Evaluation of the Effects in Fine Particle Peening on Surface Modification

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Abstract
The purpose of this research is to determine the role that fine particle peening (FPP) has on surface modification. The single particle collision was used for various processing conditions with the finite element method (FEM). This collision simulation can reproduce various processing conditions by changing various kinds of parameters. This method is suitable for studying various influencing factors. LS-DYNA was used for this simulation.
As target material to be shot peened, steel was used and as shot media, steel shot, Al_2O_3, ZrO_2, and Sn particles were utilized. In addition, analysis was conducted under the collision energy controlled condition. As a result, it was shown that the plastic strain produced at the time of collision depends on the yield stress ratio and the Young's modulus ratio of shot particles and the steel to be shot peened. It could be shown that the plastic deformation produced at the time of a collision depends on the yield stress ratio of the shot particles and the target material. The yield stress ratio and the Young's modulus ratio of the shot particles and the target material are the influencing factors of the surface modification by FPP.

Keywords FEM, Fine particle peening, Plastic deformation, Yield stress, Young's modulus

Introduction

In recent years, the continuous reduction of the fuel-consumption in automobiles is called for from global environment issue. Therefore, various surface modification processes are performed to improve steel materials as the main materials for construction in automotive engineering. There are various methods to improve the fatigue performance of steels. Thus, mass reduction leading to reduction of fuel consumption is possible. A classical method for improving fatigue performance is shot peening. Recently, FPP is considered special kind of shot peening that is very cost effective and efficient [1~3].
FPP as a disposal method gives rise to a high velocity impact. The surface modification effects differ significantly from the effects caused by conventional shot peening. Egami and others have shown that the improvement of the fatigue strength by fine particle peening can be higher than that by conventional shot peening [4]. Moreover, it is reported by Takagi and others that very fine crystals can be formed in near-surface regions [5] Because of these beneficial effects, FPP is expected to be put in practical use in the near future.
However, the selection of optimal processing parameters in FPP is still a matter of research. Presumably, the disposal methods performed up to now are not necessarily the optimal processing conditions. With the exception of the research on the particle size effects by Maeda et al., Kikuchi et al., Nambu and others, other influencing factors are not studied [6~8]. In particular, the effect of the physical properties of the particles (density, yield stress, etc.) on the surface modification effect is hardly studied. There is no doubt that it is difficult to determine the extremely high velocity of the particles. In order to shed some more light on this problem, we propose an impact simulation by a finite-element method. The characteristic of this impact simulation using a finite-element method is shown below.

1. Parameters such as physical properties of the particles and particle velocity can easily be varied.
2. By changing an element model, plastic deformation, generating of heat etc. can be taken into consideration.

It is thought that the impact simulation can simulate the phenomenon produced at the time of the impact. The purpose of this research is to study the interaction between the properties of the particles and the target on the resulting surface modification in FPP.

Analysis Methods

The software we adopted in order to perform an impact simulation is LS-DYNA. This method is mainly used in collision analysis. Figure1 illustrates the model used for the analysis. The diameter of the particles was 50 micrometer and the target was a 200 micrometer regular hexahedron. In addition, mesh size of particles was set to 9 and the mesh size of the target was set to 10x10x100. Moreover, an elastic-plastic element was adopted in this research because the deformation in this impact situation is elastic-plastic. Furthermore, strain hardening effects need to be taken into account by using a strain hardening coefficient. The mechanical properties of the materials used in this analysis are shown in Table 1.

Table 1 Mechanical properties of the peening materials

Material	Density	Young's modulus	Yield Stress	Strain-hardening coefficient	Poisson's ratio
	(kg/m3)	(GPa)	(GPa)	(GPa)	
Al_2O_3	3.95E+03	380	5	3.8	0.23
Sn	5.77E+03	42	0.032	0.42	0.17
ZrO_2	6.00E+03	220	4	2.2	0.31
Steel	7.83E+03	207	0.24	2.07	0.3

In this analysis, Al_2O_3, ZrO_2, Sn, and steel particles were used. The target material was steel. The velocity of the steel particles was set at 100 m/s. The velocity of the other particles was adjusted according to the same kinetic energy as the steel particles. The simulation was performed under these conditions. Investigated was the resulting plastic strain of the target because this is related to the induced hardness and residual stress. In addition, the plastic deformation of the particles was investigated.

