

Investigation on the Wettability of Ridge-textured Surface Created by Angled Fine Particle Peening

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Abstract. Angled fine particle peening (angled-FPP), which is an abrasive jet machining process conducted using a peening nozzle set at inclined to the material surface, can create periodically-aligned peaks and valleys (ridge texture) on the peened surface. This study aimed to explore a possibility of angled-FPP as a technique to modify the wettability of the surface. Contact angle of distilled water was determined on ridge-textured aluminum alloy surfaces prepared by angled-FPP using various shot particles: steel particle, glass particle and alumina grit. The height and pitch of ridge texture depended on shot particle materials. Topography of the surface prepared using steel particle and alumina grit was “hierarchical”, since wave-pattern of several ten micrometers in pitch was covered with finer-scale roughness. In contrast, angled-FPP using glass particle created waves whose surface was quite plain. Surface texture having “hierarchical topography” slightly increased the contact angle, i.e. more hydrophobic, than a polished surface of the aluminum alloy. Clear difference in contact angle was not observed between smooth specimen and “plain-skin” ridge texture created by glass particle. Results imply that dominant influence on the wettability of the specimens came from superficial morphology of the ridge texture in accordance with Cassie-Baxter theory.

Introduction

Textured surfaces have attracted great interests in the engineering field because of their various benefits [1]. One of the possible benefits come from appropriate texture is modification in wettability. Wettability should be controlled to obtain various advanced surfaces which shows biocompatibility [2], anti-contamination ability [3], and so on.

Textured surface have been fabricated by chemical etching combined with photolithography, laser processing, precision cutting and so on. As an alternative process to fabricate textured surface, the authors have been proposed angled fine particle peening (angled-FPP: abrasive jet processing using peening nozzle set at oblique to workpiece surface) [4]. This method can create ridge texture, which consists of periodically aligned peaks and valleys, on the peened surface. The pitch and height of ridge texture can be ranged by adjusting peening conditions such as peening time, particle supply rate and nozzle distance. Angled-FPP allows mask-free fabrication of textured surface on the metallic surface in a simple manner, thus, it has potential as a novel surface texturing process.

One of the authors has reported that an appropriate ridge texture could improve tribological properties. To explore a new benefit brought by angled-FPP, this study aimed to evaluate

wettability on ridge texture. To vary the size and the geometrical characteristics of ridge texture, angled-FPP was conducted using a variety of shot particles. The influence of surface texture on the wettability property was investigated.

Experimental procedure

AA6061 aluminum alloy was machined into disks of 15mm in diameter and a 5mm in thickness followed by polished with emery papers. Angled-FPP and wettability evaluation were conducted on the aluminum disks.

Angled-FPP was carried out using air-suction type peening apparatus. A peening nozzle with a 6mm diameter was set at 15° to the disk surface (Fig.1). A peening pressure of 0.5MPa, a nozzle distance of 30mm and peening time of 30s was applied. For comparison, fine particle peening where the peening nozzle was set vertically to the disks (normal FPP) was also conducted using steel particle. A variety of shot particles: alumina grits with a grain mesh number of #360 and #1000, spherical glass particles with a grain mesh number of #40 and #200, and spherical steel particle of 70μm in a mean diameter, were employed for angled-FPP and then compared in terms of texture formation on the surface. Typical feature of particles are compared in Fig.2. Hereafter, specimens prepared with angled-FPP using alumina grits, glass particles and steel particle are referred as: AG#360, AG#1000, GP#40, GP#200 and SP series, respectively. Ones prepared with normal FPP is referred as n-SP series.

After preparing the specimens, the surface was examined by using optical microscopy (OM), scanning white light interferometry (SWLI), and scanning electron microscopy (SEM) to determine the geometrical characteristics of the texture. The pitch and the height of ridge were measured from profiles obtained with contact profilometer as shown Fig.1.

Wettability was evaluated by conducting sessile drop method, where contact angle of distilled water of 2uL volume on the textured surface was measured through optical microscopy. The surface created by angled-FPP is anisotropic so that contact angle might differ depending on the direction of observation. In this study, all measurement was conducted from the direction of particle flow during angled-FPP process; observation direction was transvers to the ridge texture.

