THE 7th INTERNATIONAL CONFERENCE ON SHOT PEENING — ICSP 7 — INSTITUTE OF PRECISION MECHANICS WARSAW, POLAND

COMBINING CASE HARDENING AND SHOT PEENING FOR GEAR STEELS: INFLUENCE ON RESIDUAL STRESS

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ABSTRACT : *Carburised steels are largely used in the gears industry to improve the wear resistance of parts. 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 fatigue flexion strength and the fatigue contact strength. Several specimens were treated in an industrial furnace, and it was demonstrated that it is possible to obtain two* ***retained austenite contents*** *(23% and 37%) under industrial conditions. The specimens were shot peened under three conditions. In the first part, we show the influence of the initial austenite content on the final residual stress and austenite levels after shot peening. The different residual stress distributions, obtained after the three shot peening treatments, are compared. The results of the fatigue flexion and fatigue contact tests should allow the optimum combined treatment to be defined (carburising + shot peening).*

KEYWORDS : gears, carburised steel, shot peening, residual stress

INTRODUCTION

Surface treatments to improve the fatigue resistance of mechanical parts have developed considerably over the last few years. In the particular case of gears, case hardening is the main surface treatment used at the present time.
The aim of surface treatments is twofold: to improve the mechanical surface properties through hardening, and to improve fatigue strength through the introduction of residual compression stresses (1). However, the specifications, particularly in the field of gears, allow a maximum retained austenite content of 25% (2).
To achieve high levels of residual compression stress and hardness, without exceeding the required austenite content, it is possible to combine case hardening and shot peening treatments.
Shot peening converts the austenite into martensite, thus reducing the austenite content, and increasing the compression stress by increasing the volume of martensite with respect to that of the austenite.
Some of the literature shows that this type of treatment, when applied to gears, can considerably influence the fatigue strength (3, 4, 5).
The study presented here shows the results obtained for a 18NCD6 steel to which two case hardening treatments were applied, T1 and T2, and 3 shot peening treatments, G1, G2 and G3.

I – AIM OF STUDY

The study is aimed at optimising combined surface treatments (case hardening and shot peening) in order to improve the fatigue flexion strength and contact fatigue strength of gear teeth.

It is not designed to simply determine the influence of shot peening on a previously defined case hardening treatment, but to take matters a step further by proposing a case hardening treatment which is specifically adapted to the shot peening 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 STUDIED AND TREATMENTS CARRIED OUT

An initial phase was aimed at validating the homogeneity of a case hardening treatment in an industrial furnace involving forty or so test specimens distributed throughout the furnace.

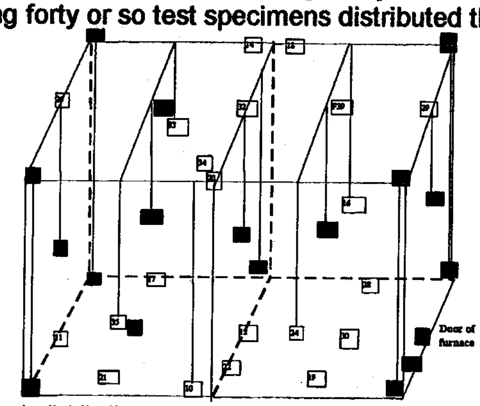

Figure 1: distribution of test specimens in a case hardening furnace

Figure 1 shows the distribution of the test specimens. Table 1 gives the results of the retained austenite content measured on the surface and in the subsurface layer of the specimens.

Table 1: Results of the retained austenite content measured for selected specimens.

Reference n°	Surface Austenite (%)	Subsurface layer (%)	Difference (%)
R1	23.4	23.0	0.4
R2	23.1	23.2	0.1
R3	21.7	23.2	1.5
R4	22.8	23.3	0.5
R5	21.9	21.4	0.5
R6	23.1	23.0	0.1
R7	20.2	20.5	0.3
R8	22.3	23.6	1.3
R9	22.1	22.2	0.1
13	21.4	22.9	1.5
15	22.5		
23	22.5	22.5	0
25	22.3		
27	21.9	21.8	0.1
31	22.2	23.0	0.8
Average	**22.2**	22.6	
Standard deviation	**0.8**	0.9	

The study shows that the dispersion in terms of retained austenite content was very low.
During the second phase, heat treatments were developed to produce two different austenite contents (a conventional austenite content and a higher austenite content).
Specimens (discs with a diameter of 70 mm and thickness of 10 mm) were taken from a 18NCD6 steel, ground (Ra = 0.8 µm) and treated in an industrial furnace according to one of the two treatments described in table 2.

