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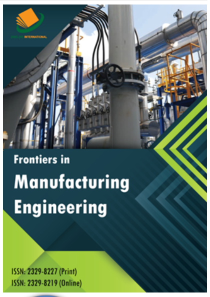

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GRINDING FORCE STUDY IN MICRO END GRINDING OF HARD AND BRITTLE MATERIALS

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ABSTRACT

Hard and brittle materials with good physical properties of high hardness, high uniform structure et al, are occupied with a larger proportion in microproducts yearly, but the current processing method can not solve the difficult-to-machine property of it commendably. For this purpose, this paper proposes a promising processing method, Micro End Grinding (MEG). Abrasive's random distribution and material inhomogeneity generate that the study of the microgrinding mechanism is difficult, so this paper researches the grinding forces and the grinding force ratio through experiments which test material is silica glass, which are important factors of the grinding process. The influences of grinding parameters on variation tendency of grinding forces are investigated, and they are affected very much by the size effect. Meanwhile, experimental results verify that the ratio of the grinding forces is much less than the value of peripheral grinding. It will lay a good foundation for further mechanism study.

KEYWORDS

Job shop scheduling, multi-objective, genetic algorithm, logistic chaotic mapping model

1. INTRODUCTION

In recent years, micro parts made of hard and brittle materials with good physical properties of high hardness, high uniform structure etc, have been used reliably and continuously in the environments of high temperature, high speed and overloading [1]. Therefore, the efficient processing method, which can realize high-precision microproducts made of hard and brittle materials, has recently become an important research direction [2]. Study showed microgrinding is the important method on this research [3]. Researchers have got significant achievements in microgrinding research field during last several years. A researcher microgrinded cemented carbide and obtained the good processing surface which Ra attained 5.1nm and certified that microgrinding could improve machined surface quality of materials which are difficult to cut [4]. A researcher also conducted the microgrinding tests on different hard and brittle materials, in which fine slots with 0.1mm width and high aspect ratio of 15 were produced [5]. A group of researchers adopted small diameter grinding wheels to microgrind the complex structure of hard and brittle materials and achieved 10nm roughness surface [6]. However, there are many challenges that lie in microgrinding. The previous study mainly adopted the peripheral grinding, and the grinding forces were great [7]. According to a study, high grinding forces in microgrinding result in high heat generation and rapid micro wheel wear [8]. These will limit the development of microgrinding of hard and brittle materials.

On account of this, this paper proposes a promising processing way, Micro End Grinding (MEG). It introduces the principle of MEG firstly, and then researches grinding forces by the experiments in which test material is silica glass. At last, the influences of grinding parameters on variation tendencies of grinding forces and grinding force ratio are investigated. The results will lay a good foundation for further MEG study.

2. MECHANISM OF MICRO END GRINDING

As is shown in Figure1, MEG uses grains on the wheel face, and removes the surface material. Based on a study, the abrasives on outer rings contact with unmachined artifacts firstly, play the role of cutting and most of the grinding forces are produced by these abrasives' impact [9]. Those on inner rings mainly polish machined surface repeatedly, and produce little force. Meanwhile, the size effect is an important feature in micromachining [10]. An abrasive is considered to be a cutting edge. According to a research, the grain radius and the grinding depth are in the same range of micron, and the grinding edge is supposed to the circular arc, rather than sharp like conventional machining [11]. The plastic deforming area near the grinding edge is obviously larger than the sharp tool, and the energy of removing unit material becomes higher [12]. The elastic recovery and material's discontinuity in microgrinding process consume higher energy, therefore, these lead to higher unit cutting force.

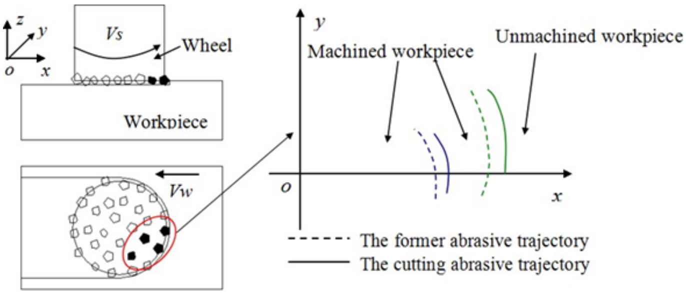

Figure 1: Simplifications for MEG process.

