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Experimental Investigation of the Cutting Force Measurements in Machinability Evaluations of Metals

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Reference

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ABSTRACT

Cutting tools need to be changed constantly while the machinability of materials is evaluated by cutting force measurements. However, little attention has been paid to the variation of the cutting force caused by such a tool change. In this study, a homogeneous material was used as the cutting object and an ordinary, mechanically clamped, external cutting tool was used. For the same cutting parameters, when the tool wear can be ignored, the effects of the insert resetting and the whole mechanically clamped cutting tool remounting on the main cutting force were examined. The change in the cutting force caused by the insert resetting and replacing is less than 2 %, while that caused by remounting of the whole mechanically clamped cutting tool is as great as 11 %. If the cutting force is used to evaluate the machinability of materials, a mechanically clamped tool should be used, and the insert can be replaced, but the tool holder should be mounted once only for all subsequent tests. This conclusion is very important for accurate measurement of the cutting force and accurate evaluation of the metal machinability.

Keywords

machinability evaluation, cutting force, insert, remounting, replacing

Introduction

Cutting force, cutting heat, and tool wear are generally used to evaluate material machinability [1,2]. Tool wearing capacity is the most direct way to evaluate tool-workpiece matching. However, it is a static evaluation that cannot provide the real-time cutting behavior during the working process. In addition, it requires large amounts of testing material and takes considerable time. The measuring device for the cutting-generated heat is more complicated. The influence of the experimental environment factors is rather obvious and the measurement error is quite large. Generally, it is used as a supplement to the other two evaluation indices. The measuring device and the measuring process of the cutting force are comparatively simple and direct that can reflect the dynamic behavior during the cutting process [3].

Many materials cutting behavior investigations have been conducted utilizing the cutting force combined with other parameters, such as surface roughness and flank wear. Seker et al. [4] studied the effects of the austempering time at constant temperature and contents of Cu and Ni in austempered ductile irons on the cutting force and surface roughness. Chen et al. [5] compared the cutting force, tool wear, surface quality, chip deformation, and morphology of several new low carbon, sulphur-free, cutting steels. Ozcatalbas et al. [6] investigated the effects of microstructure and mechanical properties on the cutting force of hot rolled SAE1050 steel. Wu et al. [7] used the cutting force and tool wear to evaluate the influence of adding sulphur, rare earths, and bismuth on machinability of austenite stainless steel. Akdemir et al. [8] investigated the effects of cutting speed and depth of cut on machinability characteristics of austempered ductile iron. Karagiannis et al. [9] investigated the effects of the cutting speed, the peripheral second relief angle, and the core diameter on the surface texture. Still, there are many other studies evaluating materials machinability using the cutting force, but they stated only the cutting process parameters and did not explain whether only one tool was used to cut different materials or whether the cutting force measurements were completed with one mounting of the cutting tool for all tests. If the cutting force measurements of different materials were completed by one tool with one mounting, then the change of the cutting force caused by the tool wear during long time cutting was not considered in those studies. If tool change (including insert change) and tool remounting had been carried out in the cutting process, then the caused change of the cutting force was neglected. Moreover, the influence of the cutter realignment on the cutting force was not considered.

When researchers used the cutting force to evaluate materials machinability, they quite often changed the cutting tool in fear that tool wear influenced the cutting force (the whole tool replacement, including the cutting inserts of the mechanically clamped tool). Even if the tool parameters were identical, the small deviation of the tool remounting position in the tool changing process would cause a cutting force change. The change in the cutting force caused by the tool replacement can even exceed the change caused by material differences. As a result, the machinability of materials could not be accurately evaluated. However, this influence is frequently ignored.

In the present study, a homogeneous metal material was used as the cutting object with ordinary, mechanically clamped, external cutting tool. Identical cutting parameters were used and the cutting tool had not been worn or the tool wear could be ignored (under these conditions, the actual cutting force should be identical for a homogeneous material). The influence of the insert resetting, insert replacement, and the whole mechanically clamped cutting tool remounting on the cutting force was examined (a cutting insert was fastened on a tool holder and was not reset, and the combination of the cutting insert and tool holder was seen as a whole mechanically clamped cutting tool). The results discussed in this paper could offer some guidance for evaluation of the cutting force of different metals.

