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Calculation of Residual Stress on the Surface Layer of Workpiece When Surface Grinding the Aisi 1018 Steel

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Key words: Calculation of residual stress when grinding, Johnson-Cook's material model, AISI 1018 steel, surface layer, grinding, steel

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Abstract: This study presented a study on calculation of residual stress on the surface layer of workpiece when grinding AISI 1018 steel. Johnson-Cook's material model has been applied to build a relationship between residual stress on the surface layer and the parameters of the machining process. This relationship was used to calculate the values of residual stress when grinding. The calculated results of residual stress were compared with the experimental results. The results showed that the residual stress values when calculating were quite close to the values from experimental works. The average deviation between the calculated results and the experimental results is only about 15.96%. The results of this study offer a promising method for calculation residual stresses on surface layer when grinding AISI1018 steel.

INTRODUCTION

Grinding is a popular processing method used in mechanical engineering. When researching on the grinding process, parameters are often chosen as criteria to evaluate the efficiency of the machining process such as surface roughness, cutting force, residual stres on surface layer. The residual stress on the surface layer of machine part has a great influence on the ability of the part to work through the effect of the residual stress on the fatigue strength of the product. The study of residual stress on surface layer of parts when grinding has been carried out by a number of scientists. Zhang *et al*.[1] conducted experiments to determine the influence of the cutting speed, the feed-rate and the cutting depth to residual stress on surface layer when using WA60L6V grinding wheel to grind 42CrMo steel. Nie *et al*.[2] conducted a simulation of prediction of residual stress on surface layer using a coupled thermo-mechanical modeling method based on FEM analysis of the cutting process of a abrasive grain, then they conducted experiments to evaluate the simulation results when grinding 2Cr12Ni4Mo3VNbN steel with WA400×30× 27A80L5V35 grinding wheel. Shen *et al*.[3] investigated the residual stress on surface layer when grinding 3J33 Maraging steel with CBN grinding wheel. Xiao *et al*.[4] studied to build a model of residual stress on surface layer and then conducted experiments when using CBN grinding wheel to grind camshaft of nodular cast iron material. Chen *et al*.[5] simulated the residual stress on surface layer when grinding by assuming heat source infuses the surface of parts processed in triangular and rectangular form and then they conducted the experiments of grinding En9 steel with 19A60L7V grinding wheel to verify the simulation results. Huang *et al*.[6] investigated residual stress on surface layer when using SA80KV grinding wheel to grind GH4169 material. Tonissen *et al*.[7] Mahdi and Zhang[8] analyzed the effect of grinding heat on residual stress on surface layer when grinding based on analysis of phase transformation of materials, then they conducted the experiment of grinding EN23 steel to evaluate the accuracy of the calculated results compared with the experimental results. Nguyen Van Cuong calculated the residual stress of surface layer when grinding AISI 1045 by Norton 38A120-KVBE grinding wheel. Xu *et al*.[9] investigated residual stress on surface layer when using diamond grinding wheel with four different grain sizes of 80, 150, 320 and 600 to grind two materials: Polycrystal Xirconia (Y-TZP) and a Zirconia-Toughened Alumina (ZTA). Da Silva *et al*.[10] conducted experiments to determine residual stress on surface layer when grinding AISI 4340 steel with FE38A60KV grinding wheel. Sallem *et al*.[11] studied the determination of residual stress on the surface layer when grinding High-Speed Steel (HSS) outside with CBN grinding wheel. Brosse *et al*. used SYSWELD software to determine the residual stresses on surface layer using finite element analysis. LeMaster *et al*.[12] experimented to determine the effect of the grinding depth on the change of stress on the gear surface when using vitrified alumina grinding wheel for grinding gears made of hard material 58-62 HRC. Gunwant *et al*.[13] used ANSYS software to simulate the residual stress on surface layer when grinding AISI 52100 steel. Li *et al*.[14] experimented to investigate the effect of some machining conditions on residual stress on surface layer when using CBN grinding wheel to grind Ti-6Al-4V alloys (TC4 alloys). The residual stress was investigated when using B126N11VD47ST140 grinding wheel to grind 1.4108 (DIN-code) steel with hardness 62 HRC. Hamdi *et al*.[15] investigated the residual stress on surface layer when using two different types of grinding wheel, 2A60I6V and 2A80J7V to grind AISI 52100 steel. Grum and Zerovmk.[16] used RAPOLD 8A60-H7B14 grinding wheel to investigate the residual stress when grinding 80WCrV8 steel, etc. In this study, a model was built to predict residual stress on surface layer when grinding ASIS 1018 steel. The predicted residual stress values were compared to the experimental results.