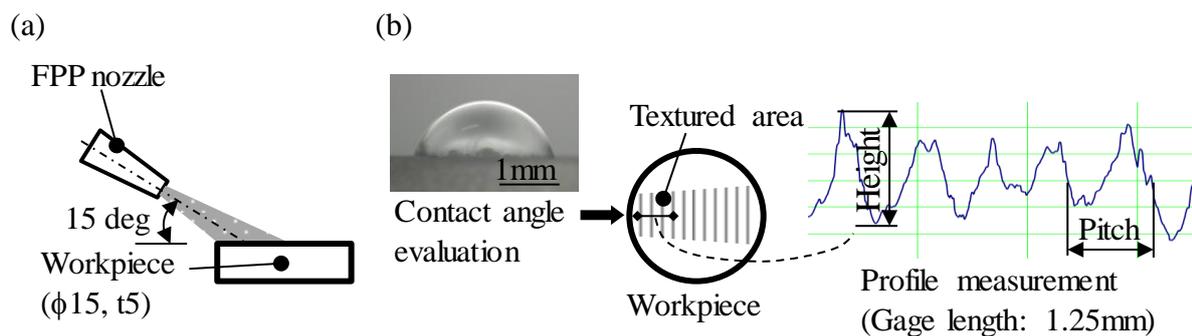


Fig.1 (a) Experimental setup, and (b) characterization of the texture.

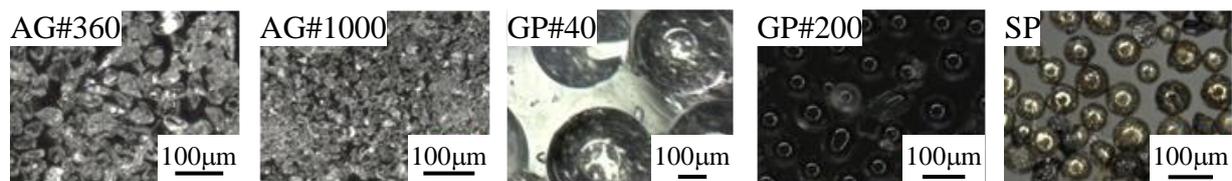


Fig.2 Typical appearances of shot particles employed for angled-FPP.

Results and discussions

Characterization of ridge texture geometry. Fig.3 represents topographical feature of the angled-FPP specimens. OM and SWLI images indicated that ridge texture transverses to the particle flow direction was created by angled-FPP regardless of the choice of the shot particles. While OM observation of the GP#40 series did not exhibit the wave-like geometry on the surface very clearly, SWLI analyses have proved that the texture of that specimen actually comprised aligned bumps, which were formed by particle collision. This implies that such feature should be an initial state of the ridge formation; development of ridge texture might require further peening time. The authors have indicated that ridge formation proceeded when particles repeatedly collided onto the surface. In this experiment, total mass of shot particle to be projected was fixed regardless of the particle size. Therefore, employment of larger particle

