A LIFE PREDICTION AND FATIGUE CHARACTERISTICS OF DIFFERENTIAL GEAR APPLIED BY OPTIMAL PEENING CONDITION

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ABSTRACT

Experiments and fatigue analysis were accomplished to evaluate and predict the fatigue life of shot peened gear in this paper. The fatigue life was evaluated depending on the peening intensity. From A-N (Almen intensity - Number of fatigue cycles) curve for a bevel gear, the specific time and velocity having a maximum fatigue life were determined. Microscopic observation of crack surface was done through “Scanning Electron Microscope : SEM”. Fatigue life of a peened gear was predicted by fatigue analysis.

The result shows that the optimal peening condition is 65m/s of shot ball velocity and 8 minutes of shot peening time. An error range between experimental and fatigue analysis data is 20% to 25%. Predicted life data of unpeened and peened gear under load 2,200kgf are 4.46×10^{6} and 1.0×10^{20} cycles, respectively. Optimal shot peening process tremendously improves the fatigue life of a bevel gear. Life prediction technique using FEM is reasonable and makes us reduce the designing time and costs.

Keywords: Shot Peening, Life prediction, MSC_Fatigue, Optimal peening

EXPERIMENT AND ANALYSIS

Specimens of this paper are real bevel gear used for automobile parts whose chemical compositions(in wt.%) are 0.81 Mn, 0.08 Si, 0.01 P, 0.18 C, 0.009S, 0.61 Mo, 0.17 Ni, 1.33 Cr, 0.023 Nb and rest Fe. A tensile test was conducted by applying force to the specimen based upon the specification ASTM E-8. The mechanical characteristics of the specimen are as follows: Yong’s modulus E= 209 GPa, yield stress σ_y= 734 MPa, ultimate stress σ_u= 1181MPa.

The thickness of the bevel gear for the fatigue test is 20mm and the angle between the teeth is 22.3°. The loading angle on the gear for the bending test is 66.5°. For each step of the heat treatment, the specimen was carburized and spread for 270min at 900℃, quenched for 90 minutes and cooled

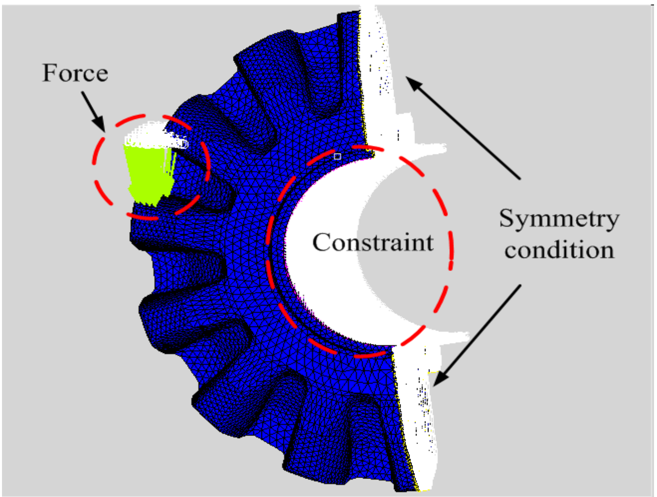


Fig. 1: Finite element model

Table 1: Analysis condition according to convergence test

No.	Part name	Number of nodes	Number of elements	Type of element
1	bevel gear	56,769	89,871	tetrahedral

