The research on tools wear and surface qualityof TC4 Titanium alloy Under extreme conditions

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Abstract

In this paper, high speed cutting experiment of TC4 titanium alloy which was disposed by low temperature progressive aging treatment was conducted under the extreme conditions at -120℃ and 300℃. Superdepth of three-dimensional microscopic system was used to examine the tool worn surface morphology.The millin-g processing surface topography was explored by 3D probe-type Surface Plasmon Resonance Analyzer. At the sa-me time,The microstructures of TC4 titanium alloy before and after the cutting were compared by using TEM. Theresult shows that the main form of tool wear is abrasive wear incorporated with brittle tipping at -120℃. The main form of tool wear is oxidative wear and adhesive wear at 350℃. It was found that the high hardness and brittlenes-s of TC4 titanium alloy due to the cryogenic treatment at -120℃ lead to the poor quality of processing surface. On the contrary, the lower-hardness and brittleness and higher toughness and ductility of material owing to the retrogression heat treatment at 350℃ can bring benefits to the good quality of the processing surface than the first processand the tool life is longer than before. By observing the TEM microstructure of the materials, it was shown that thediscrete grain phases of TC4 titanium alloy become tiny and fine after high speed cutting at-120℃. Discrete phases of TC4 titanium alloy mostly disappear after high speed cutting at 300℃. The microstructure retrogression phenom-enon emerged.

Keywords

Extreme condition, tool wear, quality of the surface, Discrete Phase, regression.

1. Introduction

Titanium alloy has the characteristics of good specific strength and high specific stiffness as well as good corrosion resistance and good comprehensive mechanical properties, which is widely used in aerospace product manufacture. Titanium alloy is a new kind of alloy which possessed ultra-high strength,hardness and the stress corrosion properties et al.Therefore, it has been widely used in aerospace industry. Some of the large skeleton parts of Aircraft and spacecraft are directly hollowed by the blank.so the research of high speed cutting of TC4 titanium alloy is very significant. Zhang, Yuan liang research Diamond Tool Wear in Precision Turning of Titanium Alloy; Gui mu, Zhang research the milling of thin parts of titanium alloy (TC4) ;Zeng Hui Jiang research surface residual stress of Titanium Alloy TC4 by finite element method based on high speed cutting;Wei Hua research the influence of Cutting Parameters and Tool Geometric Angles on TC4 Titanium Alloy; Xiao Hui Zhang research parameter optimization based on force and heat constraint in milling TC4 Titanium Alloy; Chao feng Liu research the effect of cutting speed on residual stresses when orthogonal cutting TC4; Zhen Ya Che research TC4 surface crack detection of Titanium Alloy. Although the study of titanium alloy increases with the the development of science and technology, the research on tools wear and surface quality of TC4 titanium alloy under extreme conditions is blank. In this paper, high speed cutting experiment of TC4 titanium alloy which was disposed by low temperature progressive aging treatment was conducted under the extreme conditions at -120℃ and 350℃.

2. Experimental materials, equipment and methods

2.1 Experimental material sand equipment

TC4 titanium alloy was selected experimental materials. The size of workpiece is 30 × 10 ×50 mm. The heat treatment of TC4 titanium alloy include solid solution of 830℃45 min+ pre aging 450 ℃30 min + 120 ℃ low temperature aging which continues 192 h. The yield strength of TC4 titanium alloy is 830 Mpa, the tensile strength of TC4 titanium alloy is 920 Mpa. The experiments of high speed cutting of TC4 titanium alloy are conducted on the five-axis linkage machining center and the device of heating and cooling are developed by the team of project group about the extreme environment. The tool of milling experiment is coated tools which models is CoroMill290, the rake Angle of cutting tool is 25 °.3D surface topography instrument was used to measure the surface morphology after milling; The microstructure were observed by TEM.

