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# JIP® Iron Powder Products and Technical Trends in Powder Metallurgy†

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***Abstract:***

*JFE Steel started production of iron powders in 1966, as the pioneer of the full-scale manufacturing facility of iron powder production in Japan, and has been contributing to the development of powder metallurgy industry as the only integrated iron powder manufacturer producing both reduced and atomized iron powders in Japan. In order to meet the recent demand for smaller and lighter sintered machine parts with higher strength, JFE Steel has developed "JIP® Hybrid Mo Steel Powder," for higher fatigue strength of sintered parts realized by its composite structure obtained by the distribution of the alloy element, and "JIP® Cleanmix HDX," premixed powder providing higher compact density. Moreover, the application field of iron powder covers wide range for not only sintered structural parts but also the application in chemical reaction and heat source, etc. JFE Steel develops iron powder products optimized for each technical field. This paper outlines JFE Steel's iron powder products corresponding to technology trends of these applications.*

## 1. Introduction

Industrial iron powders include reduced iron powders, which are produced by reducing iron oxide in a solid phase, atomized iron powders produced by atomizing and solidifying molten steel, electrolytic iron powders produced by electrical decomposition of a solution containing Fe ions, and carbonyl iron powders produced by thermal decomposition of iron pentacarbonyl, among others. However, the types which are used most widely and in the largest quantities are reduced iron powders and atomized iron powders.

In October 1966, JFE Steel established the first integrated manufacturing process for reduced iron powder in Japan at its East Japan Works (Chiba District) (at the time, Kawasaki Steel, Chiba Works) and realized domestic production of iron powder, which had depended on imports until that time. Subsequently, JFE Steel began operation of atomized iron powder facilities in April 1978. The company has contributed to the development of industry up to the present as the only total iron powder manufacturer in Japan which produces both reduced iron powders and atomized iron powders[1)].

JFE Steel has devoted much effort to the development of iron powder products suited to specific applications under the trade name "JIP®" iron powder (until March 2004, "KIP®"). These products are used in a wide range of fields, as well as powder metallurgy.

This Special Issue on Iron and Steel Powders presents a summary of technical trends in the respective fields of use, including powder metallurgy applications, and an outline of JFE Steel's "JIP®" iron powder products.

## 2. Industrial Fields of Application for Iron Powders and JIP® Products

### 2.1 Sintered Structural Parts

#### 2.1.1 Trends in sintered parts in transportation machinery field

Among powder metallurgy (PM) products, the transition in the production of sintered bearings and

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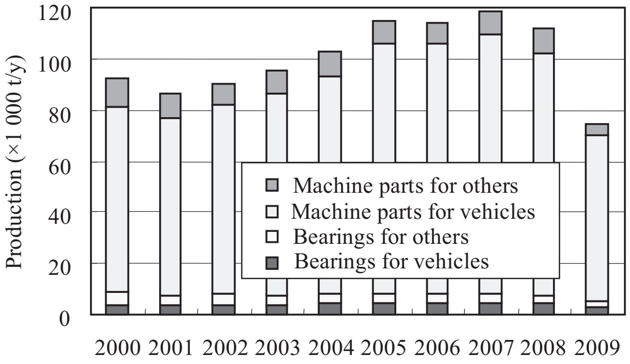
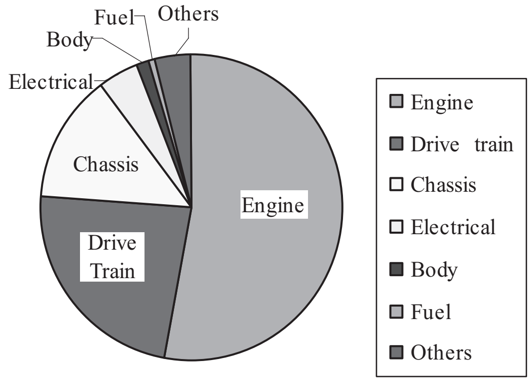



(Source: Japan Powder Metallurgy Association)

