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EFFECT OF HARDNESS VARIATION ON SURFACE INTEGRITY OF CARBURIZED P20 STEEL

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Abstract. *Variations in case hardness of carburized steels can occur, especially due to the high content of carbon giving rise to retained austenite formation. This paper studies the residual stresses and surface roughness variations after shot peening applied to carburized and quenched AISI P20 tool steel. In order to analyze the effect of carbon content, and consequently the hardness of pieces, specimens were carburized in the same batch, followed by different grinding operations, resulting on the removal of 0.3 and 1.0 mm of the original carburized case. The surface roughness was analyzed using the Rz parameter. The residual stresses were measured by X-ray diffraction. The variation of hardness from 650 to 850 HV was barely significant, for both compressive residual stresses as to the Rz values. These findings have implications in the quality control requirements for case hardened components and they are discussed in the light of technological applications.*

Keywords: *tool steel; carburizing; surface roughness; residual stresses; hardness*

1. INTRODUCTION

Compressive residual stresses can be introduced in a ferrous material by different methods, in order to increase the fatigue life. For gear components, a combination of shot peening and carburizing is usually applied. However the increase of compressive residual stresses may result totally ineffective on enhancing fatigue life if surface becomes excessively rough. Therefore, an optimization of processing variables that lead to a combination between the maximum residual compressive stresses and the minimum surface roughness is necessary to achieve the best results of fatigue life (Macodiyo and Soyama, 2006).

Although the process parameters could be investigated (Guagliano et al., 2002) the initial hardness of previously heat treated steel play an important role on the surface roughness after shot peening. It is expected that the lower the hardness, the higher the average roughness after shot peening (Grinspan and Gnanamoorthy, 2006).

Widmark and Melander (1999) investigated the influence of the process order, grinding and case hardening, on the surface roughness and residual stresses of carburized steels. The authors found that the R_z parameter was higher (7.7±1.7 μm) when the sequence grinding → case hardening → shot peening was applied. When the case hardening was performed before grinding, the final R_z was 4.3±0.8 μm. However, these authors observed that the residual stresses profile was not affected when the case hardening was performed before grinding. Since Widmark and Melander (1999) did not study the effect of surface hardness on residual stresses, it remains opened to be explored.

The aim of this investigation is to evaluate the influence of surface hardness of carburized tool steel on the surface roughness and the residual stresses obtained by shot peening performed after these operations. The variation of surface hardness is achieved with different grinding process before the shot peening, which allows obtaining different hardened case depths, which are associated to different carbon contents.

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2. EXPERIMENTAL PROCEDURES

The specimens were taken from a P20 steel (0.35% C; 1.7% Cr and 0.4%Mo) bar with diameter of 19 mm. Six samples of approximately 50 mm height were prepared. The specimens were gas carburized in order to reach superficial carbon content between 1.0 and 1.2%wt. It was intended to produce a hardened layer of 1 mm with hardness higher than 550 HV after carburizing and quenching. Figure 1 presents the cycles employed to reach the desired hardness.

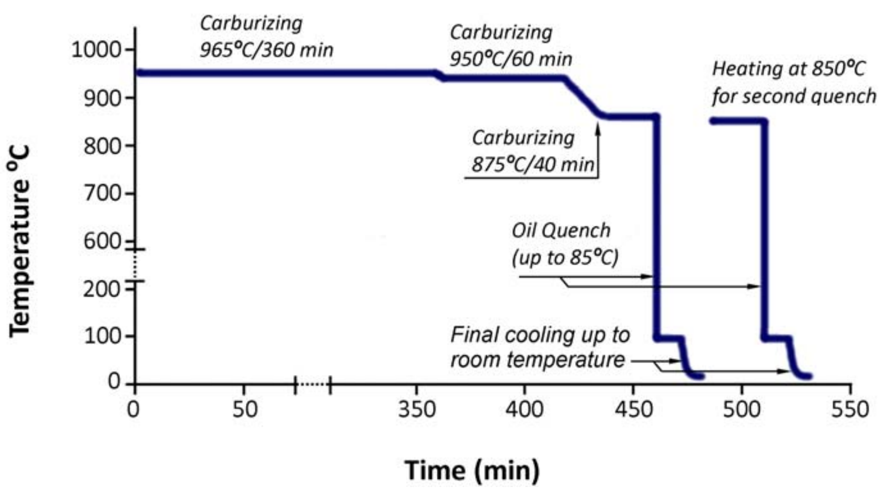

Figure 1. Heat treatment cycle applied to P20 steel.

Double oil-quenching after carburizing was applied to reduce the level of retained austenite, avoiding at the same time the requirement of a tempering treatment.

Considering gas carburizing was performed in only one batch, carbon profiles of all samples can be assumed as equal. Then, in order to create groups of specimens with different superficial carbon contents, grinding operation was conducted with the purpose of removing different amounts of material from the surfaces of the carburized specimens. The first group was evaluated with no grinding, or as carburized. The second and third ones were ground until 0.3 mm and 1.0 mm depths, respectively. Such amounts of material were determined based on hardness profiles obtained by Vickers hardness, using 4.9 N (500 gf) load.

Ground surfaces were obtained in a plane grinding machine, using an aluminum oxide grinding wheel, grade AA80K60V2. The parameters used in lubricated grinding were the same for all specimens: in-feed of 30 μm, and a cut speed of 32.5 m/s.

Shot peening was applied to specimens with initial hardness of 850HV and 650 HV. Thus, two new groups of specimens emerged from shot peening processing: one ground up to depth of 0.3 mm (850 HV) and the other up to 1.0 mm (650 HV). Figure 2 shows the hardness profiles of both specimens groups. In both cases the effects of carburizing on hardness is noticeable.

