Performance Characteristics of Newly Developed Additive for Machinability Enhancement of Sintered Steel

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ABSTRACT
Machining of sintered steel parts is sometimes necessary in order to produce complicated geometries like undercut which are hard to realize by uniaxial pressing and to meet customer requirements of higher dimensional accuracy. Although cutting costs account for a high percentage of the total manufacturing cost of sintered steel parts, and improvement of the machinability of sintered steel is desired. In this paper, performance characteristics of newly developed additive to improve the machinability of sintered steel were investigated on several conditions. The amounts of tool wear were significantly different according to the tool materials and cooling condition of cutting. However, in comparison with sintered steels without an additive and with the manganese sulfide, the machinability of sintered steel with new additive was improved simultaneously in drilling and turning for remarkable effects under various conditions.

KEY WORDS
sintered steel, machinability, turning, drilling, additives

1 Introduction
With the progress of powder metallurgical technology, near-net shape sintered parts can now be produced with complex shapes and high dimensional accuracy. In particular, sintered steel is widely applied in automotive parts. However, machining of sintered steel parts is sometimes necessary in order to produce complicated geometries like undercut which are hard to realize by uniaxial pressing and to meet customer requirements of higher dimensional accuracy. Unfortunately, sintered steel parts are difficult to cut in comparison with cast steel parts due to their internal porosity\(^1,2\). Pores contribute to lower thermal conductivity, resulting in increased temperature at the cutting edge/workpiece interface. Porosity also introduces microscopic shock and impact in the cutting edge as interrupted cutting. As a result, cutting costs account for a high percentage of the total manufacturing cost of sintered steel parts, and improvement of the machinability of sintered steel is desired. Various additives for machinability improvement of sintered steel have been reported up to the present. Among them, MnS powder is the most common additive, as this material offers good cost performance. Moreover, some additives have been introduced to improve the machinability in drilling as JFM\(^4\) and also in turning as JFM\(^4\)\(^5\). A new machinability enhancing additive (JFM\(^4\)X) maintains the excellent high-speed turning performance of JFM\(^4\) and simultaneously provides improved low-speed turning performance. Superior drilling performance is a distinctive feature of this additive\(^5\). However, the effect of these additives to the machining performance varies according to the cutting conditions. This paper presents the performance characteristics of additives in machinability on the several conditions such as cutting tools, coolant usage, base powders and heat treatment of workpieces.

2 Experimental procedures
2.1 Materials
In this work, four types of base powder made by JFE Steel Corporation were used. These powders are marketing products as water atomized iron powder (JIP\(^3\)301A), reduced iron powder (JIP\(^3\)255M), Fe-4 mass%Ni-1.5% mass%Cu-0.5 mass%Mo partially alloyed powder (JIP\(^3\)SIGMALOY415S) and Fe-0.45 mass%Mo fully alloyed powder (JIP\(^3\)4MOA). Base powder was mixed with atomized copper powder (average particle diameter 35 micron), natural graphite powder (average particle diameter 22 micron) and wax lubricants. Compositions of mixture are shown in Table 1. The additives used in this work.

2.2 Process conditions
These powder mixtures were compacted into ring workpieces
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with dimensions of 60 mm in outer diameter, 20 mm in inner diameter and 20 mm in thickness and disc shaped workpieces with dimensions of 60 mm in diameter and 10 mm in thickness. Green density of the workpieces were 6.6 Mg/m$^3$ for 255M mixture, 6.9 Mg/m$^3$ for 301A, 7.0 Mg/m$^3$ for 415S and 7.1 Mg/m$^3$ for 4MOA. Sintering was carried out in a conveyor belt sintering furnace. The green workpieces were sintered at 1130 °C for 20 min in an endothermic gas. Several workpieces of sintered steel made of 301A mixture were heat treated as follows; carburizing in 870 °C for 60 min under carbon potential of 0.8 %, quenching in oil at 60 °C and tempering at 180 °C for 60 min.

