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And much, much more!

Residual Stress Induced by Machining of Steel

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Abstract

Cylindrical steel (0.45%C) was machined under usual machining conditions by lathe. The surface and under surface residual stress were measured on axial and peripheral directions by X-ray method. Induced residual stress was affected by various machining conditions especially nose radius of cutting tool. Tensile residual stress induced by machining was easily changed to compressive residual stress by shot peening by glass beads.

Keywords

Machining, Residual Stress, Residual Stress Distribution, Shot Peening, Glass Beads Peening.

Introduction

Many machined products which have the accuracy within allowance are finished without after process. Nowadays, machine parts must have not only the accuracy but also suitable mechanical properties for fatigue strength, wear and corrosion resistivity. These properties are closely related to the residual stress.

The relation between the residual stress and several machining conditions are reported hitherto [1] [2] [3] [4]. This report is on the affects of tool geometry, feed rate and cutting force to the residual stress.

Machining was performed on various tool geometries such as side rake angle and nose radius and on several feed rate with wolfram carbide tip (P20) under two dimensional and three dimensional machining for normalized medium carbon steel.

Shot peening is the unique procedure which induces compressive residual stress. Machined specimens almost have surface tensile residual stress, therefore shot peening was performed after machining.

Experiment

The specimen and the method of measurement of residual stress are shown in Table 1 and machining conditions are shown in Table 2 as [A], [B], [C]. Cutting tool geometry in this paper are shown in Fig. 1. The types of two dimensional and three dimensional machining and three components of cutting force are shown in Fig. 2. Three dimensional cutting conditions [D], [E], geometry of cutting tool and tip non breaker and with breaker are shown in Table 2 and Fig. 3 respectively. (Tables and Figures are on pages 30 and 31.)

After machining, surface residual stress and residual stress distribution peripheral (//) and axial (⊥) were measured by X-ray method. Because majority of the surface residual stress were tensile, shot peening was tried on machined surface by glass beads under the condition [F] as shown in Table 4.

Results of Experiment

Relation between the Surface Residual Stress and Cutting Force

The relations between surface residual stress and three component of cutting force were shown in Fig. 4 and surface residual stress have the same tendency to perpendicular component of cutting force.

Residual Stress Distribution

Owing to that almost residual stress distributions under machined surface are similar, representative distributions are shown in Fig. 5. (See Figure 5 on page 32).

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Generally, appreciable affected zone of residual stress is within 0.2 mm under the surface. The measurement of residual stress distribution took place the method of small area etching.

The Maximum Residual Stress Under the Surface

The maximum residual stress under the surface is compressive under 0.05 mm from the surface, and varies by side rake angle, nose radius and feed rate as shown in Fig. 6 (a), (b), and (c). (See page 32.) The most affective factor in these three variables was nose radius of cutting tool and it was especially affected to the residual stress of peripheral direction. On the other hand, feed rate was not so affected.

Behavior of Half Width

The half width in X-ray analysis means the degree of plastic deformation related to the size of microcrystal. Metal cutting is a sort of plastic deformation and shearing strain of chip is several hundred percent, therefore, the affect of such high strain remains on the machined surface. The influence of plastic deformation of machined surface appears on the surface hardness resulted from work hardening and the surface roughness resulted from plastic flow.

The relations between half width after machining and both surface hardness and roughness are shown in Fig. 7. Both hardness and roughness are proportional to half width, and because of machining is the directional working process, half width of peripheral direction is larger than axial.

Comparison between Two Dimensional and Three Dimensional Machining

The three components of cutting force of two dimensional and three dimensional machining are similar to each other, but the surface residual stresses are different as shown in Fig. 8 (a) (b) (c). (See page 32). Surface residual stresses of peripheral direction of these machinings are tensile, but axial directions are reverse each other and small. Residual stress distributions are not so different.

Effects of Chip Breaker

Nowadays, chip breaker is employed for ordinary machining process, therefore it must be clear to induce residual stress. As the result, the differences between the machining by non-breaker and with-breaker are small on three components of cutting force on surface residual stresses and in residual stress distributions as shown in Fig. 9. (See page 32).

