Shot Peening of Carburized Gears. Influence of Main Shot Peening Parameters.

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Abstract

Damage on gears is mainly due to fatigue in fillet radii of teeth roots or pitting near the pitch diameter.

No to little available articles in existing literature clearly show the influence of main shot peening parameters on life time of shot peened gears. Furthermore most available articles are devoted to fatigue in fillet radii which seems to be the most important factor of field failure.

This paper is based on a bibliographical research and tries to gather all pertinent information concerning the main shot peening parameters that could be used to determine the characteristics of a shot peening applied on a gear.

Results of the Research

All materials are carburized and tempered with a surface hardness of 60-62 HRc. The difficulty of the research laid in the fact that very often, in existing literature, more than one shot peening parameter was changed from one experiment to another yielding to the impossibility of isolating each individual main shot peening parameter.

I) Influence of Shot Peening on Physical Properties

I-1) Surface Roughness after Shot Peening

Reference: Table 1 and 2 and Figure 3

Due to high hardness of surface, the shot peening parameters have little to no effect on surface roughness. A slight increase can be observed after shot peening, the harder the shot the greater the increase.

If surface roughness is different from one part to another, increasing the shot peening time will tend to make the surface finish uniform.

I-2) Surface Hardness After Shot Peening

Reference: Figures 4, 5, and 6

Hardness will increase with shot peening time. This increase is more effective for the layers located near the surface (Figure 4). Magnitude of increase is between 100 and 250 Hv.

Surface hardness seems to be independent of shot peening intensity (Figure 5).

The maximum hardness in sub-surface (Figure 6) can be explained by the fact that the maximum stress is also in subsurface and hardness increase, in hard steel, is directly related to compressive stresses.

I-3) Surface Tolerance After Shot Peening

On a general standpoint, shot peening will slightly increase the thickness of the shot peened surface. In the case of gears with a hardness of a minimum of 58 HRc this increase is less than 0,01 mm.

I-4) Transformation of Austenite into Martensite

Reference: Figures 7 and 8

This transformation increases with shot peening intensity and time. It seems at given intensity, that the smaller the shot diameter, the greater the transformation but this point needs to be confirmed. This transformation, being done with volume increase, will create additional beneficial compressive stresses.

II) Influence of Shot Peening on Stress Distribution

II-1) Residual Stresses After Shot Peening

Reference: Figures 9, 10 and 11

Shot peening induces compressive stresses in the subsurface mainly due to the Hertz pressure. Maximum stress is located below the surface at a distance between 0,01 to 0,03 mm; its value mainly depends upon the mechanical properties of the material and in smaller proportion upon the shot peening parameters.

The thickness of the compressive layer, for a given material, is a function of the shot peening intensity; with standard shot peening characteristics and hardness of about 60 HRc, this layer is between 0,1 and 0,3 mm thick.

II-2) Influence of Shot Diameter at Constant Intensity

Reference: Figure 12

At a given shot peening intensity, the maximum stress increases with the decreasing of shot diameter.

This can be explained by the fact that the surface of the impact decreases with the shot diameter and thus the Hertz pressure increases; this pressure increase will also increase the plastic deformation which will increase the compressive stresses.

II-3) Influence of Shot Hardness

Reference: Figures 9 and 11

The stress distribution and the maximum stress value is strongly dependent upon the hardness of the shot. The shot hardness must be as close as possible and, if possible, greater than the hardness of the gear to be shot peened.

The higher the shot hardness the greater the maximum stress value and the gradient of the stress distribution.

II-4) Influence of Shot Peening Intensity at Constant Shot Diameter

Reference: Figures 10 and 13

With a given shot diameter, the value of the maximum stress increases slightly with the shot peening intensity. This can be explained by the increase of the Hertz pressure; the influence of the intensity is nevertheless less important that the shot diameter. Using the formula: P=F/S, one can see that increasing the intensity will increase F but also S although with a given intensity F is constant but S will increase with the shot diameter. The thickness of the compressive layer will greatly increase with the shot peening intensity.

II-5) Stress Relaxation After Loading

Reference: Figures 14 and 15

Residual compressive stresses partly relax during the first cycles of loading; this important factor is very seldom taken into consideration. The relaxation is much more important in the axial direction than in the tangential one; this relaxation can reach 50% of initial values.

III) Influence of Shot Peening on Fatigue Life of Fillet Radius

If it is well known that shot peening increases fatigue life of gears it is unfortunately impossible to mathematically calculate the percentage of life increase. From available data it can be reasonably stated that life will increase, at constant load, by 2 to 5 times. Test on pitting have shown a 28 time increase.

III-1) Influence of Shot Peening Intensity

Reference: Figures 16 and 19

Fatigue life will increase with increasing shot peening intensity to reach an optimum then decrease. This law seems to be valid for all shot peenable materials. In Figure 16 the maximum fatigue life is given for an Almen intensity of F38 A (15A).

III-2) Influence of Shot Peening Coverage

Reference: Figure 20

Percentage of coverage will have little influence on fatigue life as long as initial shot peening time will yield to saturation of the material. Figure 20 shows that if coverage is increased from 200 to 600%, fatigue life will increase by only 9%. In other words, it can be stated that if fatigue life obtained with 200% coverage is not sufficient, shot peening will not be able to solve the problem and another material will have to be used or the part will have to be redesigned.