2.2 Test method

TC4 titanium alloy materials belongs to the typical difficult-to-machine materials. The heat is an important factor which can lead to tool wear in the high-speed cutting processing. Tool wear properties and surface morphology is known as one of the most intuitive measure of quality indicators. The influence factors of material cutting process is various. For certain processing technology, the spindle speed machine tool, each tooth cutting depth and feed rate are all important parameters about the influence of cutting process ability.Therefore, three parameters which include milling speed, each tooth cutting depth and feed rate were selected for the research.In order to explore the tool wear and surface quality of TC4 titanium alloy at extreme environment, - 120 ℃ and 350 ℃ were selected to experiment. Experiment plan shows in table 1.

Table1 Single factor experiment of milling speed

No.	speed（m/min）	depth (mm)	feed (mm/z)	spindle speed (r/min)
1	600	2	0.1	1910
2	900	2	0.1	2866
3	1200	2	0.1	3821
4	1500	2	0.1	4777
5	1800	2	0.1	5732

After the completion of the high-speed cutting experiment, tool wear morphology and surface morphology are measured. Single factor experiments of the cutting depth which choose 0.15 mm, 0.3 mm and 0.45 mm, 0.6 mm and 0.75 mm five levels will be carry out.Single factor experiments of the feed rate which choose 0.05 mm / 0.025 mm/z, 0.075 mm/z, 0.1 mm/z and 0.12 mm /z will be carry out.

3. Results and discussion

3.1 The analysis of friction and wear under two extreme environment

Figure 1 shows the friction of tools in the high speed cutting process.The friction of high speed cutting prompted the tool failure(wear and tear) in the process and affect the service life of the cutting tool, accuracy of workpiece machining and the quality of the machined surface. In recent years, the technology, that with high efficiency, high precision, low cost as represent of high speed cutting of aviation materials develops rapidly.The high loss, worse surface quality and unstable machining precision is the bottleneck of the development of high speed cutting processing of high strength aluminum alloy. It is very important to explore the tribological mechanism of high speed cutting. A main friction phenomenon in the process of high speed cutting is the cutting tool wear- workpiece. The research content mainly includes the knife abrasion resistance and the sword of the wear morphology after below.

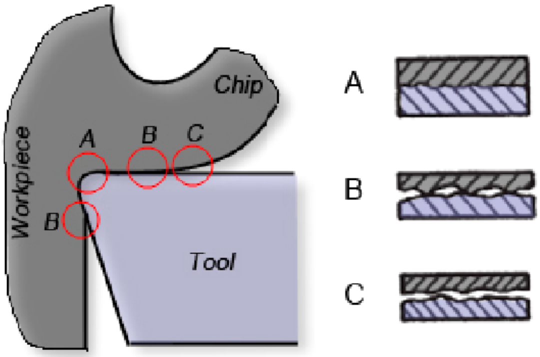

Fig.1 The friction of cutting

(1) Abrasion resistance of the flank surface of the tool

The friction of chip-tool and tool-workpiece is the main reasons for the wear of the flank surface of the tool. Figure 2 shows the diagram of tools wear of high-speed cutting of TC4 titanium alloy. Figure 2 (a) shows the relationship between times of using of tool and wear quantity at different cutting speed; Figure 2 (b) shows the relationship between times of using of tool and the friction of flank surface of the tool at different cutting speed.

According to the figure 2 (a) suggest that abrasion speed of flank tool surface increases with the continuous increase of spindle speed. The wear curve of flank tool surface is difference at the different spindle speed. when the speed is 600 m/min, tool wear is relatively flat, wear curve accords with typical graph of wear of flank tool surface;When the speed is 1800 m/min, the degree of tool wear is very big, wear curve shows the trend of steep; When the speed is 1200 m/min, the degree of tool wear fall in between 600 m/min and m/min. According to the figure 3 (b) suggest that abrasion loss of flank tool surface of the low temperature is much greater than that of high temperature at the same time of using. This is because the environment in the process of cryogenic cutting temperature below 120 ℃, it could be regard the high speed machining as the super cold.When the tool and workpiece undergo cryogenic treatment ,material hardness has obviously improved, the cutting wear is become more larger. when the temperature above 350 ℃, cutting process on the contrary. This is because environment temperature is much higher than that of aging temperature, phase transformation occurs incompletely in the process,and material hardness return to the original.

