THE EFFECTS OF SHOT-PEENING ON RESIDUAL STRESSES AND FATIGUE STRENGTH OF CARBURIZED GEAR STEELS

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ABSTRACT

In order to clarify precisely the effects of shot-peening on the fatigue strength of carburized gear steels,residual stresses,retained austenite and hardness in the surface layers before and after shot-peening were investigated in detail and fatigue tests were also conducted using fillet type specimens as a model of gear with two kinds of steels of as carburized and shot-peened. As the results,it is found that tensile residual stresses are formed by oxidation during carburizing treatment. The residual stresses change to compressive one through shot-peening. The maximum values of the compressive residual stresses as well as hardness near the surface layer increase by increasing duration of shot-peening. And it was also found that the fatigue strength is improved remarkably by shot-peening because of the increases of the compressive residual stresses and hardness near the surface layer.The estimated expression for the fatigue limits in the both cases of as carburized and shot-peened is proposed. It is confirmed that the estimated values of the fatigue limits agree well with the experimental ones.

KEYWORDS ; Carburized Gear, Shot-Peening, Fatigue Strength, Residual Stress, Retained Austenite, Hardness

INTRODUCTION

In order to improve the fatigue strength, steel specimens are often processed by such surface treatments as carburizing, shot-peening. But a few research has been published on the detailed data about the distribution of residual stress, retained austenite, and hardness in relation to the fatigue strength caused by these surface treatments[1-5].

The purpose of this study is to clarify the effect of shot-peening on the fatigue strength of carburized gear steels and also to investigate the influence of residual stress, hardness and retained austenite on the fatigue strength caused by shot-peening level.

MATERIALS AND METHODS

(a)SPECIMEN

Specimens used in the present study are alloy steels which are denoted JIS standard. The chemical composition is shown in Table 1. Steels, SCM822 and SNCM420 are indicated by symbol C and N, respectively.

Table 1. Chemical composition

(%)

Material	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
C(SCM822H)	0.22	0.32	0.79	0.023	0.011	0.07	1.04	0.35	0.10
N(SNCM420H)	0.20	0.25	0.69	0.021	0.012	1.61	0.50	0.20	0.13

(b)SHOT-PEENING

Each specimens are carburized in the atmosphere of gaseous butane B_4H_{10}. Effective case depths d_{eff}, as here defined by the depth from the surface which Vickers hardness number Hv indicates 550, of C and N steels are 1.3mm, 0.9mm respectively.

Shot-peening conditions after carburizing are listed in Table 2.The grain size of shot was about 1.5mm. Rockwell hardness number of shot particle was 46-50, shooting velocity was 64m/sec. Shooting duration of maximum 12 minutes was divided into four intervals, from S1 to S4 which mean also shot level, with other condition fixed.

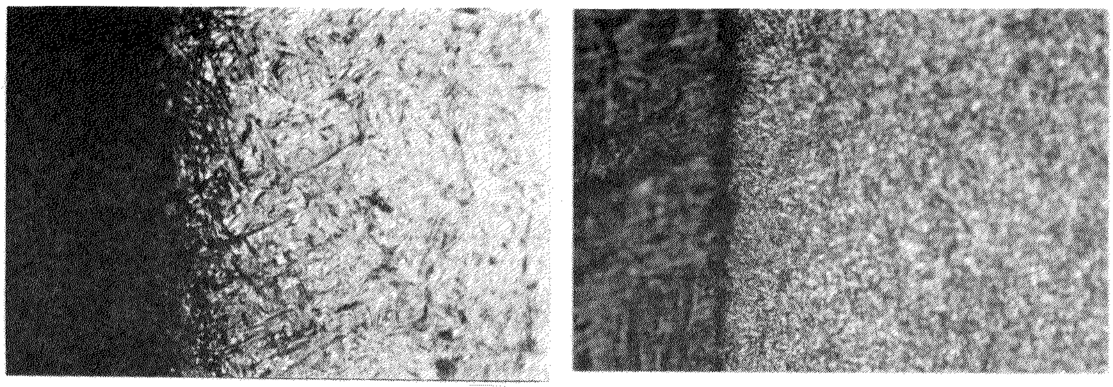
Examples of microstructure near the surface layer of steel C and steel N in both cases of as carburized and shot-peened are shown in Fig.1.