A model to determine residual stress on surface layer when grinding asis 1018 steel: AISI 1018 carbon steel is a free machining grade that is the most commonly available grade around the world. Although its mechanical properties are not very unique, it still can be easily formed, machined, welded and fabricated. Equivalent symbols of ASIS 1018 steel of some countries are presented in Table 1. In Table 2 and 3 respectively, the chemical composition and some characteristics of ASIS 1018 steel. The Johnson-Cook stress model is shown as follows [17, 18, 19]:

Table 1: Equivalent of ASIS 1018 steel[18]

USA	Germany	Japan	England
ASTM/AISI/UNS/SAE	DIN, WNr	JIS	BS
1018	CK15	S15	1.1141

Table 2: Chemical composition ASIS 1018 steel[19]

Element	C	Mn	p-values	S	Fe
[%]	0.15-0.20	0.60-0.90	<0.04	<0.05	Balance

$$\sigma = \left(A+B\varepsilon^{n}\right)\left(1+C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)\left(1-\left(\frac{T-T_r}{T_m-T_r}\right)^{m}\right) \quad (1)$$

Where:

- σ : Residual stress
- A : Initial yield strength
- B : Strain hardening coefficient
- ε : Equivalent plastic strain
- $\dot{\varepsilon}$: Equivalent plastic strain rate
- $\dot{\varepsilon}_0$: Reference plastic strain rate
- n : Strain hardening exponen
- C : Strain rate coefficient
- T : Current Temperature
- T_r : Reference Temperature
- T_m : Melting Temperature
- m : Thermal softening exponent

For AISI 1018 steel, the value of some parameters in Eq. 1 is valid as shown in Table 4[17, 18, 19]. About the values of equivalent plastic strain (ε) and equivalent plastic strain rate ($\dot{\varepsilon}$) are quantities that are difficult to determine. Thus, in this study, the value of equivalent plastic strain and equivalent plastic strain rate will be selected according to the research by Buchelya *et al*.[20], Shao *et al*.[21] and Davim *et al*.[22], ε = 2.36 and $\dot{\varepsilon}$ = 6.3×10^{6}. Since, then, the Johnson-Cook stress model of AISI 1018 steel is written as follows:

$$\sigma = \left(520+269\times2.36^{0.282}\right)\left(1+0.0476*\ln\left(\frac{6.3\times10^{6}}{1.0}\right)\right)\left(1-\left(\frac{T-25}{1470-25}\right)^{0.553}\right) \quad (2)$$

Or:

$$\sigma = 1505.608\times\left(1-\left(\frac{T-25}{1445}\right)^{0.553}\right) \quad (3)$$

Thus, in order to determine the residual stress, it is necessary to determine the value of the heat component

Table 3 Characteristic properties of ASIS 1018 steel[20]

Properties	Metric	Imperial
Tensile strength	440 Mpa	63800 psi
Yield strength	370 Mpa	53700 psi
Modulus of elasticity	205 Gpa	29700 ksi
Shear modulus (typical for steel)	80 Gpa	11600 ksi
Poisson's ratio	0.29	0.29
Elongation at break (in 50 mm)	15%	15%
Hardness, Brinell	126	126
Hardness, Knoop (converted from Brinell hardness)	145	145
Hardness, Rockwell B (converted from Brinell hardness)	71	71
Hardness, Vickers (converted from Brinell hardness)	131	131
Machinability (based on AISI 1212 steelas 100 machin ability)	70	70

Table 4: Parameters of AISI 1018 steel in Johnson-Cook model

Parameters	A	B	n	C	ε_0	T_m	m
Units	Mpa	Mpa	-	-	s^{-1}	^0C	-
Values	520	269	0.282	0.0476	1	1470	0.553

