SIMULATION ON CUTTING FORCES AND CUTTING TEMPERATURE IN BROACHING OF 300M STEEL

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In this paper, using the method of single factor experiment, set the test parameters of 300 M steel through AdvantEdge software broaching process simulation test, simulation results for the finishing, analyzed the influence of broach rake Angle and relief Angle, tooth lift and cutting speed on cutting force and cutting temperature in the process of broaching, observed the cutting temperature in the broaching process of regional changes, through the analysis, provides theory basis for reasonable design of the broach. The results show that the tooth lift has the greatest influence on the cutting speed,andthetooth lift and cutting speed have the greatest influence on the cutting temperature.

Keywords*: 300M steel; broaching test;cutting force; cuttingtemperature;toothlift*

1. Introduction

300M steel is a kind of low-alloy ultra-high strength steel with good fatigue performance, wear resistance and high strength. Because of its good stability, 300M steel is widely used in the aviation industry.300M steel is a typical refractory material because of its high performance, poor cutting efficiency and severe tool wear [1,2].

Due to the wide application of 300M steel in the aviation industry, many scholars have studied it. In terms of processing, Yan Xue et al. established an empirical model of 300M high speed milling cutting force of ultra-high strength steel, and studied the influence of cutting parameters on milling force through orthogonal test [3]. Zhang Huiping et al. obtained the influence law and primary and secondary relation of milling parameters on cutting force and surface roughness by single factor test and multi-factor orthogonal test; The influence of cutting parameters on surface hardening, residual stress and surface roughness was studied;Analyzed the influence of minimum lubrication on cutting force and cutting temperature during 300M high speed milling. The law of cutting force and cutting temperature changing with cutting parameters and the influence of cutting parameters on cutting force and cutting temperature during 300M high speed milling under drying and cryogenic minimum quantity lubrication conditions are studied by single factor contrast test and orthogonal test[4-6].SimaZhongwen et al. Conducted a high-speed dry turning test on 300M steel, and studied the influence of cutting parameters on the roughness and residual stress of the machined surface[7].Since the introduction of finite element model into machining simulation, the analysis method of finite element modeling has been widely used in machining simulation, Zhang Huiping et al. studied 300M steel high-speed cutting process through finite element simulation technology, created a high-speed cutting simulation model, and studied the influence of cutting morphology, stress distribution and cutting parameters on cutting force and cutting temperature in the process of cutting[8].Xing Wanqiang studied the surface quality performance parameters such as cutting force, roughness and residual stress when turning 300M steel through the combination of finite element simulation and experiment[9].Huang Qi et al. established the finite element model of circular broach cutting process by using finite element software, and obtained the cutting force and stress distribution during broaching.The influence of cutting parameters on stress is analyzed [10].

Broaching technology has always been an irreplaceable position in metal cutting technology, but there are still many problems in broaching difficult materials. In order to improve machining efficiency, machining accuracy and surface roughness, it is necessary to study the broaching performance of 300M steel.

2. Finite element analysis modeling of 300 steel

2.1 Introduction to AdvantEdge finite element software

AdvantEdgefinite element software is fully called Third wave AdvantEdge FEM. Developed byThird Wave Systems,AdvantEdge FEM is a finite element metal cutting simulation software based on material properties, which is specifically used to optimize metal cutting process. This software is suitable for improving parts quality, increasing material removal rate, extending tool life and so on. Using this software can reduce the number of times of cutting, so that the product quickly marketization.

2.2 Establishment of simulation model

Broach is a kind of multi-tooth cutter; the height difference between adjacent two teeth becomes the amount of tooth rise, because in the broaching process, each cutter tooth only cuts once in the working stroke, so the amount of tooth rise between adjacent two teeth is also regarded as the feed in the processing process.

The broaching model was established by using AdvantEdge software, and the workpiece size was defined as 4mm in length and 2mm in height. The workpiece material is 300M steel, the tool material is Carbide-General, and the surface coating is$Al_2O_3$with a thickness of 0.001mm.

2.3 Determination of simulation parameters

Through the structure analysis of broaching tool, we determined the four main factors affect the cutting force, the detailed parameters are shown in Tab. 1.