Table 2. Conditions of shot-peening

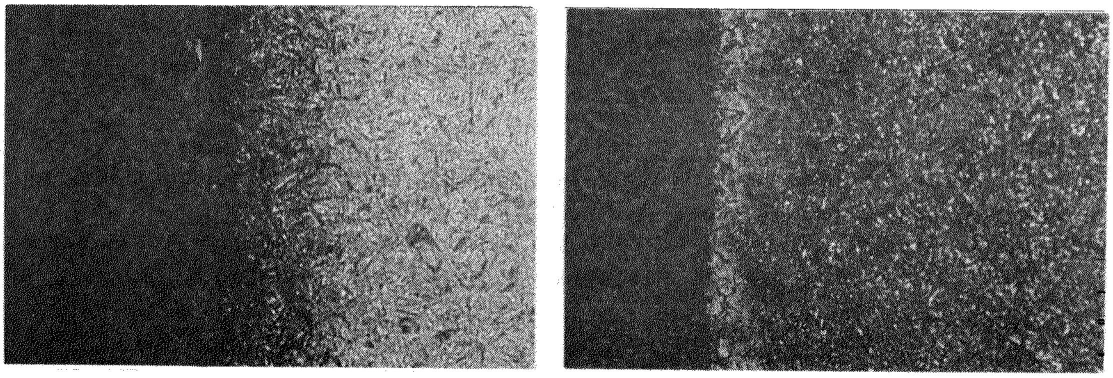
Shot-peening, C(SCM822) deff=1.3 N(SNCM420)deff=0.9			
Level	Arc height A scale (mm)	Coverage(%)	Relative exposure time(ti/tmax)
S1	0.31	80	0.25
S2	0.36	100	0.5
S3	0.41	150	0.75
S4	0.425	200	1.0

deff:Effectivecasedepth, Turn table:1.2m , Shot speed : 64m/sec

Shot size : SB 5,6 , Hardness: HRC 46~50



(a) as carburized (d_{eff}=1.3, steel C) (b) shot-peened (d_{eff}=1.3, S3, steel C)



(c) as carburized (d_{eff}=0.9, steel N) (d) shot-peened (d_{eff}=0.9, S3, steel N)

x 400

Fig. 1 Examples of microstructure near the surface

(c)MEASUREMENTS OF SURFACE CHARACTERISTICS

Residual stresses near the surface layers of carburized and shot-peened steels[6-7] were measured by X-ray diffraction method. The variations of residual stress by increasing shooting duration were measured by $\sin^2\psi$ method[8]. The residual stress distribution along the depth direction were also determined, removing the surface layers by grinding and electrolytic polishing. The stress relief caused by removing the surface layers was corrected by the method of Moore and Evans[9]. And volume fraction of retained austenite was also determined by X-ray diffraction method,with MoKα radiation. Hardness near the surface layers was measured by device of micro-Vickers hardness.

(d)FATIGUE TEST

Configurations and size of fillet type specimens for fatigue test are shown in Fig.2, modeled as one tooth of gear. Fatigue tests were carried out under the condition of cyclic constant loading at an end of thin plate.