Table 2 : Description of the treatment carried out

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

Three shot peening treatments were then applied to the case hardened specimens. The respective characteristics of each of the shot peening treatments are given below:

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

III - RESULTS

A – Test specimens after case hardening

For each of the two case hardening treatments, T1 and T2, the residual stress profiles were determined by X-ray diffraction (6) and the retained austenite profiles were obtained using the DXDE technique developed by Convert et al (7, 8). The HV1 microhardness profiles were also determined. The corresponding curves are given in figures 2 to 7.

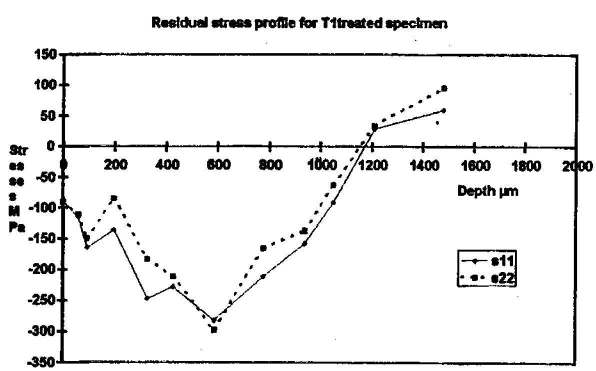

Figure 2 : Residual stress profile obtained for T1 treated specimen

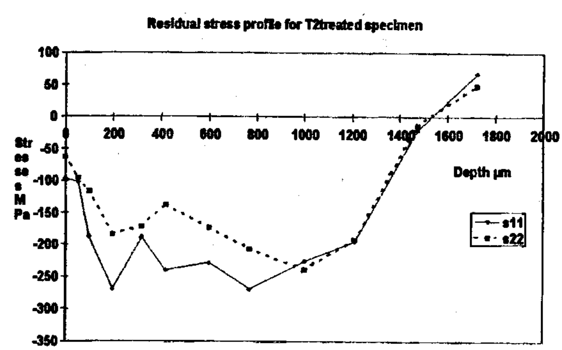

Figure 3 : Residual stress profile obtained for T2 treated specimen

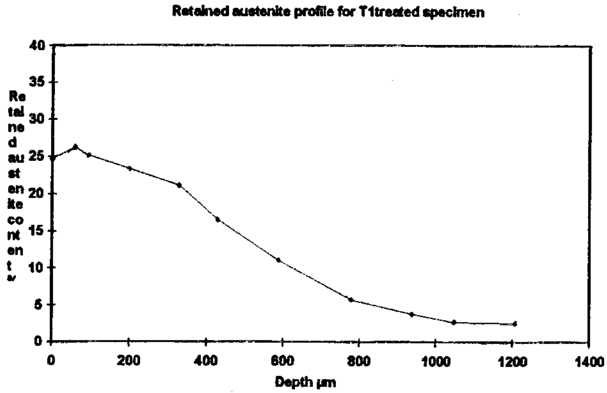

Figure 4 : Retained austenite profile obtained for T1 treated specimen

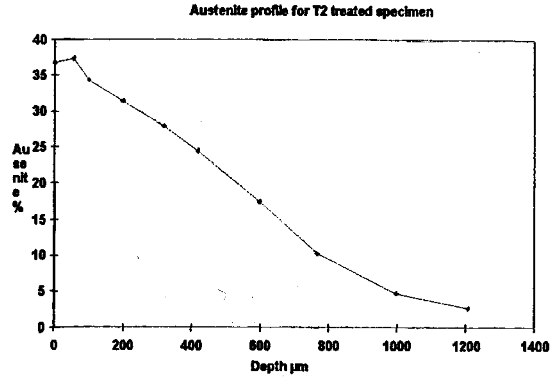

Figure 5 : Retained austenite profile obtained for T2 treated specimen

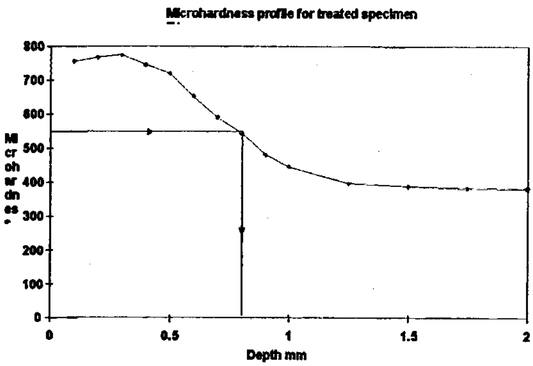

Figure 6 : Vickers microhardness profile obtained for T1 treated specimen

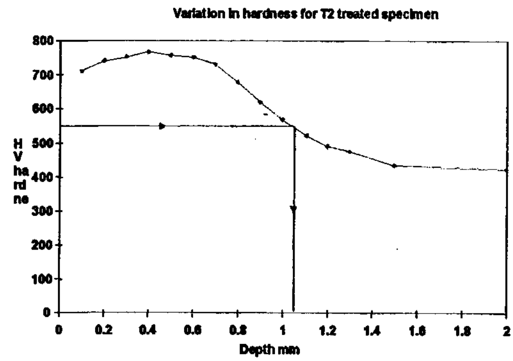

Figure 7 : Vickers microhardness profile obtained for T2 treated specimen

The T1 treatment, which corresponds to the treatment usually applied, therefore results in a retained austenite content on the surface in the order of 25%. The hardness profile indicates high values on the surface (750 HV) and a case hardened depth of 0.8 mm.