IV) Influence of Shot Peening on Fatigue Life of Gear Subjected to Pitting

Reference: Figure 18

As very few articles are devoted to shot peening of gears subjected to pitting it was not possible to clearly show the influence of the main shot peening parameters on the fatigue life. Test presented in [11] were performed on gears made of CrMo steel of following composition:

C	Si	Mn	P	S	Ni	Cr	Mo	Cu
0.24	0.24	0.89	0.015	0.008	0.11	0.13	0.21	0.12

With following properties:

	Carburized	Carburized & shot peened
Superficial hardness	752 HV	835 HV
Carburized depth	0.7 mm	0.7 mm
Heart Hardness	35 HRC	35 HRC
Surface Stress	-270 MPa	-330 MPa
Maximum Stress	-490 MPa	-990 MPa

At 2 x 10^7 cycles fatigue strength increases after shot peening by a factor of 1,35. With a Hertz pressure of 3200 MPa on pitch diameter, fatigue life is increased by 28.

V) Relationship between Stress Distribution and Fatigue Life

This study, although yet incomplete, tried to show the influence of main shot peening parameters on **Stress Distribution** and **Fatigue Life**. The questions that one can ask are:

1. Is there a correlation between the stress distribution and the fatigue life?
2. Can the quality of the shot peening be deducted from the stress distribution?

Answers to both questions are not simple.

If fatigue tests and stress distributions have been made in parallel on same sample batches in recording all the important parameters, one may say that it is possible from this data to predict the fatigue life performance of another batch of same gears by looking at the stress distribution obtained after shot peening; on the other hand, and yet for the same parts the stress distribution may show only crude mistakes in the shot peening treatment.

If no fatigue tests results are available it is next to impossible to predict the fatigue life performance by only knowing the stress distribution; in some cases it may help to detect big errors in the shot peening treatment. This assessment is confirmed by the data given in Figure 17 and the curves 1, 2, and 3.

The values of the the surface stress vary from 1000 to 1250 MPa, maximum stresses vary from 1150 to 1380 MPa. The profile of the curve 3 is very different from the curves 1 and 2 and 1 is also different from 2. Looking at fatigue tests results one can see that, despite the fact that the stress distributions and stress values are different, fatigue lives are identical:

79% for 1 • 79% for 2 • 75% for 3

The best fatigue life improvement (110%) has been obtained with profile 4(!) using aluminum oxide. It would have been interesting to know the results with profile 5 also using aluminum oxide. It can be bet it would have given the best performance!

Conclusion

Main field breakages come from fillet radius fatigue failures or pitting on thoot flanks. It is now well known that shot peening will improve fatigue life of the gears but a lot of work remains to be done yet to clearly understand and monitor the whole process. When defining the shot peening parameters one has to take into consideration the fillet radii and the surface roughness to determine, at first, the shot size. In some extreme cases a shot blasting will have to be performed prior to any heat treatment in order to improve the surface finish so it can be compatible with the available shot sizes.

Almen intensity will have to be as high as possible and compatible with a normal breakage rate to avoid abnormal percentage of broken shots. Coverage should not exceed 200% to maintain price at a reasonable level.

If one really wants to know the fatigue life improvement after shot peening there is only one good solution:

Proceed to Fatigue Tests!

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TABLE 1 [6]

Material: 16 CD 4 Superficial Hardness: 62 HRC

	Shot Peening	Ra	Rt
	NO	0.56	-
S 230	BA 600-62 HRC	0,78	5,5
S 230	RA 600-64 HRC	1,42	15
S 330	BA 800-46-51 HRC	0,67	7
S 170	BA 400-53-55 HRC	0,86	7
S 110	BA 300-62 HRC	0,85	14
S 70	BA 180-46-51	0,61	6.5

TABLE 2 [4]

MODULE	SHOT PEENING	HARD.(HV)	Rt	Ra	GAIN %
3	NO	563	7,6	0,7	-
3	BA 600-54/58HRC (S230)	703	9,0	0,9	36
5	NO	620	8,0	0,74	-
5	BA 600-54/58HRC (S 230)	735	14,2	1,3	41
5	BA 600-54/58HRC + GLASS BEAD	722	11,1	1,1	43
5	BA 800-48/52HRC (S330)	702	10,5	1,1	22
8	NO	501	8,4	0,83	-
8	BA 600-54/58HRC (S230)	684	13,7	1,3	33

FIGURE 3 [7]

Abott curve showing the convergence of surface finishes with shot peening time .

