Shot peening of nodular cast iron

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Introduction

The favourable effect of shot peening on fatigue strength of steel or light alloys parts is now well known [1], [2], [3],[4]. On the other hand, the effect of this process on cast iron has been less studied. Now, in machine building, and principally in car manufacturing, cast iron appears more and more in highly stressed parts. Cast iron, besides its advantages such as material cost savings, good energy balance, machining savings, has now qualities justifying good mechanical properties. In addition, it often allows the replacement of several mechanical parts with one foundry part. Facing the development of the use of cast iron for fatigue loaded parts, it was necessary to study the influence of shot peening on material performances, for the first published results (7), (8), (9), (10), (11), (12), were particularly by encouraging, especially with automotive parts : connecting rods, pinions, suspension arms, crankshafts...

. Studied cast irons

The studied cast iron were, first of all, nodular cast iron obtained either as cast state by treating the liquid metal with a magnesium alloy (nodular cast iron), or by high temperature (920 - 930°C) heat treatment of white cast iron containing carbides (cementite Fe_3C) (malleable cast iron).

The mechanical properties obtained with this first set of cast irons are shown in table 1.

Type	Grade	Ultimate tensile strength Rm (MPa)	Elongation A%	Hardness HB
Ferritic	MN 350-10	379 - 400	16,0 - 18,0	129 - 139
	GS 400-12	479 - 484	21,0 - 22,0	179 - 185
Perlitic	MN 700- 2	738 - 752	3,5 - 4,8	246 - 257
	GS 700- 2	691 - 790	3,2 - 6,7	239 - 262
	GS 800- 2	855 - 857	5,8 - 6,3	282 - 302

Table 1 : Mechanical properties of the tested cast irons

MN : Malleable cast iron
GS : Nodular cast iron.

The cristallographic examinations, which details can be found in reference (13), show the different microstructures studied.

The ferritic malleable cast iron is free from perlite whereas the nodular cast iron contains very small islots in the end of solidification zones.

The perlitic grade are quite different from one another. As a matter of fact, the malleable cast iron has an homogeous perlitic matrix obtained by quenching and tempering, whereas the nodular cast irons have both ferrite around the nodules : more over, one of them was as cast (800-2).

A second set of cast irons has been studied : it was two bainitic malleable cast irons, containing 1.5% of copper and 0.6% of molybdenum; obtained by step quenching and which mechanical properties are shown in table 2.

Reference	Heat Treatment	Ultimate tensite strength (MPa)	Hardness HB
MB1	1 hour at 850°C then isothermic hold at 275°C in salt bath	800- 850	310-320
MB2	1 hour at 850°C then 3.5 h isothermic hold at 265°C in fluidized bed	1300-1400	430-450

Table 2 : Mechanical properties of bainitic cast irons

. Shot peening conditions

The shot peening was only applied to the toroidal barrel of the fatigue tests specimens (diameter : 5,8 mm) which were previously ground (longitudinal ground).

The shot used was a round steel shot which hardness ranges from 46 to 51 HRC.

The distance between the blasting nozzle and the test specimen was 150 mm.

The shot peening conditions are shown in table 3.

Type of shot peening	Almen Intensity mm and NF standard	Type of shot	Shot diameter mm	Blast speed m/s
A	0,20-0,25 (F20-25A)	S 110	0,3	60
B	0,30-0,34 (F30-34A)	S 230	0,6	80

Table 3 : shot peening parameters

. Influence of shot peening on the treated material state

The material fatigue behaviour depends on the material microstructure (hardness and structure), but also on its mechanical state (residual stresses, residual stresses gradient, deformed layer depth) and on its surface finish (roughness). These factors are generally modified by shot peening and the modifications are not independant.

. Surface roughness

Blast speed, shot hardness and diameter determine the shot marks depth at the material surface :
roughness generally grows with blast speed and shot diameter (14);

Ra, Rp, Rt values, obtained with each studied material which underwent two types of shot peening (A and B), are grouped in table 4. Measures have been made on plates used for residual stresses determination.

For a material of low hardness (MN 350-10), the harder shot peening (B) gives a rougher surface than with shot peening A, less severe , as it was observed on the surfaces with an electron scanning microscope.

On the other hand, we can see that shot peenings A and B do not give significant differences on harder materials roughness (FGS 700-2 and MN 700-2).

Cast iron	Type of shot peening	Ra	Rt	Rp
GS 700-2	A	2,2	18,6	6
GS 700-2	B	3,2	23,6	8,3
MN 700-2	A	2,3	20,8	6,6
MN 700-2	B	3	21	7,3
MN 350-10	A	3,9	32,1	9,6
MN 350-10	B	5,8	37	14

Table 4 : Influence of shot peening on roughness

. Residual stresses
The residual stresses in the following cast irons : MN 350-10, MN 700-2 and FGS 700-2 have been measured on flat sheets with the incremental hole drilling method set up in CETIM (15). The results obtained appear at figures 1 and 2.

When examining these results, the following conclusions can be drawn:
. As in the case of steels, the residual stresses induced by shot peening are higher when the mechanical properties of the peened material are high (Figure 2).