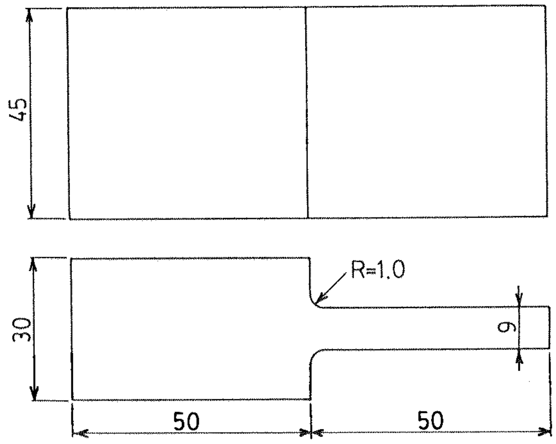
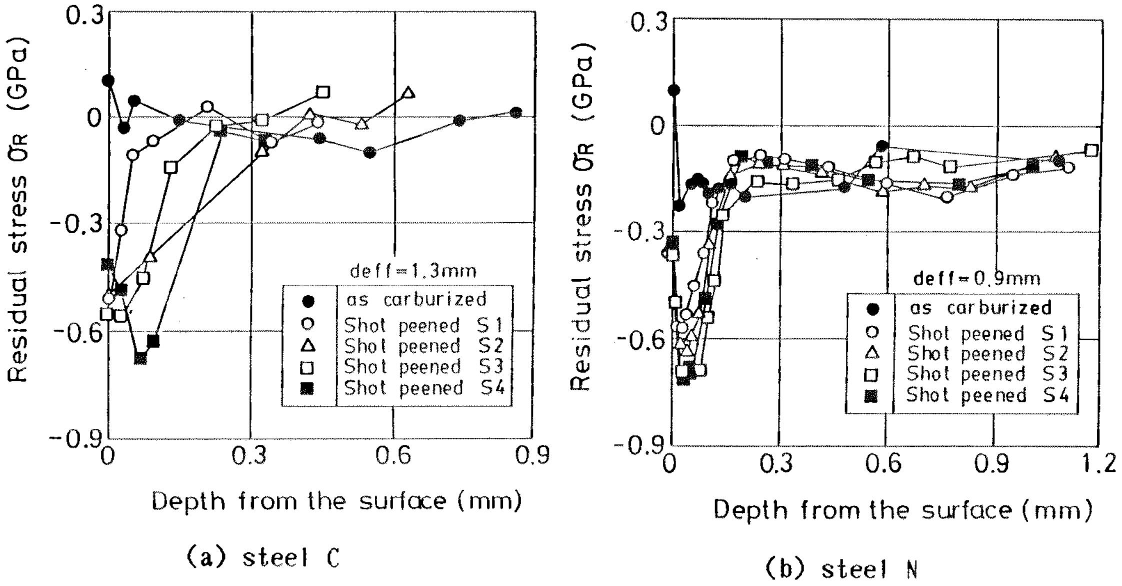


Fig. 2 Configuration and size of specimen for fatigue test

RESULTS AND DISCUSSION

Distributions of residual stress along depth direction of carburizied and shot-peened specimens are shown in Fig.3(a), Fig.3(b).
Both steels,steel C and steel N, have the same tendency of the residual stress distribution. Namely, tensile stresswas observed at the surface layer being



(a) steel C

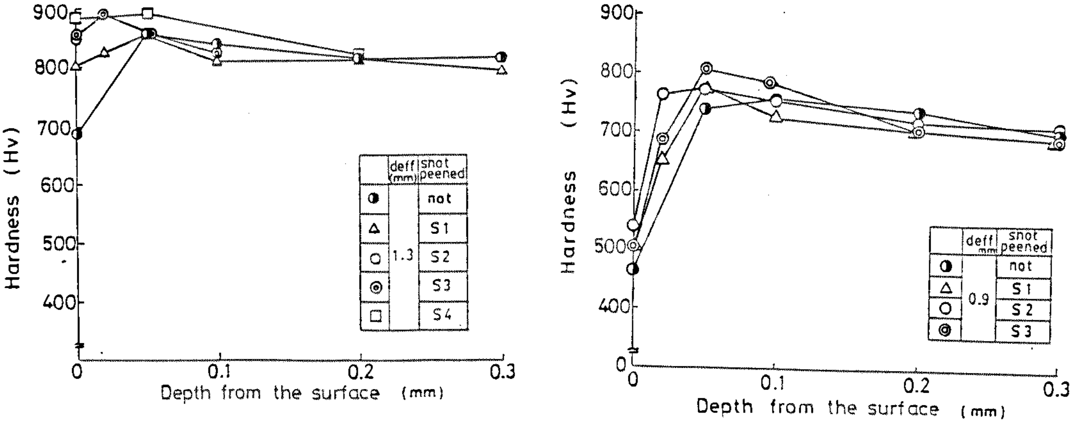
(b) steel N

Fig. 3 Residual stress distributions

formed by intergranular oxidation[2]. But in deeper region, the residual stresses change to compressive abruptly,reach to peak value and then gradually decrease to zero.

By shot-peening, residual stresses near the top surface layer change larger compressive stresses which have maximum values in a little bit deeper layer from the top surface. The larger peak stress values are obtained by longer duration of shot-peening,and the position of peak value also moves to deeper region by longer duration.Variations of hardness distributions along the depth direction by shot-peening are indicated in Fig.4(a),(b) respectively.

Hardness of as carburized steels is softer at the surface layer, being decarburized by intergranular oxidation and show saturated. By shot-peening treatment,surface hardness becomes larger than that of as carburized and the longer shot duration gives larger hardness value.