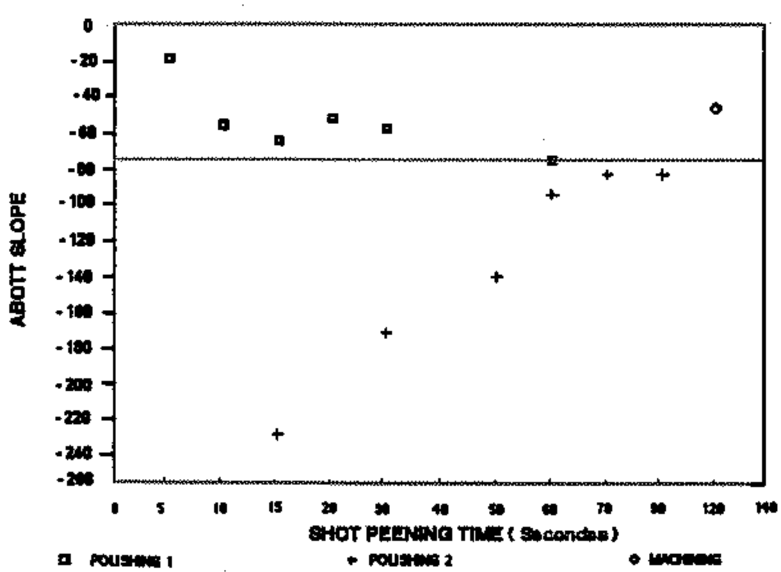
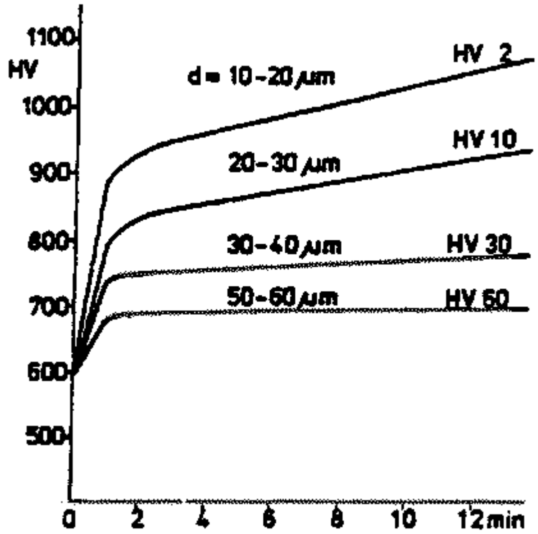
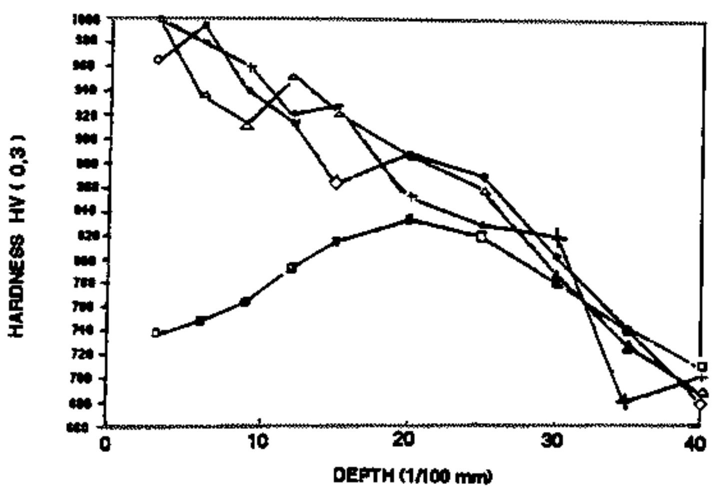


FIGURE 4 [9]



Influence of shot peening time on hardness at different depths of penetration of the diamond. Hardness increases with time for the layers close to the surface.
Hardness of deep layers is independant of time

FIGURE 5 [7]

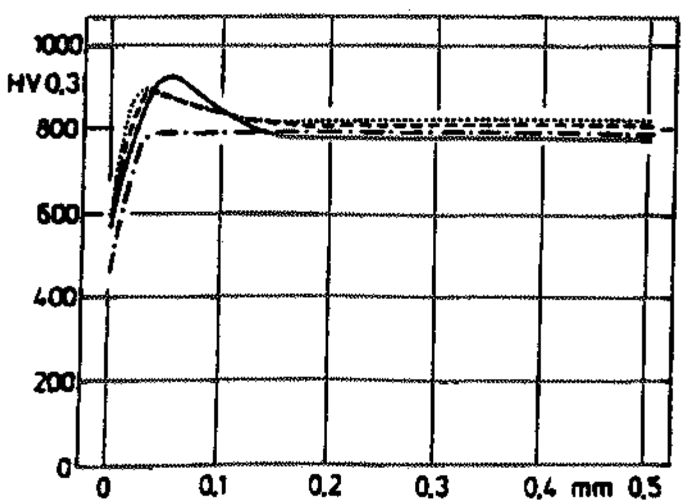


Superficial hardness in function of shot peening intensity.

