Cr-Alloyed Steel Powders for High-Strength Sintered Parts without Heat Treatment after Sintering*

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Synopsis:

New alloyed steel powders containing 3 or 1% Cr have been developed for the high strength sintered parts without heat-treatment after sintering. As-sintered compacts made from KIP 30CRV (3Cr-0.3Mo-0.3V) prealloyed steel powder have higher tensile strength of 1 150 MPa, rotating bending fatigue strength of 310 MPa and better wear resistance than those made from KIP SIGMALOY 415S (4Ni-1.5Cu-0.5Mo) partially alloyed steel powder. These superior characteristics are attributed to the martensite realized high hardenability of the compacts. In spite of lower tensile strength and hardness, the fatigue strength and wear resistance of the as-sintered compact made from KIP 103V (1Cr-0.3Mo-0.3V) prealloyed steel powder were almost equal to those of KIP 30CRV, because the higher density improved fatigue strength and the fine pearlite had better wear resistance than martensite.

1 Introduction

Various kinds of alloyed steel powders for use in high strength sintered products have been developed to reduce the size and weight of automobile parts, which are the main application of iron sintered materials.[1)] Furthermore, with improvements in safety and operation, demand is growing for sintered materials suitable for parts that require strength as well as wear resistance, such as oil pumps.

Case-hardened Cr steel has so far been frequently used for automobile parts that require wear resistance and strength. However, with conventional water atomizing process followed by annealing and deoxidation by hydrogen, it is difficult to produce Cr-containing prealloyed steel powders that have low oxygen content and high compressibility because of the strong affinity of chromium for oxygen. Therefore, Ni partially alloyed steel powders have been used in such applications. However, because the Ni-rich and soft austenite phase remains in sintered compacts even after sintering and heat treatment, wear resistance has been insufficient.

Moreover, omission of heat treatment after sintering has recently been required to lower costs in the parts manufacturing processes. An increase in strength without heat treatment after sintering has been obtained mainly by the use of large amounts of alloying components such as Ni.[2)] In recent years, a method for raising the cooling rate after sintering has been examined.[3)] This method has not yet come into widespread use because it requires new sintering equipment of high cooling rate. In addition, there is a possibility that regulations may be imposed on Ni powders[4,5)] and alloyed steel powders that do not contain Ni have recently received attention.

At Kawasaki Steel, an investigation was made on a method for improving strength of sintered compacts made from low-oxygen, high-compressibility Cr prealloyed steel powders, which are manufactured by the water atomizing and vacuum annealing method,[6,7)] at cooling rates of 5 to 30°C/min at existing sintering equipment. Based on the concept that the best microstructure of sintered compacts is achieved by optimizing alloy components suited to cooling rates for increasing strength without heat treatment in powder metallurgy, namely by optimizing the contents of Mn, Mo and V, the company has developed KIP 103V (1Cr-0.3Mo-0.3V steel powder) that provides high strength by the transformation to fine pearlite and precipitation of carbonitrides of V after sintering.[8,9)] However, the effect of the Cr content on mechanical properties has not been

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Table 1 Chemical compositions of powders used

Powder	Chemical composition (mass%)							Alloying method
	C	O	Cr	Mo	V	Ni	Cu	
KIP 103V	0.004	0.148	0.97	0.34	0.25	—	—	Prealloying
KIP 30CRV	0.004	0.164	2.94	0.29	0.28	—	—	Prealloying
KIP SIGMALOY 415S	0.003	0.080	—	0.47	—	4.26	1.65	Partially alloying

Table 2 Characteristics of powders and green compacts

Powder	Particle size distribution (%)							Apparent density (Mg/m³)	Green density* (Mg/m³)
	≧180 μm	150〜180 μm	106〜150 μm	75〜106 μm	63〜75 μm	45〜63 μm	≦45 μm		
KIP 103V	7.7	13.9	21.0	21.3	8.8	15.5	11.8	2.82	7.13
KIP 30CRV	2.2	8.4	24.2	25.0	8.2	11.8	20.1	2.69	7.00
KIP SIGMALOY 415S	0.4	10.7	20.8	22.9	9.7	15.0	20.5	2.98	7.20

*Zinc stearate addition: 1 mass%
Compacting pressure: 686 MPa

investigated extensively.