(a) steel C

(b) steel N

Fig. 4 Hardness distributions

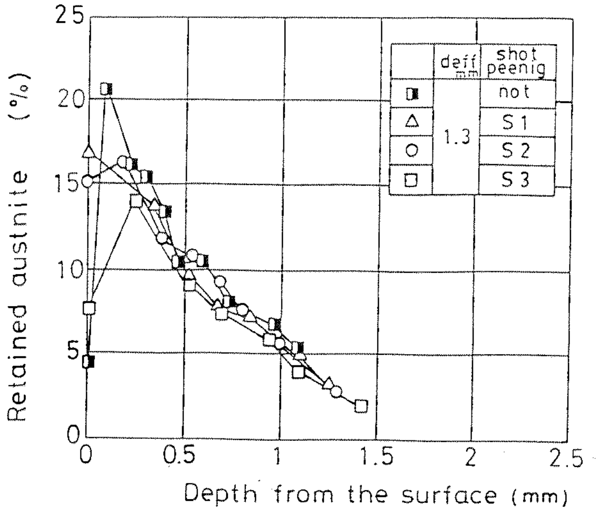


Fig. 5 Retained austenite (steel C)

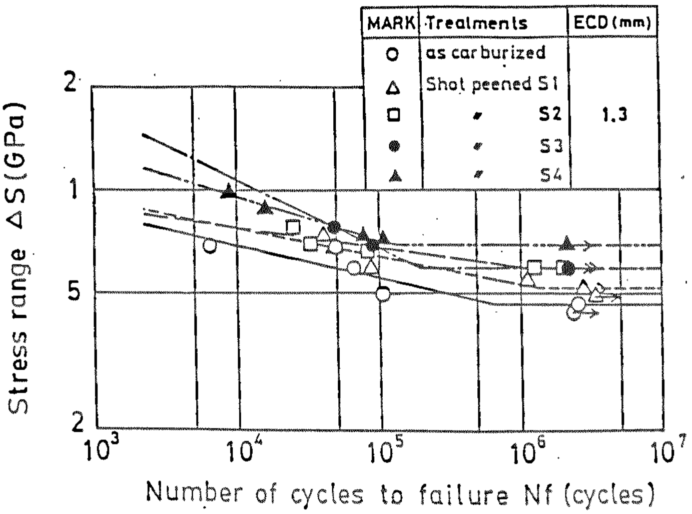


Fig. 6 S-N curves (steel C)

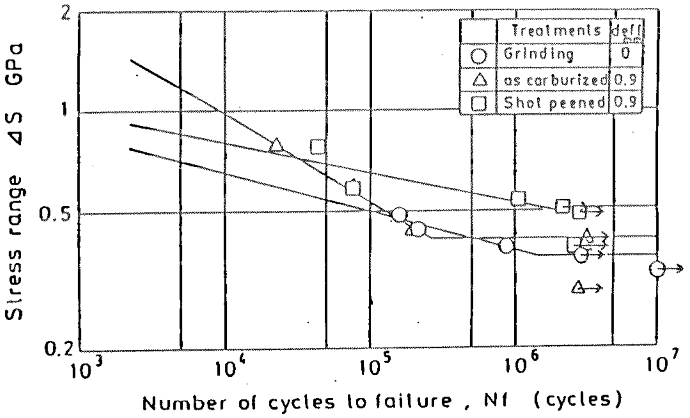


Fig. 7 S-N curves (steel N)

The volume fractions of retained austenite in as carburized steel C are shown in Fig.5. But the top surface layer is exception, where the volume fractions of retained austenite show lower values because of decarburization. Retained austenite shows high volume fraction near the surface and decrease in the deeper region. Retained austenite decreases by shot-peening treatment. The decrement is larger according as the shot duration become longer. Steel N has the similer tendencies of the distributions of hardness and volume of retained austenite as the ones of steel C by shot-peening. Judging from the above results, it is deduced there have occured process hardening near the top surface by shot-peening process.

Fig.6 and Fig.7 show S-N curves for fatigue testing. In each figure, data of as ground without carburizing are also included. The fatigue limits of as carburized happen to decrease than that of as ground because of existance of tensile residual stress in the top surface layer. But by shot-peening, the fatigue limits recover enough to overcome the fatigue limits of as ground and as carburized specimens.

Fig.8 shows relationship between fatigue limits and duration of shot-peening, simultaneously indicates arc height in the right side ordinate. Shot level S2 have shown coverage 100 percentages already. Arc height increased remarkably even by the short duration as S1, but the fatigue limits show a little increase.

