Analysis of some particular cases of shot-peening and their influence on the field of residual stresses.

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Abstract

The distribution and intensity of residual stresses due to shot-peening are dependent upon a lot of parameters ; some of them are involved with the material characteristics, the other ones are relying upon the shot-peening process conditions.
Preexisting stresses on the surface of the part in the initial state have no influence on final state after shot-peening ; on the opposite stresses applied after shot-peening operation may alter for a large part the field of residual stresses.
A theoretical approach has been developped and is conformable to experimental results.

Theoretical Determination of the field of stresses

It may be assumed for easier understanding that the part is flat in a horizontal plan and that the motion of the shot is vertical.

Creation of the field of stresses under the impact

When the shot hits the part, some of the cinetic energy is being converted into elastic or plastic deformation energy and creates a field of stresses the value of which is ($\sigma_x, \sigma_y, \sigma_z$) in the impact area and is ($\sigma_x, \sigma_y, 0$) outside of this area $\sigma_x, \sigma_y, \sigma_z$ may be expressed in function of the vertical strain ε_z according to the relation ship of the elasticity theory. ($\varepsilon_x = \varepsilon_y = 0$)

$$\sigma_z = \frac{E \cdot (1-\nu)}{(1+\nu)(1-2\nu)} \cdot \varepsilon_z \quad (1) \qquad \sigma_x = \sigma_y = \frac{E \cdot \nu}{(1+\nu)(1-2\nu)} \cdot \varepsilon_z \quad (2)$$

These relationships are available until we stay in the elastic area, i.e until $f(\sigma_x, \sigma_y, \sigma_z) \leq \sigma_E$ if f is the mathematical expression of a criterion of plasticity (Von Mises)
When the strain ε_z becomes higher than a certain value ε_{z1}, we are reaching the plastic limit in the impact area $f(\sigma_x, \sigma_y, \sigma_z) = \sigma_E$
The relationship (1) is consequently no more available but on the opposite the relationship (2) remains right as long as ε_z is lower than the value ε_{z2} which corresponds to the plastification of the area outside of the impact area ; beyond ε_{z2}, stresses are not increasing any more.

Relaxation of stresses after the impact

When the action of the shot ends, the stress σ_z retrieves the value Ø but as the elastic limit hes been reached, the curve presents a phenomenon of hysteresis ; so the vertical strain ε_z keeps a residual value different from zero and the stresses σ_x & σ_y are stabilised at a value which only depends upon the mechanical caracteristics of the material : σ_E the elastic limit and ν the poisson's ratio.

