Effect of Fine Particle Bombarding on Thermal Fatigue Property of Tool Steel for Die Casting

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ABSTRACT
Effect of the fine particle bombarding (FPB) process, which makes particles of several tens microns in diameter impact at high speed, on the thermal fatigue property of the tool steel for die casting (JIS-SKD61) was investigated. FPB processed specimens exhibited superior thermal fatigue properties as compared with that of not processed specimen. i.e. both a number and depth of heat cracks obviously decreased in the FPB processed specimens after the thermal fatigue test that the surface temperature of the specimens was gone up to 843K and down to 373K cyclically for 2,000 times. TEM observation revealed that nanocrystalline structure was produced near the surface of specimen by FPB process and that serious grain coarsening did not occur in the nanocrystalline structure even after annealing at 843K. Therefore it is considered that grain refinement by FPB process contributed to prevent initiation and grows of heat cracks.

KEY WORDS
heat crack, nanocrystalline structure, severe plastic deformation

INTRODUCTION
Shot-peening processing, which improves fatigue strength by giving compressive residual stress, has spread industrially to the machine components such as the power train parts of automotives. On the other hand, recently, the new type of shot peening processing called fine particle bomberding (FPB), which makes particles of several tens microns in diameter impact at high speed of about 200 m/sec, has been attracted because the fatigue property is superior to that of the conventional shot peening processing. Besides the superior fatigue property (N. Egami, 2000) (C. Kagaya, 2000), in this processing, it was reported that, 1) surface roughness of the works was controlled more finely because of the fine particles (H. Ogiwara, 2000), 2) the material of particles was coated mechanically on the works for improving friction property (H. Ogiwara, 2002), 3) grain refinement was occurred near surface region through severe plastic deformation by collision of the particles. Therefore FPB process has been attracted as a new type surface modification process. Especially, with concern to the grain refinement, it is reported that nanocrystallization is occurred by the shot peening including FPB and the produced nanocrystalline structure is stable at about 873K without obvious grain growth(M. Umemoto, 2003) (S. Takagi, 2006). This phenomenon suggests that the nanocrystalline structure is utilized for improving ductility or fatigue property at warm temperature region up to 873K. In this study, as one of the applications, effect of FPB

process on the thermal fatigue resistance of the tool steel for die casting of aluminum alloys (JIS-SKD61) was investigated.

EXPERMENTAL PROCEDURE

Chemical composition, the heat treatment conditions, microstructure and hardness of the specimen (JIS-SKD61) are shown in Table 1. The size of specimens for the thermal fatigue test is ϕ58x20mmt discs as shown in Figure 1. FPB treatment is conducted on the ϕ58 plane.

FPB treatment was carried out using air blast shot-peening apparatus under the conditions listed in Table 2. The fine particles made from carbon steel with 45 μm in average diameter were projected into the specimens under pressure 0.4MPa. Radical nitriding (Y. Yakushiji, 2003) was also conducted on some specimens after FPB. In radical nitriding process, formation of compound layer or spattering at specimen surface can be prevent because nitriding is performed by generating low energy plasma and making active NH radicals.

Figure 2 shows schematic illustration of the thermal fatigue test apparatus. In this test, surface temperature of the specimens rose to 843K and cooled down to 373K cyclically. Specimens were heated by means of contacting with the hot block which is pre-heated at 873K for 160 seconds. During this heating period, surface temperature of specimens

Table 1 Properties of specimen.

chemical composition	heat treatment	Vickers hardness
Fe-0.38%C-5.2%Cr-1.2%Mo-1.0%V	quench and tempering	480

Table 2 Conditions of fine particle bombarding (FPB).

particle			bombarding	
material	Vickers hardness HV	ave. diameter (μm)	air pressure (MPa)	arc hight (mmN)
carbon steel	700	45	0.4	0.14

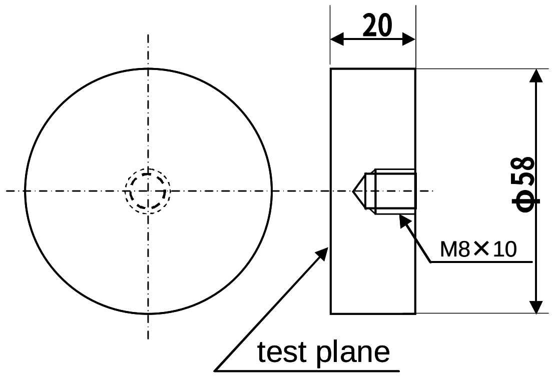

Fig.1 Size of specimen for thermal fatigue test.