The residual stresses resulting from case hardening are compression stresses up to a depth of 1.1 mm reaching a maximum level of –300 Mpa at a depth of 0.6 mm.

The retained austenite content obtained with the T2 treatment is in the order of 37% on the surface. The residual stresses and hardness levels are identical to those obtained with the T1 treatment. However, since the case hardened depth is greater for the T2 treatment (≈ 1.05 mm), the thickness of the layer under compression stress goes from 1.1 mm for T1 to 1.5 mm for T2.

All the results are summarised in table 3.

Table 3 : Comparison of treatments T1 and T2

Treatment	Austenite content on surface	Depth of case hardening	Maximum stress
T1	25 %	0.8 mm	-300 MPa
T2	37 %	1.05 mm	-300 MPa

B – Specimens after case hardening and shot peening

After each T1 and T2 case hardening treatment, three shot peening treatments G1, G2 and G3, are carried out.
The corresponding test specimens are assigned the references G1T1, G2T1, G3T1, G1T2, G2T2 and G3T2. The variation in the austenite content, the distribution of residual stress and the roughness were then measured.

B.1 – Conversion of austenite

Figures 8, 9 and 10 compare the in-depth austenite profiles before and after shot peening for each of the two treatments T1 and T2.

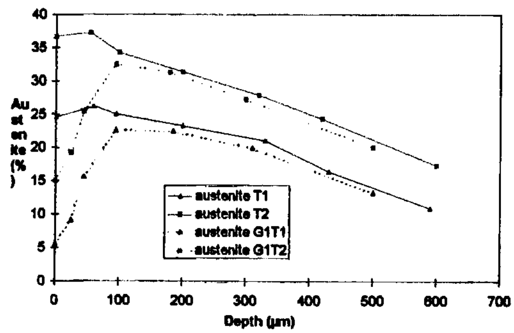

Figure 8 : In-depth austenite profile, before and after G1, for treatments T1 and T2

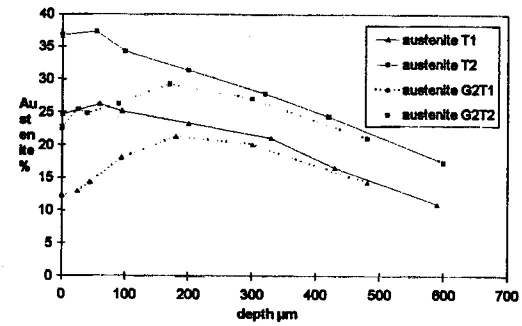

Figure 9 : In-depth austenite profile, before and after G2, for treatments T1 and T2.