- □ Without shot peening
- + Intensity = F 27 A (11 A)
- △ Intensity = F 33 A (13A)
- ◇ Intensity = F 41 A (16A)

Superficial hardness is independant of shot peening intensity

FIGURE 6 [4]

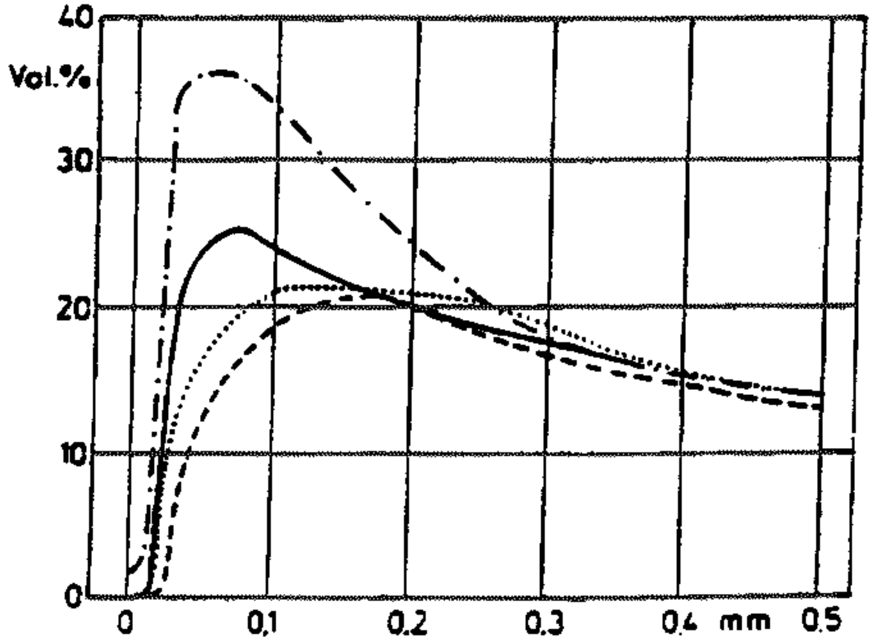


Hardness Hv function of depth for different shot peening conditions.

Hardness is maximum in sub-surface due to the fact that compressive stress is also maximum in sub layer.

- – · – Without shot peening
- ...... BA 800 48-52 HRc (S 330)
- —— BA 600 54-58 HRc (S 230)
- --- BA 600 54-58 HRc + Glass bead

FIGURE 7 [4]



Transformation of austenite into martensite .
Residual austenite in volume in function of depth

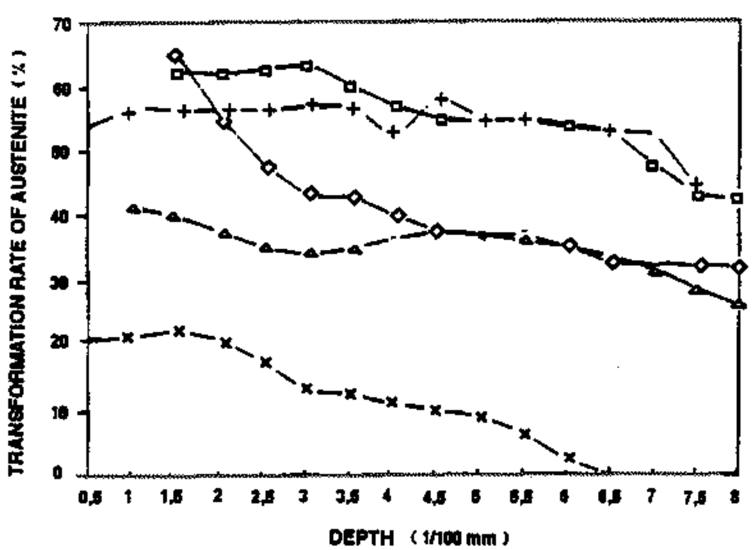
— · — Without shot peening

.... BA 800 48-52 HRc (S330)

——— BA 600 54-58 HRc (S230)

---- BA 600 54-58 HRc + glass bead

FIGURE 8 [7]



Transformation rate of austenite into matensite in function of depth and for different shot peening intensities.

+ Intensity = F 28 A (11A)

△ Intensity = F 31 A (12A)

◇ Intensity = F 35 A (14A)

× Intensity = F 38 A (15 A)

□ Intensity = F 41 A (16A)

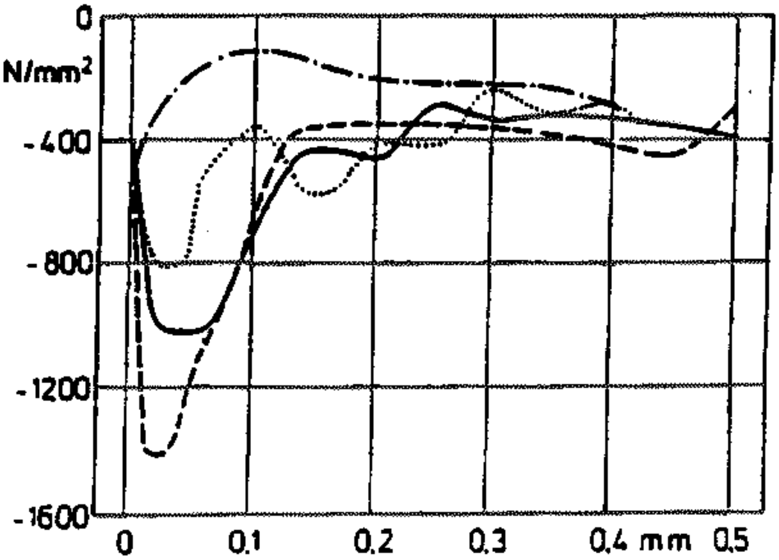


FIGURE 9 [5]

Stress distribution in a gear module 5, 23 teeth, in 16 MnCr5, carburized, quenched and tempered.