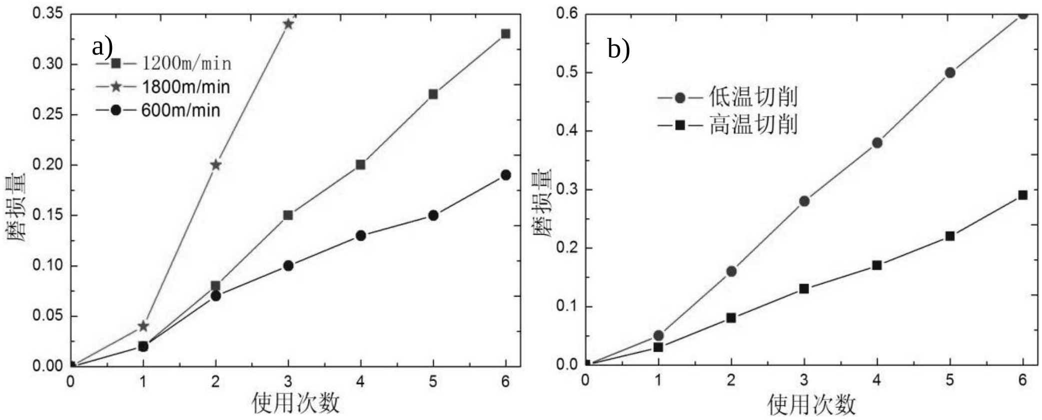

Fig.2 The relationship between the time of tool use and the tool wear

(2) The tool wear morphology

Figure 3 (a) and (b) show wear of flank tool surface of high speed cutting when the environment temperature is -120 ℃ or 350 ℃.The time of tool using is same as shown in figure 3. knives all use the same number. Large collapse edge phenomenon can be seen in figure 3 (a). The reason is that material and tool of brittleness increases when the cutting temperature is below 120 ℃, the sintering temperature of the cutting tool is much higher than temperature of the material of the heat treatment. Figure 3 (b) shows degree of tool wear is lesser , basically appear uniform wear state. The reason is that material aging temperature and environmental temperature appear larger temperature difference when the environment temperature higher than 350 ℃, it makes the phenomenon of regression of TC4 alloy occur and reduces the cutting material strength, hardness, reduces the cutting force and the tool wear.