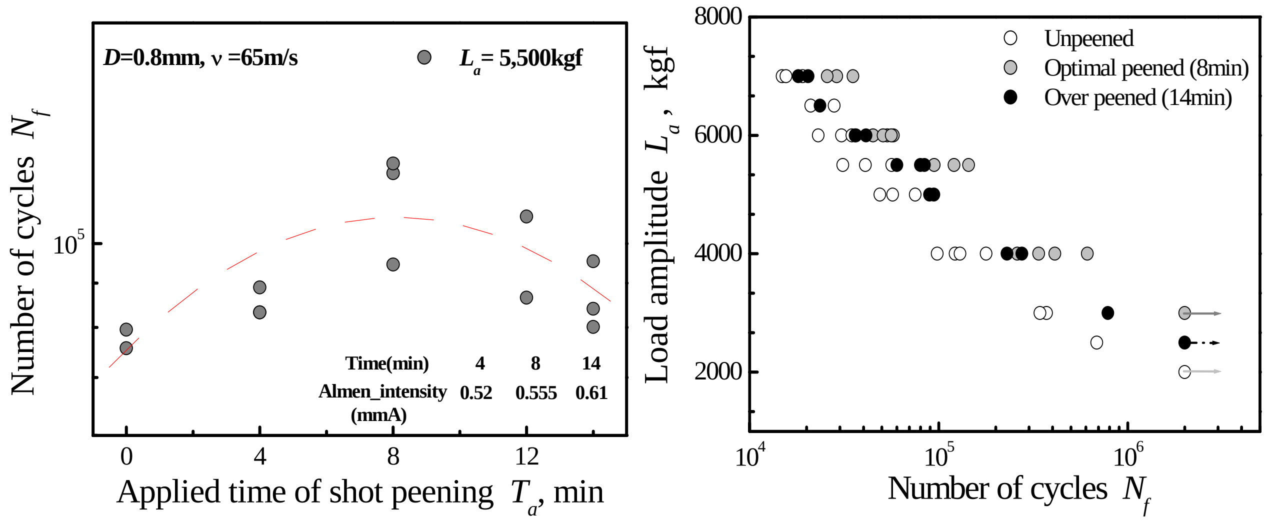
down so that the normal martensite structure could be formed from the austenite structure. Rotary bending specimens for life prediction have 8mm minimum diameter at the middle. Those specimens were polished with Emery paper, #2,000 and washed with alcohol. Based on the previous studies(1-3), shot peening velocity was fixed as a 65m/s. So, the peening intensity was controlled by peening time. A cut wire was used to make a shot ball with 0.8 mm diameter. A fatigue test was conducted by the universal testing machine(INSTRON-8516). A fixture for the fatigue test was devised for the load to be evenly distributed on the surface of gears. The applied load for the fatigue test of optimal peening condition that has maximum life was 5,500kgf. Load ratio, R was set to 0.1. Rupture life was considered as the cycles of the moment that the crack has developed more than 1mm on either side of gears. Fatigue test of base material to predict fatigue life of bevel gear was performed by rotating beam fatigue machine with fully reversed loading ratio(R=-1).

The finite element type for the analysis of bevel gear is tetrahedral full integration element having 10 nodes. The number of elements and nodes used for the finite element analysis are shown in table 1, which was determined through convergence test. Mesh generation and stress analysis were performed by HyperMesh7.0 produced by Altair and ABAQUS6.5/Standard. Fatigue analysis was performed using MSC_Fatigue 2005r2. Figure 1 shows the finite element model. All D.O.F the shaft hole of bevel gear were constrained.

RESULTS AND DISCUSSION

Figure 2 shows the fatigue characteristics of bevel gear depending on peening intensity. Figure 2(a) shows the optimal peening condition. Figure 2(b)shows the S-N data according to the optimal peening condition. In Fig. 2(a), the fatigue life increases with Almen intensity

but starts to decrease after 8 minutes due to over peening[3]. Thus, the optimal peening condition was decided at the 8min of shot peening time under 65m/s of shot velocity. In general, the effectiveness of shot peening is more effective under high cycle fatigue region than low cycle fatigue region as shown in Fig. 2(b). Figure 2(b) also shows the effectiveness of optimal peening. In Fig. 2(b), the average fatigue life for the optimal peening condition is 119,674 cycles, which is 195% longer than that for the unpeened condition, 40,470 cycles. Here, the fatigue cycle was obtained by applying 5,500 kgf. The fatigue life for over peening condition is 74,743 cycles, which is only 85% longer than that for unpeened condition. There is 110% of fatigue life gap between optimal peening and over peening condition.
The fatigue limits of unpeened, optimal peened and over peened specimens are 2,000kgf, 3,000kgf, 25,00kgf, respectively. There is 25% of fatigue limit gap between optimal peening and over peening condition.
Figure 3 shows the fatigue test results of base material for fatigue analysis. The graphs were plotted log-log scale and fitted as straight lines to get constants in equation (1). The constants SRI and b are used in fatigue analysis by MSC_Fatigue 2005r2. Table2 shows the constants in the power law equation[4] (1).