Experimental

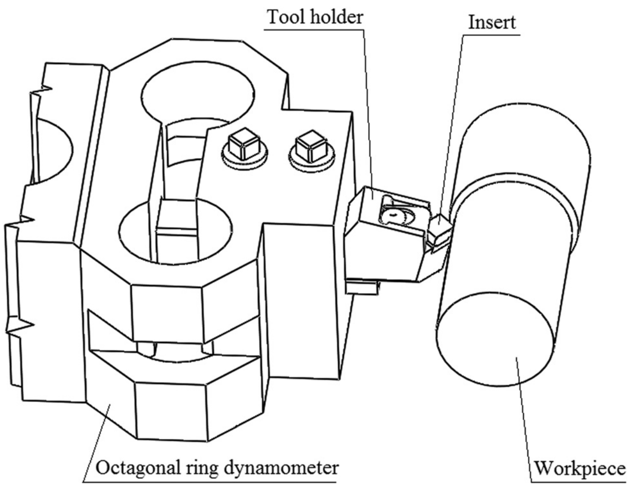
EXPERIMENTAL MATERIALS AND EQUIPMENT

Two cutting specimens of pearlitic gray cast iron were cast in the molten iron of the same ladle. The average hardness and tensile strength were 202 HB and 305 MPa, respectively. After pre-machining, cylindrical specimens with a diameter of Φ78 and 350 mm long were made. In the cutting processing, the specimens were mounted in the lathe by two center holes at both ends and the rotation driven by a poke rod fixed on one end.

Twin parallel octagonal ring dynamometer and dynamic signal measuring and analyzing apparatus (for signal acquisition and conversion) were used to measure the main cutting force F_z, backward force (radial force) F_y, and the feeding force F_x. The dynamometer was deformed elastically, and the octagonal ring-like part of the dynamometer was the elastic element. It was divided into the upper ring and the lower ring. There was a square hole at the front end of the dynamometer for mounting the lathe tool, and a round hole in the rear for fixing the tool post of the lathe. Twenty resistance strain gauges were attached on the internal surface of both upper and lower rings and connected to form three bridges to measure the F_z, F_y, and F_x forces, respectively.

A CA6140 horizontal lathe (Shenyang First Machine Tool Factory, China) was used with an ordinary mechanically clamped external cutting tool. The tool holder of the mechanically-clamped tool was an ECMNN-2525M12A type (Taiean Echaintool Industries Co. Ltd., China). Diamond-shaped cutting inserts were the CNMG 120408N-GZ AC410K type (Japan Sumitomo Electric Industries Ltd). Its dimensions and angle parameters were: a cutting edge length of 12.9 mm (side length of the diamond), a thickness of 4.76 mm and an angle of 100° between a couple adjacent edges (at nose). The tool holder was mounted in the square hole of the octagonal ring dynamometer. To ensure the identical installation location each time, the tool holder was forcibly pushed to the left wall

FIG. 1 Tool installation and cutting schematics diagram.



and the upper edge of the square hole before fastening (**Fig. 1**). On the horizontal lathe, the cutting angle parameters of the insert mounted in the holder were about: −7.7° rake angle, 7.7° clearance angle, −6.4° inclination angle and 40° side cutting edge angle.

CUTTING EXPERIMENT DESCRIPTION

The cutting force produced in the cylindrical specimen by the lathe tool in the horizontal lathe was experimentally measured. The main shaft of the lathe rotated at 160 rpm during cutting, and the feeding rate was 0.294 mm/rev. The octagonal ring dynamometer was fixed on the lathe. The tool holder was fixed on the octagonal ring dynamometer and a cutting insert was fastened on the tool holder. The surface of the specimen was slightly cut to ensure coaxiality between the processed cylindrical surface of the specimen and the rotational axis of the lathe tool after mounting the specimen.

Test 1

Tool wear was examined by applying a large cutting depth and a long cutting length. At first, the specimen was cut to Φ77.2 mm, then a new insert was fixed and the cutting experiment was conducted. The cutting depth was 2 mm. The cutting length of the specimen was 223 mm and the path length of lathe tool tip was about 174 m. The cutting force was measured in 15 s intervals. During measurements, the cutting process was not interrupted.

