Iron Powders Expand Applications of Iron with Various Functions*

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Synopsis:

Kawasaki Steel started the integrated production of reduced iron powder in 1966, when iron powder started to regularly be applied to automobile sintered parts. Moreover, Kawasaki Steel has been the only iron and steel powder manufacturer in Japan producing both reduced and atomized iron powders. KIP® brand iron powders are expanding the applications of iron via various uses, considering the nature of iron and powder. For the improvement of productivity by decreasing the dimension scattering of parts or shortening the heat-treatment of sintered products, accordingly iron powder has been applied taking account of the nature of iron mechanics and the flowability and forming by compression of powder. For this application, Kawasaki Steel supplies segregation-free powders and alloy steel powders for high strength parts. With the iron's magnetic nature and the small particle diameter of powder, the chemical properties of iron and large particle-specific area of powder, iron powder is applied to electromagnetic material, such as the dust core or oxygen absorber, body warmer, and chemical raw materials to recover metals of value in the process effluent. ISO9001 and ISO14001 certification have been granted for iron powder production and products at Kawasaki Steel since 1998, and iron and steel powders of excellent qualities are expected to be steadily supplied in the market and expand new applications for iron.

1 Introduction

In 1996, Kawasaki Steel installed integrated production facilities for reduced iron powder at the Chiba Works for the first time in Japan, and started the manufacturing and marketing of reduced iron powder under the name of "KIP". In 1978, the company installed atomized iron powder production facilities. The company is the only integrated iron powder producer in Japan that manufactures and markets both reduced iron powder and atomized iron powder and is one of the top three such manufacturers in the world. At present, the company produces and markets about 60 000 t/y of iron powder[1]. The applications of KIP iron powders are being expanded with various functions by making the most of the properties of iron and powder. This paper describes the history and features of KIP iron powders.

2 History of KIP Iron Powders

The industrial use of iron powder in the modern age dates back to the 1960s when in the United States, iron powder was adopted in automobile sintered parts on a full-scale basis. This action was quickly followed by Japanese companies in the latter half of the 1960s[2]. As a result, demand began for the manufacturing and marketing of domestic good-quality iron powder. Along with this situation, Kawasaki Steel began basic research on reduced iron powder in 1961. In 1966, the company constructed mass-production facilities of reduced iron powder[3] to produce it using mill scale as the raw material, and started marketing KIP iron powders. Since then, the company started the mass production and marketing of the atomized iron powder "KIP 300A" in 1978, the vacuum-reduced alloy steel powders "KIP 4100V and KIP 30CRV"[4] for high-strength parts in 1984, the graphite-segregation-free iron powder "KIP Clean Mix"[5] in 1989, the "KIP MG270H"[6] iron powder for electromagnetic applications in 1997, and Cu-segregation-free treated "KIP Clean Mix"[7] and a wax-lubricated "KIP Clean Mix KWAX"[8] in 1999. Furthermore, the company expanded the iron powder production facil-

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ities by installing the second atomized iron powder plant in 1991, the second vacuum reduction plant in 1992, and Clean Mix plant in 1994 and 1999, thus making efforts to meet the diversifying needs of customers by developing new technologies and new products and expanding the production capacity.

3 Applications in Sintered Machine Parts and KIP Clean Mix

In Japan, 63% of iron powder is used in sintered machine parts and 84% of sintered machine parts are used in automobiles[9]. Thus, automobile sintered parts are the greatest application of iron powder. Sintered machine parts are an application of iron that combines mechanical properties of iron, particularly strength increased by alloying, with powder that is flowable and capable of being formed by compression. In the making of sintered machine parts, alloying powders, such as graphite powder and copper powder, and solid-lubricant powder for reducing the friction among iron powder particles and between iron powder and dies are mixed with iron powder. This mixture is poured into a die, compacted by a press, and then heated in a sintering furnace (hereafter expressed as "sintered") at a temperature of about 1 000°C. Although high-precision parts of complex shape such as gear wheels can be produced without the need for machining, the required quality levels are becoming higher and higher every year and it has become difficult to meet these requirements with such simple iron powders and processes. At Kawasaki Steel, the functions of iron powder are being further enhanced by the Clean Mix technology which involves the addition of organic substances to iron powders to meet such requirements.

