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Investigation of Machined Surface Properties and Tool Wear for Drilling of Nickel-Based Superalloy FGH97

Yang Qiao, Peiquan Guo*, Hongtang Chen, Shouren Wang and Hui Wang

Department of Mechanical Engineering, University of Jinan, 336 Nanxinzhuanxi Road, Jinan, Shandong 250022, P.R. China.

Email: oss_guopq@ujn.edu.cn

Abstract. Nickel-based superalloy is widely used in aviation, aerospace, shipping and petrochemical industry. The effect of drilling parameters on work hardening and machined surface roughness of nickel-based superalloy FGH97 is summarized according to investigation of its drilling process. Machined surface roughness will increase with the increasing of feed per revolution or drilling speed. With the increase of drilling speed, the hardness of workpiece surface is decreasing. The influence of feed rate on the surface hardness of the workpiece is not significant. With the increase of drilling speed, the depth of workpiece hardening layer becomes smaller and smaller. The wear of the flank can be divided into two stages: uniform wear and rapid failure: when the wear of the flank of the bit is less than VB0.16mm, the wear of the flank is more uniform; when the wear of the flank exceeds VB0.16mm, the flank of drill bit becomes urgent from the outermost edge to the core of drill bit. The wear and tear of the play until the tool fails.

1. Introduction

U.S. has been developed and applied Ni-based powder metallurgy superalloys since early 1960s. U.S.S.R. began to develop Ni-based superalloys in the late 1960s. P.R. China began to develop Ni-based powder metallurgy superalloys until 1970s. Superalloy FGH95 is characterized as high strength at working temperature of 650 degrees Centigrade. Superalloy FGH96 can be used at temperatures up to 700-750 degrees Centigrade. It is a key material for preparing high performance engine turbine disk. Superalloy FGH97 prepared by plasma rotating electrode pulverizing and hot isostatic pressing has the advantages of high tensile strength and high creep resistance, and its crack propagation rate is one order of magnitude lower than that of FGH95 or FGH96 [1-3]. Nickel-based superalloy materials are widely used in aviation, aerospace, shipping and petrochemical industries because of their excellent high temperature strength, thermal stability and thermal fatigue properties [4,5]. Ozcelik and Bagci [6] proposed a new method for measuring drilling temperature and measured the drilling temperatures of AISI-1040 and AI7050-T651. Sato, et al. [7] found that cutting thickness is the greatest factor affecting drill wear, drill wear of processing blind-hole is more serious than that of processing through-hole as drilling the same depth of hole because the drilling temperature near the bottom of blind-hole material increases sharply. The higher the drilling temperature, the faster the wear rate of drill is. Du [8,9] investigated the microstructure of white layer appeared in the high speed machining of FGH95. Some research about cutting force [10-12], machined surface integrity [13,14], bit wear and tool life [15,16] during drilling process have been done.

Surface roughness refers to the various micro-geometric shapes formed on the machined surface by the combined action of the machining mode, cutting conditions and cutting parameters. Surface roughness directly affects the wear resistance, corrosion resistance and fatigue strength of the



workpiece. Work hardening refers to the physical phenomenon that metal materials undergo plastic deformation under the recrystallization temperature under the combined action of drilling force and drilling temperature, resulting in the increase of surface strength and hardness of metal materials, and the decrease of plasticity and toughness. Because drilling zone is semi-enclosed, the heat generated in the drilling process cannot be released in time, so that the drilling zone temperature is often going up high level. So, that metal materials within drilling zone are more likely to occur thermal softening than turning and milling. Therefore, under the same cutting parameter condition, drilling hardening is lower than turning and milling. Work hardening makes the workpiece surface become brittle and hard. When the cutter cuts these surfaces again, it will produce a larger cutting force, aggravate the tool wear rate and reduce the tool life. Because the hole processing is stereotyped processing, in the case of meeting the surface quality requirements of hole processing, it is not necessary to reprocess the hole. Moderate processing hardening can improve the surface strength, hardness and durability of the workpiece.

2. Experiment Equipment and Test Setting

Drilling experiments have been carried by means of a machining center YCM-V116B as shown in Figure 1. TiN/TiAlN coated carbide drill bit SECO made SD203-8.0-27-8R1 is used to drill FGH97. Figure 2 shows measuring instruments used in the investigation. Digital microhardness tester is used to measure the microhardness of machined surface, VHX-2000 Microscope System is used to measure the roughness and surface topography of machined surface, Dino-Lite Portable Microscope is used to measure the wear extent of drill edge. The value setting of cutting speed, feed rate are shown in Table 1.