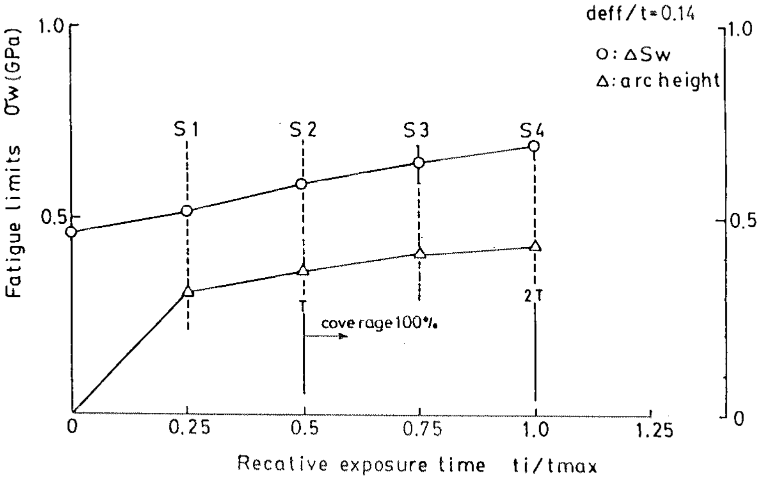


Fig. 8 Relationship among fatigue limits, arc height, and duration of shot peening (steel C)

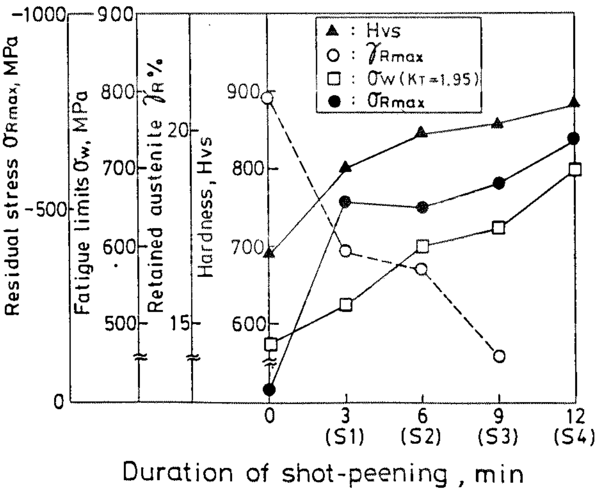


Fig. 9 Mutual relation among fatigue limits, residual stress, retained austenite, surface hardness according to the level of shot-peening (steel C)

Fig.9 shows mutual relation among the fatigue limits, maximum residual stresses, retained austenite, and surface hardness according to the level of shot-peening in the case of steel C. Residual stresses increase abruptly by short duration of shot-peening, but fatigue limits increased a little. Surface hardness become larger due to longer duration of shot-peening, but on the other hand retained austenite degregate contrastively. There is a good relationship between fatigue limits and surface hardness. This indicates that the fatigue limit depends on surface hardness and compressive residual stress and also there will exist opimal shot duration.

Fig.10 shows relationship between the fatigue limits and difference between Vickers hardness near the surface layer Hmax-Hc, here Hmax means maximum Vickers hardness near the surface layer, Hc means core Vickers hardness. It is obvious that the increasing of surface hardness improves the fatigue limit. From Fig.4, Fig.5 and Fig.10, it is affirmed that there has happened process hardening near the surface layer by shot-peening.

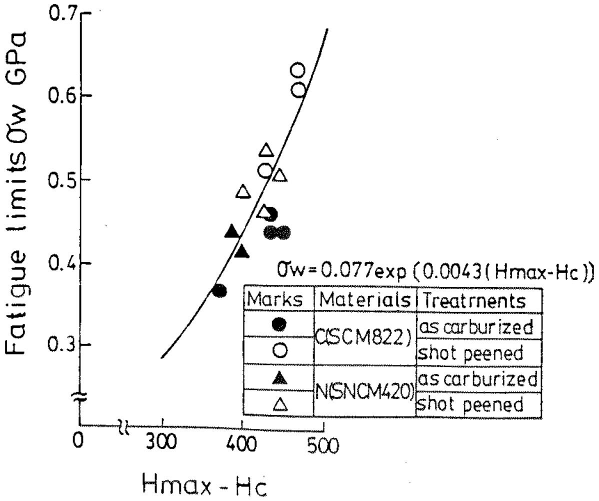


Fig. 10 Relationship between fatigue limit and difference of maximum Vickers hardness and core Vickers hardness