3.1 Graphite-Segregation-Free Powder KIP Clean Mix

Additive powders such as graphite powder have values of specific gravity and particle size different from those of iron powder. Therefore, when mixtures of these powders are transported or fed from a container into a die, segregation occurs by the separation of iron powder from additive powders. When graphite powder segregates, dust is emitted which damages the production environment. As a result, the graphite content in the initial period of a continuous forming period is sometimes different from that in the latter period. As a consequence, the strength and size of sintered machine parts vary, resulting in the deterioration of the quality of the parts. In order to solve this problem, the company developed a graphite-segregation-free powder called "KIP Clean Mix" in which graphite powder is adhered to the surface of an iron powder particle using a binder. Since Clean Mix has a high degree of adhesion of graphite powder, the volume of generated dust is 10% or less of that of a usual mixture as shown in **Fig. 1**.

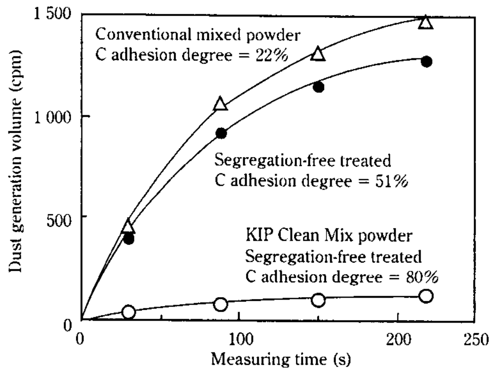

Fig. 1 Dust generation volume of KIP Clean Mix powder

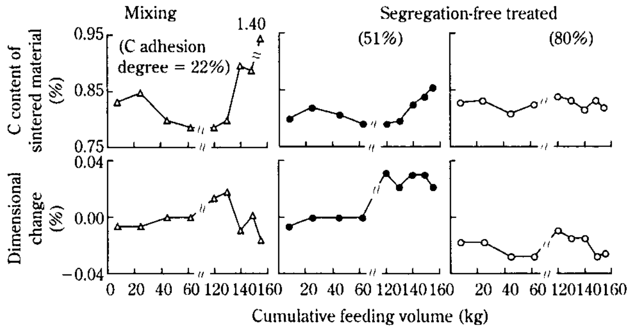

Fig. 2 Stabilization of sintered material properties with KIP Clean Mix powder

Figure 2 shows changes in the cumulative volume of powder fed from a container to a die for pressing, C content of sintered material and rate of dimensional change during sintering. A powder having a high degree of adhesion of graphite is little susceptible to variations in the C content to the last and has a stable rate of dimensional change. Clean Mix has enjoyed a reputation since its appearance on the market because it generates little dust, improves yields of raw material powder and sintered products, and makes the mixing operation by users unnecessary.

3.2 Cu-Segregation-Free Treated KIP Clean Mix

Although the prevention of segregation has been more difficult in copper powder than in graphite powder, the company developed a Cu-segregation-free "KIP Clean Mix" and is marketing it. In this Clean Mix, copper powder is adhered to the surface of iron powder particles by thermal diffusion and it is possible to obtain a segregation-preventing effect higher than with conventional adhesion by a binder.

Figure 3 shows the scattering of the copper content in compacts when 1 t of segregation-free powder of Fe-2Cu-0.8C is transported by a conveyor. In the Cu-segregation-free treated Clean Mix, the standard deviation of Cu content is reduced 70% from 0.080% to 0.024%

Table 1 Properties of powders and sintered compacts of the Cu segregation-free KIP Clean Mix powder

Powder	Apparent density (Mg/m^3)	Tensile strength (MPa)	Impact value (J)	Dimensional change during sintering (vs. die cavity)	
				Dimensional change (%)	Standard deviation, σ (%)
Cu segeragation-free Clean Mix	3.35	467	11	0.39	0.016
Conventional Clean Mix	3.35	469	11	0.38	0.020

Composition: Fe-2%Cu-0.8%graphite-0.8%lubricant
Specimen: $\phi 38 \times \phi 25 \times 10$ t
Green density: 6.85 Mg/m^3
Sintering: 1 130°C × 20 min in endothermic gas