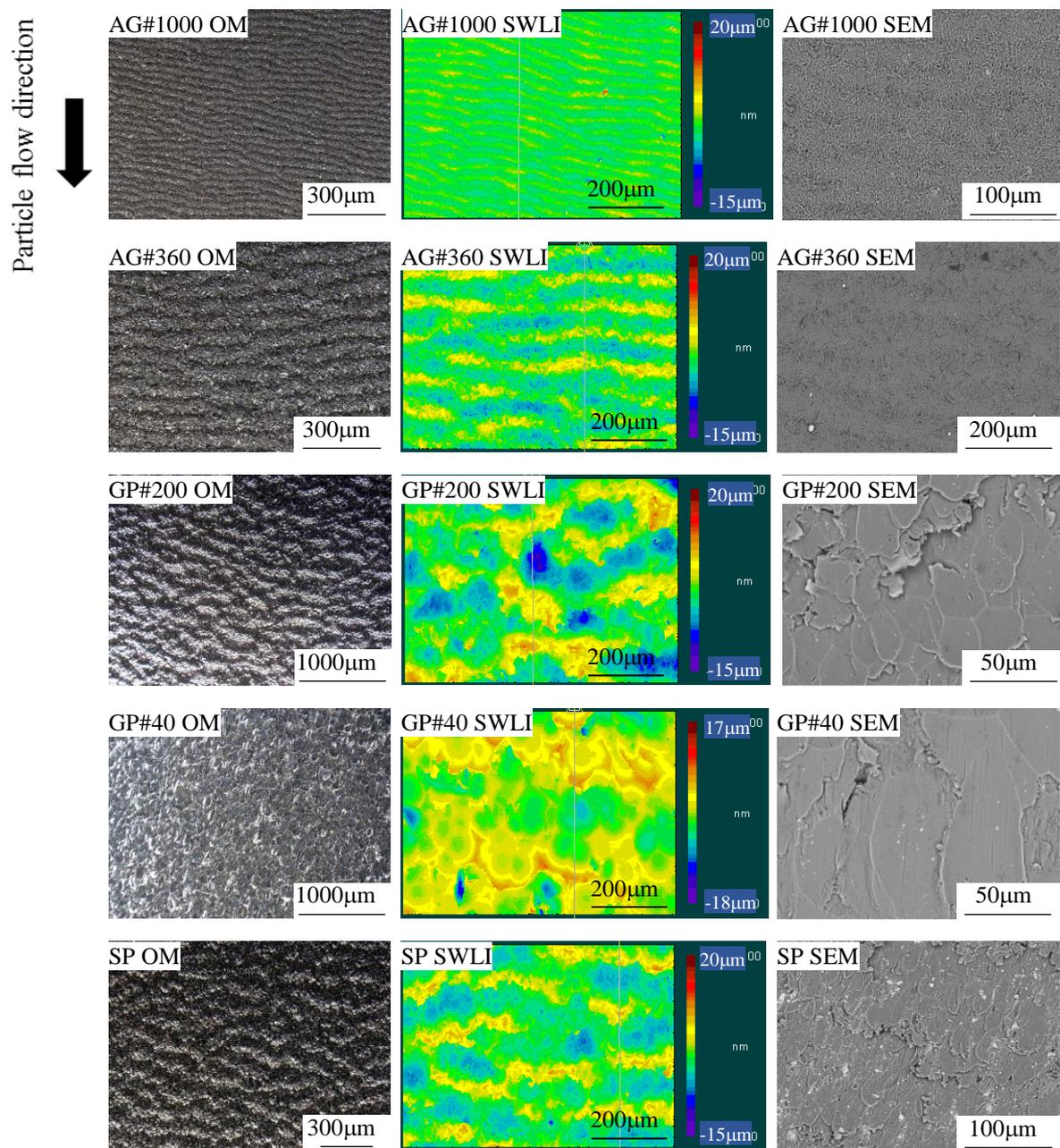


Fig.3 Typical features of surface texture created angled-FPP using a variety of shot particles.

could associated with drastically decrease in total number of particle, and this resulted in incomplete formation of ridge texture in peening time of 30s.

Morphology as well as size of the texture on each angled-FPP specimen differed depending on shot particles. Fig.4 compares the pitch and the height of ridge texture on each specimen. The height of the ridge slightly varied around 10 μ m. The pitch of the ridge was ranged from 50 μ m to 200 μ m depending on shot particle. Smaller alumina grit (#1000) was suitable to create much finer texture: peaks and valleys were more densely aligned, compared to the others. SEM images of AG#360 and #1000 revealed that the surface morphology created by alumina grits consists of wave-like geometry and much finer scratches covering the wave surface. These characteristics observed on the ridge texture be alumina grits should be associated with the erosive impact induced due to sharp corners of the particles.

It was demonstrated that SP, GP#40 and GP#200 series, their surface were covered with tongue-like scars which can be attributed to material flow induced by particle collision (see Fig.3). It should be noted that the surface of the “tongue pattern” was quite smooth on the GP#40 and #200 series, although that on SP series exhibited rough skin. Those features can be resulted from the morphology of each particle: the surface of the glass particles was plain, and that of steel was relatively rough.