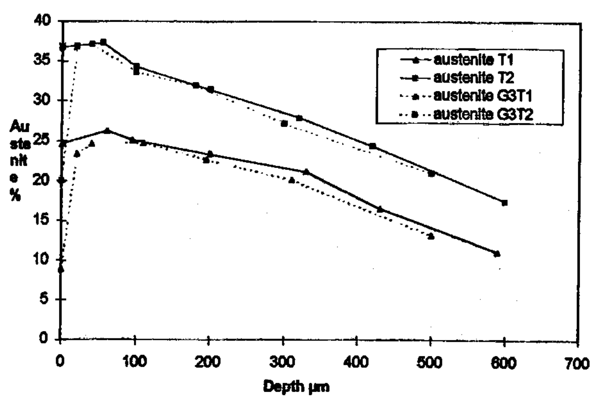

Figure 10 : In-depth austenite profile before and after G3, for treatments T1 and T2

An examination of the above curves shows that conversion of the austenite only takes place up to a limited depth. After that, the austenite profile after shot peening is identical to that of the initial profile.
The depth to which the austenite is converted is strongly influenced by the shot peening conditions. This is illustrated in figures 11 and 12 below.

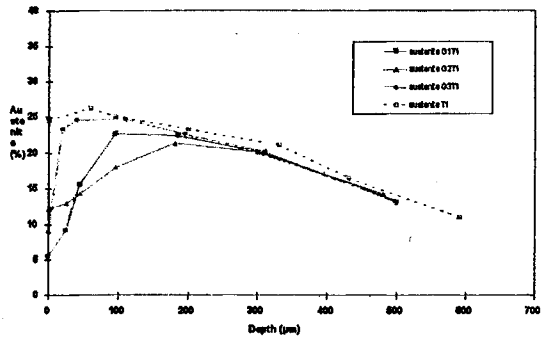

Figure 11 : Comparison of in-depth austenite profiles after 3 shot peening treatments on T1 treated specimen.

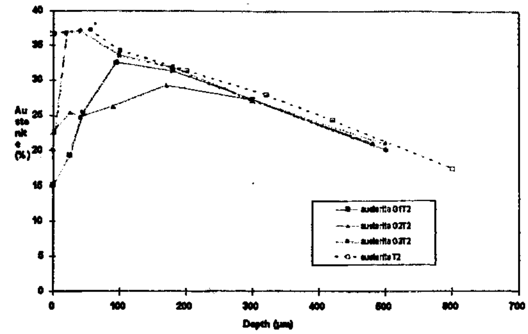

Figure 12 : Comparison of in-depth austenite profiles after 3 shot peening treatments of T2 treated specimen.

It can also be seen that, for the two case hardening treatments, T1 and T2, whose retained austenite content profiles are staggered, similar staggering is obtained after shot peening. This means that, whatever the case hardening treatment used, that is, whatever the initial retained austenite content, the percentage of converted austenite is identical for a given shot peening treatment.
As a result, shot peening test specimens with a high austenite content (37%) does not mean that a greater amount of austenite is converted into martensite.
This is demonstrated in table 4 below which also shows the depth of the austenite conversion zones.

Tableau 4 : Comparison of the percentage of austenite converted on the surface for two types of case hardening treatments and three shot peening conditions

Shot peening	Treatment	γ % converted on the surface	γ (µm) conversion zone
/	T1	/	/
	T2	/	/
G1	T1	19.0	100
	T2	21.9	100
G2	T1	12.6	200
	T2	14.6	200
G3	T1	15.5	50
	T2	16.2	50

B.2 – Residual stress profiles

Figures 13, 14 and 15 show the residual stress profiles obtained after shot peening T1 and T2 treated specimens.

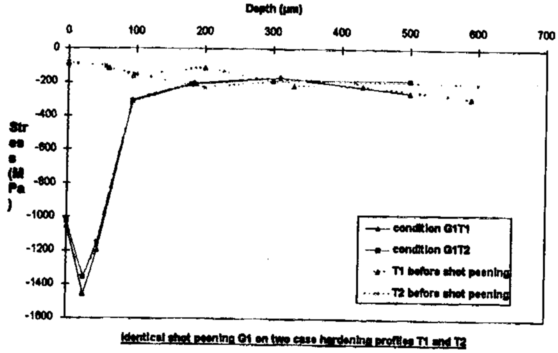

Figure 13 : Comparison of stress profiles obtained for G1 shot peening after T1 and T2

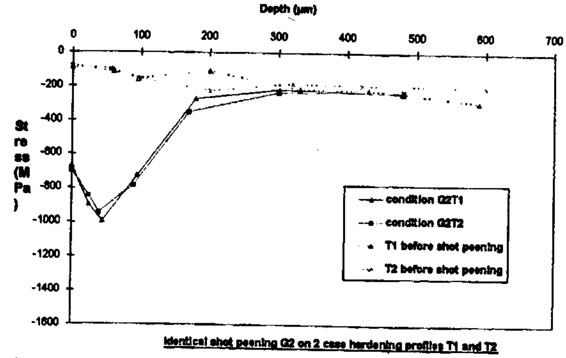

Figure 14: Comparison of shot peening profiles obtained for G2 shot peening after T1 and T2