Figure 1. Machining center YCM-V116B.



Figure 2. Measuring instruments: (a) digital micro-hardness tester, (b) VHX-2000 microscope system with super depth of field, (c) Dino-Lite portable microscope.

Table 1. Cutting parameters.

Factor	Level			
	1	2	3	4
Diameter of drill bit (mm)	8	8	8	8
Cutting speed v_c (m/min)	10	15	20	25
Feed per revolution f_r (mm/r)	0.01	0.03	0.05	0.07

3. Surface Hardening of Drilling Nickel-based Superalloy

After drilling nickel-based superalloy, the hardness of the hole wall, i.e. the machined surface, increases significantly, resulting in work hardening. There are two indicators to describe the degree of work hardening. One is the increment of the microhardness of the machined surface, and the other is the thickness of the surface material that produces work hardening, i.e. the depth of the work hardening layer. Figure 3 shows the effect of drilling speed and feed rate on the hardness of machined surface. With the increase of drilling speed, the hardness of workpiece surface decreases as a whole. When the drilling speed is 10 m/min, the machined surface hardness reaches the maximum 681.6 MPa. When the drilling speed is 25 m/min, the machined surface hardness is 626.9 MPa. With the increase of feed rate, the hardness of machined surface decreases first and then increases. Generally, machined surface hardness does not change obviously with feed rate.

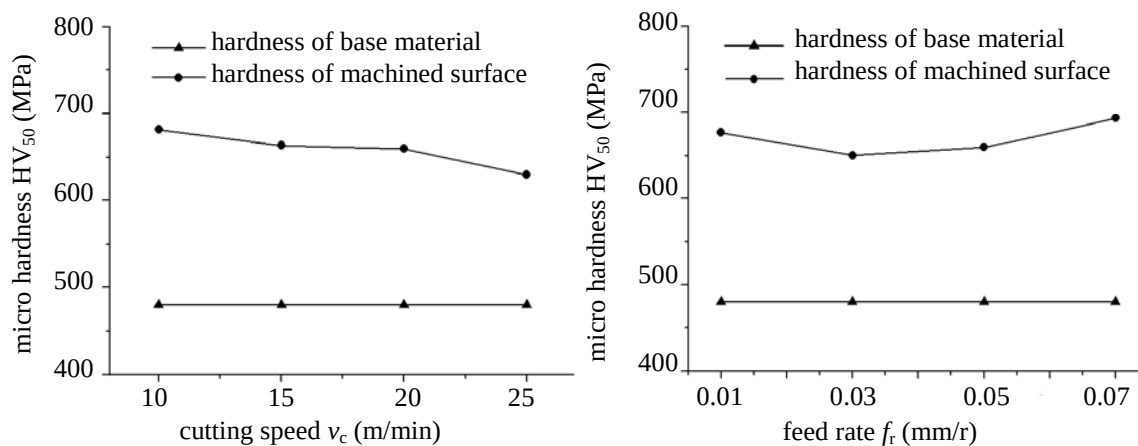
**Figure 3.** Effect of drilling parameters on machined surface hardness.

Figure 4 shows the influence of drilling parameters on the depth of hardened layer. With the increase of drilling speed, the depth of work hardening layer gradually decreases. When the drilling speed is 10 m/min, the maximum depth of hardened layer is 237 μm , which is due to the small drilling speed, low drilling temperature and high drilling force, resulting in severe plastic deformation on the workpiece surface, leading to a larger depth of hardened layer. With the increase of drilling speed, the drilling temperature increases, the drilling force decreases, the deformation of workpiece decreases, and the depth of hardened layer decreases. With the increase of feed rate, the hardened layer depth of workpiece decreases first and then increases. When feed rate is 0.03 mm/r, the hardened layer depth of machined surface reaches the minimum value of 187 μm .