- – – Whithout shot peening
- .... BA 800 48-52 HRc (S330)
- —— BA 600 54-58 HRc (S330)
- --- BA 600 54-58 HRc + glass bead

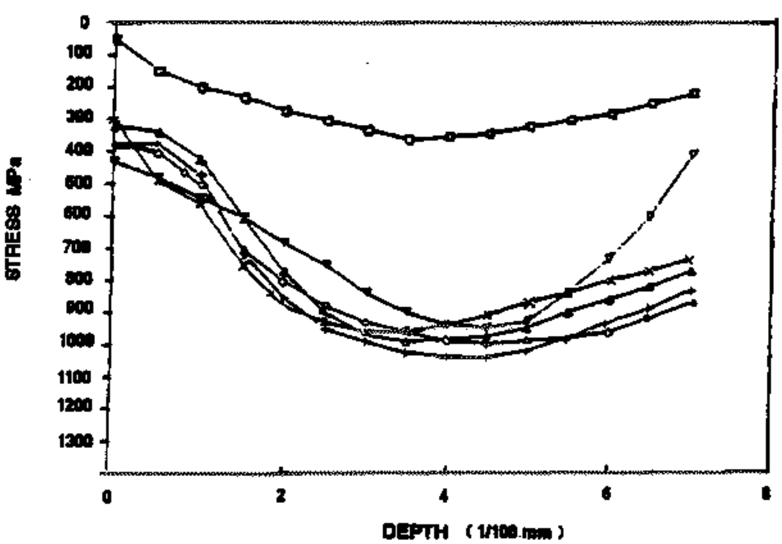


FIGURE 10 [7]

Stress distribution in samples in 27 MC5, carbonitrated,oil quenched and shot peened at different intensities.

- □ Without shot peening
- + Intensity = F 41 A (16A)
- ◇ Intensity = F 38 A (15A)
- △ Intensity = F 35 A (14A)
- × Intensity = F 31 A (12A)
- ▽ Intensity = F 28 A (11A)

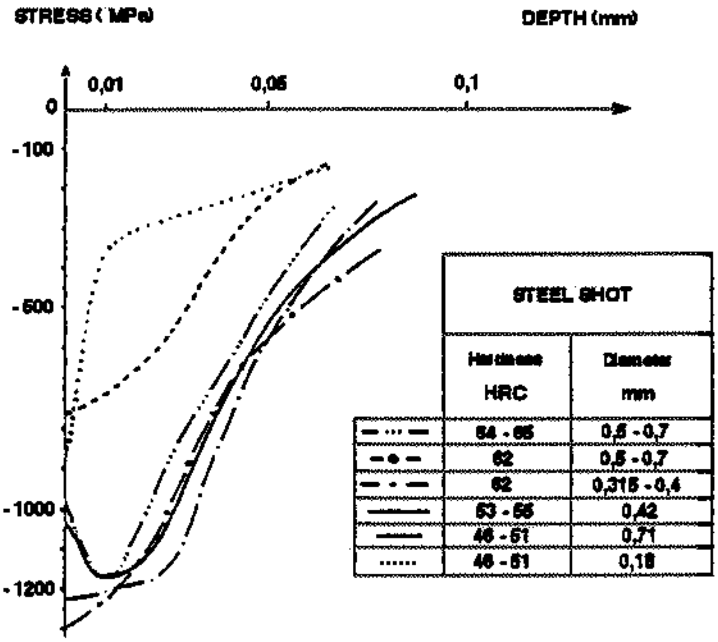


FIGURE 11 [6]

Stress distribution in samples in 16CD4, carburized,oil quenched and shot peened with different shots.

The relative part/shot hardness has a main influence on the stress values and distribution.

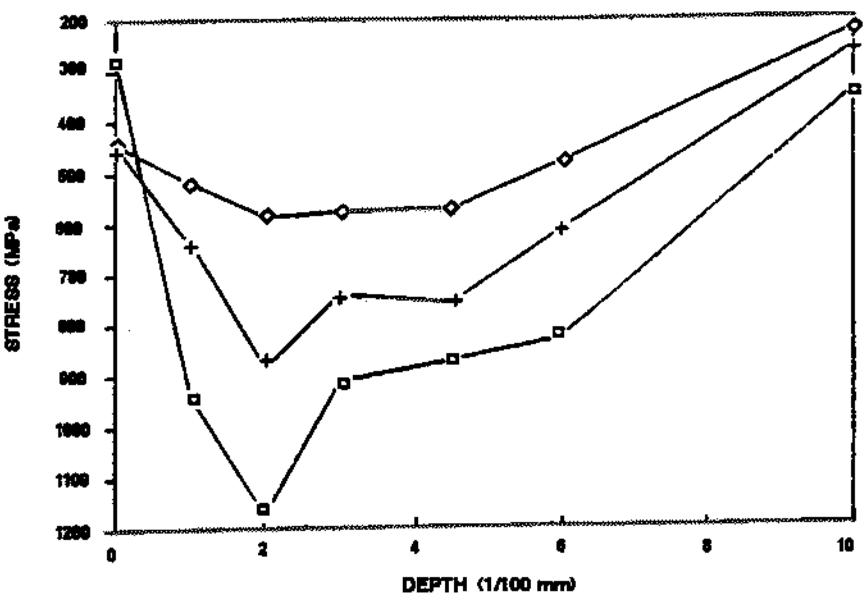


FIGURE 12 [7]

Stress distribution, at constant intensity, for different shot diameters.

