OPTIMISATION OF CARBURISING AND SHOT PEENING, IN ORDER TO IMPROVE BOTH BENDING AND CONTACT FATIGUE BEHAVIOUR FOR GEAR APPLICATIONS

C. Peyrac, Jf. Flavenot
CETIM 52 Av. Felix Louat 60304 Senlis

ABSTRACT: Carburised steels are used extensively in the gear industry to improve the wear resistance of parts [1,2]. However, it is well known that shot peening, which creates compressive residual stress, increases the fatigue strength of materials. Combining these two treatments should therefore improve both the bending and contact fatigue strength [3, 4, 5]
This paper presents results obtained for bending fatigue and contact fatigue on a 17NiCrMo6-4 steel after carburising and shot peening. They demonstrate how it is possible to obtain a 50% to 70% improvement in the fatigue strength (bending fatigue) without affecting the fatigue contact behaviour.
The results initially obtained on a test specimen are then confirmed by a test performed on gears that have received similar treatment.

KEYWORDS: gears, carburised steel, shot peening, residual stress, fatigue bending, contact fatigue

I. AIM OF STUDY

The aim of the study is to optimise combined surface treatments (case hardening and shot peening) in order to improve the bending fatigue strength and contact fatigue strength of gear teeth. The purpose is not to simply determine the influence of shot peening on a previously defined case hardening treatment, but to go a step further by proposing a case hardening treatment which is especially adapted to the shot peening that is to be carried out subsequently, in order to optimise the entire treatment procedure (case hardening and shot peening). The characteristics of the various treatments are determined by the retained austenite content, the hardness and residual stress profiles, and the surface roughness.

II. MATERIAL AND TREATMENTS

The material is a 17NiCrMo6-4 steel subjected to two carburising and three shot peening treatments. The details of the treatment and an analysis of the results (retained autenite determined by DXDE [6,7] and residual stress determined by X Ray diffraction) are given in tables 1 and 2.

Table 1: Description of the two treatments carried out

T1	T2
3 hrs at 920°C Plateau at 850°C Oil quenching at 60°C Tempering for 2 hrs at 150°C	3 hrs at 960°C Oil quenching 60°C Tempering for 2 hrs at 150°C

The respective characteristics of each shot peening treatment are given below:

G1: steel shot, BA 300, Almen Intensity F 25-30A, coverage rate 150%
G2: steel shot, BA 800, Almen Intensity F 55-60 A, coverage rate 150%
G3: ceramic shot, Z 150, Almen Intensity F 10-15N, coverage rate 400%

The main characteristics obtained after the above treatment is carried out are summarised in table 2. The residual stresses (σmax) and retained austenite (γ%) profiles are given in figures 1 to 4.

Table 2: Comparison of the results of 3 shot peening treatments after 2 case hardening treatments

Shot peening	Heat treatment	Depth modified by G (μm)	γ% on surface	γ % converted	σ max (MPa)	Ra (μm)	Rt (μm)
/	T1	/	24.7	/	-300	0.86	7.47
	T2	/	36.8	/	-300	0.73	7.06
G1	T1	100	5.7	19.0	-1450	0.67	5.35
	T2	100	14.9	21.9	-1350	0.69	5.98
G2	T1	200	12.1	12.6	-980	0.7	6.4
	T2	200	22.2	14.6	-930	0.81	6.04
G3	T1	50	9.2	15.5	-1330	0.63	5.47
	T2	50	20.6	16.2	-1300	074	6.7

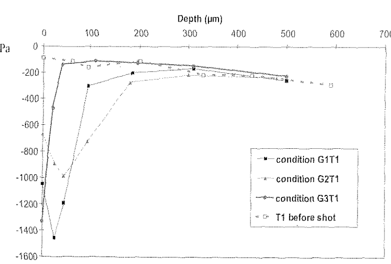


Figure 1: Comparison of stress profiles obtained for the 3 types of shot peening after T1.

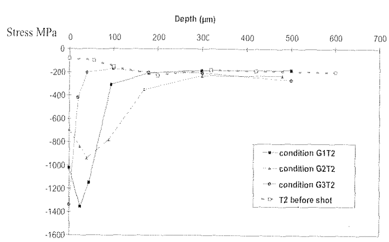


Figure 2: Comparison of stress profiles obtained for 3 types of shot peening after T2.