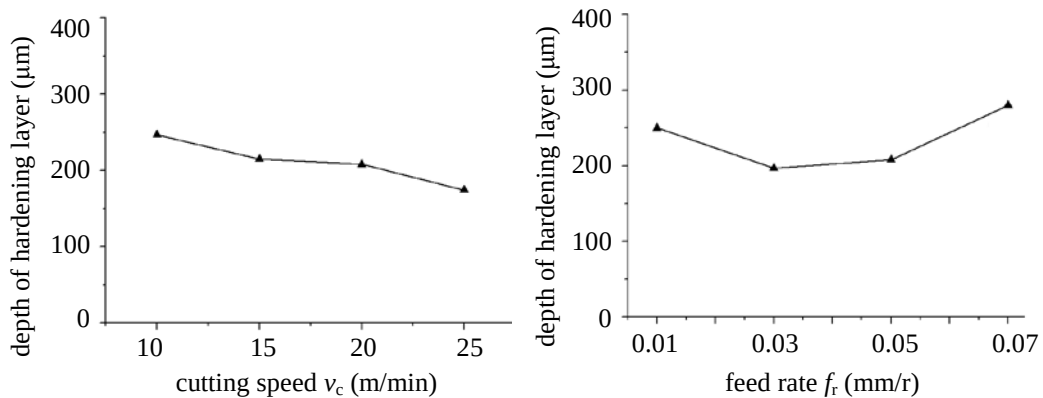


Figure 4. Effect of drilling parameters on depth of surface hardening layer.

4. Surface Roughness of Drilling Nickel-based Superalloy

As shown in Figure 5, under the condition of oil lubrication, the workpiece's surface is smooth and there is no obvious tool scratch. It shows that diesel oil has good lubrication effect between TiN/TiAlN coated cemented carbide and nickel-based superalloy, and is beneficial to improving the workpiece's surface quality. The drilling experiments involved in this paper use diesel oil to cool and lubricate.

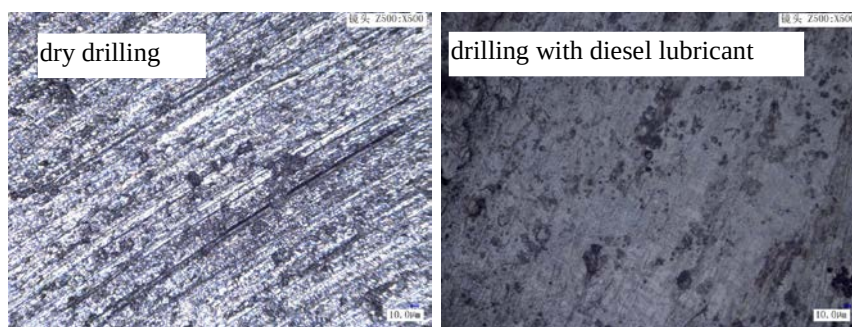


Figure 5. Machined surface topography of dry/diesel lubricating drilling.

Figure 6 describes the influence of drilling parameters on surface roughness. The roughness R_a value increases with the increase of feed rate. When the feed is in the range of 0.01-0.05mm/r, the roughness of machined surface is in the range of 0.655-0.682 micron, and the range of variation is small. When the feed rate is 0.07 mm/r, the roughness of machined surface is 0.793 μm , which is larger than that of 0.05mm/r. This is due to the increase of feed, drilling force and torque, and vibration of machine tools, which increases the surface roughness of workpieces. When the drilling speed is 10-20 m/min, the surface roughness of Ni-based powder metallurgy superalloy is gradually reduced with the increase of drilling speed, from 0.823 μm to 0.669 μm . This is because when drilling nickel-based powder metallurgy superalloy, with the increase of drilling speed, the drilling force decreases gradually, the degree of extrusion plastic deformation between tool and workpiece decreases, thus the value of surface roughness decreases; moreover, with the increase of drilling speed, the heat generated by drilling increases, and when the heat accumulates to a certain extent. Degree, high temperature makes the workpiece material soften, resulting in a significant reduction in friction coefficient, thus reducing the surface roughness. Under the combined action of drilling force and drilling temperature, the surface roughness of the workpiece decreases slightly with the increase of drilling speed, and the change is not obvious. When the drilling speed exceeds 20 m/min, the surface roughness of the workpiece increases rapidly, reaching 0.878 μm . This is because when the drilling speed is 25 m/min and the drilling speed is high, the drill bit becomes overheated and reddish during the test, and accompanied by severe wear and tear of the drill bit, which makes the surface roughness

of the workpiece larger. When drilling nickel-base superalloy, the reason for severe wear and tear of drilling tool is that the drilling speed is high, the drilling process produces a lot of drilling heat, while the heat dissipation ability of drilling process is poor. With the drilling process, the drilling temperature gradually increases, the strength and hardness of tool material decreases, which makes the tool grinding. Damage and breakage speeds up. Therefore, under the condition of oil cooling and considering only the surface roughness of drilling nickel-based superalloy, the drilling speed is suitable in the range of 15-20 m/min.

