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"Cleanmix™ JFM™ Series" for Sintered Parts with Excellent Machinability†

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Abstract:

Machining are often applied to powder metallurgical parts to meet the requirements of tight tolerance and multifunctionality, and improvement of machinability is required in sintered steels to reduce cutting costs. In the Cleanmix™ lineup of segregation-free mixed powders, which is produced by an original manufacturing process pursuing greater convenience for customers, JFE Steel has commercialized the Cleanmix JFM™ (JFE Free Machining) series to meet the demand for excellent machinability in order to reduce the cost of manufacturing powder metallurgical parts made of iron-based sintered steels. The JFM series has been widely applied to automotive parts and is expected to support further expansion of the application of sintered parts and reduction of manufacturing costs in the future.

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. 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[1)]. 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[2)]. Moreover, new additives have also been reported in recent years[3, 4)].

In 1989, "JIP™ Cleanmix™" was commercialized by JFE Steel to solve the problems of segregation and dust emission of premixed powders which include iron powder, graphite powder and lubricants[5)]. In the Cleanmix lineup, the JFM™ series was developed by applying advanced powder metallurgical technology in an original manufacturing process. This series includes JFM3[6)] to reduce interrupted shock and impact stress in drilling, JFM4[7)] to reduce tool wear in high-speed turning and JFMX[8)] with excellent turning and drilling performance.

This paper introduces the features and cutting performance of these products in the JFM series.

2. Technology of Machinability Improvement

2.1 Mechanism of Machinability Improvement in Free-Cutting Steel

Cast and wrought steels containing S, Pb, Se, Te, Bi, and Ca are known as free-cutting steel for machine structural components[9)]. The sulfide inclusions in sulfur free-cutting steel contribute to crack initiation and elongation as stress concentration points in chip breakage.

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These sulfide inclusions also prevent adhesion of chips on the tool or atomic diffusion to the tool. In particular, MnS has been investigated in detail and its effects are proposed as (1) abrasion reduction[10)], (2) embrittlement by stress concentration[11,12)], (3) internal lubrication[13)], and (4) formation of a tool protective layer[14)]. In lead free-cutting steel, lead, which has a low melting point of 600 K, is melted by the heat generated during cutting, and the melt contributes to stress concentration and lubrication between the tool and the chips or work material[15)]. In calcium free-cutting steel, complex oxides are intentionally formed as compounds of CaO, SiO_2, Al_2O_3 in order to secure appropriate cutting performance. A coating material called belag with approximately the same composition as the complex oxides adheres to the tool surface during cutting, preventing diffusion of elements between the tool and the chips or work material, which is the main cause of tool wear in high speed cutting[16)].

Therefore, it is considered that the functions of additives required for machinability improvement are stress concentration, prevention of adhesion of chips to the tool and lubrication between the tool and the chips or work material, and prevention of diffusion of elements of the material to the tool.

2.2 Concept of Machinability Improvement in JFM™ Series

Sintered steel manufactured by powder metallurgy contains a large number of pores, and it is known that these pores have an adverse effect on cutting performance. Pores contribute to a reduction of thermal conductivity. As a result, the temperature at the cutting edge/workpiece interface easily increases due to heat generation in cutting, and this results in damage of the tool at high temperature. Porosity also introduces microscopic shock and impact to the cutting edge as interrupted cutting[1)]. Therefore, as the concept of machinability improvement in the JFM™ series, additives with the following functions are selected, and these additives are dispersed uniformly in the sintered steel by Cleanmix processing. A schematic diagram of the concepts is shown in **Fig. 1**.

(1) Additive which concentrates stress in order to generate a large number of cracks in chips and break the chips finely, resulting in shortening of the contact time between the tool and the chips.
(2) Additive which fills pores in order to reduce the load fluctuation of the tool and to reduce the impact stresses in interrupted cutting.
(3) Components for additive melting and softening in cutting so as to adhere to the tool surface as a lubricative and protective film in order to reduce tool abrasion.