Table 5: Parameters for calculation residual stress

Parameters	Symbols	Values
Type of grinding wheel	Norton 38A120-KVBE	
The diameter of the grinding wheel	d_g	150 (mm)
The equivalent diameter of grinding wheel (surface grinding)	d_g*d_w/d_g+d_w	150 (mm)
The mesh number used in the grading sieve of the grinding wheel	M	120
The thermal diffusivity of the part material	α	5.8
The thermal conductivity of the material	k	16.7 (W mK^{-1})
The ratio of the volume of the grinding grain cut to the surface of the part	f	0.5
The chip width to thickness ratio	r	10
The positive coefficient	n_1	1
The percentage of the volume of the grinding grain compared to the total volume of the grinding wheel	s	0.2
The ratio of heat transferred to the workpiece compared to the total heat source generated during the grinding process	t	0.75
The speed of the grinding wheel	v_g	23.94 (m/sec)
The depth of cut	t	15.24 (μm)
The speed of the workpiece	v_w	1.524 (m/min)

acting on the part surface during machining T. The relationship between cutting heat and grinding parameters is determined by the following equation:

$$T = 1.13.\tau.\alpha^{(1/2)}.M^{(n_1)}\frac{1}{k}\frac{1}{12,5n_1}\frac{1}{\frac{n_1}{f_2}}\frac{1}{\frac{n_1}{r_2}}t \quad \frac{3-n_1}{4}V_g^{n/4}V_w\frac{2-n_1}{4}\left(\frac{d_g.d_w}{d_g+d_w}\right)^{\frac{1+n_1}{7}}\left(\frac{3s}{4\pi}\right)^{\frac{n1}{3}} \quad (4)$$

Where ε is the ratio of heat transferred to the workpiece compared to the total heat source generated during the grinding process. When grinding Al_2O_3 wheel, the value of ε ranges from 60-90%[23] when grinding CBN wheel, this value is about 84%; α-is the thermal diffusivity of the part material, α can be found in[24]; M-is the mesh number used in the grading sieve of the grinding wheel n_1-is the positive coefficient, ranging from 0.8-1[25]; k-is the thermal conductivity of the material, k can be found in f-is the ratio of the volume of the grinding grain cut to the surface of the part, f = 0.5[26]; r-is the chip width to thickness ratio, "r" ranges from 10-20[27]; t -is the depth of cut v_g-is the speed of the grinding wheel v_w-is the workpiece speed; d_g-is the diameter of the grinding wheel; d_w is the workpiece diameter when surface grinding, $d_w = \infty$ so, it can be considered $dg\times Dw/(d_g+d_w) = d_g$; s is the percentage of the volume of the grinding grain compared to the total volume of the grinding wheels value ranges from 12.5-37.5%[23].

Combining Eq. 3 and 4 will be the relationship between residual stresses and parameters of the machining process when grinding AISI 1018 steel. This relationship allows predicting the value of residual stress in each grinding condition of AISI 1018 steel in each specific case.

Comparison of residual stresses when predicted and when tested: Experimental research data when examining the effect of cutting condition to residual stress on surface layer when grinding AISI 1018 steel with vitrified-bond aluminum oxide wheel (Norton 38A120-KVBE) by Shao[21] was selected for comparison with the residual stress value when calculating in this study. Some parameters determined from the experimental conditions by Shao[21] were presented in Table 4 and 5.

Table 6: Value of residual stress when calculating and experiment

	Residual stress (Mpa)		
Current temperature by Eq. (4), T (°C)	Calculated	Measured [26]	Deviation of residual stress (%)
905.69	360.64	311	15.96

Use the data in Table 4 and 5 to calculate the value of residual stress according to two Eq. 3 and 4 in two different cases of the value of the workpiece velocity. Calculation results and experimental results are presented in Table 6. From the results in Table 6, the residual stress values are quite consistent compared to the experiments with an average deviation of only about 15.96%.

CONCLUSION

This study applied Johnson-Cook's material model to build the relationship between the residual stress on surface layer and parameters of machining process when grinding AISI 1018 steel. The predicted results have been compared to the experimental results. The residual stress values that were predicted were quite consistent with the values of experimental. This shows that the results of this study can be used to predict residual stress on surface layeres when grinding AISI 1018 steel in each specific case of grinding method, type of grinding wheel, parameters of technology. This significantly reduces machine adjustment cost, test machining cost, contributes to improving the economic and technical efficiency of the AISI 1018 steel grinding process.

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