2.3 Machinability evaluation methods

Machinability of sintered steel was evaluated through turning and drilling tests by CNC lathe (Mazak QTN200M). Three ring shaped workpieces were connected and formed like a tube with 60 mm length as shown in Fig. 1. Turning conditions are shown in Table 3. Workpieces were turned in the cutting speed at 100 and 200 m/min, cutting depth at 0.5 mm and feed rate at 0.1 mm/rev. Three different materials of insert tool (SNMN12408 Sumitomo Electric Hardmetal) as non coated cemented carbide K10, non coated cemented carbide P10 and non coated cermet were used for this outer periphery turning with or without a coolant (in other words, wet or dry condition). In the turning of heat treated samples, CBN insert (NP-TNGA160404FS3 Mitsubishi materials) was used in a cutting speed at 120 m/min, cutting depth at 0.1 mm and feed rate at 0.2 mm/rev without a coolant. Under these cutting conditions, the maximum width of flank wear on the insert was measured with a stereomicroscope. Disk shaped workpieces were drilled by using milling function of the CNC lathe. Drilling tests were conducted by drilling through-holes with a depth of 10 mm at a drill speed of 5000 rpm and feed rate of 0.02 mm/rev using a coated HSS drill bit (HMD026M, Diameter 2.6 mm, Sumitomo Electric Hardmetal). Machinability was evaluated as the thrust force and the number of drilled holes until drill bit was damaged. The thrust when drilling the 1st, 752nd and 1503rd holes was measured by a tool dynamometer without a coolant, and the other through-holes were drilled with a coolant.

3 Results and discussion

Firstly, sintered samples made of atomized iron powder 301A mixture were turned by different tool materials. Fig. 2 shows the comparison of tool wear at 1000 m turned distance in 100 m/min dry turning of workpieces with or without machinability enhancing additives. Not depending on additive usage, tool wear of K type cemented carbide insert had remarkably exceeded a criterion for the maximal flank wear (0.2 mm). The wear of the cermet insert was the least in this tests. Even in wet turning, this tendency was similar. Therefore, the cermet was favorable in low speed turning for sintered steel. It is reported that the affinity of cermet and iron is lower than that of cemented carbide and iron\[5\]. This low affinity might be one of the reasons for low abrasion of cermet. Regarding

### Table 1

Compositions of mixture.

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<th>Mixture Composition (mass%)</th>
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<tr>
<td>301A + 2.0 %Cu + 0.8 %Gr + 0.8 %Lub</td>
</tr>
<tr>
<td>255M + 2.0 %Cu + 0.8 %Gr + 0.8 %Lub</td>
</tr>
<tr>
<td>415S + 0.6 %Gr + 0.8 %Lub</td>
</tr>
<tr>
<td>4MOA + 2.0 %Cu + 0.8 %Gr + 0.5 %Lub</td>
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### Table 2

Additives for machinability test.

<table>
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<th>Additive (mass%)</th>
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<tr>
<td>0.5 %MnS</td>
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<tr>
<td>0.3 %JFM™X</td>
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![Fig. 1 Schematic diagram of turning test.](image)

![Fig. 2 Tool wear of each insert material in turning sintered steel with or without additives.](image)
machinability enhancing additives, JFM™X was most effective to reduce wear of tools except K type cemented carbide.

Fig. 3 shows the wear of cermet insert at 2000 m turned distance in wet and dry turning of workpieces with or without machinability enhancing additives. The wear in MnS usage became remarkable in 200 m/min turning with a coolant. JFM™X was effective under wide speed range and with or without a coolant.

The turning machinability of reduced iron powder 255M mixture was compared to that of atomized iron powder 301A mixture. Fig. 4 shows the tool wears of cermet insert at 1000 m turned distance in 200 m/min wet and dry turning of workpieces without additive or with JFM™X. Turning properties of both iron powders were equivalent even in the difference of green density of workpieces as 6.6 and 6.9 Mg/m³. The influence of density to the turning machinability might be small in this density range.

For alloy powders, Fig. 5 shows the turning machinability of sintered alloy powder 415S mixture with or without additive at a turning speed of 100 m/min using cermet insert with or without a coolant. The wear in MnS usage became remarkable under wet turning. Machinability improvement by MnS addition under dry turning is known well[7]. Therefore, this deterioration of tool wear under wet turning is a problem that should be examined in the future. On the other hand, JFM™X was effective for machinability improvement in turning with or without a coolant.