Tab.1 Broaching test parameters design

Number	Rake γ (°)	Relief α (°)	Tooth lift f(mm)	Cutting speed Vc(m/min)
1	3	4	0.03	200
2	5	4	0.03	200
3	7	4	0.03	200
4	9	4	0.03	200
5	5	1	0.03	200
6	5	3	0.03	200
7	5	5	0.03	200
8	5	7	0.03	200
9	5	4	0.02	200
10	5	4	0.04	200
11	5	4	0.06	200
12	5	4	0.08	200
13	5	4	0.03	170
14	5	4	0.03	210
15	5	4	0.03	250
16	5	4	0.03	290

3. Finite element simulation results and analysis

3.1 Simulation results andanalysisofcutting force

In the simulation process, cutting force, chip shape and cutting temperature can be obtained.Fig.1is a schematic diagram of cutting force in the cutting process, and Fig.2is a schematic diagram of cutting state and chip shape in the cutting process.

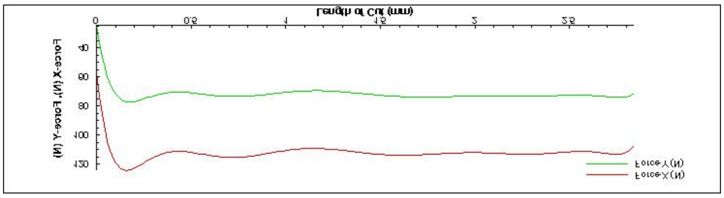

Fig.1 Schematic diagram of cutting force

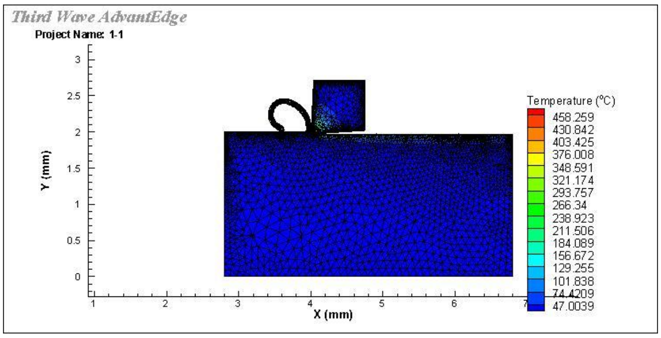

Fig. 2 Schematic diagram of cutting state and cutting shape

3.1.1Influence of rakeangle on cutting force

Through the simulation of 1-4 groups of different parameters in Tab.1, the average cutting forces Fx and Fy in X direction and Y direction of each group were obtained as shown in Tab.2, and the changing trend diagram of cutting forces as shown in Fig.3. was drawn.

Tab.2 Influence of rake angle on cutting force

Number	Rake γ (°)	Fx (N)	Fy (N)
1	3	112.021	73.206
2	5	111.805	72.664
3	7	109.139	69.074
4	9	106.932	63.153

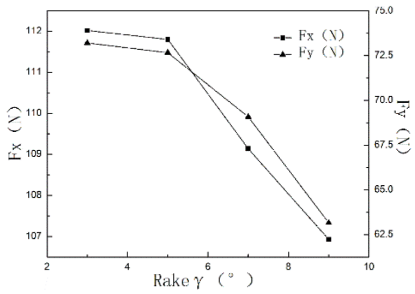

Fig. 3 Trend of cutting forces at different rake angles

3.1.2Influence of relief angle on cutting force

Through the simulation of 5-8 groups of different parameters in Tab.1, the average cutting forces Fx and Fy in X direction and Y direction of each group were obtained as shown in Tab3, and the changing trend diagram of cutting forces as shown in Fig.4 was drawn.

Table 3. Influence of relief angle on cutting force

Number	Relief α (°)	Fx(N)	Fy(N)
5	2	110.886	72.071
6	4	109.451	67.809
7	6	108.48	66.825
8	8	107.823	66.564

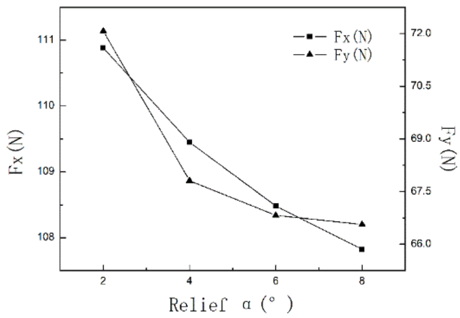

Fig. 4 Trends of cutting forces at different relief angles

3.1.3 Influence of tooth lift on cutting force

Through the simulation of 9-12 groups of different parameters in Tab 1, the average cutting forces Fx and Fy in X direction and Y direction of each group were obtained as shown in Tab 4, and the changing trend diagram of cutting forces as shown in Fig.5 was drawn.