This report describes the mechanical properties (strength, fatigue strength and wear resistance) of sintered compacts without heat treatment that are made from Cr-Mo-V steel powders (KIP 103V and KIP 30CRV) with different Cr content in comparison with KIP SIGMALOY 415S, which is a Ni partially alloyed Ni steel powder and is widely used in high-strength sintered parts.

2 Experimental Procedure

Steel powders used in the test were Cr alloyed steel powders KIP 103V and KIP 30CRV produced by the water atomizing and vacuum annealing method and KIP SIGMALOY 415S, a Ni partially alloyed steel powder in which Ni, Cu and Mo are diffusion bonded to iron powder particles. The chemical compositions and powder characteristics of these steel powders are shown in **Tables 1** and **2**, respectively. In order to obtain the highest tensile strength after sintering, 0.9 mass% graphite powder was added to KIP 103V and KIP 30CRV and 0.6 mass% graphite powder was added to KIP SIGMALOY 415S. Furthermore, 1 mass% zinc stearate was added as a lubricant to these test steel powders and compaction was performed at pressures of 490 to 686 MPa.

Sintering was performed in an N_2-10 vol% H_2 atmosphere, at 1 250°C for 60 min. The cooling rate was about 20 °C/min. Tensile, Charpy impact, hardness, rotating bending fatigue and wear resistance tests were conducted using these sintered compacts. Small round bar test pieces with a diameter of 5 mm and a length of 15 mm in parallel portion were used in the tensile test, and notchless test pieces of 10 mm thickness, 10 mm width and 55 mm length were used in the Charpy impact test.

The tensile test and Charpy impact test were carried out at room temperature. Hardness was measured by means of the B-scale of Rockwell hardness. Furthermore, the rotating bending fatigue test was conducted using an Ono-type rotating bending fatigue tester and smooth round bar test pieces with a diameter of 8 mm and a length of 15.4 mm in parallel portion were used. The endurance limit was determined as a fracture stress at 10^7 cycles.

The wear resistance test was an Ohgoshi-type wear test. The wear environment of the test was such that oil was added dropwise in the atmosphere at a rate of one drop per second, a wear rate was 4.21 m/s under a load of 124 N, and SUJ-2 was used as the counterpart material in the wear test.

3 Results of Experiment and Discussion

3.1 Sintered Density

The relationship between compacting pressure and sintered density is shown in **Fig. 1**. When the compacting pressure was the same, the densities of sintered compacts made from KIP 103V and 30CRV were lower than those of sintered compacts made from KIP SIGMALOY

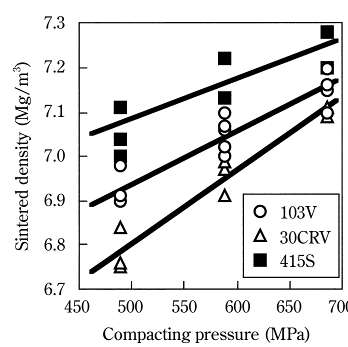

Fig. 1 Relationship between compacting pressure and density for sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

415S. Furthermore, density decreased when the Cr content of Cr alloyed steel powders was raised from 1% to 3%. This might be explained as follows: Because KIP 103V and 30CRV are prealloyed steel powders, they become hard according to the degree of solid solution hardening of Cr, Mo and V into iron, resulting in their reduced compressibility. In the case of KIP SIGMALOY 415S, Ni powders diffusion bonded promote sintering, which induces great shrinkage.

3.2 Tensile Strength

The relationship between tensile strength and the density of sintered compacts is shown in **Fig. 2**. In all of the sintered compacts, tensile strength increased with increasing density. The sintered compacts made from KIP 30CRV had the highest tensile strength, although their density was lower than those of the sintered compacts made from KIP 103V and SIGMALOY 415S.