Fig. 1 Powder metallurgy parts production

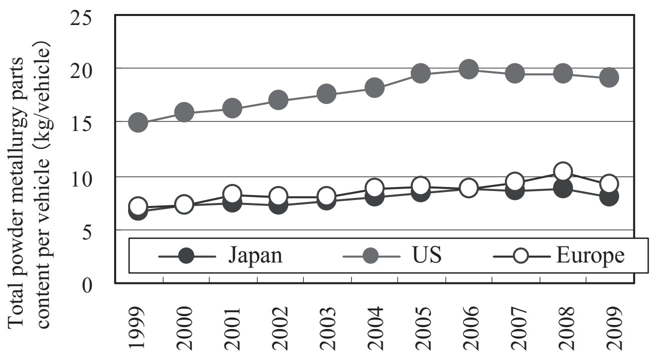



(Source: Japan Powder Metallurgy Association)

Fig. 3 Breakdown of machine parts for automobile

machine structural parts by demand sector is shown in **Fig. 1**. In 2000, the percentage of products for use in transportation machinery was less than 80%, but this showed an increasing tendency up to 2006, reaching 86%, and has remained on the same level since that time. This shows that PM parts are heavily dependent on the automobile industry. During 2009, these results were affected by the financial crisis, but in 2010, PM parts have shown a recovering tone.

On the other hand, no large growth can be seen in the weight (unit consumption) for sintered parts used for one car. This is attributable to downsizing/weight reduction by adoption of high strength sintered parts. The transition in the unit consumption of sintered parts per automobile is shown in **Fig. 2**. Expanded use of sintered parts has been stagnant, with no remarkable changes in Japan, the United States, or Europe. In particular, because unit consumption in Japanese-made automobiles is approximately one-half that in American-made automobiles, expanded use of sintered parts is desired in the future. The high unit consumption in American-made automobiles is due to progress in the adoption of large-scale sintered parts such as connecting rods, bearing caps, and the like. In Japan, sintered parts have not been adopted in parts of this type due to fierce competition with forgings and castings, which are machine part




(Source: Japan Powder Metallurgy Association)

Fig. 2 Total powder metallurgy parts content per vehicle

and tooling fields that compete with powder metallurgy. The weight of sintered parts is substantially similar in Europe and Japan, but in recent years, Europe has slightly exceeded Japan in this area.

As new parts which have contributed to increased unit consumption, variable cam timing (VCT) parts are comparatively recent. However, the adoption of sintered parts in next-generation new machinery is desired for increased unit consumption.

The composition of production by automotive part is shown in **Fig. 3**. More than 50% of sintered parts are used in critical parts related to the engine, including cam sprockets, valve guides, valve seats, oil pumps, etc. Thus, sintered parts can be considered an indispensible part of automobile engines.

In recent years, there has been a trend toward new types of engines in automobiles, as seen in the increasing use of motor drive systems, including hybrids, in place of the conventional internal combustion engine. This trend is expected to accelerate in the future. Accompanying this, changes in the composition of sintered parts in response to these new drive systems are also expected. Therefore, in place of the present structural parts, the development and practical application of parts for applications in motors, batteries, and power supplies is expected.

### 2.1.2 Outline of "JIP®" products for sintered structural parts

As materials for sintered structural parts, JFE Steel has continuously promoted the development of pure iron powder, alloyed iron powder, and "JIP® Clean Mix," which is a line of segregation-free iron powders consisting of pure and alloyed powders and additives, thereby playing a key role in automotive weight reduction and environmental countermeasures. JFE Steel has established and completed a mass production technology for alloyed iron powders which is suited to the compositions of these products with the aim of responding to needs that include high strength, high toughness, wear resistance, oxidation resistance, and others. JIP® Clean Mix is a line of premixed powders which are given segregation-free treatment by fixing the graphite on the surface of the iron powder. The main ingredients of these powders are pure iron powder (reduced iron powder) or atomized iron powder, and alloyed steel powder, which are blended with submaterials (copper powder, graphite powder, etc.) and lubricants according to the customer's specifications. In addition to the excellent properties of the base materials, these are also high value-added products which contribute to increased productivity, stable product quality, and cost reduction for the customer.

Recently, there have been increased needs for low alloyed steel powders due to instability factors in alloy market conditions. To meet these needs, JFE Steel has developed resource-saving alloyed steel powders which feature the minimum limit chemical composition and minimize process costs. On the other hand, in response to increased development of sintered products with high strength by high density compaction of Fe-Cu-C system materials, which are more economical than alloyed powders, the company developed high performance "JIP® Clean Mix" which enables high density compaction with low ejection force by realizing higher functionality in lubricants.

