Properties of Cold Work Tool Steel Shot Peened by 1200 HV-Class Fe-Cr-B Gas Atomized Powder as Shot Peening Media

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Shot peening is widely used for automobile parts such as springs and gears to improve fatigue strength. In general, high hardness media is required for shot peening to targets with high hardness. Recently, shot peening to various tool steels such as cold and hot tool steels and high speed tool steel has been investigated and is used in some applications, and improvements in fatigue strength and die life by the increase of compressive residual stress and hardness at their shot peened surface have been reported.

In this study, the properties of cold work tool steel shot peened by Fe-8%Cr-6.5%B (mass%) gas atomized powder (FeCrB powder) with 1200 HV-class Vickers hardness and long life as shot peening media were examined. Quenched and tempered JIS-SKD11 followed by shot peening by FeCrB powder with high speed steel powder sieved between 45 and 125μm was used.

Vickers hardness and compressive residual stress of the shot peened JIS-SKD11 surface by FeCrB powder were higher than these by high speed steel powder. As a result, JIS-SKD11 shot peened by FeCrB powder showed excellent fatigue property, Charpy impact value and wear resistance property. [doi:10.2320/matertrans.MBW200922]

1. Introduction

Shot peening is a kind of cold work treatment to obtain compressive residual stress at the peened surface by projecting metal or ceramics particles called shot peening media on workpieces. Fatigue strength of the workpiece imposed compressive residual stress by shot peening is improved, and shot peening is widely applied for automobile parts such as springs and gears. Shot peening to high hard workpieces such as cold and hot work tool steel and high speed tool steel has been researched and is used in some applications.1,2)

Shot peening media with low hardness can deform plastically at collision to workpieces with high hardness, and effects to give high compressive residual stress on hard workpieces are not large. Therefore, high hardness is required for shot peening media to obtain high compressive residual stress on hard workpiece.3) Generally, high hardness and high density are required for shot peening media to obtain high compressive residual stress. Shot peening media is worn out and broken by colliding with workpieces during shot peening repeatedly. Therefore, high toughness is also desired for shot peening media. In other words, shot peening media with high toughness shows long life because media crush is suppressed.

In our past study, various properties of Fe-Cr-B gas atomized powder with boron amount of hypereutectic composition region in Fe-B phase diagram had been investigated.4) As a result, Fe-8%Cr-6.5%B gas atomized powder (FeCrB powder) had been developed with the microstructure of fine and high hardness boride Fe2B connected by the high ductility eutectic structure consisting of αFe and Fe2B as shot peening media with high hardness, high density and long life. Vickers hardness of FeCrB powder is approximately 1200 HV, density is 7.4 Mg/m³, and life is longer than that of high speed steel powder as shot peening media.5) Furthermore, FeCrB powder shows excellent corrosion resistance by the addition of 8%Cr and no rust is observed in corrosion resistance test with 95%RH condition at 343 K for 96h. It was reported that fatigue strength (stress concentration factor α = 1.96) of carburizing JIS-SCM420 after shot peening by FeCrB powder sieved between 45 and 125μm was higher by approximately 400 MPa than that before shot peening and higher by over 100 MPa than that with shot peening by high speed steel powder.6)

In this study, distribution of residual stress and surface hardness, fatigue property, Charpy impact value and wear resistance property of quenched and tempered JIS-SKD11 workpiece before shot peening and after shot peening by high speed steel powder were examined as reference.

