X-ray computational tomography non-destructive observation of modified microstructure created by fine particle peening.

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Fine particle peening (FPP), which is a shot peening technique using relatively smaller shot particles, has been widely applied for improving fatigue strength of machine components. Besides those benefits, it has been reported that FPP can transfer shot particle elements onto the peened surface. As a result, a specific lamellar microstructure enriched with transferred elements is created along the FPP-treated surface. Such a feature potentially provides a new advantage of FPP: adding beneficial substances to the original material. To obtain the benefit, it is important to understand the detailed mechanism of the lamellar structure formation. In this study, the authors attempted an X-ray computational tomography (X-ray CT) to observe the lamellar structure created in a commercially pure aluminum substrate treated with FPP using a steel particle. After 30 s of FPP, the lamellar structure with a depth of up to 50 micrometers has been formed. The structure was clearly visible on the non-destructively obtained images by X-ray CT. X-ray CT could prove transferred fragments with a size of less than 10 micrometers. It could be concluded that X-ray CT analysis was a potential method that enabled the realization of time-dependent changes in the lamellar structure evolution during the FPP process in a non-destructive manner.

Keywords : *fine particle peening, particle fragments transfer, X-ray computational tomography, non-destructive observation, time-dependent changes*

1. Introduction

Material transfer[1)] from the shot particle to the substrate is one of the attractive features of fine particle peening (FPP) because it can add beneficial substances to the peened surface. In previous studies, FPP-induced transfer has been qualitatively evaluated on the cross sections of the peened workpieces; the workpiece needed to be cut in advance. Such a destructive observation method only allows an observation at a particular position of the workpiece and is impossible to follow the evolution process of the lamellar structure, which typically forms by mixing the transferred products into the substrate. In this study, therefore, we attempted X-ray computational tomography (X-ray CT) to nondestructively observe the cross-section of a peened specimen. The results obtained by X-ray CT were compared with the observation results utilizing scanning electron microscopy (SEM) to verify the validity of the X-ray CT observation of transfer products.

2. Experimental procedure

In this experiment, several specimens were prepared by conducting FPP using steel particles with an approximate size of 70 µm onto an industrial pure aluminum (JIS-grade A1070) substrate. The specimen was machined into a stepped cylindrical shape: the holding section of 20 mm long and 6 mm in diameter, and the examining section of 10 mm long and 3 mm in diameter. The cylindrical geometry of the specimen is suitable for reconstructing a cross-sectional image from raw dates obtained by X-ray CT. In addition, a part of the specimen holding section is polished to make it flat for position adjustment.

FPP was conducted using a suction-type pneumatic peening apparatus with a nozzle diameter of 2.8 mm. Compressed air to project the particle was supplied from a compressor (tank capacity: 25 L, discharge rate: 96 L/min). Table 1 lists the FPP condition.

Figure 1. Specimen shape.

Then the peened part of the specimens was observed with X-ray CT. Table 2 shows the observation conditions of X-ray CT. In Table 2, Focus Center Distance(FCD) represents the distance from the X-ray irradiation tube to the center of rotation of the specimen for observation, and Focus Image Distance(FID) shows the distance from the X-ray irradiation tube to the detector.

For comparison, a cross-section of the peened specimens was also analyzed by scanning electron microscopy. The sectioned specimen was fixed with resin and then mirror-finished. Elemental maps of the cross-section were obtained by electron dispersive X-ray spectroscopy (EDX).

Table 1. Projection conditions for FPP process.

Projection conditions	
Peening pressure	0.3 [MPa]
Particle feed rate	1 [g/s]
Peening distance	25 [mm]
Peening angle	90 [°]
Peening time	30 [s]

Table2. Observation conditions for FPP processed specimens with XCT.