#### 2.1.3 Alloyed powder for structural parts

In order to respond to higher performance and more compact designs in automotive parts, which are the main application of PM steel material, JFE Steel developed various types of alloyed powders for high strength PM materials.

In 1984, JFE Steel began marketing low oxide, high compressibility Cr-alloyed steel powder, which is manufactured using a combination of water atomizing and vacuum reduction[2)].

"JIP® 103V" (1%Cr-0.3%Mo-0.3%V) alloyed powder with optimized contents of Mn, Mo, and V was developed and commercialized in 1995[3)]. With this material, it is possible to obtain high strength at the normal cooling rate in sintering furnace due to sintering hardening, which secures high strength while omitting the heat-treatment process after sintering.

In 2004, JFE Steel commercialized a hybrid type alloyed powder "JIP® 21SX," in which fine Ni powder, Cu powder, and graphite powder are bonded to a 2%Ni-1%Mo pre-alloyed powder by a binder[4)]. This product was developed by studying the contents of the alloys and method of alloy addition suitable for the sinter hardening process[4)].

JFE Steel also developed the hybrid type Mo alloyed powder "JIP® AH6020" in 2007 in order to obtain high fatigue strength under the sintering conditions on the mesh belt type of sintering furnaces[5)]. As shown in **Fig. 4**, "JIP® AH6020" is a hybrid type alloyed powder in which a highly concentrated Mo part is deposited on the surface of the powder particles by diffusion bonding 0.2% Mo to a 0.6% Mo pre-alloyed powder.

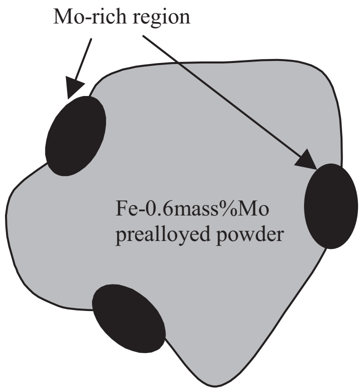



Fig. 4 Schematic illustration of particle structure of the molybdenum hybrid-alloyed steel powder "JIP® AH6020"

In the past, diffusion bonded 4% Ni alloyed powder was widely used in PM steel materials of tensile strength 600–1 000 MPa class[6)]. In order to respond to the demand for reduced consumption of Ni due to the sharp rise in the price of Ni raw materials, JFE Steel developed the Ni-free "JIP® FM Series" and began marketing tensile strength 600 MPa class "JIP® FM600" and tensile strength 1 000 MPa class "JIP® FM1000" in 2009. The "JIP® FM Series" is a line of pre-mixed alloyed powder products in which Cu powder is mixed with 0.45% Mo pre-alloyed powder, realizing the same level of tensile strength as diffusion bonded 4% Ni alloyed powder by the effects of Mo, which has a large multiplying factor for steel hardenability, and Cu, which melts below the sintering temperature and is effective in strengthening of neck parts[7)].

#### 2.1.4 Segregation-free powder "JIP® Clean Mix"

JFE Steel began marketing the previously-mentioned "JIP® Clean Mix" in 1989 in order to solve the problems of segregation of additives in mixed powders containing iron powder and scattering of the additives and dust generation during handling[8)]. In 1998, JFE Steel developed a "Clean Mix" product that was the first such product in the world to prevent segregation of Cu powder[9)], and also developed a segregation-free powder with excellent flowability, "JIP® Clean Mix J-WAX," by reducing the use of metal soap, which is a cause of contamination of sintering furnaces, and using a wax-type lubricant[10)]. At present, these "JIP® Clean Mix" products are one of the company's main iron powder product lines and account for more than half of shipments of powders for PM.