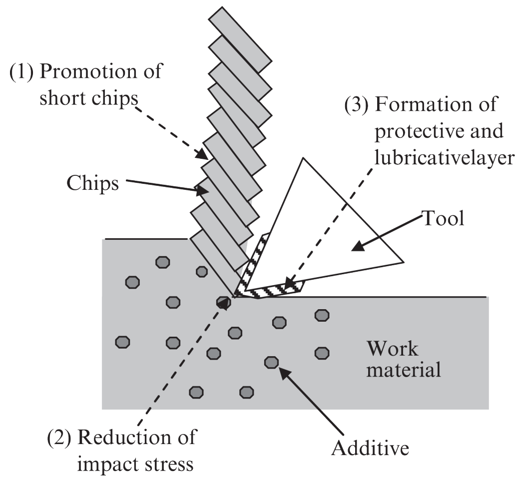


Fig. 1 Concept of developed additives for machinability improvement

3. Features of Cleanmix™ JFM™ Series

3.1 Drilling Characteristic of JFM™3

In sintered parts having several drilled holes, such as shock absorber parts, drilling performance is particularly important. JFE Steel developed Cleanmix™ JFM™3 to reduce drill abrasion and torque fluctuation in drilling.

3.1.1 Drilling performance

Drilling performance was evaluated by comparing the machinability of sintered materials without an additive and with an additive of MnS or JFM™3. Water atomized iron powder (JFE Steel, JIP™260A) was used as the raw material. Zinc stearate (0.8 mass%) and natural graphite powder (0.7 mass%) and an additive as required were added to the iron powder. The mixture was processed as Cleanmix™ powder to prevention segregation. The quantity of additive was 0.3–1.5 mass% in the specimen with MnS and 0.75 mass% with JFM3. The Cleanmix powders were compacted into cylindrical specimens with a diameter of 60 mm, thickness of 10 mm and green density of 6.6 g/cm^3. The specimens were sintered at 1 423 K (1 150°C) for 15 min in a 5% hydrogen-95% nitrogen gas atmosphere. Drilling tests were conducted at a drill speed of 10 000 rpm and a feed rate of 0.02 mm/rev. using a cemented tungsten carbide drill bit with a diameter of 2.4 mm. After 100 through-holes were drilled, the circumferential wear of the drill was measured. The influence of the additive quantity on flank wear is shown in **Fig. 2**.

When more than 0.3 mass% of MnS was added, drill wear decreased to 1/3 in comparison to the material without the additive. The drill wear with 0.75 mass% addition of JFM3 was equivalent to the wear with MnS addition.

Drill life is shown in **Fig. 3**. Drill life was obtained by investigating the number of holes until the drill broke