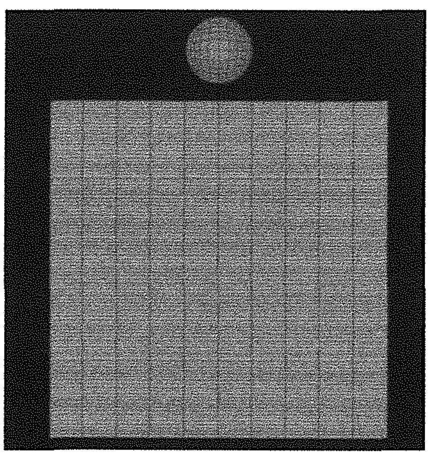


Fig.1: Analysis model

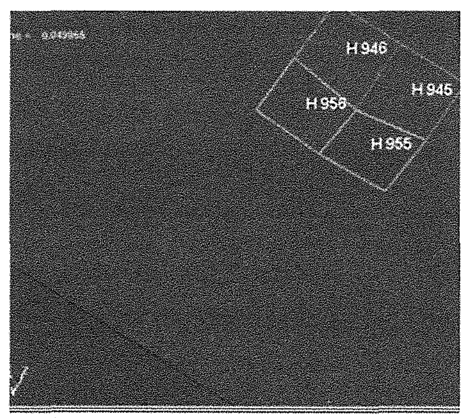
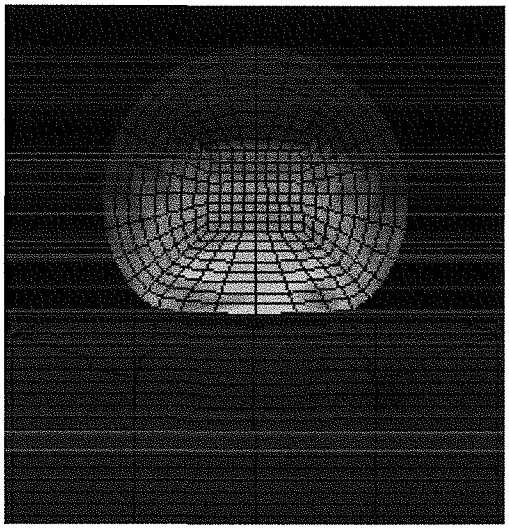
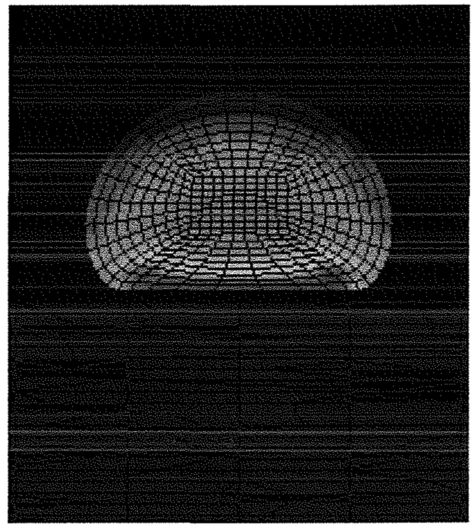


Fig.2: Particle directly under element

Analysis results for each particle

The analysis result is illustrated in Figure 3.





a) Steel particle b) Sn particle

Fig.3: The plastic strain analysis result after impact

The impact effect of steel particles is shown in Figure 3 (a). For comparison, the impact effect of Sn particles is shown in Figure 3 (b). In the case of steel particles, both target and particles are deformed. In the case of Sn particle impact, only the particles are deformed. The deformation of the Sn particle is clearly larger than that of the steel particle. This is because the Sn particles are much softer compared to steel (see Tab. 1).

The analysis result of the various particles is shown in Table 2. After the impact of Al_2O_3 particles, the plastic strain of the target was the largest. This is because Young's modulus and yield stress of Al_2O_2 particles are the highest. Obviously, the mechanical properties of both the particles and the target play a role in the surface modification.

In order to determine the influence of these mechanical properties, the Young's modulus ratio and the yield stress ratio were used. These values are calculated by the ratios of Young's modulus and yield stress of target and particles (Tab. 2).

Table 2: Analysis result

Material	Plastic strain	Young's modulus ratio	Yield stress ratio	Young's modulus ratio+Yield stress ratio
Steel	0.06	1	1	2
Al_2O_3	0.015	0.54	0.048	0.59
ZrO_2	0	0.94	0.06	1.00
Sn	0,08	4.92	7.5	12.43

The plastic strain as dependent on yield stress ratio plus Young`s modulus ratio is plotted in Figure 4. The plastic strain is inversely related to the sum of yield stress ratio and Young`s modulus ratio. The highest values are calculated for Sn followed by steel, Al_2O_3 and ZrO_2.

Discussion about the influence of a yield stress ratio

In order to consider the influence of the yield stress ratio, the yield stress of the particles was varied between 200 and 2400 MPa. The plastic deformation increases as particle yield stress increases. Accordingly, the plastic strain decreases as the yield stress ratio increases as illustrated in Figure 5.

According to additional calculations, the yield stress of the target was varied from 200 to 1200 MPa whereas the particle yield stress was kept constant. The result is shown in Figure 6. While target yield stress increases under a given particle yield stress the plastic deformation of the particles increases. As demonstrated in Figure 6, there is a linear relationship between plastic deformation and the yield stress ratio for the given yield stresses of the particles. It can be seen that the gradient of the straight line for each yield stress is almost the same. Figure 7 demonstrates the relationship between plastic deformation the target yield stress.