(a) Fatigue life vs. peening time

(b) S-N data vs. peening condition

Fig. 2: Fatigue characteristics of SCM920 bevel gear

$$S = SRI\ (N)^{b} \qquad (1)$$

Table 2: Constants from the S-N curve (SRI: Stress Range Intercept, b: slop of S-N curve)

Condition	SRI(MPa)	b
Peened specimen	5151	-0.1397
Uneened specimen	7320	-0.19459

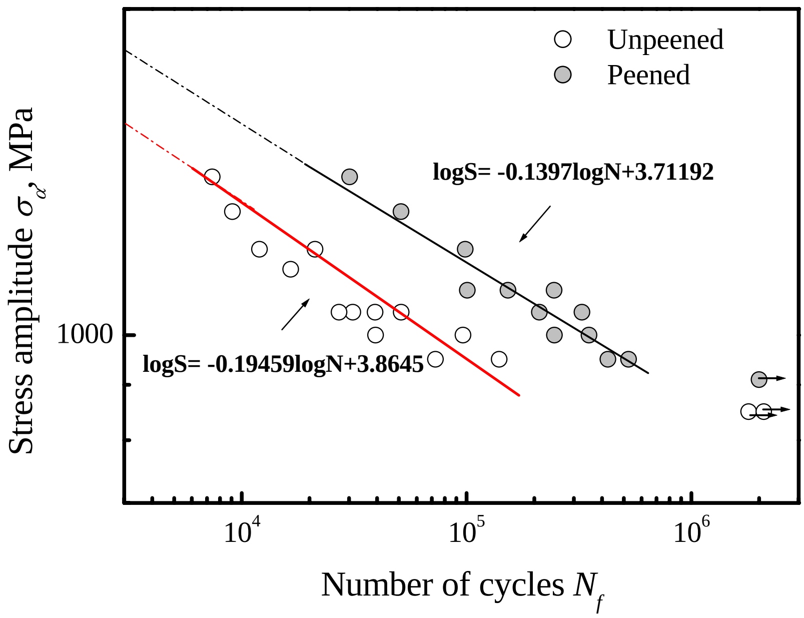


Fig. 3: S-N curves of base material for fatigue analysis

The stress value and distribution at the stress concentration region such as the root of gear tooth are necessary to accomplish the fatigue analysis. Figure 4 shows the stress distribution under the real load condition(5), 2,200kgf. In Fig. 4, maximum principal stress is 289.9MPa and von-Mises stress is 315.6MPa.

In the equation(4) (1), If logarithm apply both side of an equality, the equation change into the form of Fig. 3, losS = blogN + logSRI. In this case, unknown constant will be only N of life because constants b and SRI are defined by graph of Fig. 3 and S(stress) is defined by ABAQUS. Therefore the fatigue life can predict as MSC_Fatigue program consider those constants and stress ratio and make predict line by itself.

Figure 5 shows the result for predicting fatigue life on the basis of stress analysis in Fig. 4. In case of unpeened specimen, the fatigue life is 4.64×10^{6} cycles. But, in case of optimal peened specimen, the fatigue life is 1.0×10^{20} cycles.