Table 4. Influence of tooth lift on cutting force

Number	Tooth lift f(mm)	Fx(N)	Fy(N)
9	0.02	81.468	59.875
10	0.04	110.57	68.612
11	0.06	193.617	102.783
12	0.08	239.776	105.768

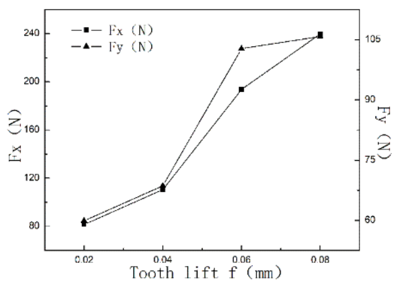

Fig. 5 Trends of cutting forces at different tooth lift

3.1.4 Influence of cutting speed on cutting force

Through the simulation of 13-16 groups of different parameters in Tab 1, the average cutting forces Fx and Fy in X direction and Y direction of each group were obtained as shown in Tab. 5, and the changing trend diagram of cutting forces as shown in Fig.5 was drawn.

Table 5. Influence of cutting speed on cutting force

Number	Cutting speed Vc(m/min)	Fx(N)	Fy(N)
1	170	111.328	69.909
2	210	110.677	69.634
3	250	108.86	66.904
4	290	107.674	66.272

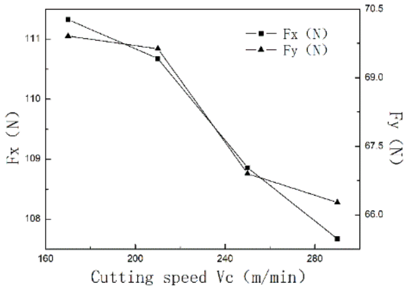

Fig.6 Trends of cutting forces at different cutting speed

3.1.5Results analysis

The influence of the rake angle γ on the cutting force can be obtained through the analysis of Fig.1. During the broaching test, with the increase of the rake angle, the cutting force in the x direction an y direction generally shows a downward trend, but the overall change is not very great; The influence of relief angle on cutting force can be obtained from the analysis of Fig.2. During the broaching test, with the increase of relief angle, the cutting force in x direction and y direction generally shows a downward trend, but the change range is not very large. The influence of the tooth lift on cutting force can obtained the analysis of Fig.3. During the broaching test, with the increase of the tooth lift, the cutting force in x direction and y direction generally shows a rises trend; The influence of the cutting speed Vc on cutting force can be obtained through the analysis of Fig.4, During the broaching test, with the increase of the cutting speed, the cutting force in the x direction and y direction generally shows a downward trend, but the variation range is not large.

3.2 Simulation results and analysis of cutting temperature and cutting stress

Fig. 7 shows the cutting temperature distribution in the cutting area. It can be seen from the figure that the cutting temperature is mainly distributed in the first deformation area and the second deformation area. Among them, the workpiece and cutting tool, the contact area between the highest temperature maximum cutting temperature is 458.25 ℃, gradually reduce the cutting temperature along the cutting face. Can be seen from Fig.7, the chip temperature is higher, the average temperature of 403.425 ℃. In the whole process of cutting, chips bear a lot of heat and play an important role in the process of heat dissipation. Fig. 8 shows the cutting temperature variation curve. It can be seen from the figure that the cutting temperature is gradually stable with the passage of time, and the average cutting temperature under various cutting parameters can be read out through the image.

