Experimental Research on Drilling Force of Stainless Steel

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Abstract. Accurate measurement of cutting force is an important means to study metal cutting process. In this paper, the measurement of drilling force for stainless steel is studied by means of drilling experiments. It is found that the measured values of drilling force are dispersive under the same conditions. The uniformity of mechanical properties of workpiece materials has a great influence on the value of drilling force. In calculating cutting force by finite element method, it is necessary to ensure that the performance parameters of the input material are consistent with the actual performance parameters of the workpiece.

1. Introduction
Cutting force is an important problem in metal cutting process. It is not only an important characteristic parameter to measure the machinability of workpiece materials[1,2], but also an important index to evaluate the performance of cutting tools[3,4,5]. In addition, it is also an effective parameter to monitor the machining process[6,7]. Therefore, it is an important work to accurately obtain the cutting force value and its changing law. At present, in the actual process, there are usually three ways to master cutting force including empirical formula method, simulation calculation method, and actual measurement method respectively. Among them, the empirical formula method is simple to calculate, but because the formula contains more correction coefficients, its calculation results are significantly different from the actual application. In addition, this method only calculates the steady-state average value, and can not get the relationship between cutting force and time. The simulation calculation method usually establishes the cutting simulation model according to the actual cutting conditions, and uses the finite element method to calculate. This method can fully simulate the cutting process without any real measurement, so it has gradually been widely applied. The calculation results of this method depend first on the accuracy of modeling, and the higher the accuracy of modeling, the longer the calculation time. At the same time, the reliability of the calculated value is closely related to the calculation parameters. The results of direct actual measurement method are accurate and the change of cutting force in the whole process can be obtained. But the construction of measurement system is more complex and expensive, and the operation process is more complicated as well. Thus it affects the practical application. In summary, the three methods have their own advantages and disadvantages. In the actual application process, the appropriate methods are usually selected according to specific requirements. In practical application, it is found that there is a big difference between calculation and measurement method, which brings more difficulties for the determination of cutting force.

In practical application, the accuracy of cutting force measurement has become the key to many problems. In general, a set of cutting force values are measured according to the experimental conditions, and then the average value are taken as the final result. This method is simple to operate, but has some limitations. Because this method does not fully consider the dispersion of cutting conditions, it has a great impact on the experimental results. In order to deeply study the relations
between measured cutting force and cutting conditions, cutting experiments are systematically carried out to effectively guide future practice.

2. Experimental Design
In order to ensure the comparability of the experimental data, drilling experiments were carried out. The cutting tools applied in experiments are standard twist drills of high speed steel with diameter $d=10\text{mm}$. The workpiece material is 304 stainless steel, and the machine tool is YCM-V116B NC machine tool. The Kistler 9257B force measuring system was used to measure and record cutting forces. According to practical cutting conditions, the cutting parameters were selected as cutting speed $v_c=12\text{m/min}$ and feed $f=0.05\text{mm/r}$. In order to compare the cutting performance between different cutting tools, five twist drills marked as 1, 2…5 respectively are used in cutting experiments.

3. Experiment Methods
Figure 1 is a measured signal of a drilling axial force in the whole process. Through observing signal waveform, it is found that the signal contains more high frequency noise signals which affect the accuracy of measurement. For the convenience in analyzing the problem, the measured signal is further processed by high frequency filtering and smoothing further as shown in Figure 2. The average value of each point on the signal is taken as the value of cutting force. Thus all experimental signals are processed in this way, and the drilling axial force values for twist drill 1 are obtained as shown in Table 1. The material hardness is measured by HXD-1000 MSC/LCD digital microhardness tester.

