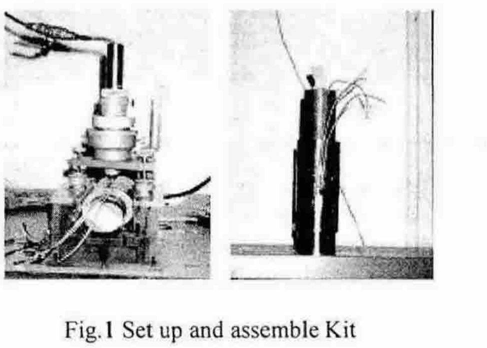

Fig.1 Set up and assemble Kit

The procedure to measure residual stresses is shown in Fig.2.

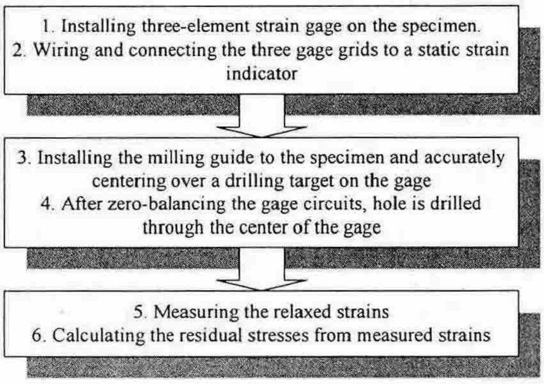

Fig.2 Procedure to measure residual stresses

3. Results and Discussion

The stresses at the measured depth were also calculated using Eq. (1).

$$\sigma_i' = \frac{\sigma_i Z_i - \sigma_{i-1} Z_{i-1}}{Z_i - Z_{i-1}} \quad (1)$$

where Z_i is distance from the machined surface to the measured depth. Fig. 3 shows stress variation along the depth when cutting speed was 50 m/min, feed rate was 0.1 mm/rev, and depth of cut was 0.05 mm. The stress on the machined surface was compressive and changed to tensile as the measured depth increased. More compressive stress appeared at higher cutting speed and feed rate but the depth of cut didn't have influence on the stress variation as strong as the other two parameters had. Usually white layer is generated in the subsurface below 10 μm during hard turning operation. Since it is not easy to measure stress profile within the 10 μm using hole drilling machine, stresses in the layer below 25 μm without considering the white layer were measured. Table 2 shows the average stress of each component

Table 2 Each direction residual stress on surface [MPa]

direction / test	tangential	feed	shear stress
1	-999.0	-1128.1	116.2
2	-236.7	-340.0	77.4
3	-1009.7	-828.9	-374.4
4	-386.3	-334.7	51.6
5	-345.1	-267.7	-142.0
6	-453.1	-556.3	77.4
7	-340.0	-236.7	103.2
8	-510.1	-355.1	-25.8
9	-885.9	-808.5	-167.8

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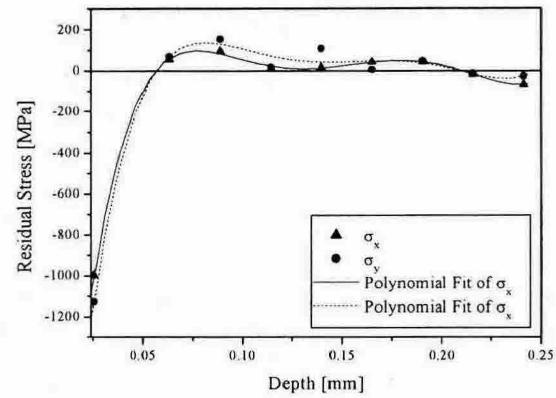

Fig. 3 Residual stress variation with depth

From the ANOVA analysis in the design of experiment test, the influence level of cutting speed on the residual stress in the tangential and feed directions was 1 and level of feed rate was 3. For the higher compressive residual stress, lower cutting speed and depth of cut, and higher feed rate were recommended.

4. Conclusions

From the research, the following conclusions were made to figure the effect of cutting parameters on residual stresses in hard turning process.

- The feed rate had strongest influence on feed directional and tangential residual stresses.
- Lower cutting speed and depth of cut were recommended for the higher compressive tangential residual stresses.

5. REFERENCES

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