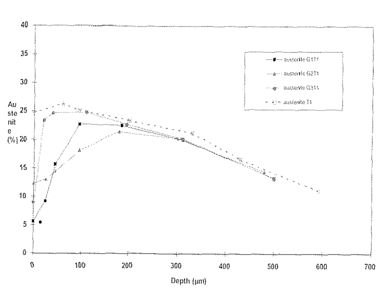


Figure 3: Comparison of in-depth austenite profiles after 3 shot peening treatments on T1 treated specimen.

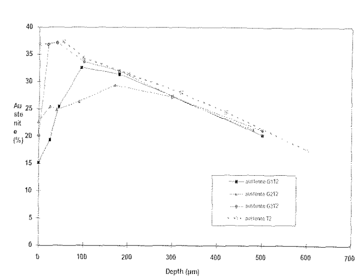


Figure 4: Comparison of in-depth austenite profiles after 3 shot peening treatments of T2 treated specimen.

These results show that a higher initial austenite content does not result in higher compressive stress after shot peening. The stress profiles obtained, however, depend to a large extent on the shot peening conditions applied:

- The two shot peening treatments G1 and G2 result in conventional profiles with maximum stress in the subsurface layer (30-50 µm).
- G3 shot peening (ceramic shot) results in a particular type of profile with high stress levels (-1300 MPa) on the extreme surface, but affecting a very small depth (50 µm).

The final austenite content after shot peening, on the other hand, is very different, but the initial difference obtained in relation to the different case hardening conditions is nevertheless maintained, which means that in the case of both heat treatments (T1 and T2), shot peening converts the same amount of austenite (about 16%)

III. FATIGUE TESTS

Two different kinds of tests were performed: four-point bending test (representative of tooth root bending), and rolling contact fatigue (representative of gear contact)

III. 1.Bending Fatigue

a) Test Conditions

The geometry of the test samples is given in figure 5.

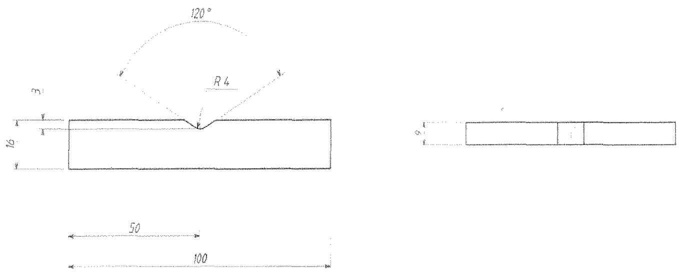


Figure 5: Geometry of test samples

The tests conditions are as follows: Fatigue strength determination by means of the "staircase" method with an electrohydraulic fatigue machine, R=0,1, Frequency = 30 Hz

Table 3: Comparison of fatigue strength obtained for the different combined treatments

Shot peening	Thermal Treatment	Fatigue strength (MPa) 10^7 cycles	Improvement %
/	T1	550	/
	T2	500	/
G1	T1	800	45
	T2	645	30
G2	T1	780	42
	T2		
G3	T1	970	76
	T2	860	72

b) Results

The tests were performed on specimens having undergone various combined treatments (carburising and shot peening). The fatigue strength (10^7 cycles) values obtained are given in table 3.

c) Conclusion of bending fatigue tests

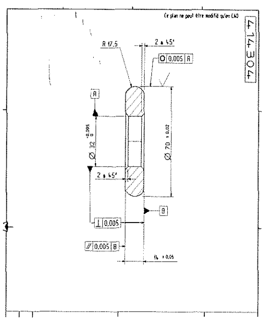
The results show that without shot peening, a higher retained austenite rate leads to a lower fatigue strength. As can be expected, after shot peening, regardless of the type of heat treatment or shot peening used, there is an increase in the fatigue strength due to the presence of high compressive residual stress. However, an increase in the fatigue strength largely depends on the shot peening conditions, and, to a lesser extent, on the initial carburising. It can be noted that the increase in fatigue strength is related to the level of compressive residual stress generated by shot peening. Nevertheless, G3 shot peening using ceramic balls, which leads to compressive stress levels similar to those of G1 peening, improves the fatigue strength to a much greater extent. This is due to two factors:

1) G3 shot peening with ceramic balls leads to maximum compressive stress on the surface, whereas other types of shot peening result in more conventional profiles with maximum compression at a depth of about 30 to 50µm. During bending, the stress level is highest on the surface.
2) A better surface finish seems to be obtained with G3 shot peening, which eliminates machining scratches. This is certainly due to the high coverage rate.