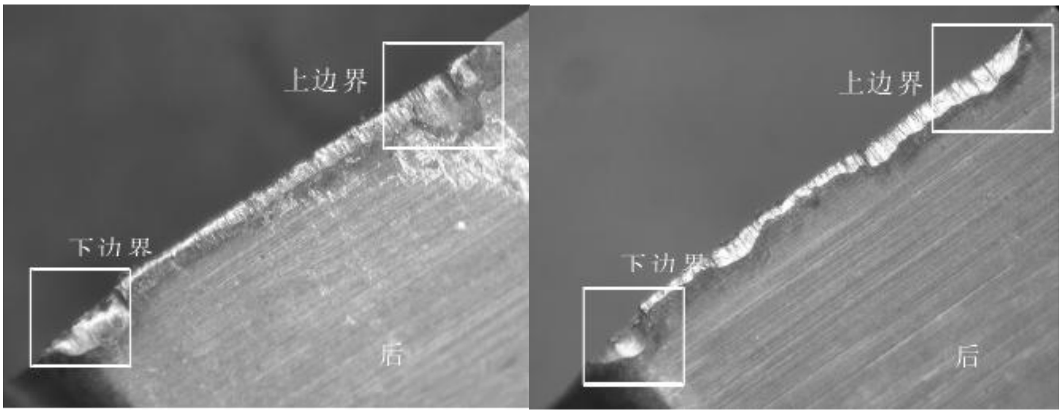

Fig.3 The shape of tool wear

3.2 The analysis of surface quality at two extreme environment

(1) surface quality of cutting under different cutting speed

Figure 4 shows the relationship between three cutting force, surface roughness and milling speed under two extreme conditions. Figure 4 (a) shows the relationship between three cutting force and cutting speed under the two kinds of extreme environment; Figure 4 (b) shows the relationship between surface roughness and cutting speed under the two extreme conditions. Fx expresses transverse cutting force, Fy expresses radial cutting force, Fz expresses axial cutting force and Ra expresses surface roughness. According to figure 4 (a) ,the force of the experiment reduces along with the increase of cutting speed in high speed milling. The most important reasons for the above trend is the cutting temperature, who increases with the cutting speed increasing. The increasing temperature reduces the hardness and shear strength of workpiece material and the coefficient of friction between cutter and workpiece. According to figure 4(b) ,it can be seen that the surface roughness of the two extreme environment value is first increases and then decreases with the increase of cutting speed, however, the value of surface roughness of when the temperature is 350 ℃ environment is less than that is-120 ℃.

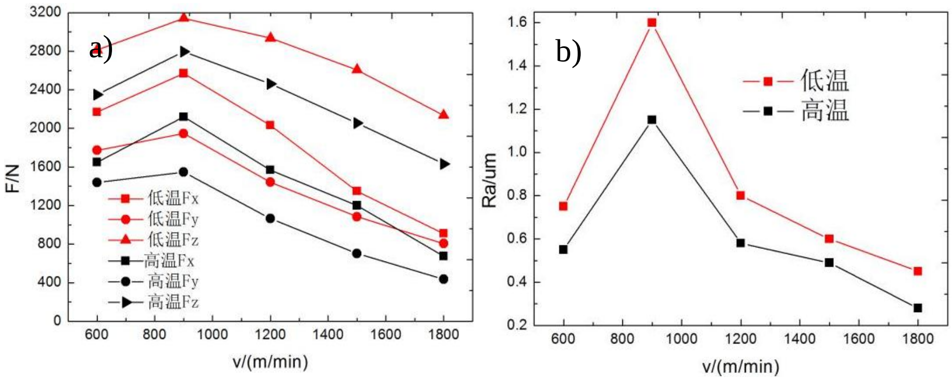

Fig.4 The relationship between cutting force, surface roughness and cutting speed

Figure 5 (a) and (b) shows the 3D surface morphology of TC4 titanium alloy which environment temperature is 120℃and 350℃. According to the figure 6 (a) , it can be seen that the surface quality is poorer which has larger burrs when the environment temperature is -120℃; According to the figure 6 (b) it can be seen that the cutting surface has smaller plough and surface is smooth at 350 ℃.This is because oxide film form easily at the high temperature in the cutting process , and its wear way are oxidation wear and tear.