The microstructure of the sintered compacts made form KIP 30CRV was a mixed structure of fine lower bainite and martensite as shown in **Photos 1** and **2**. This may be because, as is apparent from the CCT diagram shown in **Fig. 3**, the hardenability of the sintered compacts made from KIP 30CRV was high and martensite was formed even at cooling rates of an ordinary sintering furnace, resulting in high strength.

As shown in Photo 1, martensite was formed also in the sintered compacts made from KIP SIGMALOY 415S. However, because alloys such as Ni and Mo do not become uniform during sintering, it appears that in portions with low concentrations of alloys, hardenability decreases and coarse bainite and pearlite are formed, whereas in portions of high concentrations of Ni, soft retained austenite is formed and hence high strength could not be obtained.

Higher tensile strength was obtained in the sintered compacts made from KIP 103V than in the sintered compacts made from KIP SIGMALOY 415S. The microstructure of sintered compacts made from KIP 103V was uniform and fine pearlite, as shown in Photos

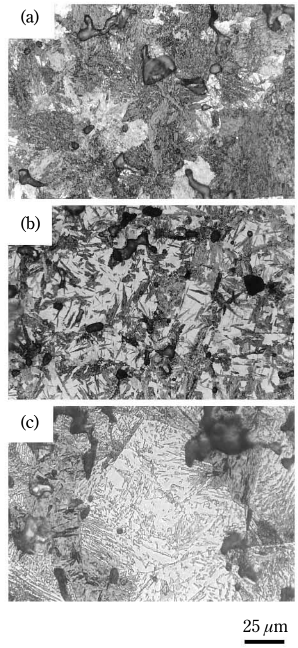

Photo 1 Optical micrographs of the sintered compacts made from (a) KIP 103V, (b) KIP 30CRV and (c) KIP SIGMALOY 415S

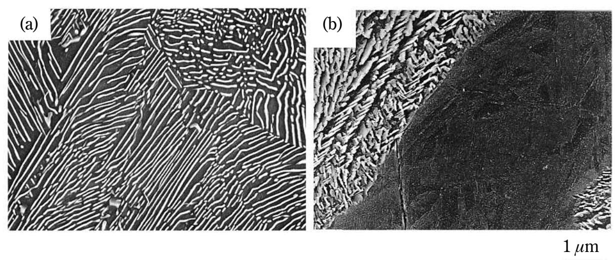

Photo 2 SEM micrographs of the sintered compacts made from (a) KIP 103V and (b) KIP 30CRV

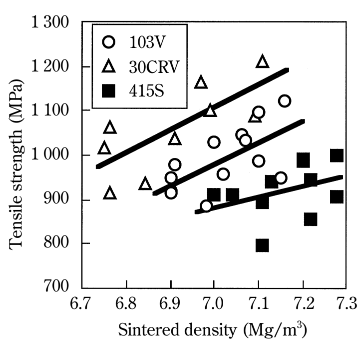

Fig. 2 Relationship between tensile strength and density for sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

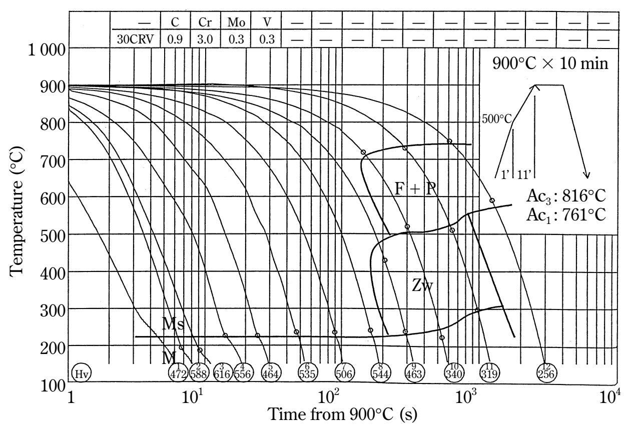

Fig. 3 CCT diagram of sintered compacts made from 3% Cr prealloyed steel powder (KIP 30CRV)