III. 2 .Rolling Contact Fatigue

a) Test Conditions

The test carried out is a standard rolling test in which the two test specimens (sown in figure 6) roll over each other, at a given pressure and a given slip rate.



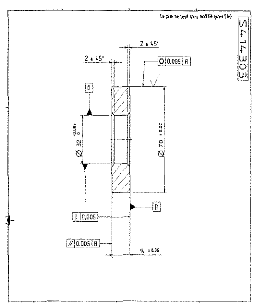


Figure 6:

Geometry of curved specimen — Geometry of plane specimen

The tests are performed under the following conditions: slip rate 20 %; curved specimen speed: 2684 rev/min; plane specimen speed: 3353 rev/min; lubrication: Mobil Gear 629 oil. The tests are stopped at $3 \cdot 10^7$ cycles, and the failure criterion is flake detection.

b) Results

Tests were carried out under the conditions described above for the following combined treatments: T1, T2 - G1T1, G1T2 - G3T1, G3T2

✔ *Effect of carburising*

Figure 7 compares the results obtained for rolling contact fatigue on a specimen without shot peening. They demonstrate the effect of carburising and, more particularly, the effect of retained austenite.

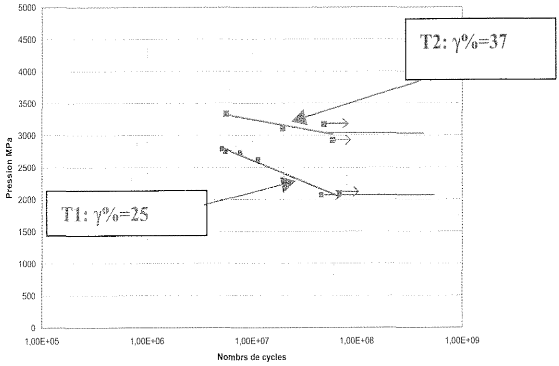


Figure 7: Contact fatigue test results without shot peening

The results obtained show that when the retained austenite increases, the rolling fatigue contact behaviour improves. This corresponds to what is to be expected. More precisely, it can be seen that the fatigue strength after 3.10^8 cycles increases from 2000 MPa to 3000 MPa when the retained austenite rate increases from 25% to 37%. This is a very significant improvement.

✔ *Effect of shot peening*

Figures 8a and 8b compare the results obtained for rolling contact fatigue with different types of shot peening for each heat treatment (T1, T2).

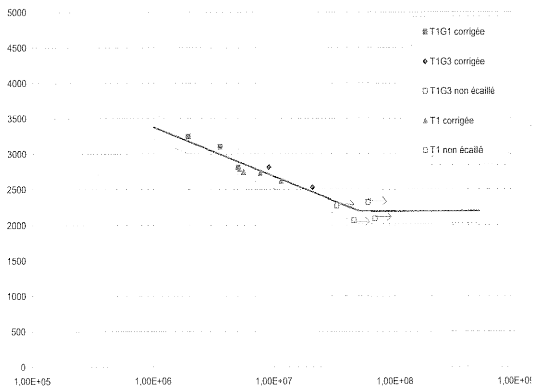


Figure 8a: Effect of different shot peening conditions after T1 heat treatment (T1, T1G1, T1G3)

It can be noted that for each type of carburising, the shot peening conditions have no significant effect on the contact fatigue.

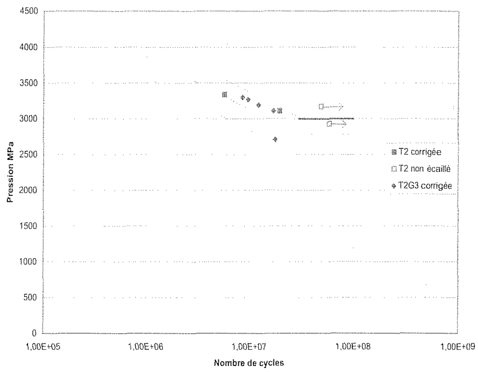


Figure 8b: Effect of different shot peening conditions after T2 heat treatment T2, T2G3)

In fact, figures 8a and 8b show that the results lie along the same line, regardless of the shot peening conditions applied. This can be explained by the high pressure applied to the specimens during testing, which can result in hardening, which in turn leads to elastic shake down.