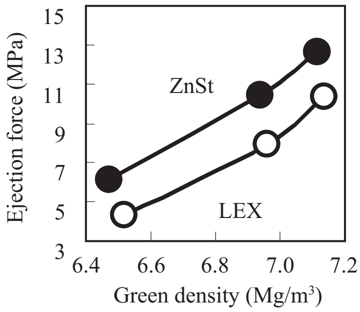



Fig. 5 Relationship between ejection force and green density Fe-2.0mass% Cu-0.8mass% graphite-lubricant

### 2.1.5 Segregation-free powder for high density compaction

Mechanical characteristics such as tensile strength and fatigue strength improve as the density of sintered compacts increases. For this reason, various methods of higher density compacting have been studied.

Warm compacting[11] is one method of higher density compacting. For this process, JFE Steel developed "JW Wax," which is suitable for use at warm temperatures, and began marketing a line of segregation-free powders for warm compacting, "JIP® Clean Mix HW Series," in 2001[12].

JFE Steel also developed the die wall lubrication method with warm compacting by combining the die wall lubrication method[13] with warm compacting, and developed "JIP® Clean Mix DL," which is suitable for this method[14].

However, in these warm compacting methods, it is necessary to heat the powder and die, and there were many problems in maintenance control of these heaters. Therefore, in 2009, JFE Steel began marketing "JIP® Clean Mix HDX," which makes it possible to obtain high density at room temperature[15].

On the other hand, because higher density in compacting causes an increase in ejection force, breakage of green compacts and appearance defects on the sides of the green compacts easily occur. In 2005, JFE Steel commercialized "JIP® Clean Mix LEX," which reduces ejection force[16]. During compacting, the lubrication effect is heightened by concentrating a special lubricant on the side face of the compact. As shown in **Fig. 5**, the ejection force of LEX is reduced by 20% in comparison with the conventional material.

### 2.1.6 Sintering and cold-forging process

The sintering and cold-forging process was proposed in order to obtain higher densities which cannot be achieved in the general PM product manufacturing process[17]. The JFE Steel sintering and cold-forging process makes it possible to achieve densification up to a density of 7.8 Mg/m$^3$, which is equivalent to 99% of true density (absolute density) by imparting sufficient transformability to withstand cold-forging to the material by compacting and pre-sintering Mo low alloyed powder under specified conditions.

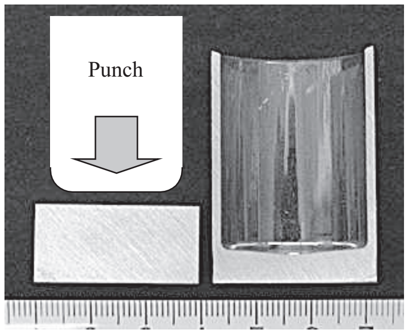



Photo 1 A sintered preform (left) and a backward extruded material (right)

Rotating bending fatigue strength of 600 MPa is achieved by heat treatment after cold-forging, and hardness of 60HRC can be obtained, which is comparable to the hardness of hardening steel made of solid metal. As shown in **Photo 1**, extrusion molding with reduction in area of 85% is possible with no cracks.

### 2.1.7 Free-machining powder "Clean Mix"

In order to produce more sintered parts with more complex shapes and meet higher dimensional accuracy requirements, virtually all sintered parts are machined after sintering. Therefore, improvement of machinability had been demanded. Conventionally, S content addition had been used as a free-machining addition which improves the machinability of sintered compacts by addition to the iron powder. However, this resulted in contamination of the sintering furnace, among other problems.

In order to solve this problem, in 2009, JFE Steel developed the "JIP® Clean Mix JFM Series."[18] Addition of a composite oxide powder promotes shear deformation of chips, and the composite oxide forms a protective film on the tool, thereby reducing tool wear.

## 2.2 Other Fields of Application

### 2.2.1 Chemical reactants

Iron powder is used as an iron source in chemical reaction applications, in the same manner as iron scrap. However, iron powder has various advantages in comparison with iron scrap, in that the reactivity of the powder is high due to the small particle diameter and uniform particle shape, and automation of the equipment is possible. Utilizing these advantages, iron powder is used as an iron source for various types of Fe-based chemical compounds. Iron powder is also used to recover metals from waste etching solutions. In this technology, Cu and Ni, which have a smaller tendency to ionize than iron, are chemically reduced and recovered as metals by dissolving iron powders as divalent ions in waste etching solutions containing Cu or Ni ions. On the other hand, ferrous oxide, which is a raw material for ferrite, can be recovered from the solution after dissolution of the iron powder, and injection of Cl causes formation of trivalent iron ions, making it possible to regenerate the etchant as a ferric chloride solution.