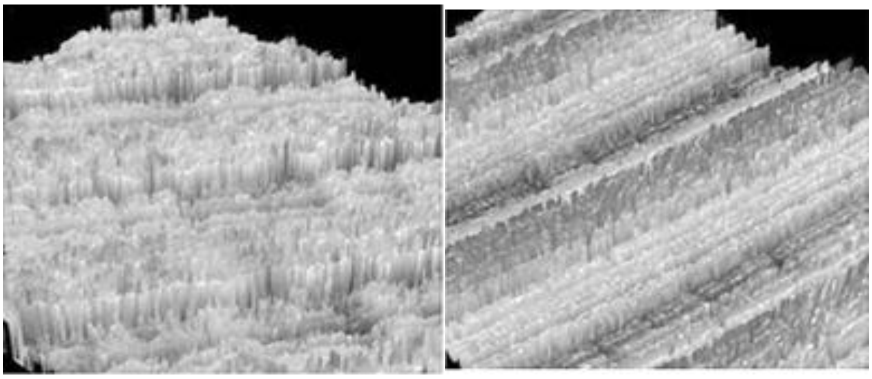

Fig.5 The surface morphology under different environment at the same speed

under different cutting depth, cutting surface quality

Figure 6 shows the relationship between cutting force, surface roughness and cutting depth of TC4 titanium alloy. Figure 6 (a) shows the relationship between three cutting force and cutting depth under the two kinds of extreme environment; Figure 6 (b) shows the relationship between the surface roughness and cutting depth under the two kinds of extreme environment. According to figure 6(a) ,it can be seen that three cutting force were obvious rising trend with the continuous increase of cutting depth.The trend of radial cutting force growth cutting force is the same as the transverse cutting force, The trend of axial cutting force along with the change of cutting depth is higher than the transverse cutting force and radial cutting force.The most important reasons is he volume of the cutting edge to remove material per unit time become larger with the cutting depth increases in the process of high speed cutting, the cutting force also will increase. Three cutting force when the environment temperature is 350℃ is lower than that of low temperature.According to figure 6(b) ,it can be seen that that surface roughness was obvious rising trend with the continuous increase of cutting depth. Three cutting force when the environment temperature is -120℃ is higher than that of high temperature.The reason is that the impact of machine and tools for the whole machining system with the increasing of cutting force lead to surface roughness of machining workpiece increases in the high speed cutting , the surface quality becomes poor.

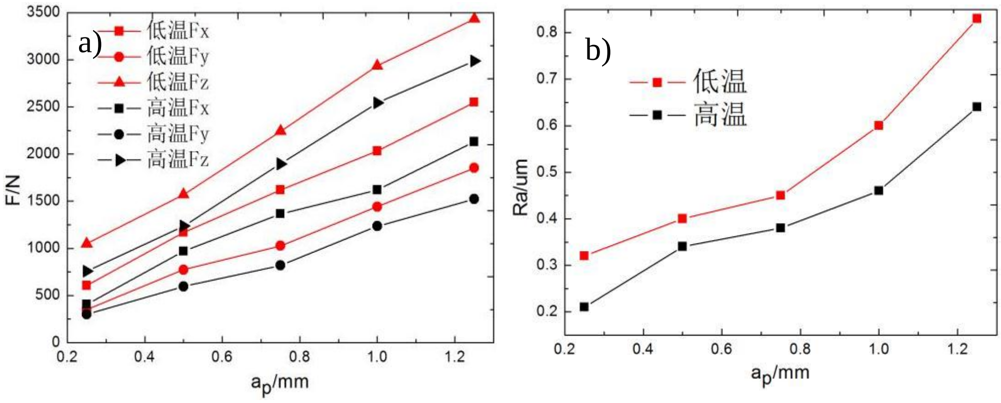

Fig.6 The relationship between cutting force, surface roughness and cutting depth

Figure 7 (a) and (b) shows the 3D surface morphology of TC4 titanium alloy which environment temperature is 120℃and 350℃. According to the figure 7 (a) , it can be seen that cutting surface has the deep furrows, and accompanied by a large bulge, when temperature is -120 ℃, the surface quality is poorer;According to the figure 7 (b) , it can be seen that cutting surface has the little furrows when temperature is 350 ℃, this is because machining surface of softening in a flash , brittleness is abate, enhanced toughness at the high temperature in the process of cutting.

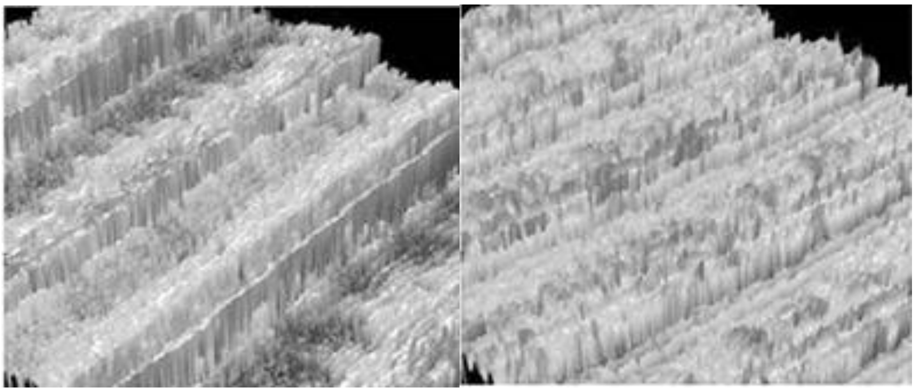

Fig.7 The surface morphology under different environment at the same speed

Machining surface quality under different feed rate

Figure 8 shows the relationship between cutting force, surface roughness and feed rate of TC4 titanium alloy. Figure 8 (a) shows the relationship between three cutting force and feed rate under the two kinds of extreme environment; Figure 8 (b) shows the relationship between the surface roughness and feed rate under the two kinds of extreme environment.Compare to figure 7 and figure 9 ,it can be seen that cutting force and surface roughness has a good consistency under different feed and cutting depth.That is because cutting depth and feed rate are making the material per unit time change, so mechanism is same.