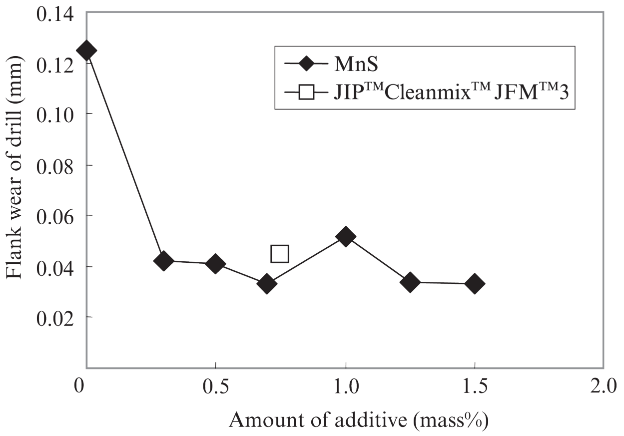


Fig. 2 Effect of amount of additives on flank wear of drill

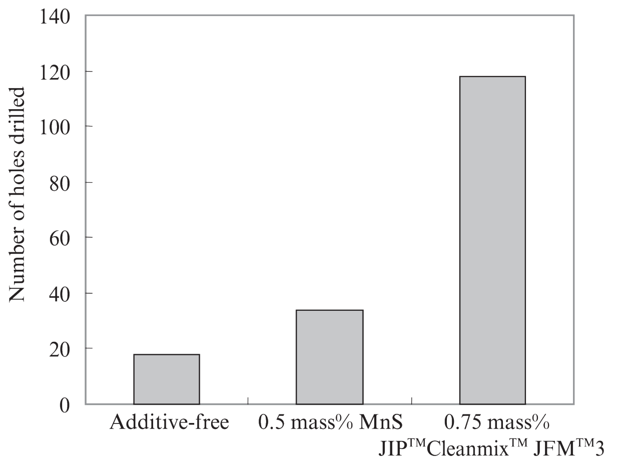


Fig. 3 Machinability of materials with and without additives in drilling tests

with a drill speed of 10 000 rpm and a feed rate of 0.03 mm/rev. using a cemented tungsten carbide drill bit with a diameter of 1.2 mm. The drill life when drilling specimens with JFM3 was greatly extended to 6.5 times of that without an additive and 3.5 times that with MnS addition. Thus, in comparison with MnS, JFM3 had an equivalent effect for improvement of drill circumferential wear and a superior effect for extension of drill life.

3.1.2 Analysis of drill damage

JFM$^{\text{TM}}$3 had a remarkable effect in drill life extension. To clarify the reason for this performance, the condition of drill damage was investigated in detail.

Figure 4 shows the results of torque as the cutting resistance when drilling the 100th hole in specimens with 0.7 mass% MnS and 0.75 mass% JFM3 as additives. Torque was measured with a tool dynamometer. Torque fluctuation was drastically reduced in the material with 0.75 mass% JFM3 compared to the material with 0.7 mass% MnS. Thus, it was considered that the shock and impact to the cutting edge as interrupted cutting were reduced by JFM3.

Conversely, these results indicate that drill damage

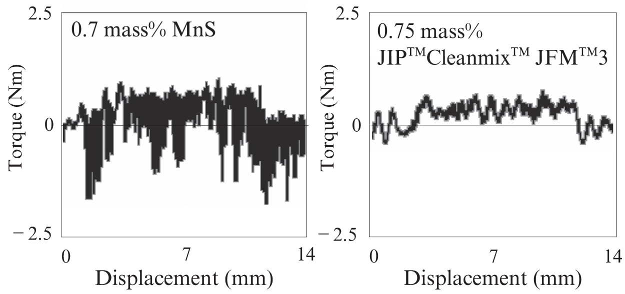


Fig. 4 Torque fluctuation in drilling

increases and drill life is shortened with increasing torque fluctuation. Therefore, an investigation of the relationship between torque fluctuation and tool damage was carried out to obtain supporting evidence for this phenomenon. Because cemented tungsten carbide has a structure in which WC is connected with a cobalt binder, it is considered that the cobalt binder phase is also damaged by the interrupted stress on the drill. Generally, the coercive force of soft magnetic materials such as cobalt increases due to the existence of defects which disturb the movement of magnetic walls. Therefore, the damage of the drill could be evaluated by measurement of the coercive force of the cobalt binder. As a trial to evaluate the damage of the drill tip, the coercive force of this part was measured with a vibrating sample magnetometer (VSM). The relationship of the torque fluctuation amplitude and the coercive force of the drill tip is shown in **Fig. 5**. A tendency in which the coercive force of the drill tip increased with increasing torque fluctuation was found. This suggests the possibility that the cobalt binder phase was damaged by interrupted stress, inducing torque fluctuation. Although the evaluation of drill damage will require a detailed examination, it was estimated that suppression of torque fluctuation contributed

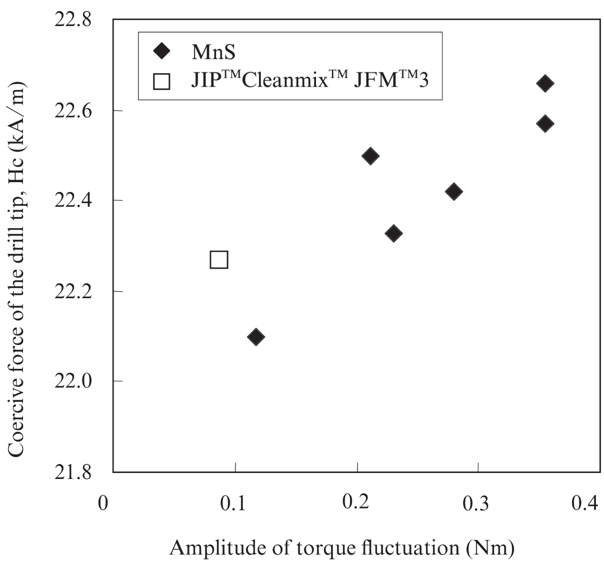


Fig. 5 Relationship between amplitude of torque fluctuation and coercive force of drill tip

to the decrease of drill damage and extension of drill life with JFM3.