2. Experimental Procedure

FeCrB and high speed steel powder produced by gas atomization, followed by sieving between 45 and 125μm were used as shot peening media in this study. Chemical composition of high speed steel powder was approximately Fe-1.3%C-4%Cr-5%Mn-3%V-6%W-8%Co. Table 1 shows Vickers hardness and density of both shot peening media. Vickers hardness of the FeCrB powder is 1130 HV and is higher than that of high speed steel powder with 740 HV, and densities of both media are approximately equal. Appearance of FeCrB powder is almost spherical as shown in Fig. 1. JIS-SKD11 workpieces with approximate composition of Fe-1.5%C-12%Cr-1.0%Mn-0.35%V after quench and temper

<table>
<thead>
<tr>
<th>Media</th>
<th>Vickers hardness</th>
<th>Density</th>
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<tbody>
<tr>
<td>High speed steel powder</td>
<td>740 HV</td>
<td>8.1 Mg/m³</td>
</tr>
<tr>
<td>FeCrB powder</td>
<td>1130 HV</td>
<td>7.4 Mg/m³</td>
</tr>
</tbody>
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were used as test specimens for shot peening by FeCrB and high speed steel powder. Hardness of these workpieces is 61 HRC.

In the followings, the specimens after shot peening by FeCrB and high speed steel powder are expressed with FCB-SP and HSSP-SP, respectively, and the specimen before shot peening is expressed with Non-SP.

Surface roughness and distribution of Vickers hardness and residual stress were examined. Surface roughness was measured by surface roughness tester and scanning electron microscopy (SEM). Vickers hardness and residual stress as a function of distance from the shot peened surface were measured by Vickers hardness tester with a load of 25 or 50 g and X-ray diffraction, respectively. In order to examine the effects of shot peening on fatigue properties, fatigue test was carried out with plane specimen by Ono-type rotary bending test machine. Figure 2 shows the shape of the specimen for Ono-type rotary bending test. Fracture origin after fatigue test was observed by SEM. Charpy impact value was examined with 10R-C notched specimen, and shot peening was carried out on the face with 10R-C notch. Figure 3 shows the shape of 10R-C notched specimen for Charpy impact test. Wear resistance were examined on shot peened surface by Ohgoshi-type abrasive test. The test conditions were as follows, friction ring was JIS-SCM420 with approximately 90 HRB, friction distance was 200 m, final load was 61.8 N and friction speed was in a range of 0.054–2.38 m·s⁻¹.

3. Results and Discussions
3.1 Surface observation, roughness and distribution of Vickers hardness and residual stress

Figure 4 shows SEM images of the shot peened surface. The surface of Non-SP with polishing finish was smooth, and slight abrasive flaws in polishing direction were observed. On the other hand, HSSP-SP and FCB-SP had fine crater-like surface patterns generated by collision with shot peening media. Arithmetical mean roughness of Non-SP, HSSP-SP and FCB-SP were 0.1, 0.4 and 0.6 μm, respectively.

Figure 5 shows distributions of Vickers hardness in depth from the shot peened surface. Vickers hardness of Non-SP, HSSP-SP and FCB-SP at 10 μm in depth from the surface were 770, 830 and 930 HV, respectively. The surface hardness increased by shot peening, and the surface hardness of FCB-SP shot peened by FeCrB powder with high hardness of 1130 HV was higher by 100 HV than that of HSSP-SP.

3.2 Distribution of residual stress

The distributions of residual stress near the surface of specimens are given in Fig. 6. The value of compressive residual stress of Non-SP at the surface was 600 MPa, and this is thought to be due to surface finish by polishing. On the other hand, shot peened specimens showed compressive...
residual stress in the ranges from the peened surface to about 30 µm in depth. The maximum of compressive residual stress of FCB-SP was 1270 MPa, and it was higher by 190 MPa than that of HSSP-SP. This phenomenon is understood as follows; FeCrB powder with 1130 HV has much higher hardness than the surface of JIS-SKD11 workpiece with 770 HV and hardly deforms at collision with workpiece; as a result, the surface peened by FeCrB powder obtains higher compressive residual stress than that by high speed steel powder with 740 HV same as workpiece. The depth at compressive residual stress value of FCB-SP with 1000 MPa was deeper by about 15 µm than that of HSSP-SP.