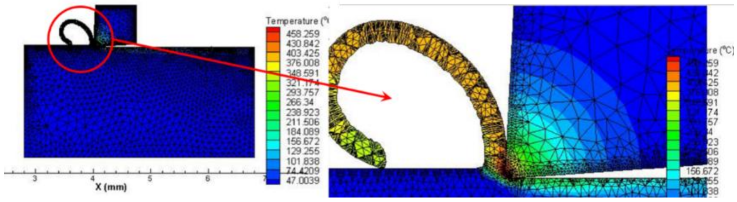

Fig. 7 Cutting temperature profile of cutting area

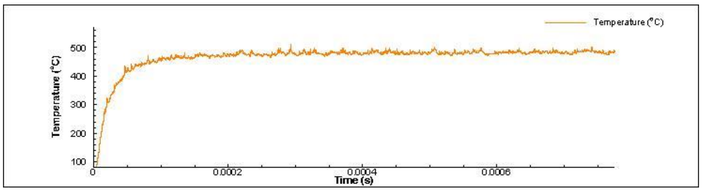

Fig. 8 Cutting temperature variation curve

3.2.1 Influence of rake angle on cutting temperature

Relief angle α=4°,toothlift$f$=0.03mm,cutting speed Vc=200m/min,The simulation temperature distribution of broaching during the process of increasing the rake angle is shown in Fig.9. When the rake angle γ increases, the high-temperature area of the cutting temperature gradually shrinks and gets close to the tool tip.The average cutting temperature was obtained by changing the cutting temperature curve, and Tab.7 was sorted out. According to the data in Tab.7, the cutting temperature variation trend of different rake angles was drawn, as shown in Fig.10

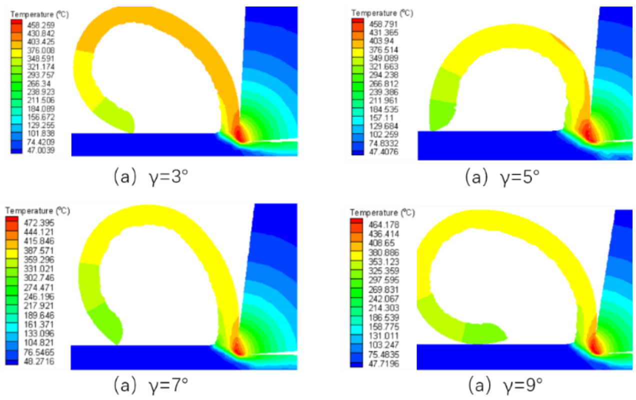

Fig. 9 The change of cutting temperature when the rake angle increased

Table 6. Influence of rake angle on cutting temperature

Number	Rake γ(°)	Cutting temperature T(°C)
1	3	489.4
2	5	485.9.
3	7	479.9
4	9	471.1

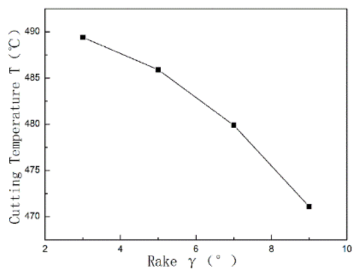

Fig.10 Trends of cutting forces at different rake angle

3.2.2 Influence of relief angle on cutting temperature

Rake angle γ=5°,tooth lift f=0.03mm,cutting speed Vc=200m/min,The simulation temperature distribution of broaching during the process of increasing the relief angle is shown in Fig.11. When the relief angle α increases, the high-temperature area of the cutting temperature gradually shrinks and gets close to the tool tip. The average cutting temperature was obtained by changing the cutting temperature curve, and Tab.7 was sorted out. According to the data in Tab.7, the cutting temperature variation trend of different relief angles was drawn, as shown in Fig.12.

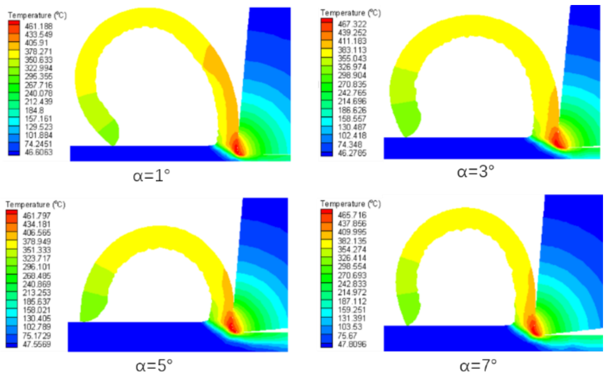

Fig. 11 The change of cutting temperature when the relief angle increased

Table 7. Influence of relief angle on cutting temperature

Number	Relief α(°)	Cutting temperature T(℃)
5	2	473.3
6	4	476.2
7	6	480.5
8	8	487.2