$$\sigma = \sigma_E \frac{1-2\nu}{1-\nu} \qquad (3)$$

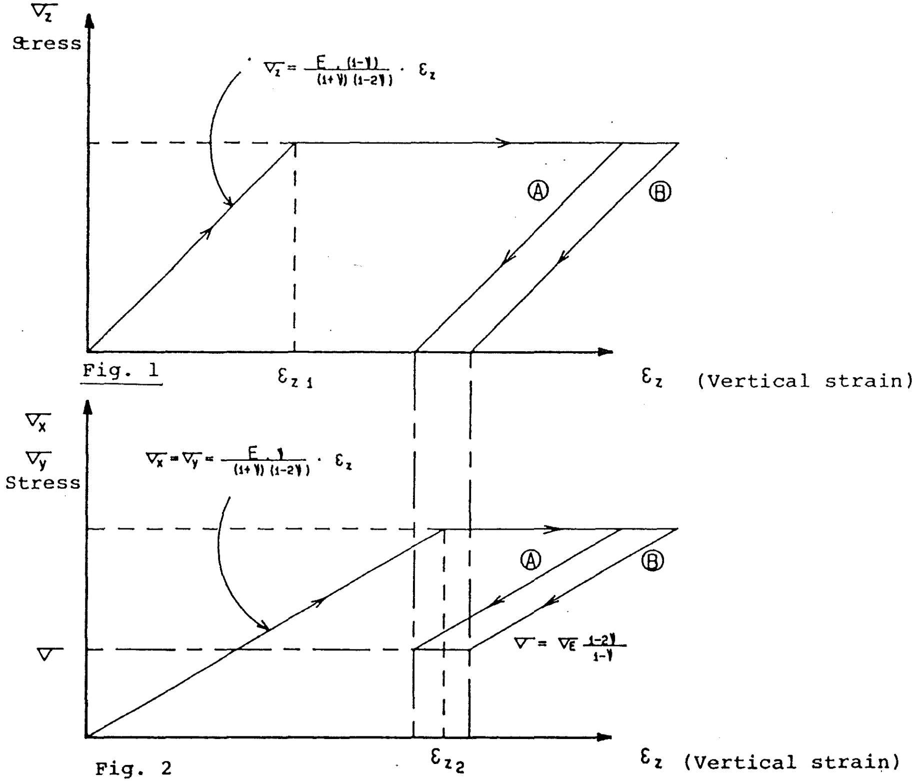


Fig. 1

Fig. 2

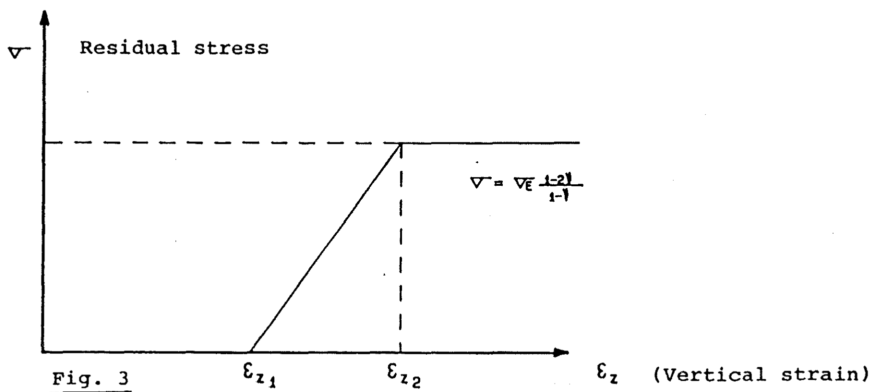


Fig. 3

Curves 1 and 2 show how the stresses σ_x, σ_y and σ_z are depending upon the strain ε_z ; on figure 2 two different ways have been drawn, they correspond to two values for the maximum of applied strain ε_z . (in other words, it corresponds to two different values of the cinetic energy of the shot)
It's easy to see that the residual stress on the surface is not dependent upon the way A or B.
This result is a consequence of the relationship number 3 , which allows to explain some experimental results ; and particulary
- the fact that residual stresses on the surface after shot-peening are not linked with stress which could exist before. (fig 8 9 and 10)
- the fact that residual stresses on the surface are growing up when the hardness of the material becomes higher ; this can be explained by the relationship number 3 and on considering the relation between hardness and the elastic limit. (fig 11)

Combination of shot-peening and presetting stresses

With the results obtained in the former paragraph, it is possible to determine by a theoretical way the field of residual stresses when shot-peening stresses combine with other stresses, even if the limit of elasticity has been reached during these transformations.
This approach has been used to exam some particular cases.
- presetting after shot-peening operation (theoretical curves 4 and 5, experimental curves 14)
- stress-peening
- presetting after stress-peening (theoretical curves 6 & 7, experimental curves 15)

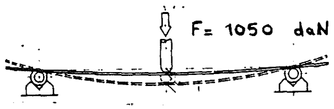
As the shot-peening creates stresses in all directions of the plan it was necessary to choose a criterion of plasticity for the theoretical approach, the octahedral shear stresses criterion has been choosen and results may depend upon it.

Experimental results

For all the tests :
- the steel which is used is the 55S7 (55Si7) steel
- the parts have the following dimensions (70mmx6mmx500mm)
- the method of Sachs is employed (removal of successive layers)
- not completely decarburized parts, and partial decarburization below 0,05mm).