3.2 Turning Properties of Cleanmix™ JFM™4 and JFMX

In sintered parts in which high dimensional precision is required in the inside and outside diameters and end face, such as automobile engine parts, the turning performance of the sintered material is particularly important. In some cases, the manufacturing process for these parts also includes drilling. Therefore, JFE Steel developed Cleanmix™ JFM™4 for reduction of tool wear in high-speed turning and JFMX with excellent performance in turning and drilling.

3.2.1 Turning characteristics of JFM™4

Turning performance was evaluated by comparing the machinability of sintered materials without an additive and with an additive of MnS or JFM™4. Water atomized iron powder (JFE Steel, JIP™301A) was used as the raw material. Lubricant (0.8 mass%), natural graphite powder (0.8 mass%), Cu Powder (2.0 mass%), and an additive as required were added to the iron powder. The mixture was processed as Cleanmix™ powder to prevent segregation. The quantity of the additive was 0.5 mass% in the specimen with MnS and 0.2 mass% with JFM4. The Cleanmix powders were compacted into ring specimens with an outer diameter of 60 mm, inner diameter of 20 mm and thickness of 20 mm, and cylindrical specimens with a diameter of 60 mm and thickness of 10 mm. The green density was 6.9 g/cm^3. The specimens were sintered at 1 403 K (1 130°C) for 20 min in an endothermic gas using a mesh belt furnace. Three ring specimens which were connected to formed a tube-like shape 60 mm in length were turned with a computer numerical control (CNC) lathe. Turning tests were conducted at a turning speed of 200 m/min, cutting depth of 0.5 mm and feed rate of 0.1 mm/rev. using an uncoated cemented carbide insert ST10P without a coolant. **Figure 6** shows the flank wear of the turning inserts. The flank wear in turning the specimen with JFM4 decreased to 1/4 and 1/3 in comparison to the materials without an additive and with MnS addition, respectively.

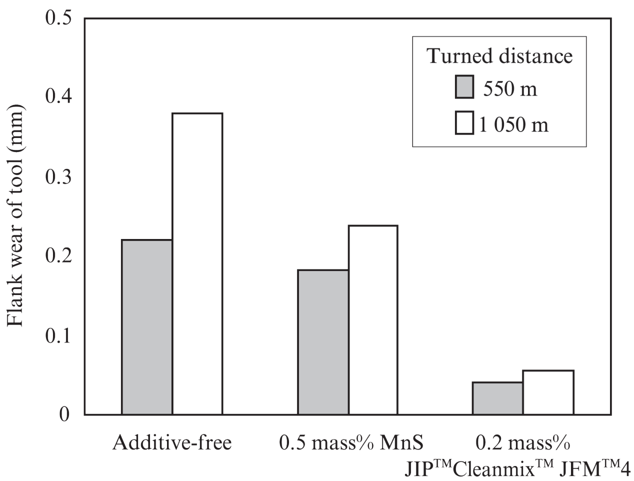


Fig. 6 Machinability of materials with and without additives in turning tests (Turning speed: 200 m/min)

3.2.2 Turning and drilling characteristics of JFM™X

The cutting characteristics of Cleanmix™ JFM™X were evaluated. The specimens were prepared in the same manner as in the JFM4 evaluation. Turning tests were conducted at a turning speed of 100 m/min, cutting depth of 0.5 mm and feed rate of 0.1 mm/rev. using an uncoated cermet insert T1200A with a coolant. Drilling tests were conducted by drilling through-holes at a drill speed of 5 000 rpm and feed rate of 0.02 mm/rev. using a coated HSS drill bit (Diameter: 2.6 mm) . The thrust when drilling the 1st, 752nd and 1 503rd holes was mea-