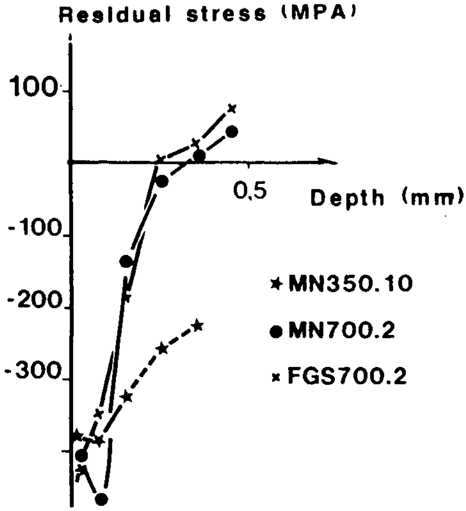

Figure 1 : Residual stresses-shot peening A

. The maximal values of the compression stresses obtained for peening B (F30 to 35) are of the same order as the tensile strength of the base material for Mn 350-10 cast iron and to the order of 80 to 85% of the tensile strength of the base material for the MN 700-2 and GS 700-2 cast irons.

. The increase of peening intensity and of the size of shots gives rise to an increase in the residual stresses in the two most resistant cast irons. As for the MN 350-10 cast iron the maximum residual stresses do not change when changing from peening A to peening B.

. The prestressed depth increases with peening intensity. It changes from about 0,25 mm for peening A (F20-F25) to 0,35 mm for peening B (F30-F35).

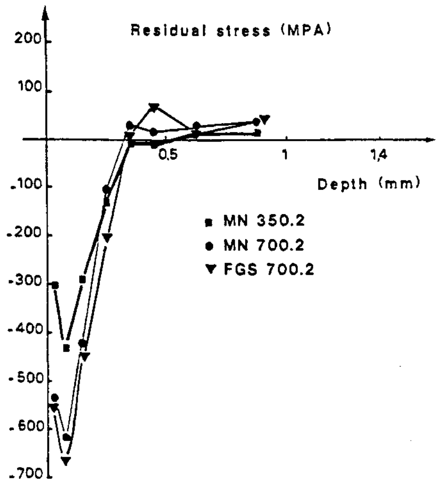

Figure 2 : Residual stresses-shot peening B

. Effect of shot peening and fatigue resistance.

Figure 3 shows the improvement of fatigue strength obtained with malleable cast iron (grade 700-2) treated with the most severe peening (B).

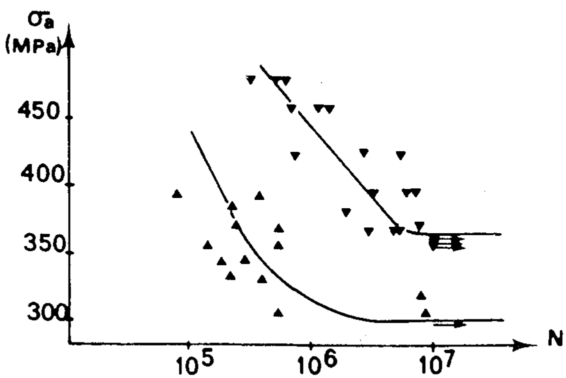

Figure 3 : WOEHLER curve of the malleable 700-2 cast iron before (▲) and after (▼) peening (rotating bending).

All the results obtained are given in Table 5 :

Cast Iron	Rm	Endurance limit at 10^7 cycles in the rotary bending (MPa)			% Improvement	
		Before shot peening	After shot peening A	After shot peening B	A	B
MN 350-10	379	230	258	285	12	24
GS 400-12	479 484	300		393		31
MN 700-2	738 752	305	362	368	18,6	20,6
GS 700-2	691 790	367		456		24,2
GS 800-2	855 857	385	413	438	7	14
MB1	800 850	343		388		13,1
MB2	1300 1400	355				

Table 5 : Fatigue strength in rotating bending of the various cast irons (determined according to the staircase method)

A clear improvement of the fatigue resistance can be noted for shot peening B, the most severe one. The MN 800-2 et MB1 cast irons do not seen to be so sensitive to shot peening although they show high mechanical properties. This particular behaviour results probably from the microstructure of these cast irons and from the evolution of the residual stresses. The GS 800-2 nodular cast iron for example contains graphite nodules surrounded with ferrite islets likely to bring about more stress relaxation. A microfractographic study and a deeper analysis of the residual stresses would be necessary to explain these results.

. Relaxation of the residual stresses during fatigue

In order to determine the stability of shot peening residual stresses in fatigue, residual stresses have been measured by X rays diffraction method on rotating bending specimens that remained unbroken after the fatigue testing. These tests have been performed with peening A for the MN 350-10 malleable ferritic cast iron and with peening B for the MB1 cast iron. The residual stresses obtained are seen on Figures 4 for MB1 cast iron, no important relaxation can be established for both cast irons.

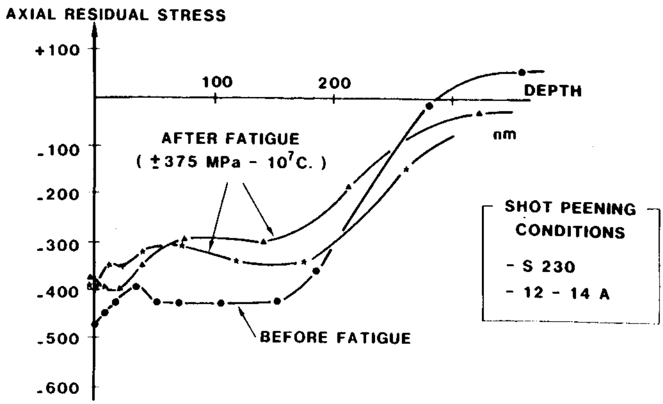

Figure 4 : Stresses before and after fatigue testing of MB1 cast iron (Shot peening B)

. CONCLUSION

Shot peening applied to cast irons brings about a clear improvement of the fatigue resistance. That improvement depends on the type of material studied : between 7 and 31% as the case may be. The particular microstructure of the different cast irons studied does influence the improvement of the expected fatigue behaviour after shot peening and residual stresses relieving during fatigue.

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