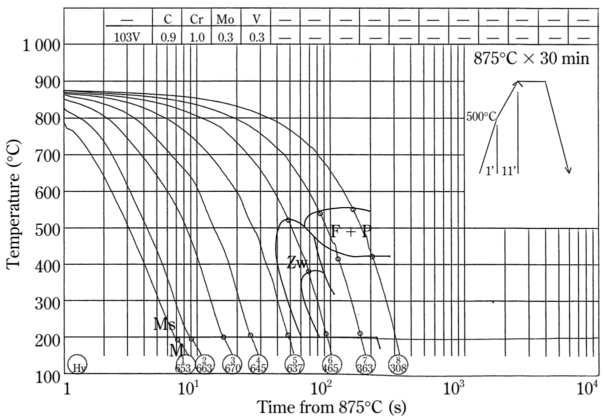

Fig. 4 CCT diagram of sintered compacts made from 1% Cr prealloyed steel powder (KIP 103V)

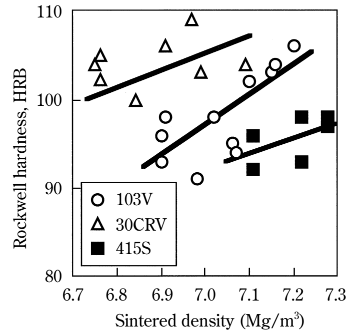

Fig. 6 Relationship between Rockwell hardness and density for sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

1 and 2. This is because, as shown in the CCT diagram of sintered compacts made from KIP 103V in **Fig. 4**, the chemical composition is optimized[8,9] so that coarse upper bainite is not formed at the cooling rates of an ordinary sintering furnace.

3.3 Impact Value

The relationship between the impact value and density of sintered compacts is shown in **Fig. 5**. In all of the sintered compacts, the impact value increased with increasing sintered density. The sintered compacts made from KIP 103V and KIP 30CRV showed lower impact values than those made from KIP SIGMALOY 415S, even when the sintered density was the same. This may have been because in the sintered compacts made from KIP SIGMALOY 415S, a phase having high toughness with a high Ni concentration remained even after sintering due to the diffusion bonded Ni powder and because the carbon content of the sintered compacts made from KIP SIGMALOY 415S was lower than that of the sintered compacts made from KIP 103V and KIP 30CRV.

3.4 Hardness

The relationship between the hardness and density of sintered compacts is shown in **Fig. 6**. This relationship shows the same tendency as tensile strength, and the hardness of sintered compacts made from KIP 30CRV is higher than those of the sintered compacts made from KIP 103V and KIP SIGMALOY 415S.

3.5 Fatigue Characteristics

The results of the rotating bending fatigue test are shown in **Fig. 7**. The sintered compacts made from KIP 103V and KIP 30CRV showed almost equivalent endurance limits (310 and 300 MPa, respectively), which were higher than that of the sintered compacts made from KIP SIGMALOY 415S. Furthermore, the endurance limit ratios of the sintered compacts made from KIP 30CRV and KIP 103V were 0.31 and 0.33, respectively, which were higher than the 0.24 of the sintered compacts made from KIP SIGMALOY 415S. This may be because in the sintered compacts made from KIP 103V and KIP 30CRV, which are prealloyed steel powders, a low-strength phase such as coarse bainite is not formed while the exists in portions of low alloy concen-

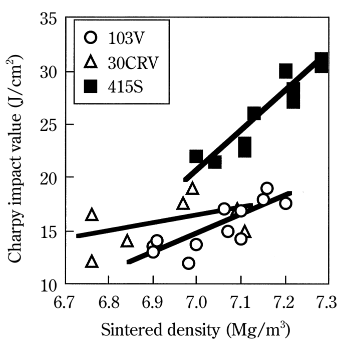

Fig. 5 Relationship between impact value and density for sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