* Predominance of the shot-peening residual stresses (fig 8,9 &10)

Residual stresses before shot-peening have been created by two different ways :
(1) residual stresses due to quenching (hardness 670 HV)
(2) residual stresses due to presetting ; the parts have been quenched then tempered at 440 C in order to have a hardness of 470HV and finally presetted as shown on the picture besides



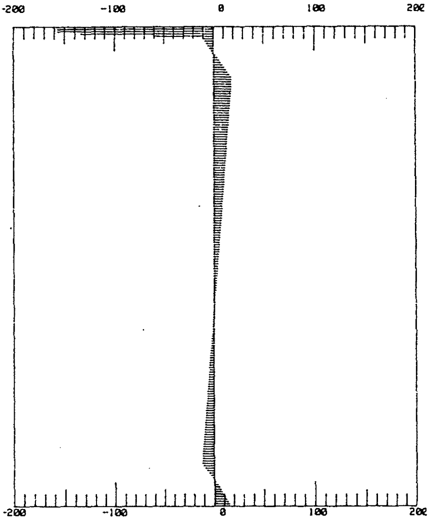


Fig. 6 Stress-peening only

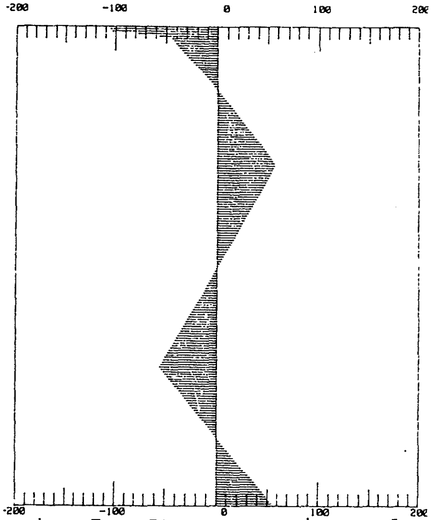


Fig. 7. Stress-peening and presetting

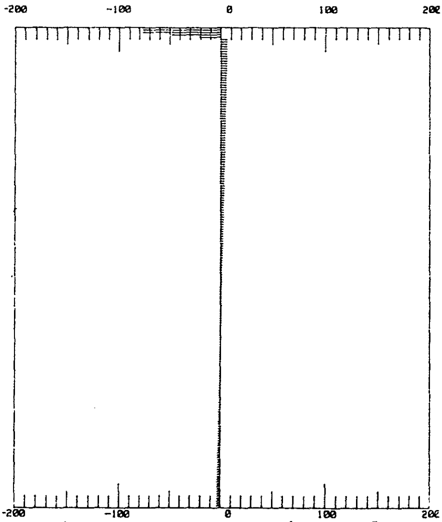


Fig. 4 Shot peening only

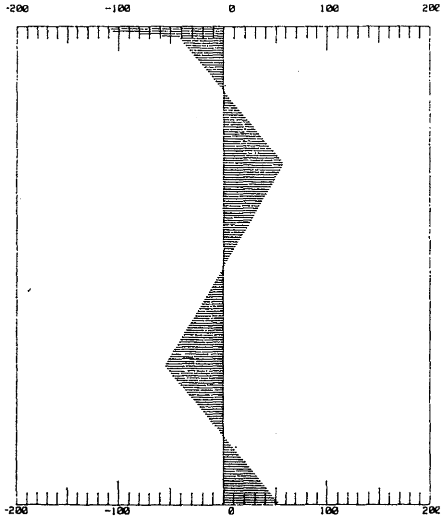


Fig. 5 Shot peening and presetting

THEORETICAL CALCULATION OF STRESSES DISTRIBUTION
RESIDUAL STRESSES IN THE WHOLE PART.