IV. BENDING TEST ON GEARS

The same treatment (carburising and G3 shot peening) was performed on real gears, tested on a teeth bending fatigue machine using the "staircase" method.
The test conditions were as follow: R = 0,1, Frequency = 20 Hz, Test end-point = 3.10^6 cycles, and 15 teeth tested / gear

IV. 1.Results

The results obtained for the gears are given in figure 9 and compared in table 4 with those obtained for the test specimens.

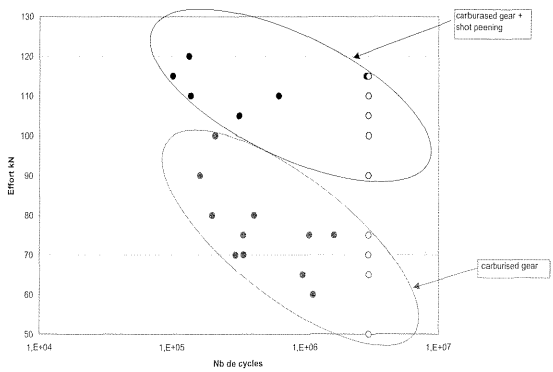


Figure 9: Results of teeth bending fatigue for gears

Table 4: Comparison of bending fatigue results for gears and test specimens

Treatment	Bending Fatigue strength 3.10^6 cycles (gears)	Bending Fatigue strength 3.10^6 cycles (samples)
Carburised	511 MPa	510 MPa
Carburised + Shot peening	786 MPa	871 MPa
improvement %	54%	70%

A comparison of the results shows that:

1) In the case of carburising, the same bending fatigue strength values were obtained for both the test specimens and the gears, which means that the bending test carried out with test specimens is representative of bending tooth behaviour.
2) The application of shot peening leads to a lower increase in the bending fatigue strength for real gears (54% for gears and 70% for test specimens). This can be explained by the fact that shot peening is easier to carry out and is more precise in the case of a notched test specimen than it is for the tooth root of a gear.

Nevertheless, the 54% improvement obtained for the gears is very good result.

V. CONCLUSION

The fatigue tests carried out on specimens having undergone combined treatments (carburising + shot peening) lead to the following conclusions:

- The initial retained austenite rate does not influence the residual stress profiles, because shot peening converts the same amount of austenite (20%)
- **In bending fatigue**, the fatigue strength is greatly improved when carburising is combined with shot peening. In the particular case of ceramic balls (with a coverage rate of 400%), improvement can be as high as 70%. For steel shot (coverage rate of 150%), the improvement is 30 to 40%. With G3 shot peening conditions, the improvement in the case of real gears is 54%.
- **In contact fatigue**, the results do not show any improvement or deterioration in the contact fatigue behaviour. All the results lie along the same line in the fatigue diagram. Subsequent shot peening does not change the contact fatigue behaviour.

All the above tests and results lead to the conclusion that it is possible to improve gear behaviour by using combined treatment (carburising and shot peening).

REFERENCES

(1) "Influence des traitements mécaniques sur la résistance à la fatigue." HP. Lieurade, JF. Flavenot, Journées de Printemps 1987 SF2M Paris
(2) "Spécification technique pour les traitements thermiques des engrenages." Extraits de CETIM - Informations N°102, 108, et 119
(3) "Effect of shot peening on the fatigue strength of carburised steels."K. Naito, T. Ochi, T. Takahashi, N. Suzuki, Proceeding of ICSP4, pp 519-526
(4) " Effect of shot peening on the pitting fatigue strength of carburized gear."M. Kobayashi, K. Hasegawa, Proceeding of ICSP4, pp 465-475
(5) " Optimization of the fatigue strength of heat treated steels as a consequence of an optimum state of the surface and subsurface layers after shot peening." A.Sollich, H. Wohlfahrt, Proceeding of ICSP6
(6) "Doser rapidement l'austénite résiduelle avec précision." F. Convert, B. Miège, Colloque RX et Matière, Editions de Physique, PYC Edition, 1995
(7) "La diffraction de RX au service des engrenages – Analyse des contraintes et dosage de l'austénite." F. Convert, 4ème Congrès Mondial des Engrenages et des Transmissions de Puissance, 1999