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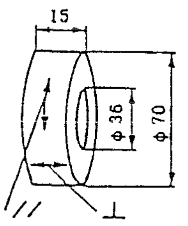
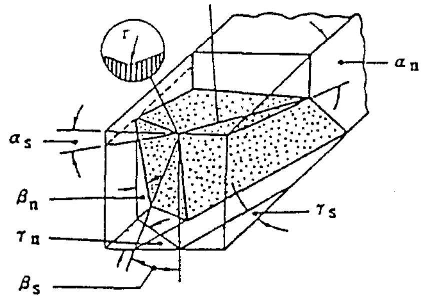
Table 1 Residual Stress Measurement and Specimen

work material : normalized carbon steel (C:0.45%, HV:232)		
residual stress measurement		specimen
formula	$\sigma_R = -\frac{E}{2(1+\nu)}\cot\theta_0\frac{\partial 2\theta}{\partial \sin^2\phi}$ $\nu=0.28$, $E=206$ GPa	
crystal face	(2 1 1)	
X-ray	Cr-Kα	
ϕ	0, 15, 30, 45 (deg)	

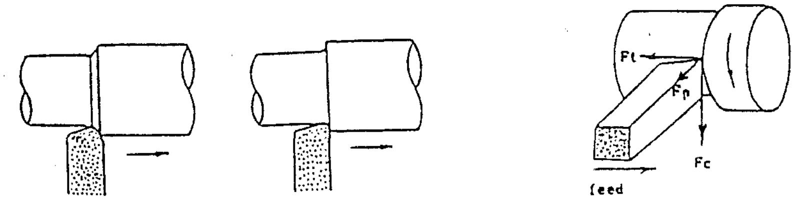
Nomenclature

Fc : cutting force
Ft : thrust force
Fp : perpendicular force
HV : Vickers hardness
Rmax : surface roughness
r : nose radius of cutting tool
β : half width
δ : distance from surface
σ_{RO} : residual stress under surface
σ_{ROmax} : maximum residual stress under surface
σ_{RS} : surface residual stress
// : peripheral direction of specimen
⊥ : axial direction of specimen



tool geometry: α_n α_s β_n β_s $\tau_n \cdot \tau_s$ r

Fig.1 Cutting tool



three dimensional two dimensional cutting force: Fc, Ft, Fp

Fig.2 Type of machining and three components of cutting force

Table 2 Machining Condition

[A]

side rake angle	-5, 0, 5, 10 (deg)
cutting speed	218 (m/min)
depth of cut	1.5 (mm)
feed rate	0.10 (mm/rev)
tool material	P20
tool geometry	0, Var, 11, 11−α_s, 30, 0, 0.4
cutting fluid	dry

[B]

nose radius	0.2, 0.4, 0.8, 1.2 (mm)
cutting speed	218 (m/min)
depth of cut	1.5 (mm)
feed rate	0.10 (mm/rev)
tool material	P20
tool geometry	0, 5, 11, 6, 30, 0, Var
cutting fluid	dry

[C]

feed rate	0.05 ~ 0.175 (mm/rev)
cutting speed	218 (m/min)
depth of cut	1.5 (mm)
tool material	P20
tool geometry	0, 5, 11, 6, 30, 0, 0.4
cutting fluid	dry

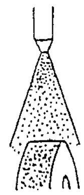
Table 3 Three dimensional Cutting Condition

cutting speed	218 (m/min)	
depth of cut	1.5 (mm)	
feed rate	0.10 (mm/rev)	
tool material	P20	
tool geometry	0, 5, 11, 6, 15, 15, 0.4	
condition	[D]	[E]
	non-breaker	with breaker
cutting fluid	dry	

Table 4 Shot Peening Condition

[F]

shot material	glass beads
shot diameter	0.137 (mm)
peenig machine	air blasting
peening pressure	6 (atm)
peening time	full coverage