As discussed above, ridge texture created using a variety of shot particles differed in terms of not only geometry and size, but also superficial feature. The specimens prepared using alumina grits and steel particle exhibited “hierarchical topography”; superfine roughness overlap the wave-like geometry of the ridge. This was probably because the specific geometry and morphology of the particles were imprinted onto the surface of ridge.

Contact angle evaluation. Fig.5 demonstrates the relationship between sizes in ridge and contact angle measured on each specimen. The contact angle obtained on the polished aluminum disk, indicated by the horizontal broken line, was approximately 50°. The AG#360, AG#1000, and SP series, specimens prepared using alumina grits and steel particle, showed the

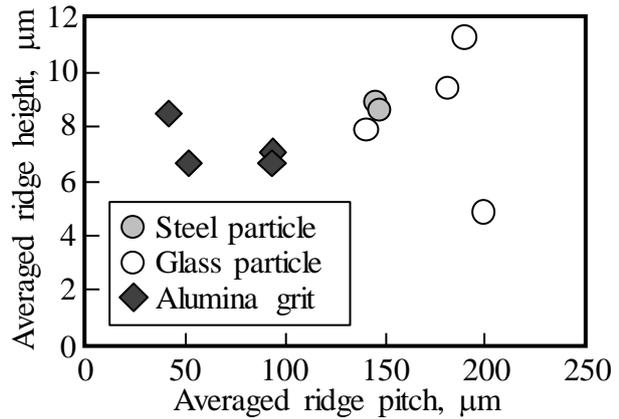


Fig.4 Geometry of ridge texture prepared with a variety of shot particles.

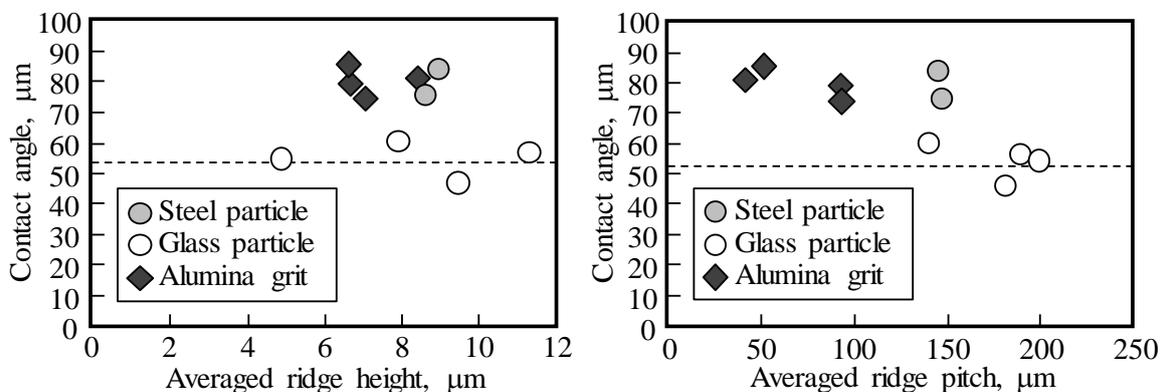


Fig.5 Contact angle of distilled water determined on the ridge texture prepared using various shot particles.