□ BA 400 (S170)

+ BA 600 (S230)

◇ BA 800 (S330)

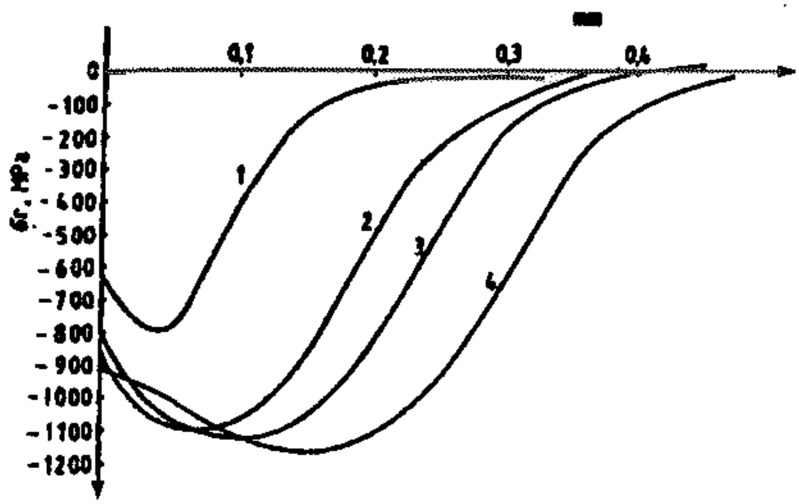


FIGURE 13 [3]

Depth of the compressive layer for different shot peening intensities

Curve	Intensity	Depth
1	F 20 A	0,23 mm
2	F 37 A	0,36 mm
3	F 50 A	0,40 mm
4	F 65 A	0,50 mm

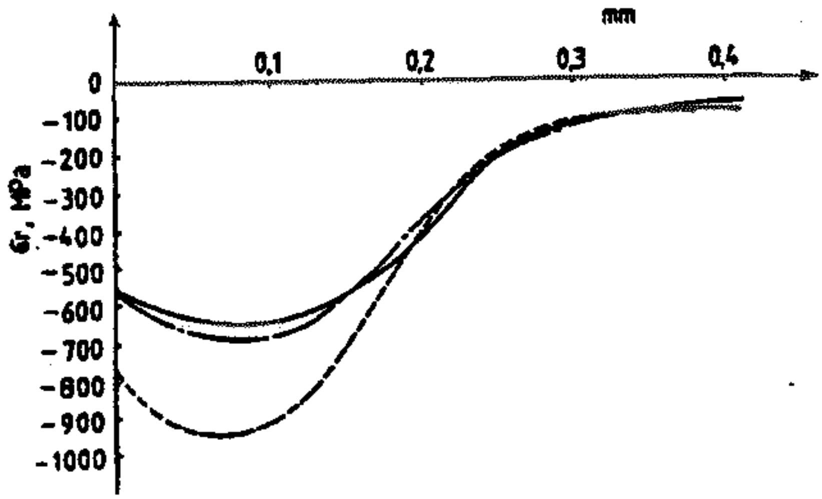


FIGURE 14 [3]

Stress relaxation after loading

--- After shot peening

— · — After 1 to 3 cycles

—— After 100.000 cycles

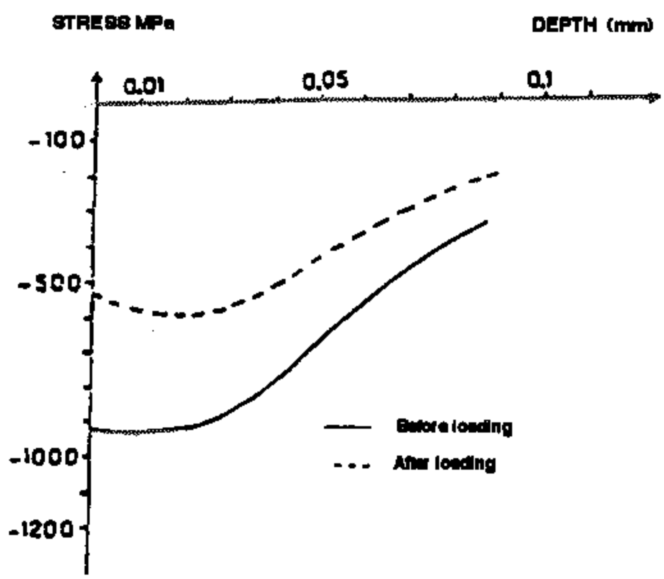


FIGURE 15 [8]

Stress relaxation on gears after severe loading from RNUR

Maximum stress has lost 37% of initial value.