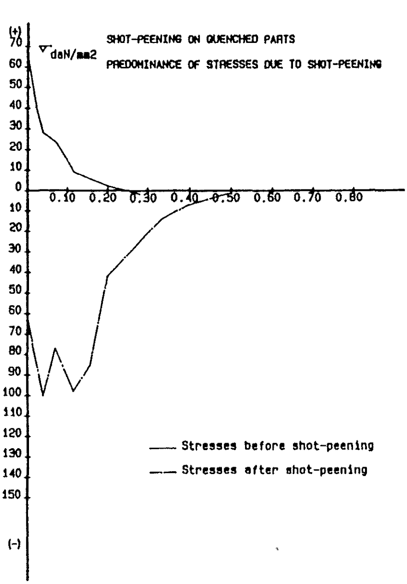


Fig. 8

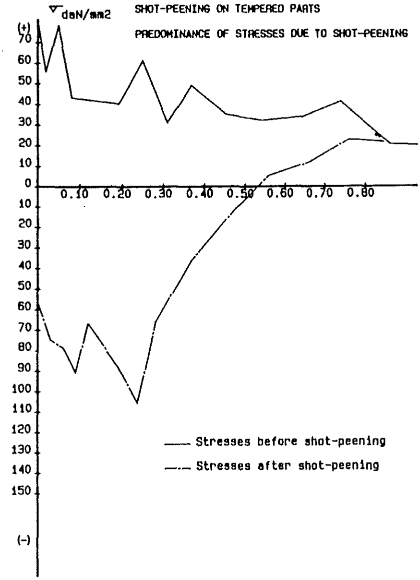


Fig. 9

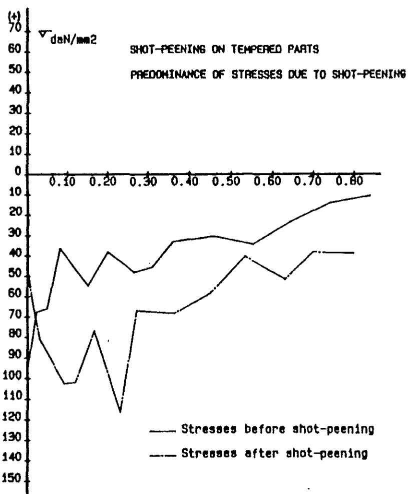


Fig. 10

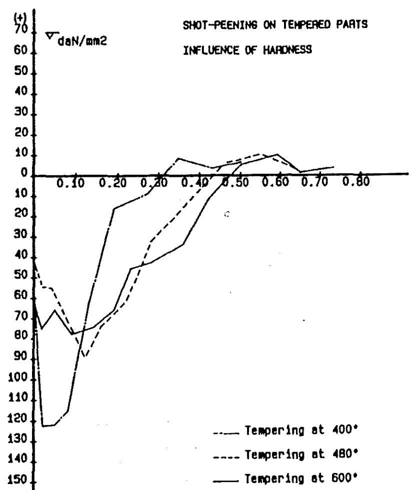


Fig. 11

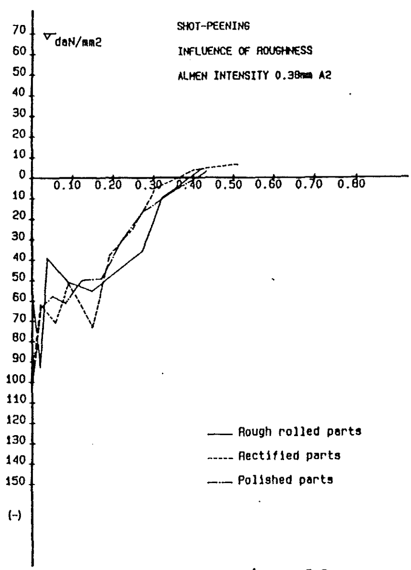


Fig. 12

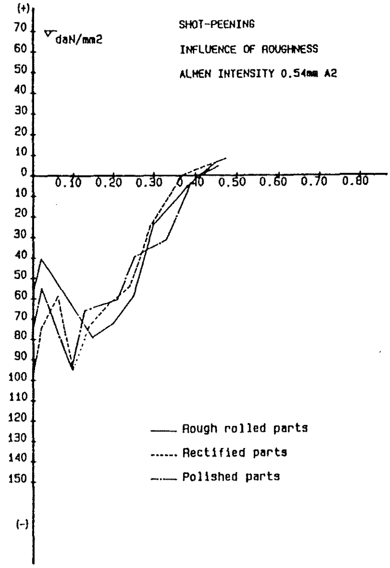


Fig. 13

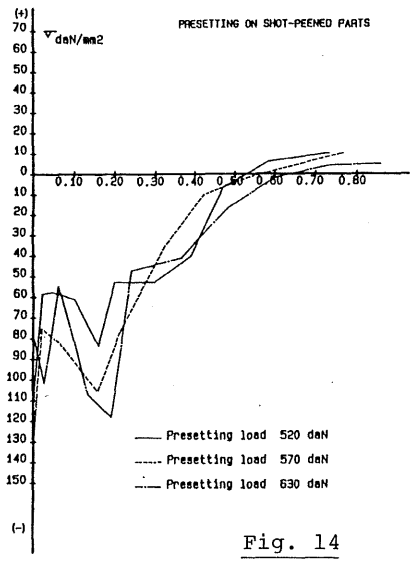


Fig. 14

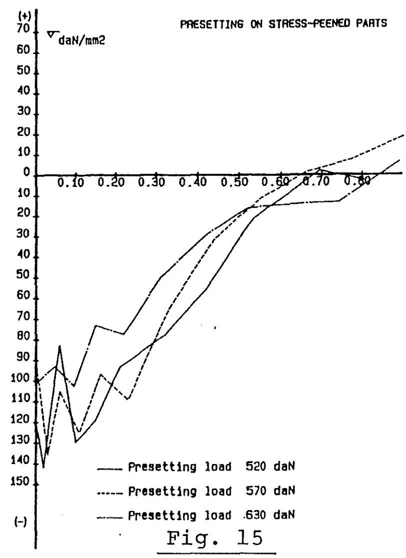


Fig. 15

Either the parts which have positive residual stresses (figure 8 quenched part and figure 10 presetted part) or the parts which have negative residual stresses (figure 9 presetted part) all of them have been shoted in the same conditions with spheric chilled-shot (hardness 460HV, diameter 1mm) and an intensity of 0,54mm A2.

In all cases, the stresses after shot-peening are always compression stresses and the intensity is quite the same (-110 daN/mm2) in the layer near the surface.

The effect of shot-peening may be discussed regarding to the depth; in the range 0-0,3mm the stresses are stresses due to shot-peening, in the range 0,3-0,6mm the stresses are a combination of shot-peening stresses and preexisting stresses, beyond 0,6mm the stresses are identical to those which could exist before shot-peening.

Influence of hardness (Fig.11)
In order to test the influence of this parameter on the residual stresses for that kind of steel, the parts have been treated in the following conditions;

- oil quenching
- tempering at different temperatures
- shot-peening (intensity 0,56 Almen)

The results are given in the table below

TEMPERATURE OF TEMPERING	Yield Strenght	Tensile Strenght	Hardness HV	RUGOSITY AFTER Shot Peening		INTENSITY	Compression layer thickness
				Ra (μm)	Rmax (μm)		
400	155	171	520	7,4	50	120	0,30
480	136	150	470	7,4	52	90	0,43
600	104	118	370	9,2	63	80	0,48

The higher the hardness of the part is, the thinner the compressive layer is and the higher the residual stresses are.

The combined influence of shot-peening conditions and presetting