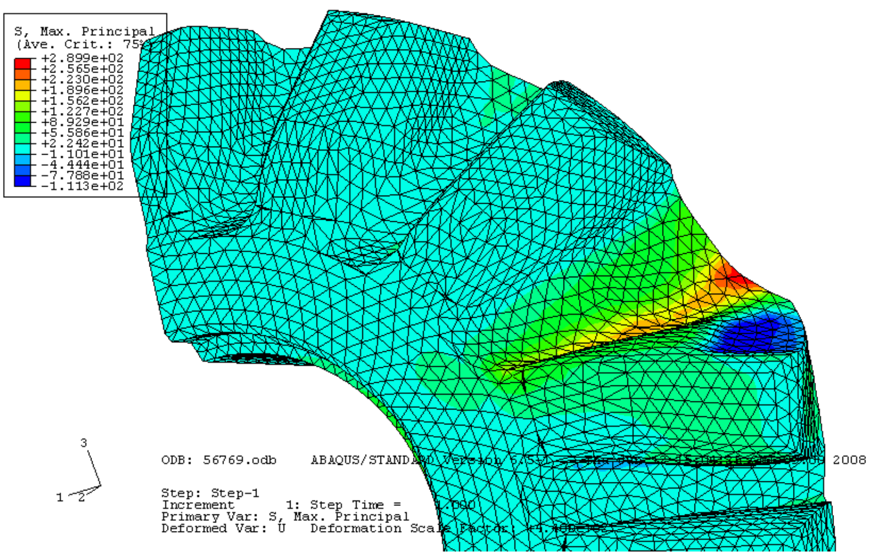
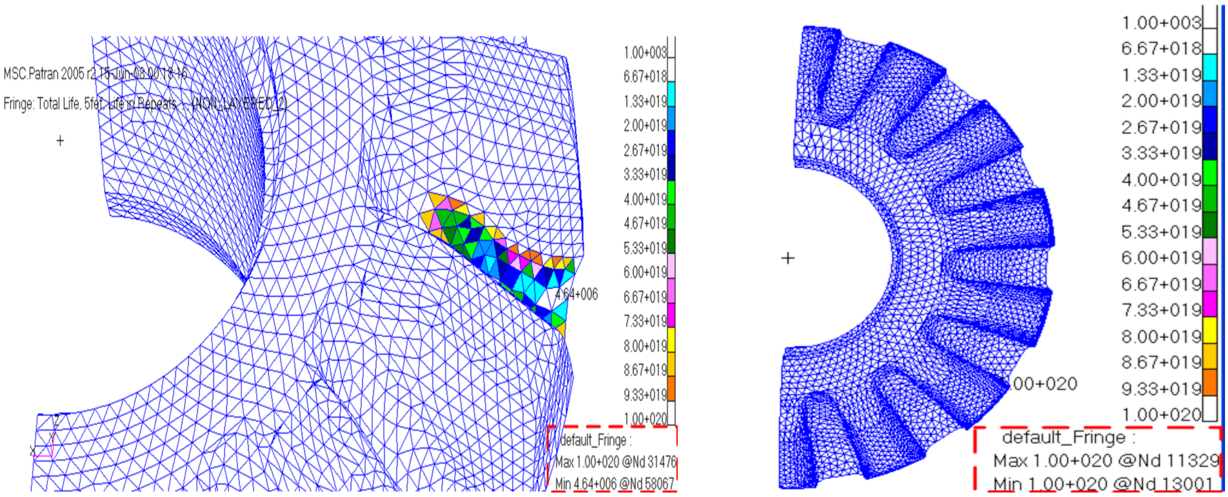
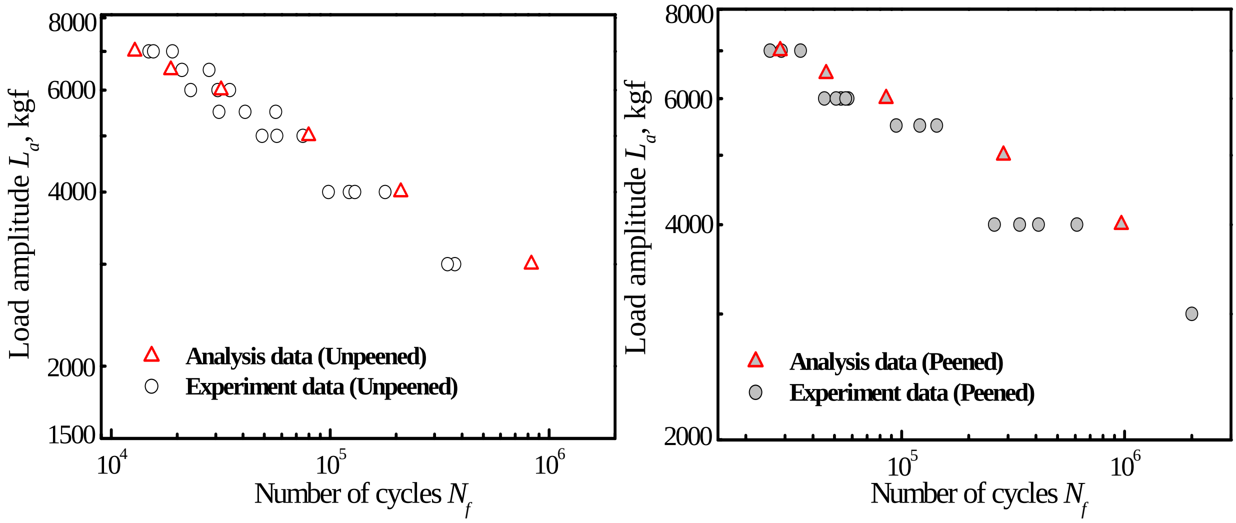