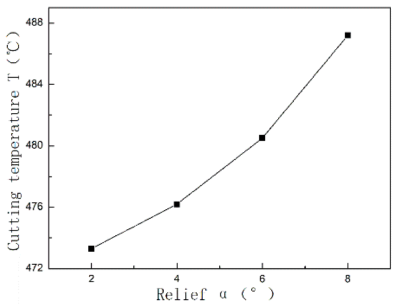

Fig. 12 Trends of cutting forces at different relief angle

3.2.3 Influence of tooth lift on cutting temperature

Rake angle γ=5°,relief angle α=4°,cuttingspeedVc=200m/min,The simulation temperature distribution of broaching during the process of increasing the toothlift is shown in Fig.13. When the tooth lift f increases, the area of the high-temperature cutting temperature region gradually increases, while the chip temperature decreases. The average cutting temperature was obtained through the change curve of cutting temperature, and Tab.8 was sorted out. According to the data in Tab.8, the cutting temperature variation trend of different front angles was drawn, as shown in Fig.14.

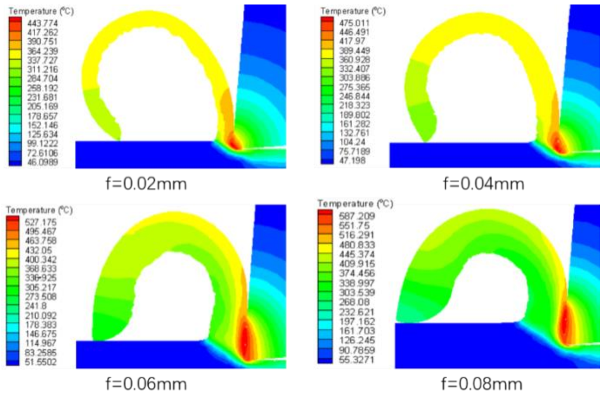

Fig. 13 The change of cutting temperature when the toothlift increased

Table 8 Influence of tooth lift on cutting temperature

Number	Tooth lift f(mm)	Cutting temperature T(℃)
9	0.02	455.1
10	0.04	484.6
11	0.06	572.3
12	0.08	609.5

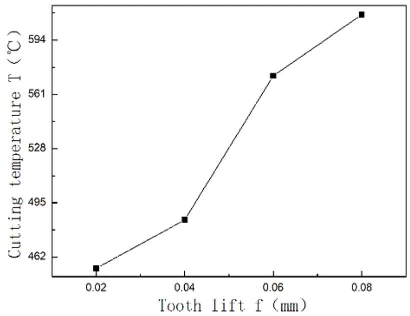

Fig. 14 Trends of cutting forces at different tooth lift

3.2.4Influence of cutting speed on cutting temperature

Rake angle γ=5°,relief angle α=4°,tooth lift f=0.03mm, The simulation temperature distribution of broaching during the process of increasing the toothlift is shown in Fig.15. When the tooth lift f increases, the area of the high-temperature cutting temperature area first increases and then decreases, while the maximum temperature increases.The average cutting temperature was obtained through the change curve of cutting temperature, and Tab.9 was sorted out.According to the data in Tab.9, the cutting temperature variation trend of different front angles was drawn, as shown in Fig.16.

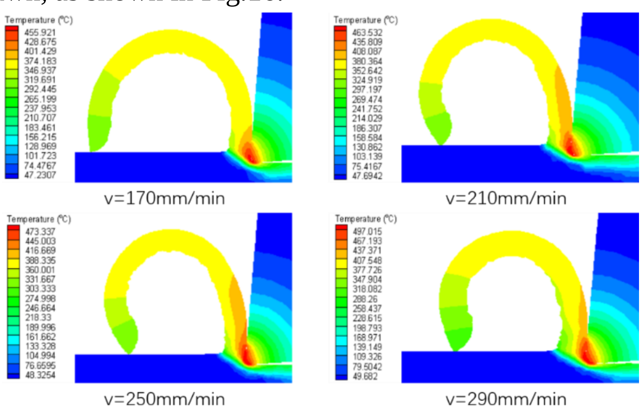

Fig. 15 The change of cutting temperature when the cutting speed increased

Table 9. Influence of cutting speed on cutting temperature

Number	Cutting speed Vc(m/min)	Cutting temperature T(℃)
5	170	461.1
6	210	491.4
7	250	503.5
8	290	529.8