Fig. 6 shows the turning machinability of sintered alloy powder 4MOA mixture without additive or with JFM™X at turning speed of 100 and 200 m/min using cermet insert with a coolant. Turning of the workpieces made of alloy powder 4MOA mixture was not hard relative to iron powder 301A or 255M mixtures. JFM™X was also effective for machinability improvement in this alloy mixture under wide speed range with a coolant.

For heat treated samples made of water atomized iron powder 301A mixture without additive and with JFM™X, Fig. 7 (a) shows the change of Rockwell hardness scale A corresponding to a depth from surface of workpiece. The surface hardness was HRA65 or more, therefore these samples were quenched enough. Because the
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hardening was not effective in 3 mm depth, turning was done up to 2 mm depth from surface at each workpiece set. Fig. 7 (b) shows the wear of CBN insert at turning speed of 120 m/min without a coolant. JFM™X was also effective for machinability improvement to heat treated sintered steel and the wear of CBN insert was suppressed by 1/3.

The drilling performances were tested with sintered steel made of water atomized iron powder 301A mixture. Table 4 and Fig. 8 show the comparison of drilling machinability between sintered steel with and without additives. As shown in Table 4, the drill life of both the workpieces with MnS and with JFM™X additives exceeded 1503 holes in all the workpieces, but was only 1183 holes with the workpieces without an additive. Therefore, the drilling machinability was improved by the enhancing additives. In all workpieces, thrust rose with the number of drilled holes. The thrust in drilling the JFM™X workpiece was lower than that without an additive but higher than that with MnS. However, because MnS content was higher than JFM™X content in the workpiece, it should be considered that the difference of drilling performance between MnS with JFM™X was small.

In order to investigate an effect of the machinability enhancing additive on chip breaking behavior, the chips from sintered workpieces were observed by an optical microscope. The cross-sectional microstructures of the chips obtained at turning speed of 200 m/min are shown in Fig. 9. As a most remarkable result, many micro-voids were observed in the shear deformation direction in the chip with JFM™X. It is presumed that the machinability enhancing additive JFM™X played a role in void generation and crack extension in the shear deformation area. Because the sintered material with JFM™X could be cut and broken easily into short chips, the contact area between the tool and the chip was reduced. This was regarded as one of the reasons for suppression of tool wear.

Fig. 10 shows scanning electron micrographs of the cermet tool surface after turning the workpiece with JFM™X. Adhesive materials (gray area) were observed on the rake face of the cermet.
Additive-free 0.5%MnS 0.3%JFM™X

Fig. 9 Cross-sectional microstructures of the chips in turning speed 200 m/min with cermet.

Fig. 10 Scanning electron micrograph images of the rake face of cermet inserts after machining material with JFM™X.

4 Conclusions

Performance characteristics of the newly developed additive JFM™X on the machinability of sintered steel have been investigated. In the comparison to sintered steel without an additive and with the MnS additive, the following conclusions can be made from this study.

1) In the turning test of sintered steel made of atomized iron powder 301A mixture, cermet was favorable among three different materials of insert tool. The wear in MnS usage became remarkable in 200 m/min turning with a coolant. JFM™X was effective under wide speed range with or without a coolant.

2) For alloy powders, the wear of tool in wet turning of sintered steel made of alloy powder 415S mixture with MnS became remarkable. Turning of the workpieces made of alloy powder 4MOA mixture was not hard relative to iron powder 301A or 255M mixtures. JFM™X was also effective for machinability improvement in both alloys mixture under wide speed range with a coolant.

3) JFM™X was also effective for machinability improvement to heat treated sintered steel and the wear of CBN insert in JFM™X usage was suppressed by 1/3 relative to the one without additive.

4) MnS and JFM™X improved machinability in drilling operation. Therefore, the superior property of JFM™X is the machinability enhancement simultaneously in drilling and turning.

5) Many micro-voids were observed in the shear deformation direction in the chip with JFM™X. Because the sintered material with JFM™X could be cut and broken easily into short chips, the contact area between the tool and the chip was reduced. This was regarded as one of the reasons for suppression of tool wear.

6) The adhered materials were observed on the rake surface of cermet inserts after turning of sintered steel with JFM™X. This adhesive layer would reduce friction at the point of contact between the tool and the workpiece, resulting in suppression of tool wear and oxidation of the tool surface.
References