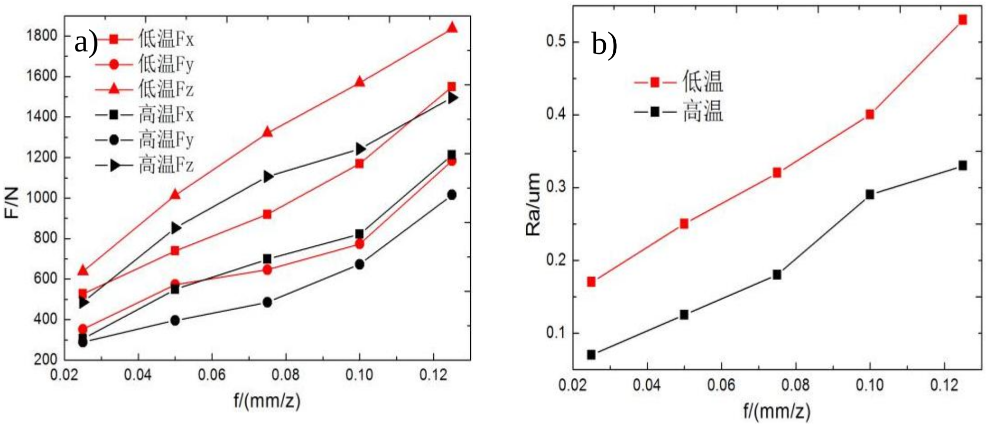

Fig.8 The relationship between cutting force, surface roughness and feed rate

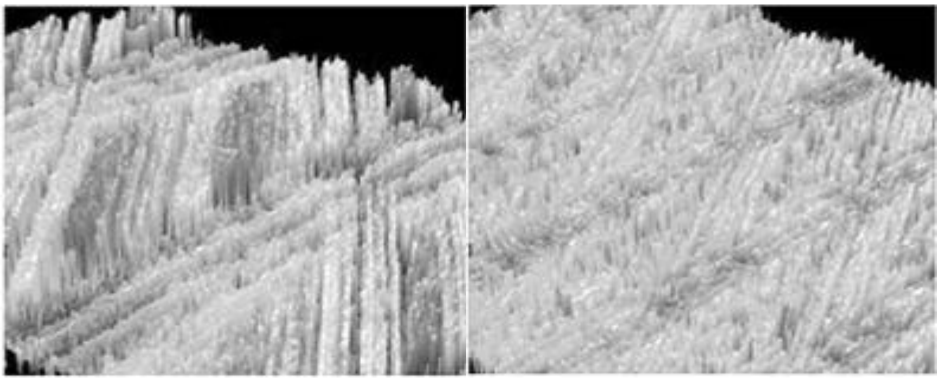

Fig.9 The surface morphology under different environment at the same feed rate

Figure 9 (a) and (b) shows the 3D surface morphology of TC4 titanium alloy which environment temperature is 120℃and 350℃. According to the figure 9 (a) , it can be seen that cutting surface of different feed rate has a good consistency which has the deep furrows with that of different cutting depth,when temperature is -120 ℃.

3.3 Microstructure analysis of TEM under two extreme environment

Figure 10 shows TEM microstructure of TC4 titanium alloy before and after secondary aging condition .Figure 10(a) shows microstructure of TC4 titanium alloy in front of high speed cutting; Figure 10(b) shows the microstructure of TC4 titanium alloy which environment temperature is -120 ℃ after high speed cutting; figure 10(c) shows the microstructure of TC4 titanium alloy which environment temperature is 350 ℃ after high speed cutting.