Observation conditions	
FCD	16 [mm]
FID	1000 [mm]
Tube voltage	120 [kV]
Tube current	40 [μA]
Spot diameter	4 [μm]
Slice thickness	0.002 [mm]
Slice image size	1024*1024 [pixels]
Voxel size	x:y:z=1.5625:1.5625:2 [μm]

3. Result and discussion

The results of X-ray CT observations of specimens in which steel particles were projected onto a pure aluminum substrate are shown in Figure 2. It shows a circular cross-section of the FPP-processed section of the specimen. The area near the surface exhibited blighter in the image than the other area. This means that this area absorbs more X-rays than other areas, and results from the concentrating transferred products of steel. Thus, the blight area could be likely associated with the lamellar structure composing transferred steel and aluminum matrix. The thickness of the iron-rich region was several tens of micrometers.

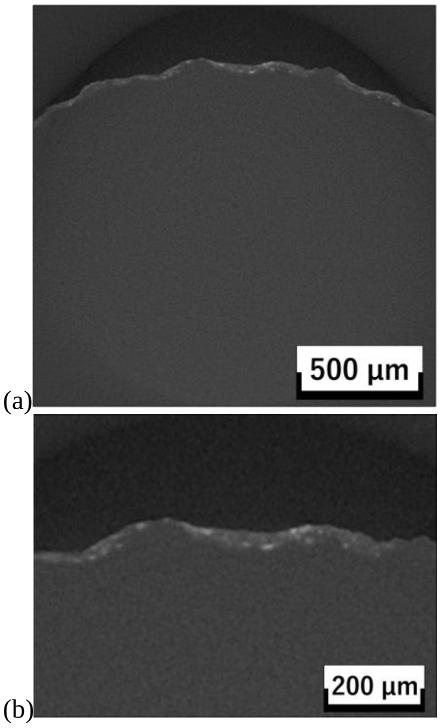

Figure 2. Cross-sectional image of FPP specimen by X-ray CT, (a) entire image, (b) enlarged image.

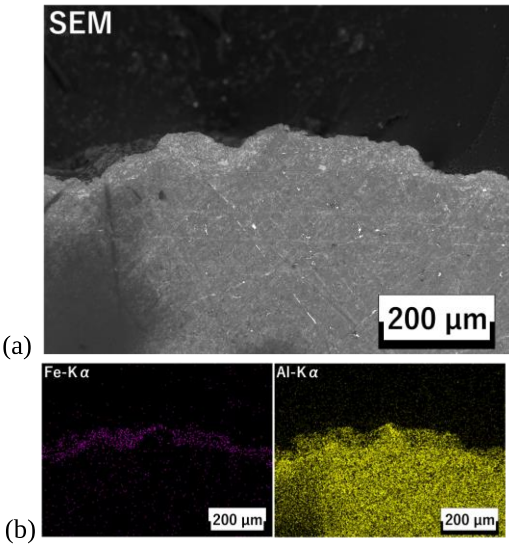

Figure 3. Observation of FPP specimen cross-section by scanning electron microscopy, (a) SEM image, (b) EDX mapping images corresponding to Fe and Al.

The results of SEM and EDX mapping obtained from the cross-sectional specimen of the FPP processed part are shown in Figure 3. SEM micrographs and elemental distribution of a cross-sectional sample produced by sectioning FPP-specimen which was another to that employed for X-ray CT analysis but prepared under the same projection conditions, showed that the lamellar structure with concentration of iron elements was formed along the peened surface. This can be attributed to transferring from steel particle fragments. Iron-rich lamellar region was several tens of micrometers thick, well agreed with the result of X-ray CT shown in Figure 2. Comparing Figures 2 and 3, we can conclude that it is possible to observe the lamellar structure accompanied by transferred elements by using X-ray CT in a non-destructive manner.

This non-destructive observation method is expected to be applicable to any combination of particles and substrate with a difference in atomic weight. This allows multiple cross-sectional observations on a single specimen, increasing research efficiency and accuracy. Furthermore, by performing additional FPP processing on the FPP-processed surface of one specimen and performing sequential X-ray CT observations, it makes it also possible to observe the evolution of the material transfer and following lamellar structure formation as peening time increases. In addition, the volume of transferred elements in the substrate matrix could also be quantitively estimated by means of image analysis software to reconstruct the FPP processed area in a three-dimensional view. These features possibly provide further understanding not only in FPP-induced material transfer phenomena but also in resulting microstructural changes.

4. References

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