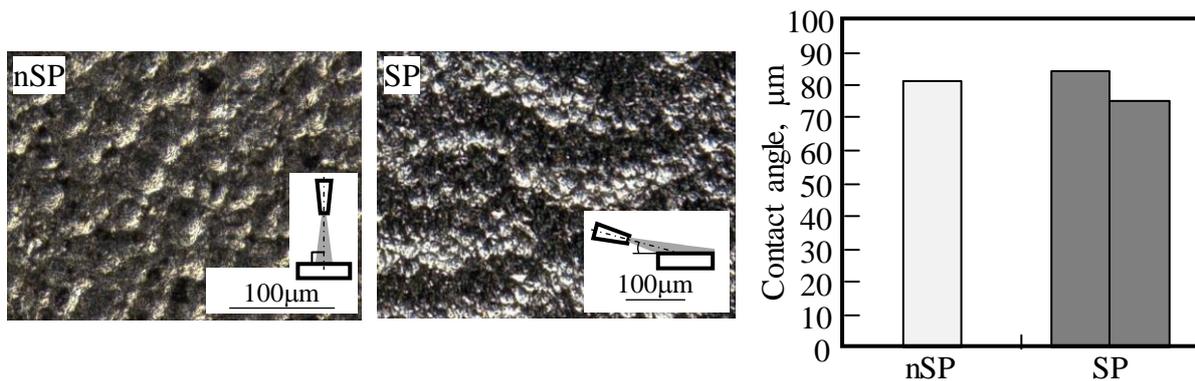


Fig.6 Comparison of the contact angle between isotropic texture created by normal FPP and the ridge texture by angled-FPP.

contact angles around 80° , slightly more hydrophobic than the polished one. In contrast, the contact angle of the GP#40 and #200 series was almost as same as the polished one. Clear differences could not be found in the contact angle depending on the height and the pitch. These results mean that the contact angle of the specimens mainly depends on the shot particle used for angled-FPP rather than the geometry and size of ridge texture.

Fig.6 compares the contact angle measured on the SP and nSP series. The surface of nSP series was isotropically roughened since it was created by vertical collision of steel particle onto the aluminum surface. Despite significant difference in the texture, the contact angles measured on both ones did not differ very clearly. This result means that the existence of the ridge texture does not play dominant role on the wettability property. This assumption can be supported by the result shown in Fig.5, where the presence of ridge textures brought very little changes in wettability property for on the GP#40 and #200 series.

A possible factor which mainly affected the contact angles of the textured surfaces should be hierarchy in topography: as we mentioned above, the surface structure of AG#360, AG#1000, and SP series consisted of relatively-larger wave geometry and finer roughness imprinted from the shot particle. The presence of the finer and superficial roughness on those ones was a specific difference compared to the GP series specimens, and can be attributed to increasing in the contact angle.

One of the model describing wettability of rough surface has proposed Cassie and Baxter [5], in which transition from hydrophilic to the hydrophobic may be caused under appropriate situation. In Cassie-Baxter state, the liquid droplet is supported by both of the solid phase and the vapor phase. Thus, necessary nature of that state is that the liquid phase incompletely penetrated into deep channels on the texture. As shown in Fig.4, angled-FPP created relatively shallow wave-like geometry. This feature might allow the water droplet to penetrate into the valley of the ridge. In case of AG and SP series specimens, the superficial roughness on the texture should likely acted as a deep crevasse, which suppressed the liquid penetration, and then achieved more hydrophobic characteristics in accordance with Cassie-Baxter theory.

It should be note that changes in material composition had occur simultaneously with texturing because angled-FPP transferred shot particle elements onto the surface. This is typical and sometimes beneficial phenomenon induced by FPP. It is supposed that transferred fragments possibly affect the contact angle while those influences had not evaluated in the present study.

Conclusions

In this study, periodical ridge textures were created by angled-FPP using varied shot particles and then examined to measure the contact angle of water. Conclusions resulted from this study are listed below:

(1) The pitch and height of ridge differed by varying shot particle of angled-FPP. In this study, alumina grit of a grain mesh number #1000 was found to be able to create the finest ridge, whose size was approximately 50 μm in pitch and less than 10 μm in height.

(2) Shot particles of angled-FPP imprinted the surface morphology of themselves onto the peened materials. As a result, surface topography of ridge textures could be changed depending on shot particles.

(3) Ridge texture created by using steel particle and alumina grits, exhibiting hierarchical topography: finer roughness were overlapped the wave-like geometry, showed slightly higher contact angle than polished ones. In contrast, usage of glass particles for angled-FPP resulted in creating ridge texture having plain surface. That texture showed the contact angle as similar as the polished one.

(4) Dominant factor affecting the contact angle was supposed to be the superficial roughness of the ridge texture rather than the wave-like geometry.

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