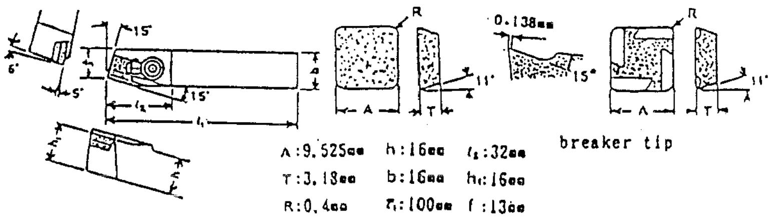


Fig.3 Three dimensional cutting tool

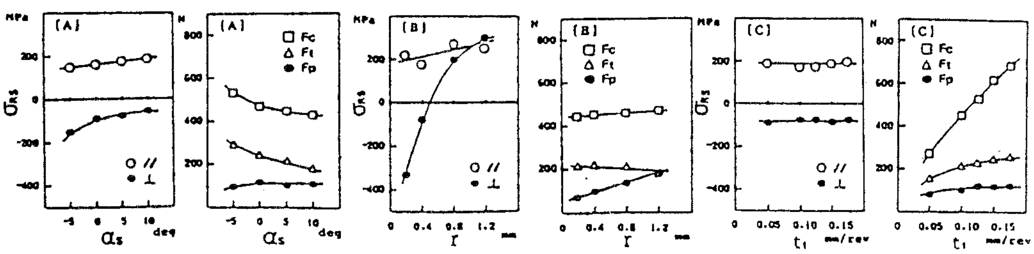


Fig.4 The relation between surface residual stress and three components of cutting force

Items of experiments are as follows:

Two dimensional	[A] Side rake angle (α_s)	-5 ~ 10 (deg)
	[B] Nose radius (r)	0.2 ~ 1.2 (mm)
	[C] Feed rate (t_1)	0.05 ~ 0.175 (mm/rev)
Three dimensional	[D] Non-braker	τ_s : 15 (deg)
	[E] With breaker	τ_s : 15 (deg)
Shot peening	[F] Shot peening after [B]	

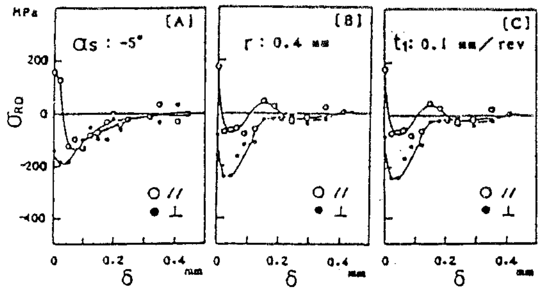
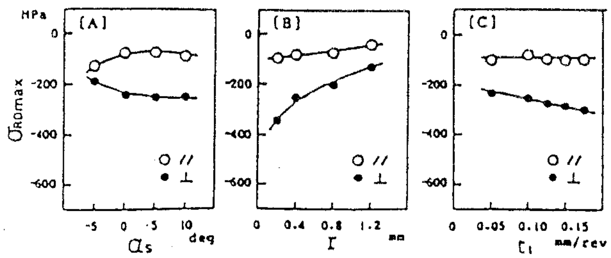


Fig.5
Residual stress distribution induced by machining



(a) (b) (c)

Fig.6 The maximum residual stress under machined surface

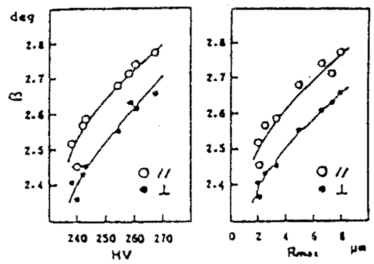
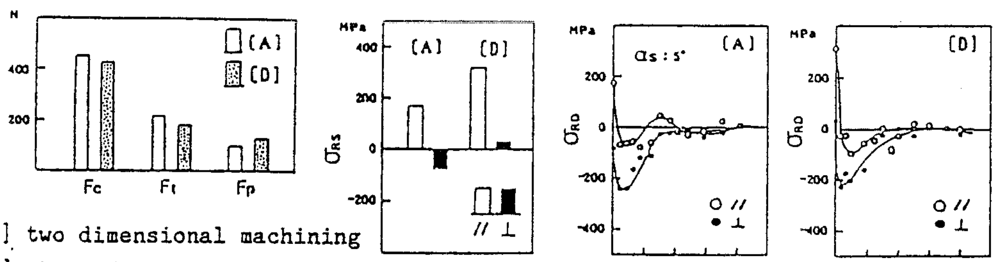