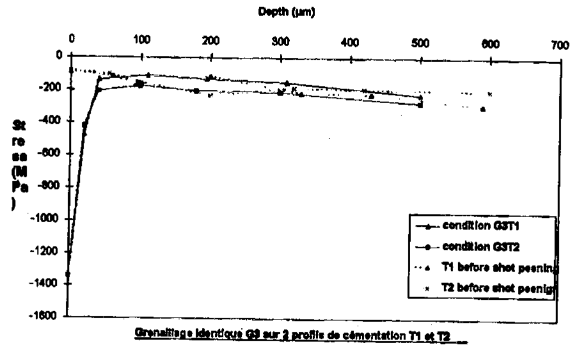

Figure 15 : Comparison of shot peening profiles obtained for G3 shot peening after T1 and T2

The curves show that, up to a depth of 500 µm, the same residual stress profile is obtained for a given shot peening treatment regardless of the initial case hardening treatment. This is explained by the fact that the same percentage of austenite is converted into martensite and that, up to this depth, the initial residual stress profile is comparable for both treatments.
However, the different shot peening treatments result in very different profiles, both with respect to the level of stress and the shot peened depth. It can be noted that the maximum compression stress increases with the converted retained austenite content.

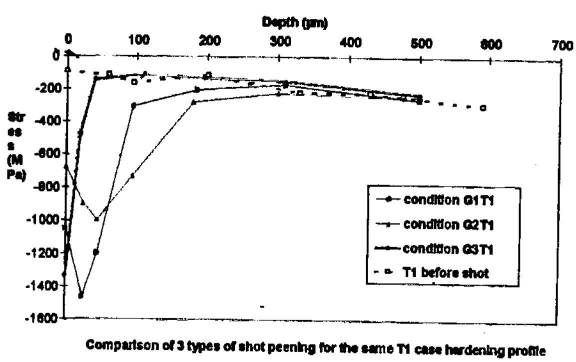

Figure 16 : Comparison of stress profiles obtained for the 3 types of shot peening after T1.

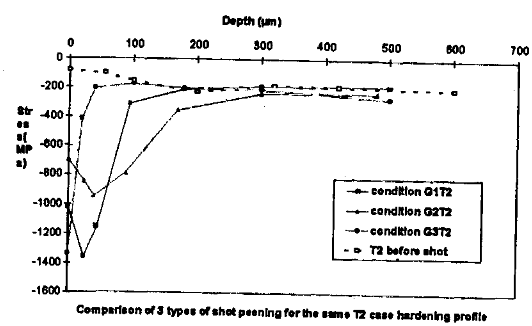

Figure 17 : Comparison of stress profiles obtained for 3 types of shot peening after T2.

The following paragraph gives a summary of the different results in order to ascertain the optimum case hardening/shot peening treatment conditions.

IV – ASCERTAINING THE OPTIMUM COMBINED TREATMENT

Table 5 compares the main characteristics obtained for the two case hardening treatments and three types of shot peening.

Table-5 : 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

These results show that a higher initial austenite content does not result in higher compression stress after shot peening. The final austenite content after shot peening, on the other hand, is very different, but the initial difference obtained by the case hardening conditions is nevertheless maintained.

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.
- 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 surface roughness measurements show that, after shot peening, the figures are slightly lower than after case hardening, regardless of whether T1 or T2 treatment is used, or G1, G2 or G3 shot peening.
The different shot peening conditions studied here result in similar types of surface roughness.

V - Conclusion

The results obtained in terms of the residual stress and austenite profiles are not sufficient to define an optimum combined treatment with regard to the fatigue strength.
The operating resistance of gears, which involves not only contact fatigue, but also flexion fatigue, depends on the combined effects of the hardness, austenite and residual stress, either on the surface or in the subsurface layer. Given the complexity of the mechanisms which are brought into play by combining the different profiles obtained, only fatigue tests will enable the optimum treatment to be defined.

Flexion fatigue tests on notched specimens, representative of a tooth root, and contact fatigue tests will be conducted to test the different combined treatments presented here and quantify the influence of the different factors mentioned above on the fatigue strength.

Acknowledgements

The authors would like the thank HIT and SFGP who carried out the heat treatments and shot peening respectively.

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