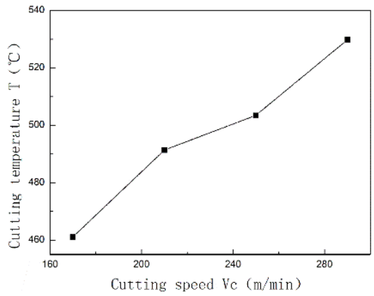

Fig. 16 Trends of cutting forces at different cutting speed

3.2.5 Results and analysis

The influence of the rake angle γ on the cutting temperature can be obtained through the analysis of Fig.10. During the broaching test, with the increase of the front Angle, the cutting temperature shows a decreasing trend, but the overall change is not very great.According to the analysis of Fig.12, the influence of relief angle α on the cutting temperature can be obtained. During the broaching test, the cutting temperature shows an upward trend with the increase of back Angle, but the change range is not large. Fig.14 analyzes the influence oftoothlift f on cutting temperature. During broaching test, with the increase of gear rise, cutting temperature shows an upward trend.The influence of cutting speed *Vc* on cutting temperature can be obtained from the analysis of Fig.16. In the broaching test, with the increase of cutting speed, the overall cutting temperature shows a downward trend.Based on the above four figures, it can be concluded that the cutting speed has the largest influence on the cutting temperature, followed by the tooth lift, and the rake angle and the relief angle have little influence on the cutting temperature.

4. Conclusion

1. Within the scope of the experimental values, cutting force decreases with the increase of rake angle, decreases with the increase of relief angle, increase with the increase of tooth lift, while decreases with the increase of cutting speed, therefore, in the design of the broach, by increasingthe length of the broach to reduce the tooth lift, so as to achieve the cutting force is reduced.

2. Within the scope of the experimental values,cutting temperature decreases with the increase of rake angle,increase with the increase of relief angle,increase with the increase of tooth lift,while increase with the increase of cutting speed, so in the design of the broach, can increase the length of the broach to reducing the tooth rise, so as to achieve the reduce of cutting temperature; In broaching, the cutting speed can be appropriately reduced to reduce the cutting temperature.

Acknowledgments

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References

[1]ZhangH. P., WangC. X.,Du X., *et al.*, Aircraft Landing Gear with Development of 300M Ultra High Strength Ste and Research, *journal of Harbin university of science and technology*, *vol. 16 (2011)*, pp.73-76.

[2]ZhaoB., XuG. X., HeF., *et al.*,Present Status and Prospect of Ultra High Strength Steel Applied to Aircraft Landing Gear, *jourmal of aeronautical materials, Vol. 37 (2017),* pp.1-6.

[3]YanX.,Tao H., GaoX. B., *et al.,* Study on Modeling of Cutting Force For 300M Ultra-High-Strength Steel In High-speed Milling Process, *journal of Mechanical Strength, Vol. 30 (2008),*pp.860-863.

[4]Zhang H. P., ZhangQ. Y., ZhangX. L., *et al.,*Study on Cutting Force and Surface Roughness in High speed Milling of 300M Ultra-high-strength Steel, *Tool Engineering,Vol. 51 (2017),* pp.12-15.

[5]ZhangH. P., ZhangX. L., ZhangH. X.,*etal.,*Surface Quality of High-speed Turning 300M Ultrahigh Strength Steel, *Surface Technology,Vol. 2 (2016),* pp.181-187.

[6]ZhangH.P.,ZhangQ. Y., RenY., *et al.,* Simulation and Experiments on Cutting Forces and Cutting Temperature in High Speed Milling of 300M Steel under CMQL and Dry Conditions,*International Journal of Precision Engineering &Manufacturing.Vol. 19 (2018),*pp.1245-1251.

[7]SimaZ. W., ZhengG. M.,Fang Y. F., Surface Roughness and Residual Stress in High-speed Dry Turning of 300M steel, *Modular Machine tool &Automatic Manufacturing Technique, Vol. 12 (2017),*pp.121-124.

[8]ZhangH. P., LiuR. H., LiZ. C., *et al.,*Finite Element Simulation of High Speed Cutting Processing of 300M Ultra-high Strength Steel, *Mechanical Science and Technology for Aerospace Engineering,Vol. 36 (2017),*pp.1550-1555.

[9] Xing W.Q., Identification of Cutting Simulation Parameters of 300M Steel and Research on Its Surface Quality in Turing [D] Huazhong university of science and technology,2015

[10] Huang Q., Yin N.D., Research on cutting process of round hole broach based on AdvantEdge, *journal of Hubei polytechnic university,Vol. 6(2013),* pp.9-11