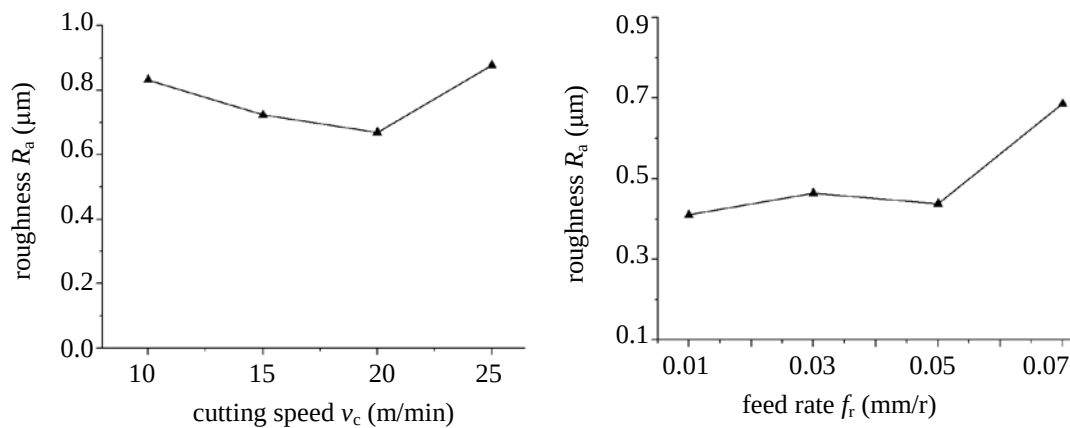


Figure 6. Effect of drilling parameters on machined surface roughness.

5. Wear of Drill Bit

Cutting speed v_c of 20m/min and feed rate f_r of 0.05mm/r are used to drill holes with diameter of 8mm and depth of 30mm. With the increase of the number of holes, the variation of the wear on the flank of the bit cutting edge is shown in Figure 7. When drilling the first seven holes, the wear of the back face of the bit increases slowly with the increase of the number of holes; when drilling the eighth hole, the edge of the bit is severely worn, which causes the bit to fail quickly. In summary, it can be concluded that tool wear is faster when drilling nickel-based powder metallurgy superalloy materials, and when the flank wear reaches a certain value ($VB_{0.16}\text{mm}$), severe wear and flake peeling occur at the outer edge of the bit and the bit fails.

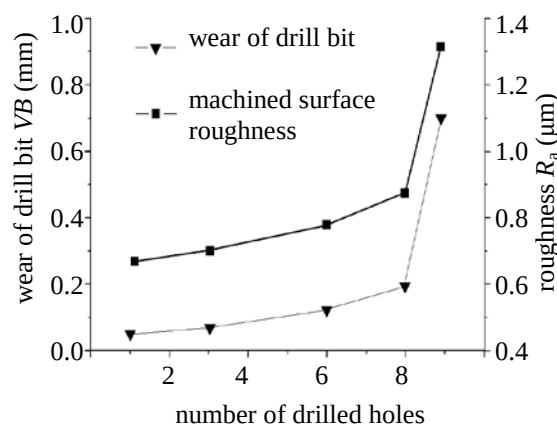


Figure 7. Wear of drill flank.

6. Conclusion

The effect of drilling parameters on work hardening and machined surface roughness of nickel-based superalloy FGH97 is summarized according to investigation of its drilling process.

(1) feed rate has a more significant effect on workpiece surface roughness than drilling speed. This is because with the increase of feed, drilling force, machine vibration and workpiece surface roughness increase; with the increase of drilling speed, drilling temperature increases rapidly, workpiece material softens, and its strength and hardness decrease, making the change of workpiece surface roughness smaller.

(2) with the increase of drilling speed, the hardness of workpiece surface is decreasing. When the drilling speed is 10 m/min, the surface hardness of the workpiece reaches the maximum value of 681.6 MPa, while the influence of feed rate on the surface hardness of the workpiece is not significant. With the increase of drilling speed, the depth of workpiece hardening layer becomes smaller and smaller; with the increase of feed, the depth of workpiece hardening layer decreases first and then increases. When the feed rate is 0.07mm/r, the depth of hardened layer reaches a maximum value of 280 μm .

(3) When TiN/TiAlN coated cemented carbide bits are drilled to process nickel-based superalloys, the wear of the flank is divided into two stages: uniform wear and rapid failure: when the wear of the flank of the bit is less than VB0.16mm, the wear of the flank is more uniform; when the wear of the flank exceeds VB0.16mm, the flank of the bit becomes urgent from the outermost edge to the core of the bit. The wear and tear of the play until the tool fails.

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