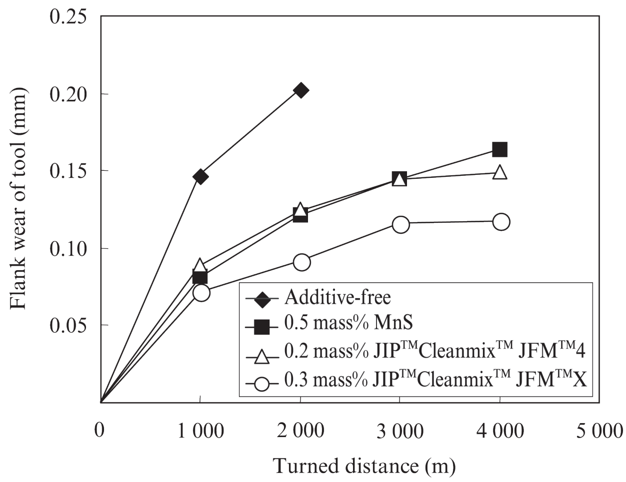


Fig. 7 Machinability of materials with and without additives in turning tests (Turning speed: 100 m/min)

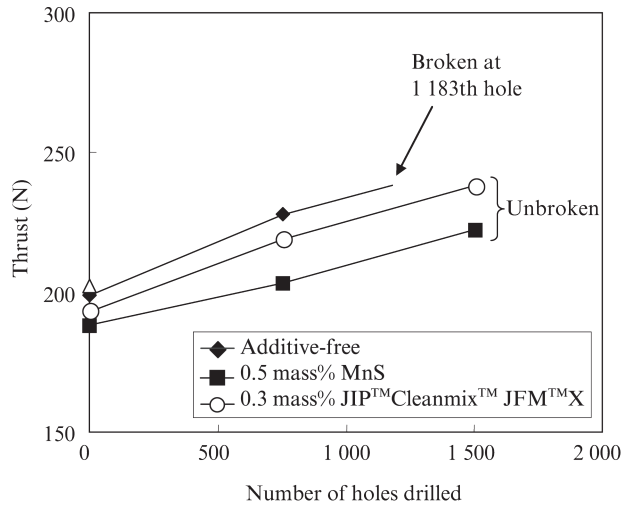


Fig. 8 Drilling machinability of materials with and without additives

sured by a tool dynamometer without a coolant, and the other through-holes were drilled with a coolant.

Figure 7 shows the flank wear of the inserts in turning. The flank wear with the JFMX specimen was much smaller than the wear with the other materials, and the machinability of JFMX was better than that of JFM4 at the low turning speed of 100 m/min. **Figure 8** shows the relationship between thrust and the number of drilled holes. In all specimens, thrust rose with the number of drilled holes. The thrust in drilling the JFMX specimen was lower than that without an additive but higher than that with MnS. The drill life of both the specimens with MnS and with JFMX additives exceeded 1 503 holes in all the specimens, but was only 1 183 holes with the specimen without an additive.

3.2.3 Analysis of turning performance

To analyze the good turning performances of Cleanmix™ JFM™4, the microstructure and hardness of the turned specimens and chips were observed and measured. The micro Vickers hardness under a load 0.245 N was measured as ten points of means at the plastically deformed outer layer of the turned surface, and not the deformed inside layer of the specimen, and the chip surface in contact with the tool. **Photo 1** shows an example of the hardness measurement at the surface of the turned specimen with JFM4. The micro Vickers hardness of the specimens without an additive and with 0.5 mass% MnS or 0.2 mass% JFM4 is shown in **Table 1**. According to the microstructural observation, pores elongated in the deformation direction and then closed; in other words, the densification of the structure with or without an additive appeared. However, the hardness at the deformed layer of the specimens with a machinability improvement additive was low in comparison to the specimen without an additive. That is, work hardening was prevented by the machinability improvement additive. Based on these results, it is considered that hardening of the deformed layer was prevented due to the reduction of accumulated dislocations by the machinability improvement additive.

In addition, to analyze the superior turning performance of Cleanmix JFMX, the microstructures of the chip were observed. The results are shown in **Photo 2**. Many micro-voids were observed in the shear deformation direction in the chip with 0.3 mass% JFMX in comparison to the chips with 0.5 mass% MnS and without an additive. It is presumed that the machinability enhancing additive JFMX played a role in void generation and crack extension in the shear deformation area. Because the sintered material with JFMX 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.