2.1 Experimental Set-up

As is shown in Figure2, MEG experiment on hard and brittle materials is conducted on the platform, which is composed of micro-feeding system, motorized spindle system, force measuring system, the grinding wheel and workpiece, etc.

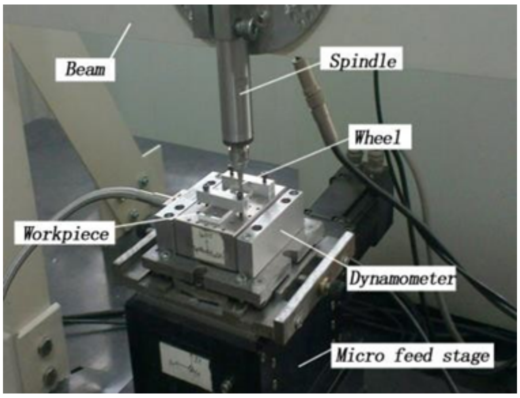

Figure 2: Experimental platform.

3. EXPERIMENTAL CONDITIONS

The sample's size of optical glass is 50×20×3 mm. The radius of electroplated diamond grinding wheels is respectively 3 mm and grain size is #180, 270#, W40. To investigate the influence of grinding parameters on variation tendency of grinding forces, the experimental grinding parameters are shown in Table 1.

Table 1: Single factor experimental parameters.

No	n(r/min)	a_p(μm)	v_w(μm/s)	wheel
1	8000	2	100	#270
2	18000	2	100	#270
3	27000	2	100	#270
4	36000	2	100	#270
5	18000	1	100	#270
6	18000	1.5	100	#270
7	18000	2.5	100	#270
8	18000	2	40	#270
9	18000	2	70	#270
10	18000	2	130	#270
11	18000	2	100	#180
12	18000	2	100	W40

4. RESULTS AND DISCUSSION

Influence of grinding parameters on variation trends of grinding forces The varying trends of grinding forces through machining under different grinding parameters are shown in Figure 4.

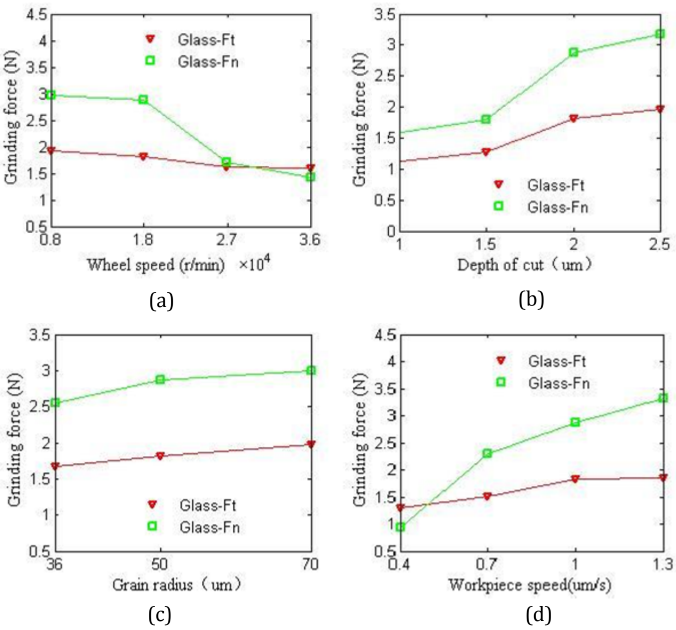

Figure 3: Effects of grinding parameters on grinding forces, a: wheel speed (vw=100μm/s, ap=2μm, #270), b: depth of cut (vw=100μm/s, n=18000r/min, #270), c: wrokpiece speed (vw=100μm/s, n=18000r/min, #270), d: grain size (ap=2μm, n=18000r/min, vw=100μm/s).

Figure 3(a) shows the variation tendency of grinding forces with wheel speed from 8000r/min to 36000r/min under other uncharged grinding parameters, and both of the normal force and tangential force decrease. With the wheel speed increasing, the number of abrasive particles becomes large in unit time, and the cutting depth of single abrasive is reduced due to invariable removed workpiece volume in unit time. Therefore, the reduced forces of single abrasive lead to the smaller grinding zone. In addition, the elastic recovery of machined workpiece becomes larger with the increasing wheel speed, and the undeformed chip thickness of next grain becomes enlarged. Hence, the size effect enhances, and the descending tendency of grinding becomes tardy.