Test 2

Measurement of the cutting force change caused by the cutter realignment. The insert was a new one at each cutting depth and was mounted once at a fixed cutting depth. At a fixed cutting depth, the specimen was first cut a short length after cutter alignment, and then it was cut a short length again after cutter realignment. The change of the cutting force before and after cutter realignment was measured. The cutter alignment and cutter realignment should be carefully performed.

Test 3

The tool holder was mounted on the octagonal ring dynamometer once for all tests. The change of the cutting force caused by the resetting of the same cutting insert (the same cutting edge) was studied. When the insert was re-mounted (reset) every time, the tightening of the insert press bolt was about the same. In order to reduce the change of the cutting force caused by the parameter difference of various cutting edges of an insert, the same cutting edge was used before and after an insert resetting.

The same specimen was used in Test 1, 2, and 3. In Test 2 and 3, the cutting initial diameters and corresponding cutting depths were Φ73.2 and 1.75 mm, Φ69 and 1.5 mm, Φ65.68 and 1.25 mm, and Φ65.68 and 1 mm, respectively.

Test 4

The influence of tool remounting on the cutting force was examined. As mentioned above, a cutting insert that was not reset was fastened on a tool holder; the combination of the cutting insert and the tool holder was seen as a whole mechanically clamped cutting tool. The whole mechanically clamped cutting tool was equivalent to an integral cutting tool welded by a cutting blade and a cutter bar. The remounting of the whole mechanically clamped tool corresponded to the remounting of the integral tool or replacing the integral tool with an identical tool parameter. The second specimen was used. The change of the cutting force caused by remounting of the whole mechanically clamped cutting tool was measured. The cutting initial diameters and corresponding cutting depths were Φ74.1 and 1.5 mm, Φ70.8 and 1.25 mm, Φ70.8 and 1 mm.

In Tests 2–4, every cutting length was about 20 mm, and in order to minimize the influence of the slight difference in material performance along the axis of the specimen on the cutting force, only a small zone (about 100 mm long) near the one end of the specimen was used.

TABLE 1 Changes of the main cutting force in the uninterrupted cutting process (Test 1).

Measurement Number	1	2	3	4	5	6	7	8
Main cutting force (N)	925	913	913	913	917	925	921	925
Relative average deviation (%)	0.65	−0.65	−0.65	−0.65	−0.22	0.65	0.22	0.65

TABLE 2 Changes of the main cutting force caused by the cutter realignment (Test 2) (Note: in **Table 2**, “before” and “after” denote “before cutter realignment” (first cutter alignment) and “after cutter realignment”, respectively).

	Φ73.2 mm, 1.75 mm		Φ69 mm, 1.5 mm		Φ65.68 mm, 1.25 mm		Φ65.68 mm, 1 mm	
Cutting Conditions	Before	After	Before	After	Before	After	Before	After
Main cutting force (N)	780	788	647	655	550	542	433	437
Deviation (%)	1.03		1.24		−1.45		0.92	

In cutting force measurements, the accurate control of the tightening torque of the pressing bolts for the insert and the holder has been generally neglected, especially in China. Since the researchers do not believe that accurately controlled tightening torque is necessarily required (only to utilize manual control), the tightening torque was not measured during these present experiments. Investigating this influence is something for future research.

Results and Discussions

While the machinability of metals was evaluated by the cutting force, only the main cutting force was usually used. In the present work, the main cutting force was measured under various cutting conditions; however, backward and feeding forces were not considered.

INFLUENCE OF TOOL WEAR

In an uninterrupted cutting process, the change of the main cutting force at the cutting depth of 2 mm and the cutting length of 223 mm (Test 1) is shown in **Table 1**.

Since the gray cast iron specimen is relatively small, the material of the whole specimen was considered homogeneous. Under identical cutting conditions, the actual cutting force was the same along the cutting length direction. Thus, the measured change of the cutting force should be caused by the tool wear.

In **Table 1**, the maximum deviation of the main cutting force is quite small, approximately 1.3 %. The first measured value of the cutting force is equal to the last measured value, implying that the tool wear did not occur. In other tests, the cutting depth is smaller than 2 mm and the cutting length of the new insert is much smaller than 223 mm in Test 1, so the tool cutting wear could be neglected.