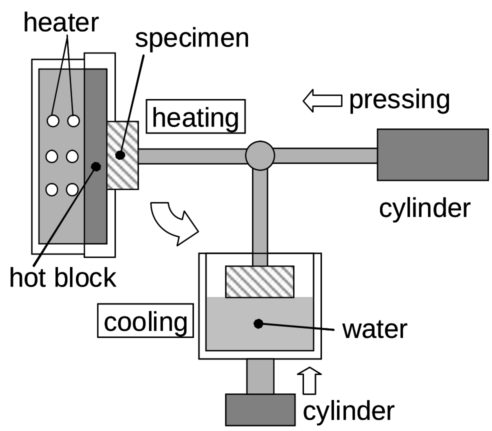

Fig.2 Schematic illustration of thermal fatigue test apparatus.

rose up to 843K. After the heating, specimens were immediately cooled down to 373K in water during 15 seconds. In this study, the heat cycle repeated for 2000 times. Thermal fatigue property was evaluated by measuring the number and depth of the developed heat cracks observed in cross section of the specimens. Microstructural observation was carried out by optical and scanning electron microscope (SEM, FEI Sirion). Other specimens for evaluation concerning thermal stability of the microstructure produced by FPB were prepared. Heat treatment or radical nitriding which are accompanied by rising temperature were conducted on these specimens after FPB. Microstructure at near surface region was observed by transmition electron microscope (TEM, TOPCON EM-002B). The thin foils for TEM observation was prepared by FIB (Focused Ion Beam, FEI FIB-2000) apparatus.

RESULTS AND DISCUSSIONS

Figure 3 shows typical heat cracks developed near the surface of the specimen without FPB. Oxide layer grows at surface of the specimen with about 15 or 20 micron meter thick. Under the oxide layer, cracks develop forward interior of the specimen as indicated by arrows in the figure. Figure 4 shows the crack distribution curve of each specimen. In the figure, horizontal axis represents depth of each crack. And vertical axis represents the number of cracks per 1mm distance counted along the radius of the specimen. It is clearly shown that the number and depth of cracks decrease in both FPB'ed and FPB + radical nitrided specimen as compared with not FPB'ed one. Namely, initiation and propagation of heat cracks are controlled by FPB process. Figure 5 shows cross sectional SEM image at near surface region of FPB'ed specimen after the thermal fatigue test. It is noted that plastic flow is clearly observed as shown in the figure. This microstructure suggests that deformed structure produced by FPB, retains at near surface region even after 2,000 cycles thermal fatigue test. It is supposed that delamination between oxide layer and substrate metal is formed in specimen preparation for microstructural examination, which indicates that adhesive strength of the oxide layer is not sufficient.
Figure 6 shows the cross sectional TEM micrographs of FPB'ed specimen. In the bright field image (Fig. 6 (a)) the plastic flow as same in the SEM observation is visible near the

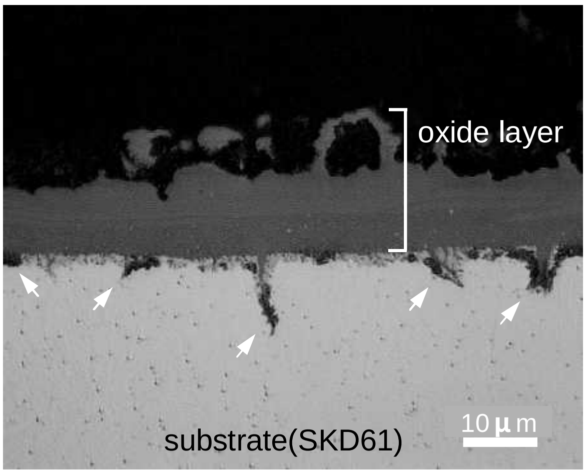

Fig.3 Typical heat cracks developed in as received specimen. The cracks are indicated by small arrows.