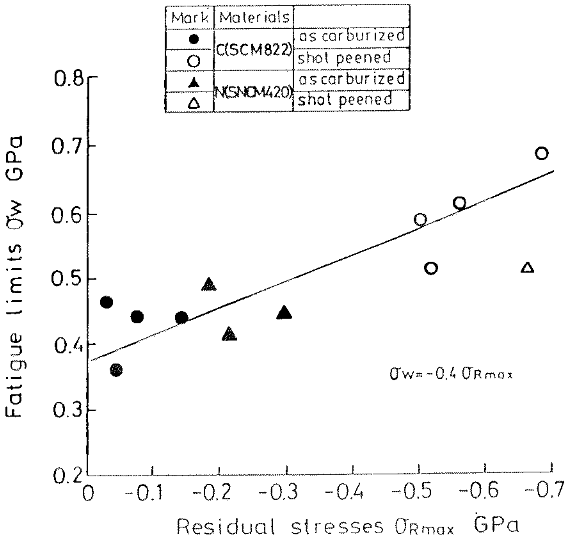


Fig. 11 Relationship between fatigue limit and maximum compressive residual stress

In Fig.11, relation between the fatigue limits and residual stress is indicated. Scattering in relation between the fatigue limits and residual stress is shown slightly,but it is considered the fatigue limits are related by 0.4 times as large as maximum compressive residual stress.

By investigating the results of relation among fatigue limit, hardness, residual stresses, and also assuming that hardness and residual stresses effect on σw independently, it is derived that the estimated fatigue limit σew is expressed by hardness and residual stress, namely.

$$\sigma ew=0.0695+0.0007(Hmax-Hc)-0.4\sigma_{Rmax} \qquad (1)$$

Fig.12 shows relation between the estimated fatigue limits and experimental ones. It is clear that there is a good linear relationship between them within 5 percentage errors generally including other study[4]. But a few data have 10 to 15 percentages errors between estimated and experimental value. This will be due to the scattering of maximum residual stresses.

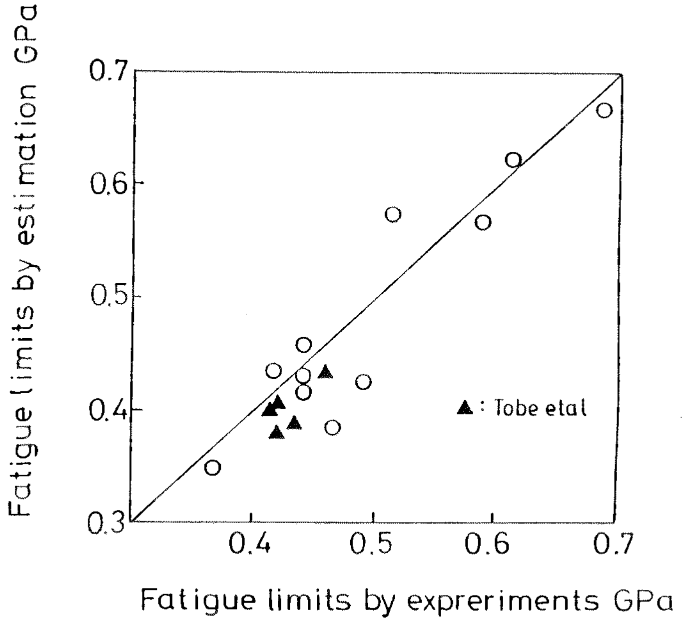


Fig. 12 Relationship between the estimated fatigue limits and the experimental ones

CONCLUSIONS

1. There exist tensile residual stress near the top surface in the case of as carburized specimen because of intergranular oxidation. But by shot-peening surface residual stresses become to indicate compressive ones.
2. The compressive residual stresses near the surface become larger according as the duration of shot-peening become longer. According to above phenomena, surface hardness becomes higher. This is because of surface process hardening. And also volume fraction of retained austenite get to degragate gradually, according as the duration of shot-peening become longer.
3. The carburized gear steels, C and N have similar tendencies of surface characteristics in relation to the fatigue strength before and after shot-peening.

4. The fatigue strength increases by shot-peening mainly because of increment of surface hardness and compressive residual stress. That is why shot-peening at as carburized gear steels is effective method from the point of view of the improvement of the fatigue strength.
5. The formura of the estimated fatigue limit is proposed, and it is confirmed that the estimated values agree well with the experimental ones.

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