Fig.7 Surface hardness and roughness after machining are proportional to half width

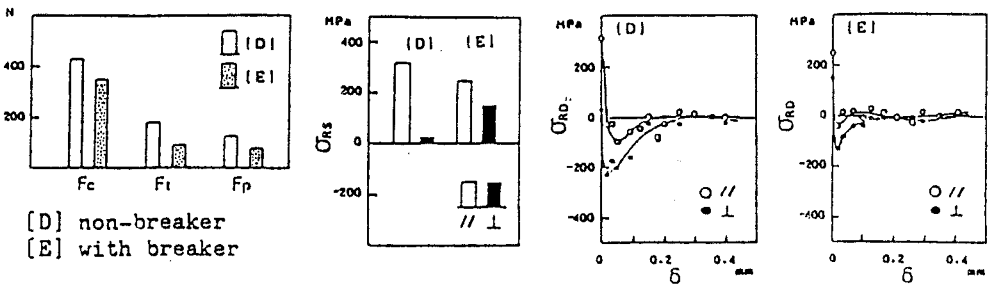


[A] two dimensional machining

[D] three dimensional machining

(a) cutting force (b) surface residual stress (c) residual stress distribution

Fig.8 Comparison between two dimensional machining and three dimensional machining



[D] non-breaker

[E] with breaker

(a) cutting force (b) surface residual stress (c) residual stress distribution

Fig.9 Comparison between non-breaker and with breaker

Effects of Glass Bead Peening

Peripheral residual stress of machined surface is tensile and axial is compressive, but increased from compressive to tensile with increase of nose radius in machining [B].

After all, surface residual stress was tensile above 0.5 mm nose radius, then glass shot was blasted on machined surfaces by the condition [F] already shown in Table 4, because it is well known that shot peening produces the compressive residual stress on peened surface.

Shot peening was performed with weak shot stream by small glass shot, therefore the surface roughness of machined surface was not so changed within 0.008 mm. The surface residual stress was dramatically changed to large compressive stress (-450 MPa), moreover, anisotropic residual stress was vanished from machined surface as shown in Fig. 10.

The reason for this phenomenon is that the dent produced by glass shot has a yield zone of about one hundred times as much as the volume of dent [5], therefore new strain occurs into peened surface zone. The new strain causes the new residual stress.

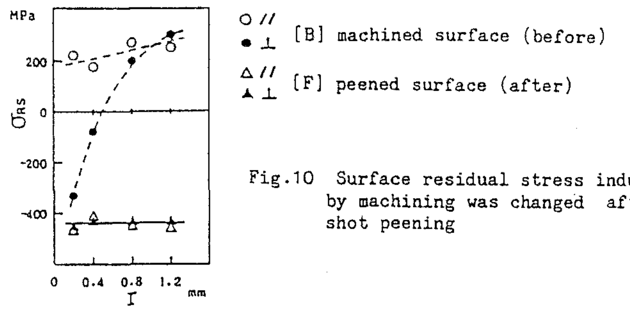


Fig.10 Surface residual stress induced by machining was changed after shot peening

Conclusion

1. Surface residual stresses of machined steel are anisotropic, peripheral directions and axial are tensile and almost compressive respectively.
2. The most affective factor to surface residual stress was nose radius, and most not affective factor was feed rate.
3. Appreciable residual stress zone induced by machining was within 0.2 mm under the surface, and the depth of the maximum compressive stress was about 0.05 mm from the surface.
4. Perpendicular component of cutting force shows similar variation to the surface residual stress.
5. The machined surface qualities such as hardness and roughness were related to the half width, the more the qualities, the more the half width.
6. In three dimensional cutting, surface residual stress were tensile, and there are not so differences between non-breaker and with-breaker.
7. Shot peening by small glass beads is very effective for the change of residual stress on machined surface, and exceedingly increases compressive residual stress, more over vanishes anisotropy of residual stress.

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