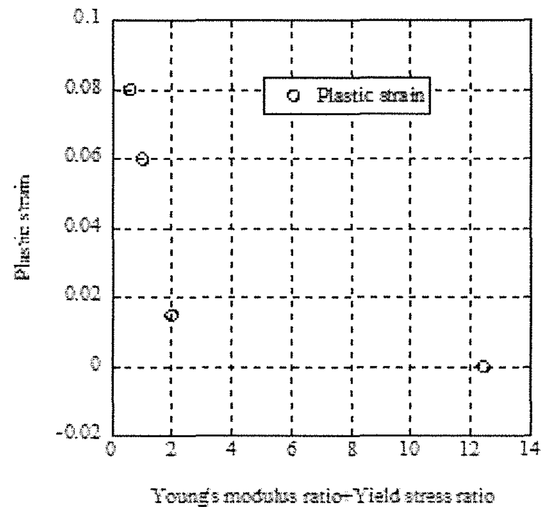


Fig.4 Relationship between plastic strain and yield stress ratio + Young's modulus ratio

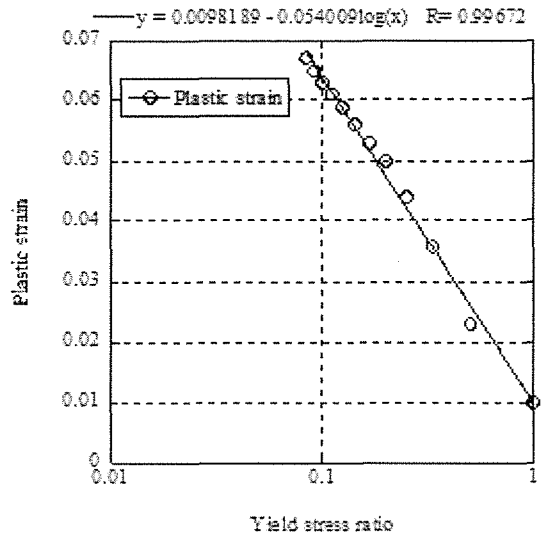


Fig.5 Relationship between plastic strain and yield stress ratio

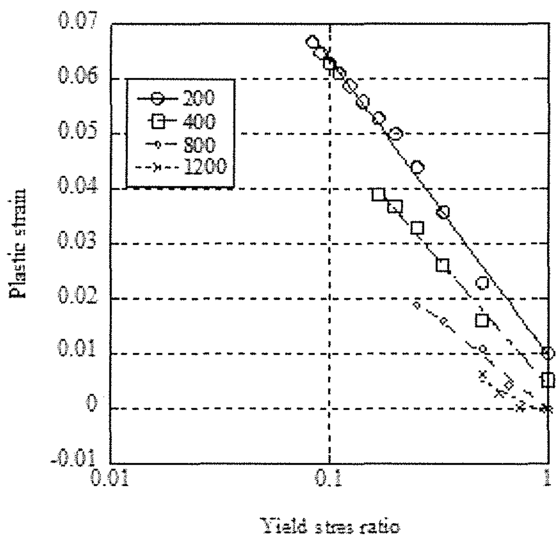


Fig.6 Relationship between plastic strain and yield stress ratio of each yield stress

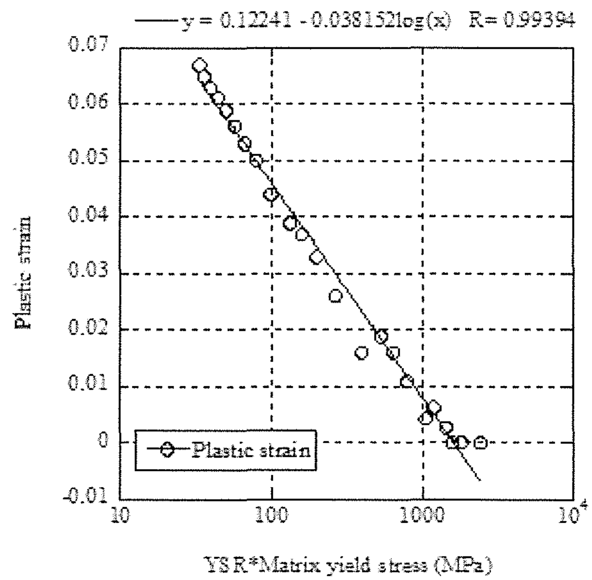


Fig.7 Relationship between plastic strain and yield stress ratio ∗ Matrix yield stress

Conclusions

(1) Plastic deformation depends on particle properties.
(2) Yield stress ratio of particle and target and Young's modulus ratio of particle and target are the main parameters.
(3) For a given particle material, plastic deformation depends on the yield stress ratio and the yield stress of the target.
(4) The surface modification depends on the Young's modulus ratio and the yield stress ratio.

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