According to figure 10(a) ,it shows that dispersion phase of TC4 titanium alloy is sparse, small, and relatively even distribution; This is because the phase of TC4 titanium alloy change slowly ,the solute atoms precipitation rate is low compare to the second time and pre-aging.Figure 10(b) shows that the dispersion phase of TC4 titanium alloy is relatively dense after the high speed cutting, this is because , cutting temperature is very high at processing of instantaneous, but due to environment temperature is -120 ℃ in the process of machining, so it can be regard the material as cryogenic treatment.According to figure10(c) ,it can be seen that dispersion phase of TC4 titanium alloy suddenly disappear under the environment of high temperature in high speed cutting. the analysis based on this phenomenon can be done as follows: TC4 titanium alloy possess regression properties. The bigger difference between aging temperature and the temperature in the manufacturing process is, the easier regression is. Cutting temperature and environmental temperature above 350 ℃ in the process of cutting, so the dispersion phase of TC4 titanium alloy disappeared.At the same time hardness of cutting layer has a larger degree of decreased, it makes the cutting more easily and reduce the cutting force, reduce the cutter wear, increase the tool life, improve the machining surface quality .

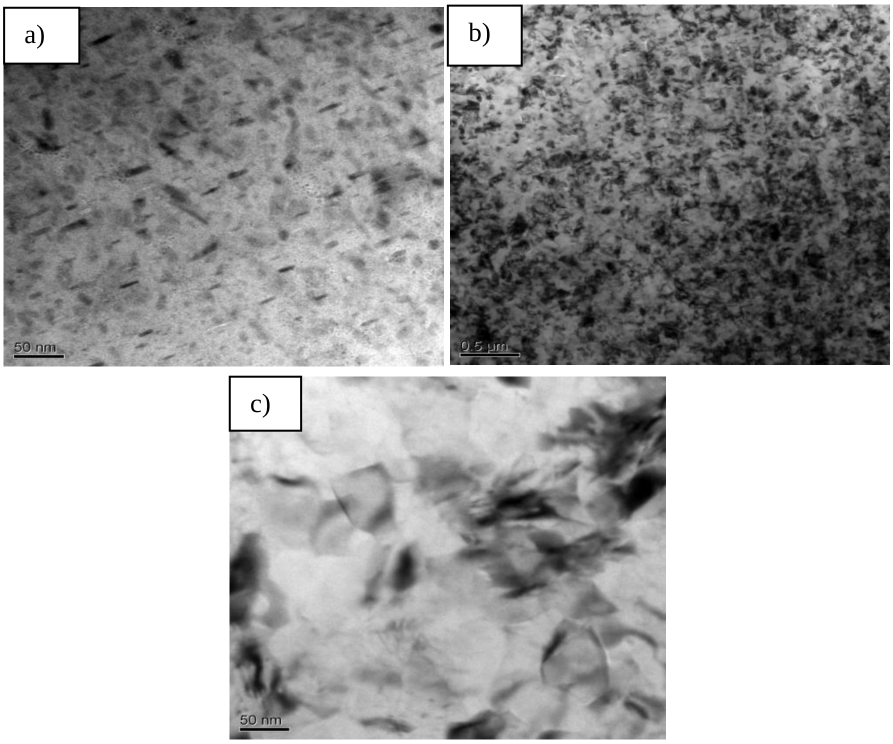

Fig.10 TEM microstructure under different environment before and after cutting

4. Conclusion

(1) Abrasive wear of tool wear is the main form in the process of cryogenic cutting, the phenomenon of collapse blade often occur at the flank tool surface, tool life is short;Oxidation wear and adhesive wear are dominant role in the process of high temperature ,tool life is long.

(2) Environment temperature is -120 ℃ in the process of machining, so it can be regard the material as cryogenic treatment during the process of cutting,it makes the material brittle hard, increases cutting force , the surface quality become worse; Environment temperature is 350 ℃ in the process of

machining,so it can be regard the material as retrogression heat treatment.It makes the TC4 titanium alloy toughness, reduces hardness, significantly reduce the cutting force, and continuously formed oxide film in the process of cutting, the main wear state is oxidation wear, greatly improve the surface quality.

(3) Dispersion phase of the cutting surface increased and distribution after cutting at -120℃; Dispersion phase most disappear after the completion of the cutting at 350 ℃, TC4 titanium alloy occur regression.

Acknowledgments

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