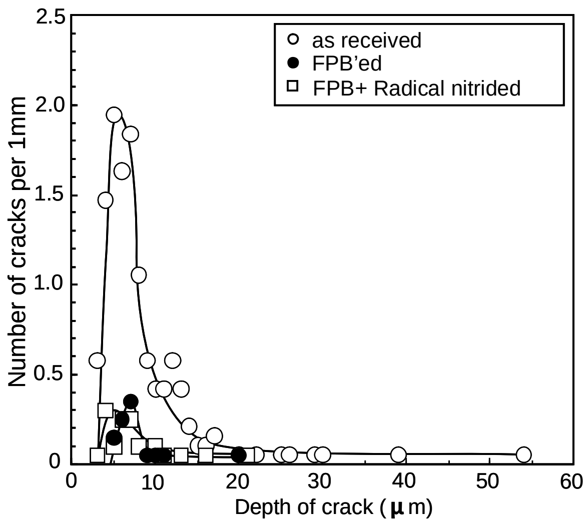

Fig.4 Crack distribution curve of tested specimens.

surface. As the SADP (selected area diffraction pattern) taken from the area of ϕ 0.8 μm (Fig. 6 (b)) has a ring-like shape, it is shown that this area consists of many grains with a random distribution of crystal orientation. Furthermore, as shown in Fig.6(c), it is revealed that the nanocrystals with grain size less than 100nm are generated near surface. Fig.7 (a) shows cross sectional TEM micrographs after annealed at 843K for 0.5hr. Although grains near surface region slightly grow, it is revealed that extremely fine grain size is still kept. Also in the case of radical nitrided specimen (Fig.7(b)), similar fine grains are observed. Therefore,

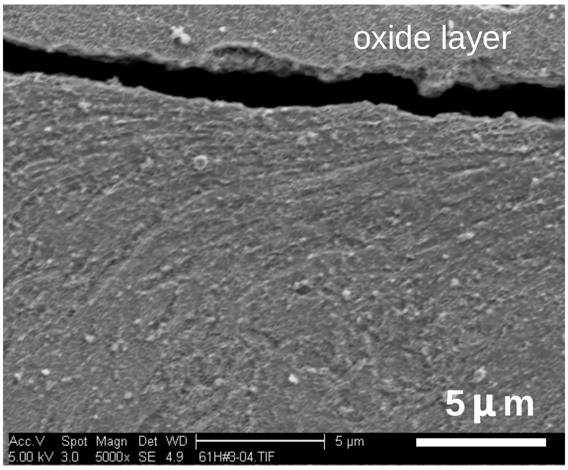

Fig.5 Cross sectional SEM micrograph of FPB'ed specimen after thermal fatigue test.