We have worked with two lots of parts ; all of them have been oil-quenched, tempered at 540 C (hardness 365HV) in order to obtain a yield strength of 113 daN/mm^2 and a tensile strength of 126 daN/mm^2.

The first lot has been shot-peened in the same conditions as formerly, the second one has been prestressed during shot-peening under a load of 390 daN.

Then the three parts of each lot have been presetted with loads of respectively 520, 570 and 630 daN.

We can observe on figures 14 & 15 that the intensity of the residual stresses and the thickness of the compressive layer increase When parts are stress-peened.
The influence of presetting is not the same for the two lots.
For the 2nd lot (stresses-peening) the intensity decreases of about 30% when the presetting load is important, on the opposite the thickness of the compressive layer increases.
For the ist lot (shot-peening) the alteration is not so important.

Influence of rugosity (Fig.12 & 13)

3 typical rugosity cases have been studied

- rough rolled parts (A)
- rectified parts (B)
- rectified and then polished parts (C)

The parts have been oil- quenched, tempered at 440 C in order to obtain a hardness of 470 HV and then shot-peened at two different intensity levels 0,38 mm Almen and 0,54 mm Almen.

The table below gives the values of measured rugosity before and after shot-peening.

	Rugosity before shot-peening			Rugosity after shot peening 0,38 mm A2			Rugosity after shot peening 0,54 mm A2		
	A	B	C	A	B	C	A	B	C
Ra	8	1,8	0,2	7,6	2,7	2,5	8,1	4,5	3,7
Rm	70	15	1	62	24	23	64	39	28

When the intensity level of shot-peening is low, the intensity of residual stresses are maximum on the skin of the part for the rectified and polished parts while the maximal intensity is under the surface for the other cases.
The decreasing of the residual stresses in the skin layer is consequently partially due to the alteration of the surface by the shots themselves.

Références :

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