3.3 Fatigue properties

3.3.1 Fatigue property of Non-SP

Figure 7 shows the results of fatigue test. In all specimens, the number of cycles to failure (Nf) was almost the same in the low stress amplitude range with less than 800 MPa, and fatigue strength was also almost the same. On the other hand, Nf of Non-SP was a one-tenth of that of shot peened specimens in the stress amplitude range with more than 900 MPa. The relationship between the distance from the surface to fracture origins of Non-SP and stress amplitude is given in Fig. 8. The depth of fracture origins was constant with about 10 µm from surface in the stress amplitude range with more than 900 MPa; on the other hand, fracture origins remarkably moved deep region as the stress amplitude decreased to less than 800 MPa.

Compressive residual stress of Non-SP was imposed to extremely shallow surface layer as shown in Fig. 6; therefore, fracture was thought to initiate from near-surface layer in the stress amplitude range with more than 900 MPa. Now, Fig. 9 shows the microstructure of JIS-SKD11 workpiece in this study. The size of dispersed coarse carbides in this workpiece was about 20 µm and fracture origins were these carbides located near-surface layer in the stress amplitude range with more than 900 MPa. As examples, fracture origins in stress amplitude with 700 and 1400 MPa are given in Fig. 10. Therefore, the remarkable decrease of Nf of Non-SP in the stress amplitude range with more than 900 MPa is thought to be due to that fatigue fracture origins moved to near-surface region from deep area as the stress amplitude increase, and this phenomenon may be related to
the fact that the compressive residual stress is limited at the surface.

### 3.3.2 Comparison of fatigue properties of HSSP-SP and FCB-SP

$N_f$ of FCB-SP in the high stress amplitude range with more than 1400 MPa was about twice of that of HSSP-SP though the difference between $N_f$ of HSSP-SP and FCB-SP in the stress amplitude range with less than 1200 MPa was not large. Figure 11 shows the range of the positions where fracture origins were observed. Fracture origins of HSSP-SP and FCB-SP were observed at the positions at about 20 and 30 µm or deeper from the surface, respectively. These positions corresponded with the depth that compressive residual stress became less than 200 MPa; therefore, this implies that compressive residual stress works to suppress fracture.

### 3.4 Charpy impact value and wear resistance

Charpy impact values measured with three test pieces are given in Fig. 12. Charpy impact values of shot peened specimens were higher than that of Non-SP. In addition, Charpy impact value of FCB-SP was highest in all specimens and higher by 8.6% and 5.2% than that of Non-SP and HSSP-SP, respectively.

Figure 13 shows the results of wear resistance test. In all specimens, specific wear rates were almost equal in high friction speed range with more than 0.1 m·s$^{-1}$. On the other hand, in the lowest friction speed at 0.054 m·s$^{-1}$ in this study specific wear rates of the shot peened specimens were smaller than that of Non-SP, and more over that of FCB-SP was smaller than that of HSSP-SP.

### 4. Conclusions

The properties of quenched and tempered cold work tool steel (JIS-SKD11) with shot peening by Fe-8%Cr-6.5%B with 1200 HV-class Vickers hardness and high speed steel with 740 HV gas atomized powder were examined. The results are summarized as follows.
(1) FCB-SP has harder surface by $100\, HV$ and obtains higher and deeper compressive residual stress by 190 MPa at the peak value and 15 $\mu$m in depth than HSSP-SP. These results are thought to be caused by FeCrB powder that is harder by almost 400 $HV$ than high speed steel powder as shot peening media.

(2) FCB-SP shows higher fatigue properties than Non-SP in stress amplitude range with more than 900 MPa and HSSP-SP in that with more than 1400 MPa. Observation of fracture origins by SEM implies that the compressive residual stress at near-surface layer works to suppress crack initiation.

(3) Charpy impact value of FCB-SP is higher by 8.6% and 5.2% than that of Non-SP and HSSP-SP, respectively. The wear resistance of FCB-SP at low friction speed is superior to that of Non-SP and HSSP-SP.

REFERENCES