The grinding force obviously increasing under different depths of cut is shown in Figure 3(b). When the cutting depth decreases, the volume of removed material in unit time reduces. It results the grinding forces lower. Besides, the contact arc length between the abrasive and workpiece wanes, and the friction and extrusion between the wheel and workpiece impact acutely. And then consumed energy which remove unit material increases rapidly. The size effect strengthens, and it causes that the trend of grinding force reduces quickly.

With the increase of the feed speed, it leads to greater grinding forces that the material removal volume in unit time becomes much more. In addition, according to a researcher's conclusion, the increasing workpiece velocity reduces the friction coefficient and weakens the effect of elastic recovery [13]. Then it will lead to greater average contact pressure, and weaken size effect. Therefore, as is shown in Figure3(c), when the workpiece velocity adds, the grinding force increases, and the rising tendency is slowing down.

Figure 3(d) shows that the grinding forces are inversely proportional to the grain size. With larger grain size, the contact length of the abrasive and the workpiece becomes longer, and then extrusion and friction between grains and workpiece aggravate. It will cause grinding force increasing. Otherwise, the grain radius is large, and the ratio of the cutting depth and it varies little. So the size effect change non-significantly, and the influence of grain size is less than other process parameters.

5. THE VARYING PATTERN OF GRINDING FORCE RATIO

As well as the grinding force, the grinding force ratio, which is defined as Cf, is also an important parameter to evaluate grinding performance. Cf can be expressed as Equation (1):

$$C_f = F_n \quad F_t \tag{1}$$

Where Fn is the normal grinding force, Ft is the tangential grinding force. Besides, Fa is the cross feed directional grinding force, and it is ignored on account of little.

Table 2: The variation tendency of Cf under different machining parameters.

n(r/min)	C_f	a_p(μm)	C_f
8000	1.543	1	1.417
18000	1.576	1.5	1.416
27000	1.053	2	1.576
36000	0.891	2.5	1.612
v_w(μm/s)	C_f	wheel	C_f
40	0.714	#180	1.521
70	1.519	#270	1.576
100	1.576	W40	1.515
130	1.801		

Because of large negative rake angle in microgrinding, Fn is larger than Ft, Cf of hard and brittle material is large and mostly exceed 5, even 24 for some ceramics in peripheral grinding. Big Cf explains that the chip deformation is little, and the phenomenon of work hardening is serious.

The value of Cf of MEG is shown in Tab.2. When wheel speed increases from 8000 r/min to 36000 r/min, the proportion of plastic deformation removal way increases, and the cutting resistance is larger than it in brittle fracture method. So Ft becomes large gradually, and Cf reduces. With the depth of cut adding, the contact arc length between the abrasive and workpiece increases, and it leads to small negative rake angle. Therefore, Fn heightens faster. It will cause Cf increasing. Undeformed chip thickness raises

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with the increasing workpiece velocity, the difference between friction and rake angles will enhance. Fn grows faster than Ft, so Cf increases. Besides, the ratio of the grinding depth and the grain radius varies little, and then Cf changes little. Generally, the value of Cf which ranges from 0.5-2, is far less than 5. It indicates that MEG is helpful to reduce the grinding force and improve the quality of grinding surface, compared with peripheral grinding etc.

6. CONCLUSION

In this paper, a promising process method-MEG is proposed to improve existing micro processing way. The machining mechanism is expounded, and the variation tendencies of grinding force and grinding force ratio under different grinding parameters have been got. The conclusions are as follows.

(1) In MEG process, the grinding force increases with the enhancing of the workpiece speed and the cutting depth, and are inversely proportional to the wheel speed and the grain size. Otherwise, the change extent effected by the size effect is explained.

(2) As well as the grinding forces, Cf of MEG rises with increasing workpiece speed and depth of cut, and reduces with enhancing wheel speed. But the value of Cf is little influenced by different abrasive radius. Cf , which ranges from 0.5-2, is far less than the value of the peripheral grinding.

(3) Analysis on MEG process is still difficult. Establishing a universal force model on the mechanism study of MEG needs further research. This paper will lay a good foundation for it.

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