Photo 3 shows scanning electron micrographs of the cermet tool surface after turning the specimen with 0.3 mass% JFMX. Adhesive materials (Gray area) were observed on the rake face of the cermet inserts. In particular, this adhesive layer became remarkable at the

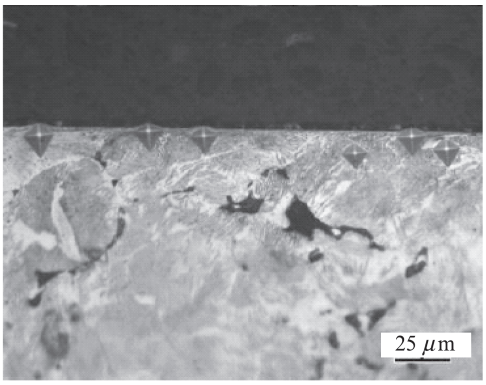
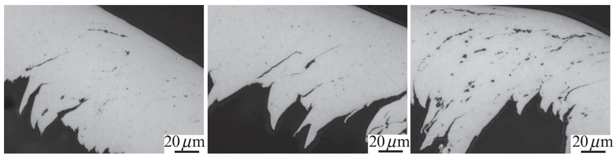


Photo 1 Example of Hardness measurement at turned surface of work with JFM™4

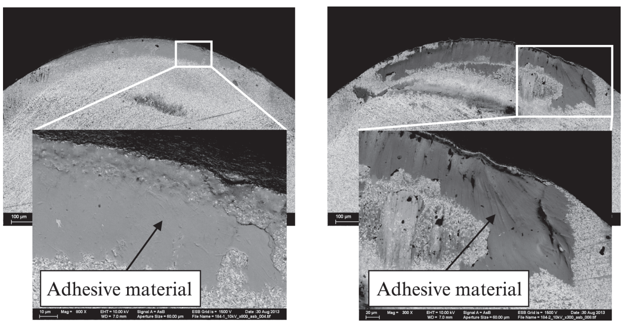
Table 1 Vickers hardness of the work and chip after turning

Material	Vickers hardness, Hv		
	Work inside	Work turned surface	Chip turned surface
Additive-free	210	378	372
0.5 mass% MnS	207	283	332
0.2 mass% JIP™ Cleanmix™ JFM™4	212	291	302



(a) Additives-free (b) 0.5% MnS (c) 0.3% JIP™Cleanmix™ JFM™X

Photo 2 Cross-sectional microstructures of chips in turning test



(a) Turning speed 100 m/min after 4 000 m turning (b) Turning speed 200 m/min after 2 000 m turning

Photo 3 Scanning electron micrograph images of tools after machining material with JFM™X turning speed of 200 m/min. It is also presumed that the constituents included in JFMX were easily melted by frictional heat and played a role as a protective and lubricative layer on the tool surface. This adhesive layer would reduce friction at the point of contact between the tool and the specimen, resulting in suppression of tool wear and oxidation of the tool surface.

4. Conclusion

The basic principles of machinability improvement and the cutting characteristics of each product in the JFE Steel Cleanmix™ JFM™ series were introduced. These products were developed to realize a reduction in the manufacturing costs of powder metallurgical parts made of iron-based sintered steels. A summary is presented below.

(1) Cleanmix JFM3 has excellent drilling performance. This additive reduces impact stresses caused by interrupted cutting due to the porosity of sintered materials. When drilling material with JFM3, drill life is extended by more than 6 times in comparison with material without an additive and by more than 3 times in comparison with MnS addition.

(2) Cleanmix JFM4 has excellent turning performance, especially at high turning speeds of more than 200 m/min. This additive promotes breakage of chips and adheres to the tool surface as a protective film. When turning material with JFM4, flank wear decreases to 1/4 and 1/3 in comparison with material without an additive and with MnS addition, respectively.

(3) Cleanmix JFMX maintains the excellent high-speed turning performance of JFM4 and simultaneously provides improved low-speed turning performance. Superior drilling performance is a distinctive feature of this additive.

JFE Steel will promote further development pursuing greater convenience for customers while continuing to deepen its collaborative relationships, with the aim of further expansion of the application and reduction of the manufacturing cost of sintered parts.

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