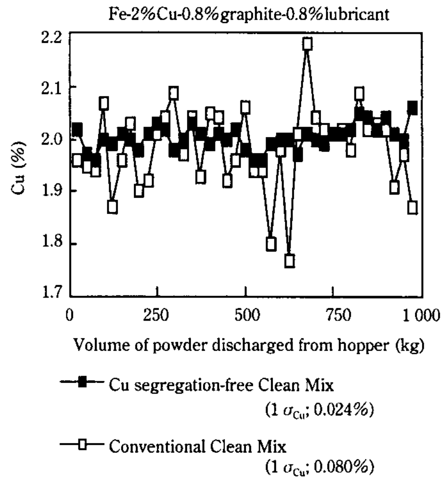

Fig. 3 Scattering of Cu content in compacts made from the powders discharged from hopper

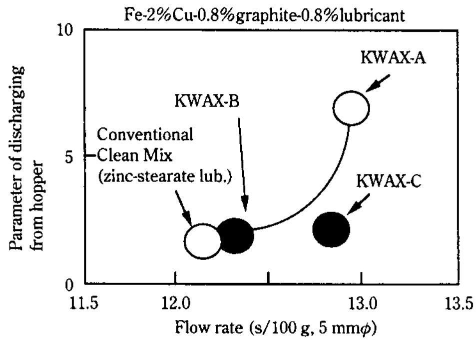

Fig. 4 Flowability of KIP Clean Mix powders with wax lubricant

compared to the conventional segregation-free powder.

As shown in **Table 1**, the properties of powders and sintered compacts of the Cu-segregation-free Clean Mix, such as apparent density, tensile strength and Charpy absorbed energy, are comparable to those of the conventional powder. Moreover, the dimensional change of the new product is equal to that of the conventional segregation-free Clean Mix and the rate of dimensional change is reduced 20% from 0.02% to 0.016% compared to the conventional segregation-free powder. Thus, variations in dimensional change of sintered machine parts can be substantially reduced without a change in the material properties.

3.3 Wax-Lubricated KIP Clean Mix KWAX

As the above-mentioned solid lubricant powder, zinc stearate is widely used in sintered machine parts in order to improve the flowability of a mixture. However, zinc stearate decomposes in the sintering furnace to form zinc oxide, which accumulates in the furnace. Removing this zinc oxide lowers productivity. Furthermore, zinc oxide forms contaminants on the surfaces of sintered compacts, deteriorating the quality of sintered parts. A wax lubricant of organic substance containing no metallic element solves these problems.

However, because the flowability of a mixture decreases, it has not been general practice to use such wax lubricants.

In the production of sintered machine parts, the flowability of a raw material powder is important for improving the production speed, the uniformity of density of sintered parts and the uniformity of dimensional accuracy ascribed to this uniform density. Kawasaki Steel has developed and is marketing the new products "KIP Clean MIX KWAX-B and C", containing a wax lubricant, these new products provide excellent flowability equal to that of the conventional Clean Mix.

The flowability of KIP Clean Mix powders is shown in **Fig. 4**. In the figure, "KWAX-A" is a conventional Clean Mix containing a wax lubricant. The new product "KWAX-B" has the same flowability as the conventional Clean Mix containing zinc stearate, but it is free from the adherence and accumulation of a lubricant within a screw conveyor during transport, which was a disadvantage of the conventional product. Another new product, "KWAX-C," which does not contain any metallic element, has excellent flowability from a hopper equal to that of the conventional Clean Mix containing zinc stearate.

The properties of powders and sintered compacts of KIP Clean Mix powders are shown in **Table 2**. The new products KWAX-B and KWAX-C have apparent densities higher than those of the conventional Clean Mix

Table 2 Properties of powders and sintered compacts of KIP Clean Mix powders with wax lubricant

Powder	Apparent density (Mg/m^3)	Tensile strength (MPa)	Impact value (J)	Dimensional change during sintering (vs. die cavity) (%)	Feature
KWAX-C	3.25	434	10	0.40	With wax lubricant only
KWAX-B	3.39	430	11	0.38	Without lubricant sticking with wax lubricant
KWAX-A	3.20	422	10	0.40	Conventional Clean Mix with wax lubricant
Conventional Clean Mix	3.25	435	10	0.34	With zinc-stearate lubricant

Composition: Fe-2%Cu-0.8%graphite-0.8%lubricant
Specimen: $\phi 38 \times \phi 25 \times 10$ t
Green density: 6.85 Mg/m^3
Sintering: 1 130°C × 20 min in endothermic gas

containing a zinc stearate lubricant. In KWAX-B and KWAX-C, the tensile strength and impact value of sintered compacts and their dimensional change during sintering are comparable to those of the conventional product. Moreover, in KWAX-C the variation in the weight of green compact during continuous pressing is reduced by 60% or more over that of KWAX-A in terms of standard deviation. Thus, the productivity and quality of sintered parts can be significantly improved by using these new products of "KIP Clean Mix KWAX."