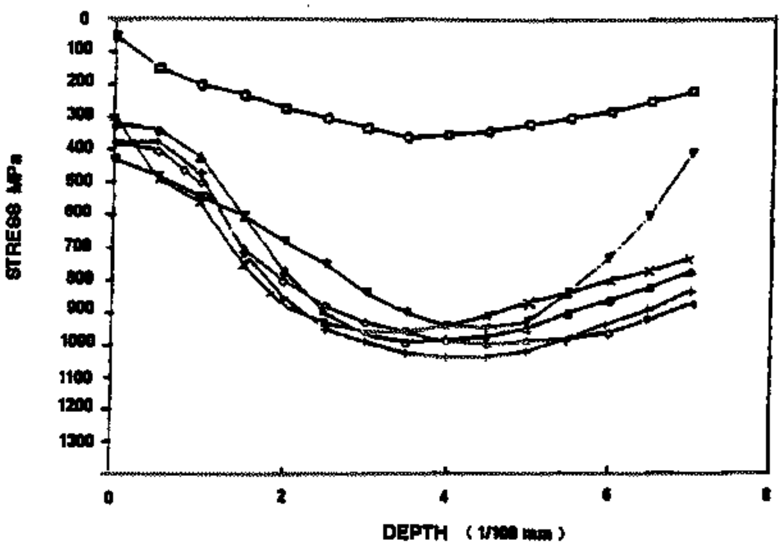


FIGURE 16 [7]

Table giving the percentage of fatigue life improvement for different shot peening intensities with a shot BA 400 (S170) 58 HRc.

	INTENSITY	GAIN %
+	F 41 A	15,3
◇	F 38 A	18,5
△	F 35 A	12,8
×	F 31 A	5

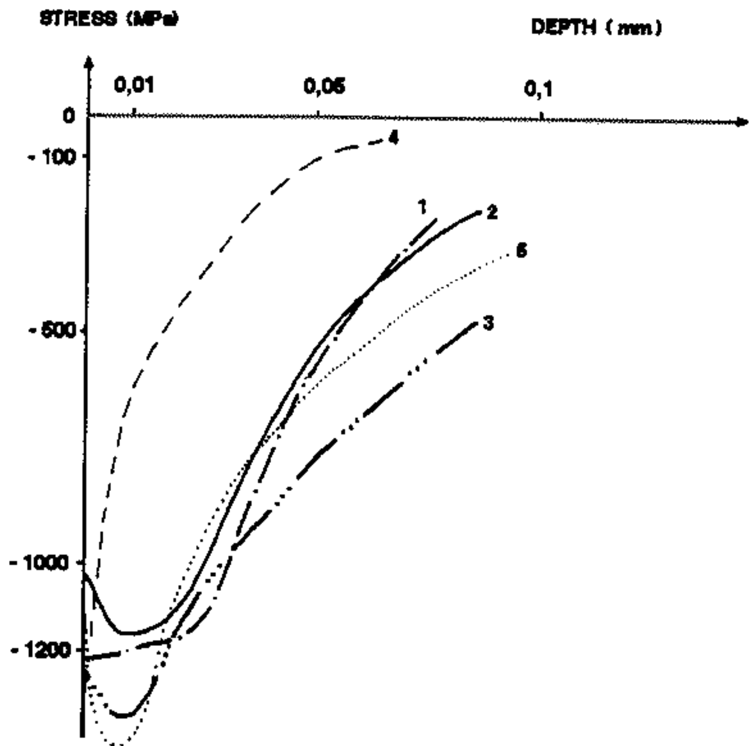
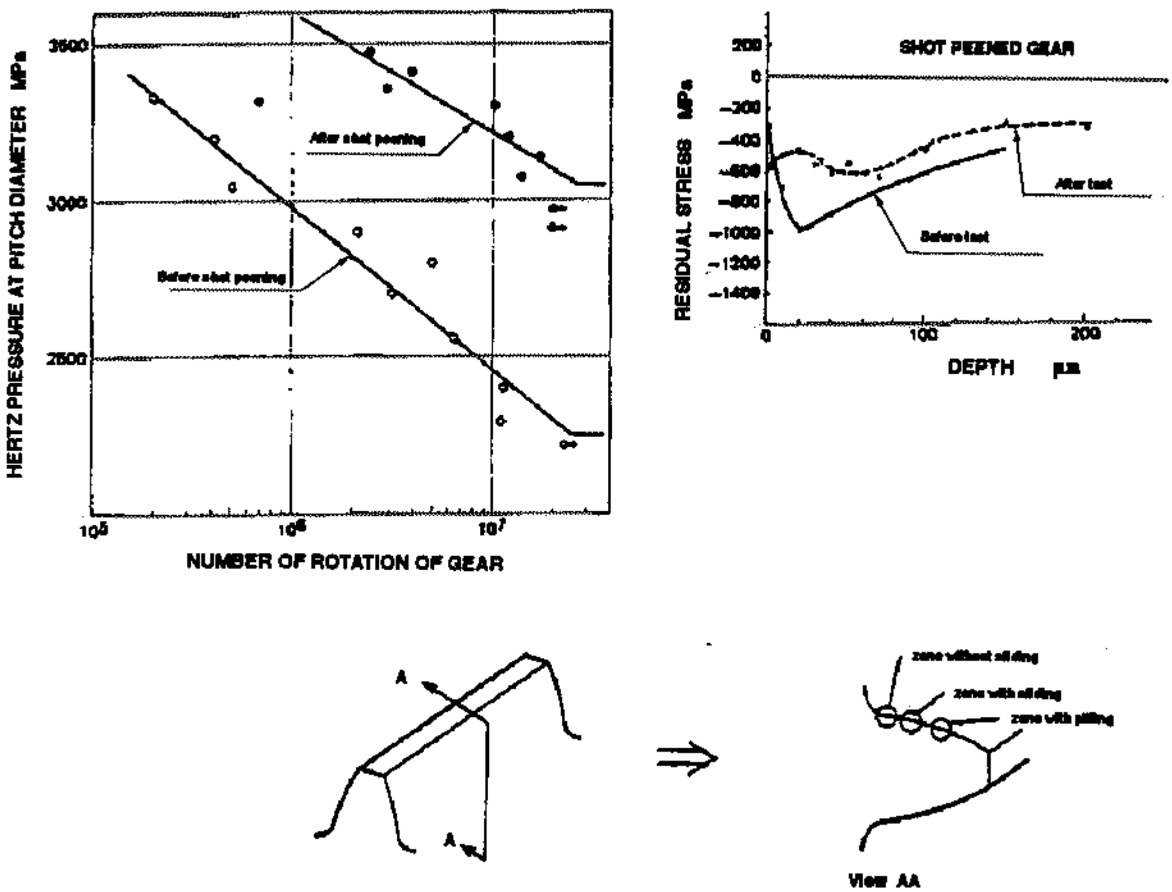