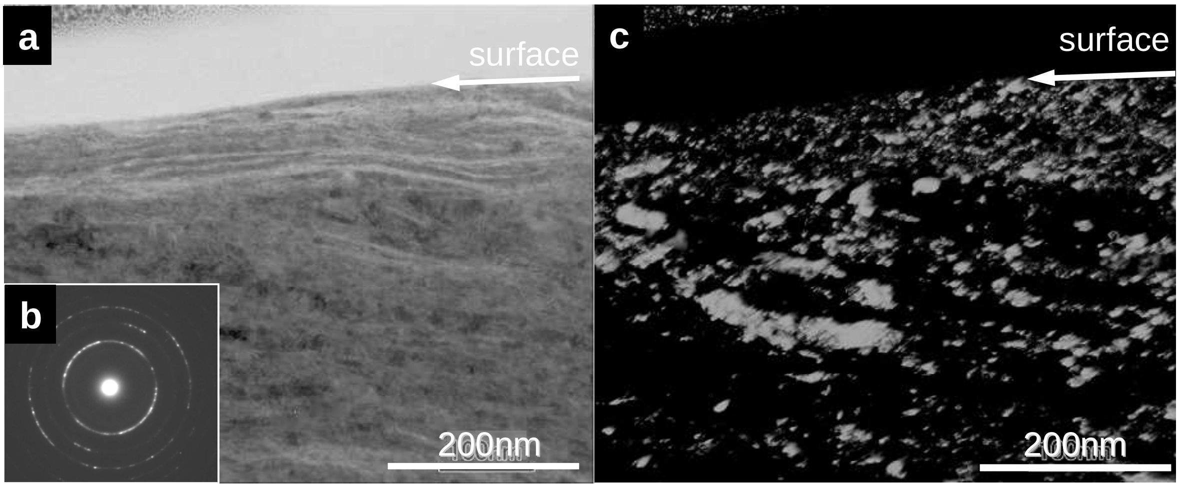

Fig.6 TEM micrographs of FPB'ed specimen. a), b) and c) are Bright field image, dark field image and selected area diffraction pattern, respectively.

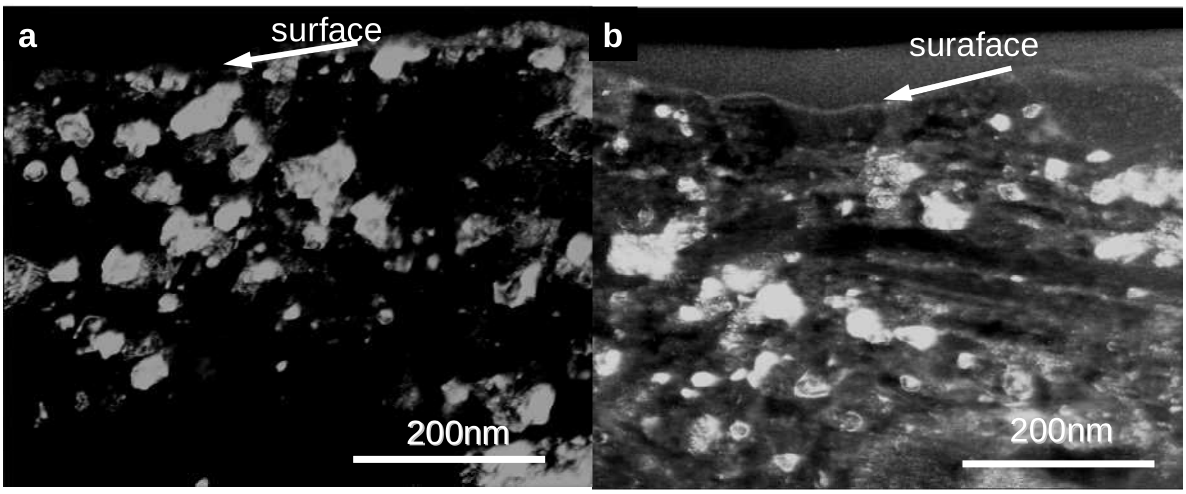

Fig.7 Dark field images by TEM. a) and b) are heat treated at 843K and radical nitrided specimen, respectively.

it is considered that grain refinement contributes to suppression of initiation and grows of thermal cracks.

High temperature oxidation process in iron, oxides layer grows forward exterior through diffuse of iron ions. Also in the case of present study, it is considered that extremely fine microstructure produced by FPB retained during thermal fatigue test in air without erosion by oxidation because the oxide layer grow forward exterior.

Compressive residual stress is also provided by FPB. However, subsequent heat cycles will relieve the stress. Therefore, it is not expected that the residual stress contribute to control of thermal crack formation.

CONCLUTIONS

Thermal fatigue property of tool steel for die casting (JIS-SKD61 steel) was markedly improved by FPB process. The nanocrystalline structure formed by FPB showed good thermal stability. Therefore, it is considered that the superior thermal fatigue property is resulted from formation of thermally stable nanocrystalline structure. Thus FPB process can form nanograins near the surface of works in low cost and high productivity without serious deterioration of surface roughness. Moreover the formed nanograins are thermally stable in warm temperature region up to 873K. These advantages suggest that FPB process can be applied industrially to various components such as dieses, tools, mechanical parts which are required high durability at warm temperature region.

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