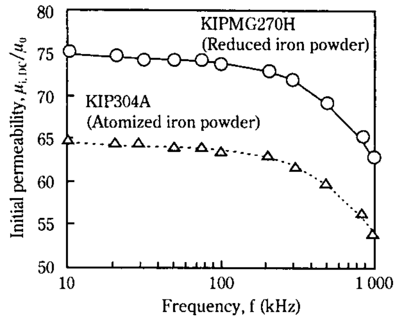

Fig. 5 DC initial permeability $\mu_{i,DC}/\mu_0$ of iron powder cores

3.4 Other Applications of Sintered Machine Parts

In the manufacturing of sintered machine parts, it is necessary to raise productivity as much as possible. In order to meet this requirement, the company has developed an iron powder which causes graphite to precipitate in a sintered compact during sintering, thereby increasing machinability by using this graphite as a lubricant during machining[10]. Furthermore, the company has developed and is marketing an alloy steel powder called "KIP SIGMALOY 2010"[11], which has high machinability in an as-sintered condition; increased strength is obtained by heat treatment after machining an Ni-base partially-alloyed steel powder, "KIP SIGMALOY[12]," which ensures high strength even in an as-sintered condition by the omission of heat treatment after sintering; and a vacuum-reduced Cr-Mo-V alloy steel powder "KIP 103V"[13].

4 New Applications

In addition to the applications as structural parts in which mainly the mechanical properties of iron are utilized as with sintered machine parts, this section describes applications of iron with other functions in which the magnetic and chemical properties of iron and the nature of powder are made the most of fully utilized.

4.1 Applications in Electromagnetic Materials

As electromagnetic materials, iron powders are used either after sintering or in an as-compacted condition. In the latter case, the product is a dust core, which is in increasing demand[14]. By making the most of the magnetic properties of iron with high saturation magnetic flux density and the small grain size of powder, dust cores of iron powder are used in the frequency band of 1 to several hundred kilohertz, which covers the gap between the frequency ranges covered by electonical steel sheets for lower frequency range and ferrites for higher frequency range. For the past several years, demand for dust cores has been increasing, especially due to an increase in the application in mobile electronic equipment as measures against noise from conventional electronic and electrical equipment. By increasing the compactability of reduced iron powder which has excellent magnetic properties in the high-frequency band due to porous particle shapes, Kawasaki Steel has developed and is marketing "KIP MG270H"[6] with a much better permeability than the atomized iron powder "KIP 304AS" (**Fig. 5**). Demand for KIP MG270H will further increase by the future application of rotary machines and parts in which ferrite materials are used in the middle frequencies.

4.2 Materials for Chemical Reactions

Iron powder is used by making the most of the chemical properties of iron, which are the results of chemical reactions of iron with oxygen and other elements, and a large specific surface area of a powder particle. In the reactions with the oxygen in the air, it is an oxidation inhibitor that absorbs the oxygen in the packaging of foods, and it is an iron powder body warmer and a hot wet pack that utilize the heat generated in the reactions. Furthermore, demand for iron powder is rising for the recovery of valuable metals, such as Cu, from iron chloride liquid wastes used in the etching of printed circuit boards etc[15].

5 Concluding Remarks

Iron powders are expected to continue to expand the applications of iron in the future by their new functions in which both the properties of the iron and the nature of the powder are fully utilized. The ISO9001 and ISO14001 certifications were granted in 1998 for the KIP iron powders. The company has established a system supplying iron powders of consistent quality that enables customers to use them with peace of mind in new applications, such as electromagnetic materials and materials for chemical reactions, in addition to applications in sintered machine parts. We hope that iron will continue to be used in diverse applications in the future.

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