As another application in which the oxidation reaction of iron powder is used, oxygen absorbers (deoxidizers) may be mentioned. The occurrence of mold and degeneration of the fats and oils contained in foods can be prevented by placing oxygen absorbers in sealed packages together with food products.

#### 2.2.2 Iron powder for body warmers

Among pure iron powders, reduced iron powder is widely used in disposable body warmers because it has the feature of a large specific surface area and is a suitable material for exothermic reaction. In addition to the iron powder, disposable body warmers also contain activated carbon, a water retention agent, water, and salts to promote the exothermic reaction of the iron powder. The temperature and time of the exothermic reaction are controlled by the amount of these substances mixed in the body warmer and the air permeability of the bag in which the warmer is packaged.

#### 2.2.3 Welding rod coating materials

Iron powder is mixed in flux coated welding rods and iron powder is blended in fluxes used in automatic arc welding in order to support more efficient and economical welding work.

Because welding rod coating materials are a supplementary source of deposited metal, the amount of iron powder blended in the coating agent, the thickness of the coating, and other factors are studied, contributing to improved performance in welding work.

The use of iron powder in automatic arc welding fluxes is one method of achieving high efficiency in submerged arc welding. In this case, the flux contains iron powder in order to increase the welding speed. Fluxes containing iron powder also offer excellent economy, as the deposition rate is fast, work efficiency is good, and wire consumption per unit of deposited metal is reduced.

## 3. Conclusion

As discussed in this paper, iron powder is used in diverse applications, and JFE Steel has developed products to meet a wide range of quality requirements, including not only those introduced here, but also a general product line.

Continuing expansion in the applications of iron powder is expected due to technical trends in use fields, such as the hybrid automobiles and electric vehicles, and changing social needs related to the environment and foods, among others.

JIP® iron powder products have received certification under ISO 9001 and ISO 14001. JFE Steel has established a system which allows customers to use these products with consistent high quality with full confidence, and hopes that these products will also contribute to the progress of a wide range of industrial fields in the future.

### References


1) Kawasaki Seitetsu Gojunenshi. 2000
2) Ogura, K.; Okabe, R.; Takajo, S.; Maeda, Y. “Production and Properties of Chromium-Containing Low-Oxygen Steel Powders.” Prog. in Powder Metallurgy. MPIF. Dallas (USA), 1987-05, vol. 43, p. 619.
3) Furukimi, O. et al. Tetsu-to-Hagané. 1995, vol. 81, p. 833.
4) Unami, S. et al. Metal and Materials International. 2004, vol. 10, no. 3, p. 289.
5) Unami, S. et al. Materia Japan. 2007, vol. 46, p. 93.
6) Ogura, K. et al. Kawasaki Steel Giho. 1987, vol. 19, no. 3, p. 202.
7) Unami, S. et al. JFE Giho. 2010, no. 26, p. 54.
8) Minegishi, T. et al. Kawasaki Steel Giho. 1992, vol. 24, no. 4, p. 262.
9) Uenosono, S. et al. Kawasaki Steel Giho. 1999, vol. 31, no. 2, p. 135.
10) Uenosono, S. et al. Kawasaki Steel Giho. 1999, vol. 31, no. 2, p. 139.
11) Engström, U. et al. Proc. of 1998 Powder Metallurgy World Congress & Exhibition. Granada, 1998-10, EPMA. p. 21–26.
12) Ozaki, Y. Kawasaki Steel Giho. 2001, vol. 33, no. 4, p. 170.
13) Ball, W. G. et al. Int. J. Powder Metallurgy. 1997, vol. 33, no. 1, p. 23–32.
14) Unami, S. et al. JFE Giho. 2005, no. 7, p. 6.
15) Ozaki, Y. et al. Kawasaki Steel Giho. 2005, no. 7, p. 1.
16) Ono, T. JFE Giho. 2010, no. 26, p. 60.
17) Nakamura, N. JFE Giho. 2005, no. 7, p. 19.
18) Ozaki, Y. et al. Abstracts of Spring Meeting of Japan Society of Powder and Powder Metallurgy. 2009, p. 133.