![Figure 1. Original cutting signals](image1)

![Figure 2. Processed cutting signals by high frequency filtering and smoothing](image2)

According to the data in Table 1, it is found that the axial forces at each hole are different, and the maximum value is 25% higher than the minimum value. Obviously, it is not caused by the experimental error, which is mainly caused by the different experimental conditions at each time. Analysis of drilling process, the main factors affecting cutting forces are cutting tools, workpiece
materials and cutting parameters. Because cutting parameters can be precisely controlled by CNC system, the influence caused by cutting parameters can be neglected. In addition, because cutting tools can be manufactured accurately in batches, the influence of cutting tools can also be neglected. Therefore, the difference of mechanical properties of workpiece materials has a significant impact on cutting force. When the workpiece materials are determined, the hardness of materials is the main factor affecting cutting forces. Therefore, the surface hardness at each drilling hole is measured according to the drilling sequence, and the measured values are shown in Table 1. It can be found that the hardness values at each point are obviously different, and the maximum value is 78% higher than the minimum value. Because the workpiece material is not well heat treated, the mechanical properties at each point of the material are quite different. In order to study the relationship between the hardness of workpiece material and the drilling force, the relationship between the hardness of workpiece material and the drilling force is drawn as shown in Figure 3.

| Drill twist number | Measured axial force for each drilling (N) | Average axial force (N) | Measured material hardness (HV) | Average material hardness (HV) |
|--------------------|-------------------------------------------|------------------------|---------------------------------|-------------------------------|
| 1                  | 1118.3, 1160, 1030.2, 964.9, 1177.3, 1035.4, 1155.4, 1204.6, 1093.2, 1137.1, 1094.6 | 1106.5 | 301, 353, 272, 252, 431, 295, 404, 450, 333, 361, 292, 265, 199, 252 | 340.3 |
| 2                  | 1033.4, 1098.2, 1108.3 | 1080.0 | 263, 272, 336, 341, 314, 261, 254, 303 | 273.8 |
| 3                  | 1172.3, 1135, 1140.2, 1084.6, 1144.5, 1100, 1013.6, 1116.7, 1105.9, 1230.8, 1244.7, 1225.6 | 1112.5 | 263, 272, 336, 360, 408, 341, 414, 320, 366, 470, 416, 477 | 369.4 |
| 4                  | 1225.9, 1239.8, 1220.5, 1235.9, 1229.9 | 1231.6 | 428, 395, 480, 476, 468, 133, 253, 226 | 451.3 |
| 5                  | 987.3, 880, 864.6, 877.8 | 902.4 | 212, 243, 262, 172, 250 | 220 |

**Figure 3.** Drilling forces variation with workpiece hardness

It can be found that the hardness of the workpiece material obviously affects the drilling force. In general, the drilling axial force increases with the increase of the hardness of the material. Using the same method, the experimental data of other drills are analyzed, and similar rules are found. Therefore, for cutting force measurement experiments, if the mechanical properties of materials are poor uniformity, only a few measurements and then the average method can not obtain satisfactory results.
Therefore, it is necessary to ensure the uniformity of mechanical properties of materials by reasonable heat treatment methods in order to ensure the reliability of measurement results. In recent years, in order to reduce the experimental work and shorten the experimental time, the finite element method is often used to directly calculate cutting forces. In order to compare the experimental data with the results of finite element calculation, solid models of tool and workpiece are established according to the experimental conditions as shown in the Figure 4. By choosing the tool and workpiece material and inputting the actual cutting parameters, the drilling axial force is calculated by the finite element method. The curve of axial force changing with time is shown in Figure 5.

![Drilling models of tool and workpiece](image)

**Figure 4.** Drilling models of tool and workpiece

![Axial force variation with cutting time](image)

**Figure 5.** Axial force variation with cutting time

The results show that the cutting force fluctuates with time. This is mainly caused by the random change of the chip contact area caused by the continuous deformation and separation of the mesh in the calculation process. The average value of stable drilling is about 795N, which is quite different from the experimental value. This is due to the difference between the calculated material performance parameters and the experimental material. Therefore, in order to improve the accuracy of calculation, it is necessary to fully ensure that the relevant performance parameters are consistent with the actual values of materials.

4. **Conclusion**

Cutting force is an important part of metal cutting, and its value is closely related to cutting parameters, cutting tool and material characteristics of workpiece. In this paper, stainless steel drilling experiments were used to prove that the uniformity of mechanical properties of workpiece materials is an important factor for the variation of cutting force. In order to ensure the reliability of finite element simulation calculation, it is necessary to ensure that the material performance parameters adopted in calculation are consistent with the actual values.
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