Fig. 4: Stress distribution under the real load condition for bevel gear



(a) Result for unpeened gear (b) Result for optimal peened gear

Fig. 5: Results for fatigue analysis under real load condition (2,200kgf)



(a) Results for unpeened specimen (b) Results for peened specimen

Fig. 6: Comparison between experimental and analysis data

Generally, unlimited fatigue life of machinery parts is considered as 1×10^6 cycles. Therefore, both results of Fig. 5 satisfy the unlimited fatigue life condition. But the peened specimen has more reliability and endurance than unpeened specimen because the various parameters are involved in operating system of the bevel gear in the automobile.

Figure 6 shows S-N data obtained by experiment and fatigue analysis. Analysis data were obtained by using the experimental data of base material and using the finite element stress data of gear. Figure 6(a) and 6(b) show S-N data for unpeened and peened specimens, respectively. The error range between experimental data and finite element data is 20% to 25%, which is not so big difference in view of ordinary fatigue data. The present results show that the life prediction for the peened machinery parts is reasonable by combining the experimental data of base material and fatigue analysis. This fact means that we can reduce the cost for designing the peened parts having the durability.

CONCLUSIONS

From the investigation on the life prediction and fatigue characteristics of optimal peened gear, the conclusions can be summarized as follows:

(1) Optimal peening condition was decided at the 8min of shot peening time under 65m/s of shot velocity and improved the fatigue life of peened specimen about 200%.
(2) From the fatigue analysis using real load data, the fatigue lives of unpeened and peened gear were predicted as 4.64×10^{6} and 1.0×10^{20} cycles, respectively.
(3) From the experimental and analysis data, the fatigue life prediction of peened parts is reasonable and the costs for designing the peened parts can be reduced.

REFERENCE

[1] Dong-Sun Lee, Kook-Jin Lee, Tae-Hyung Kim and Seong-Kyun Cheong, "A Study on the Investigation of Optimal Peening Intensity for Shot Peened Spur Gear", Transactions of the KSMTE, 2004.
[2] Ji-Hun Nam, Tae-Hyung Kim, Kook-Jin Lee, Dong-Sun Lee and Seong-Kyun Cheong, "A Study on the Fatigue Characteristics of Automotive Gear Steel by Investigating the Optimal Peening Intensity", KSAE, pp. 1117~1122, 2004.
[3] Dong-Sun Lee, Tae-Hyung Kim, Jae-Heon Lee, Tae-Kun Lee and Seong-Kyun Cheong, "A Study on the Improvement of Durability of Gear Steel by Shot Peening", International conference of the ANDE, pp. 662, 2005.
[5] Juile A. Bannantine, Jess J. Comer, James L. Handrock, "FUNDAMENTALS OF METAL FATIGUE ANALYSIS", Prentice-Hall, Inc, pp. 1~30, 1990.
[4] "Private Communication," w. s. Lim, 2007.