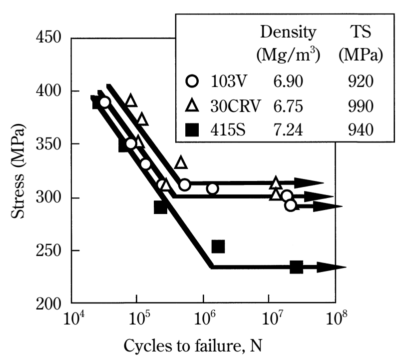

Fig. 7 Rotating bending fatigue strength of the sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

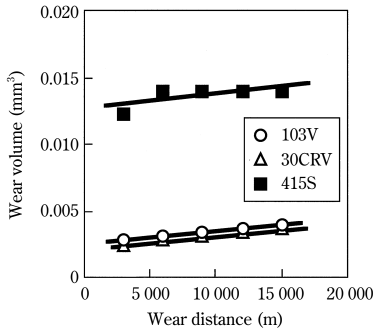

Fig. 8 Relationship between wear volume and wear distance for sintered compacts made from Cr prealloyed and Ni partially alloyed steel powders

tration in the sintered compacts made from KIP SIGMALOY 415S as shown in Photos 1 and 2. Furthermore, a possible reason why the endurance limit ratio of the sintered compacts made from KIP 103V was higher than that of the sintered compacts made from KIP 30CRV, was that the sintered compacts made from KIP 103V had a higher density and that the sintered compacts made from KIP 30CRV had higher notch sensitivity because of higher hardness.

3.6 Wear Resistance

The results of the wear resistance test are shown in **Fig. 8**. The sintered compacts made from KIP 103V and KIP 30CRV showed less wear than the sintered compacts made from KIP SIGMALOY 415S and hence showed better wear resistance. This is because in the sintered compacts made from KIP 103V and KIP 30CRV, which are prealloyed steel powders, a uniform microstructure was formed without a retained austenite phase, as observed in the sintered compacts made from KIP SIGMALOY 415S shown in Photos 1 and 2.

Also, the sintered compacts made from KIP 103V showed almost equivalent wear resistance in spite of having lower hardness than the sintered compacts made from KIP 30CRV. This is because fine pearlite has better wear resistance than martensite.[10,11]

4 Conclusions

An investigation was made on the mechanical properties of sintered compacts made from Cr-Mo-V steel powders with different Cr contents (KIP 103V (1Cr-0.3Mo-0.3V) and KIP 30CRV (3Cr-0.3Mo-0.3V)) and no heat treatment after sintering. These properties were compared with those of sintered compacts made from KIP SIGMALOY 415S (4Ni-1.5Cu-0.5Mo), which is Ni partially alloyed steel powder. The main results are summarized below.

(1) The sintered compacts made from KIP 30CRV, which were compacted at 686 MPa and sintered at 1 250°C, had a tensile strength of 1 150 MPa and rotating bending fatigue strength of 310 MPa.

(2) In spite of lower density than that of the sintered compacts made from KIP SIGMALOY 415S, the sintered compacts made from KIP 30CRV showed high tensile strength and fatigue strength. This is because the high hardenability of the sintered compacts made from KIP SIGMALOY 415S, caused a transformation to fine lower bainite and martensite after sintering even at ordinary cooling rates (30°C/min maximum).

(3) The sintered compacts made from KIP 103V, which were compacted at 686 MPa and sintered at 1 250°C, had a tensile strength of 1 050 MPa and rotating bending fatigue strength of 300 MPa.

(4) The sintered compacts made from KIP 103 V showed almost the same fatigue strength as the sintered compacts made from KIP 30CRV although their tensile strength was lower. This is attributable to high density and the homogeneous fine pearlite of the sintered compacts made from KIP 103V.

(5) The wear resistance of the sintered compacts made from Cr steel powders (KIP 103V and KIP 30CRV) was better than that of the sintered compacts made from KIP SIGMALOY 415S.

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