FIGURE 17 [8]

Table giving the percentage of fatigue life improvement obtained on samples shot peened with different shot diameters.

	GRENAILLE	GAIN %
—·—	BA 300 62 HRC (S110)	79
——	BA 400 53-55 HRC (S170)	79
—···—	Angulaire 400 62-63 HRc (Grit 170)	75
---	Alumine 0,3 > 2000 Hv Al. oxide 110	110
....	Alumine 0,7 > 2000 Hv Al. oxide 280	-

FIGURE 18



Influence of shot peening on Pitting

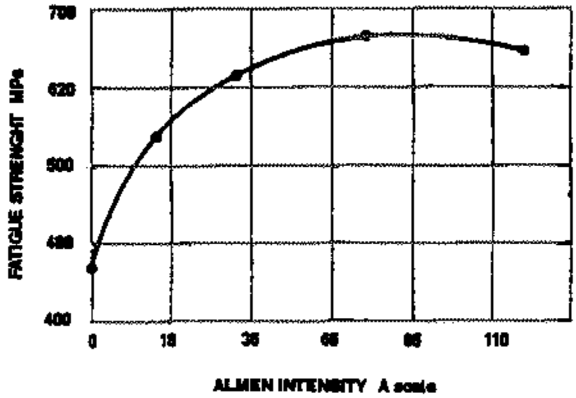


FIGURE 19 [12]

Fatigue strengh in function of shot peening intensity for SAE 4340 steel heat treated for 42 HRc

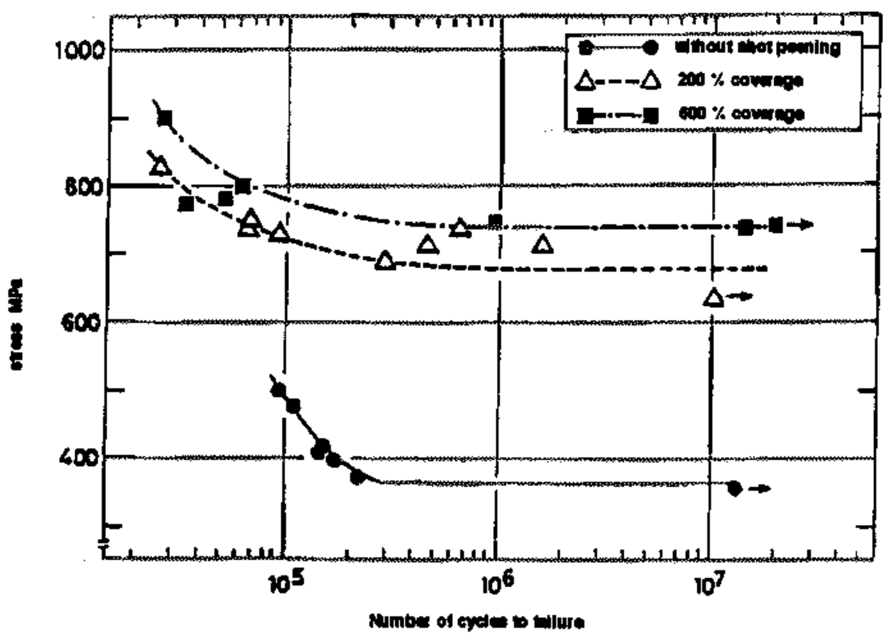


FIGURE 20 [11]

Fatigue life improvement for different coverage rate