INFLUENCES OF CUTTER REALIGNMENT AND INSERT RESETTING

The change of the main cutting force before and after cutter realignment is shown in **Table 2**. The maximum deviation of the main cutting force is rather small, approximately 1.45 %.

The change of the main cutting force before and after the insert resetting (first mounting and second mounting, the same cutting edge) is shown in **Table 3**.

In **Table 3**, the change of the main cutting force was caused not only by the insert resetting, but also by cutter realignment. Overall, the change of the main cutting force was not great, meaning the manufacturing accuracy of the inserts and the tool holder were rather high and their matching was rather reasonable.

In the above cutting situation, changes of the main cutting force caused by changing the edge of the same insert, as well as replacing the insert, were examined. The difference was less than 2 %. It was also shown that the shape parameters of different edges of the same insert and different inserts were essentially identical.

The inserts and the tool holder used in the present work were ordinary and widely used in production. There was no special requirement for their quality for the tests. Thus, it may be inferred that the same situation existed in other similar tools.

INFLUENCES OF THE WHOLE TOOL REMOUNTING

The change of the main cutting force before and after the whole mechanically clamped cutting tool remounting (first mounting and second mounting) is shown in **Table 4**.

While remounting of the whole tool, although the tool position was kept as identical as possible before remounting (closely contacting the upper edge and left wall of the octagonal ring square hole), the change of the cutting force was still comparatively large (**Table 4**). There were two possible reasons for a large change of the cutting force. First, there was a tiny difference in the tool position before and after remounting. Second, the pressure of pressing bolts of the tool on octagonal ring dynamometer might be different compared with that before remounting due to the manual control of the tightening torque of the pressing bolts. These could result in the change of some

TABLE 3 Changes of the main cutting force caused by the insert resetting (Test 3).

	Φ73.2 mm, 1.75 mm		Φ69 mm, 1.5 mm		Φ65.68 mm, 1.25 mm		Φ65.68 mm, 1 mm	
Cutting Conditions	Before	After	Before	After	Before	After	Before	After
Main cutting force (N)	788	800	655	667	542	550	437	441
Deviation (%)	1.52		1.83		1.48		0.92	

TABLE 4 Changes of the main cutting force caused by tool remounting (Test 4).

	Φ74.1 mm, 1.5 mm		Φ70.8 mm, 1.25 mm		Φ70.8 mm, 1 mm	
Cutting Conditions	Before	After	Before	After	Before	After
Main cutting force (N)	756	820	655	703	510	566
Deviation (%)	8.57		7.33		10.98	

cutting parameters and possibly in the change of the tool tip elevation, and then resulted in the change of the cutting forces. The changes of some cutting parameters and the elevation of the tool tip were closely related to the change of the cutting force. Although every effort was made to keep the tool remounting the same as the first mounting, the difference was inevitable. While this is only a speculation, the positions of lathe tool tip before and after remounting are needed to be precisely measured to confirm this (future research). Even so, the already achieved experimental results can offer valuable guidance for accurate measurement of the cutting force and accurate evaluation of the machinability.

Summary and Concluding Remarks

In this present work, an attempt was made to study the influence of cutter realignment, insert resetting, and the whole mechanically clamped cutting tool remounting on the main cutting force, while tool wear could be neglected. It can offer valuable guidance for the evaluation of machinability of metals by the cutting force. For the mechanically clamped cutting tool, the change of the cutting force caused by insert resetting and replacing was relatively minor. However, the whole mechanically clamped cutting tool remounting caused a rather large change in the cutting force. When the cutting force was used to evaluate the machinability of metals, if the difference of machinability among different materials was not very great, it was possible that the change of cutting force caused by tool remounting was greater than that caused by the different materials. As a result, it would be impossible to evaluate the machinability of materials by the cutting force alone. While integral tools were used, even if they were from the same batch, their shape parameters were not entirely identical. The greater change of the cutting force was caused by tool replacement. Therefore, when the cutting force was used to evaluate the machinability of materials, a mechanically clamped cutting tool should be used, and the inserts should be replaceable. However, the tool holder should be mounted only once for all tests.

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