Figure 2 presents the effect of grinding on the hardness profile of carburized and quenched specimens. In a general way, the grinding did not alter the hardness profile produced by carburizing.

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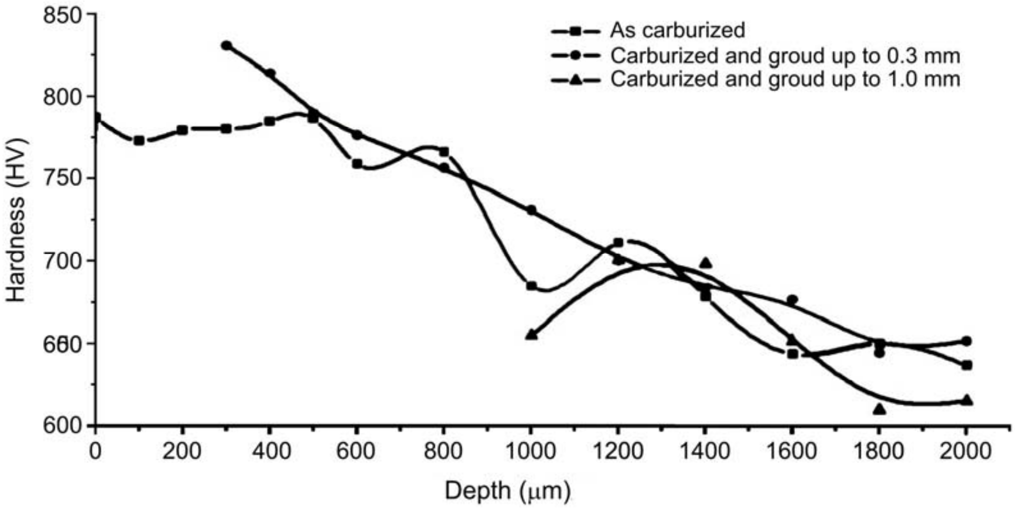

Figure 2. Microhardness profiles after carburizing and grinding.

The shot peening was carried out for 15 minutes in a George Fisher machine, which has two turbines pushing the particles towards the specimens while they rotate on the holder. Steel particles with hardness superior to 60 HRC impinged specimens surface at a flow rate of 93 kg/min. The impact angle followed the equipment directions and the resultant Almen height was 25 mm. The analysis of the cross-sections of ground specimens did not revealed any incrusted particles into the surfaces.

The residual stresses imposed by shot peening were evaluated by X-ray diffraction in a Rigaku diffractometer with specifics hardware and software to this application.

In order to analyze the superficial finishing after shot peening, the surface roughness was determined by SURTRONIC 25+ equipment. The evaluation length was 4 mm. The resulting profiles were analyzed by the software TALY PROFILE version 3.1.10, to calculate the R_z roughness parameter. The average values correspond to a series of 10 measurements.

3. RESULTS AND DISCUSSION

Table 1 shows the residual stresses after shot peening for specimens ground up to depths of 0.3 and 1.0 mm. The negative values indicate a compressive residual stress which is expected for steel parts submitted to carburizing and quenching followed by shot peening.

Table 1. Residual stresses (MPa) after shot peening for different conditions.

Condition	**Residual stress (MPa)**
As carburized	-390 ± 20
Carburized and ground up to 0.3 mm	-220 ± 10
Carburized and ground up to 1.0 mm	-415 ± 15
Shot peened after grinding up to 0.3 mm	-755 ± 25
Shot peened after grinding up to 1.0 mm	-790 ± 10

The residual stress found for carburized condition is in the same order of magnitude as reported data for carburized 8617 steel with a same diameter (Metals Handbook, 1991). Considering the depths where the grinding was performed, and balancing the effect of this process on the residual stress (Hidayetoglu, 2001), the values of Table 1 also agrees with those reported for carburized 8617 steel.

While the harder specimen (removal of only 0.3 mm by grinding) reached a residual stress of -755 MPa after shot peening, the softer one reached a higher value, -790 MPa. As the residual stress is a result of different amount of plastic deformation, this behavior is explained by the higher susceptibility of the softer specimen to be plastically deformed, which is confirmed by measurements of Vickers hardness after shot peening (Tab. 2).

Table 2. Vickers hardness after shot peening.

Condition	**HV**
Shot peened after grinding up to 0.3 mm	860 ± 35
Shot peened after grinding up to 1.0 mm	900 ± 100

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Although the final hardness of both shot peened specimens can be considered as similar, the increase in surface hardness caused by shot peening was 18% for specimen ground up to 0.3 mm, and 38% for the specimen ground up to 1.0 mm.

Another indicative of surface integrity is the parameter R_z (μm) obtained after grinding and shot peening, as presented in Table 3.

Table 3. Rz roughness parameter after grinding and shot peening.

Condition	**Rz (μm)**
Ground up to 0.3 mm	2.1 ± 0.6
Ground up to 1.0 mm	2.9 ± 0.2
Shot peened after grinding up to 0.3 mm	2.6 ± 0.2
Shot peened after grinding up to 1.0 mm	3.0 ± 0.1

The roughness of ground surfaces are within the range of expectation for this kind of material. For example, Kundrak et al. (2008) reported values of approximately 4 μm for S_z parameter for a case hardened gear. After shot peening the increase in R_z parameter can be considered as negligible. In terms of fatigue life, this is an interesting result, since the surface roughness is preserved while the compressive residual stress increases. Nonetheless, it would be expected an increase in the surface roughness after shot-peening. A possible explanation for the results described in Table 3 is the contribution of grinding process to the work hardening process, which was not evaluated. As a relatively large amount of material was removed, it is plausible that some level of hardening can be occurred after grinding, avoiding shot particles to imprint at the surface their geometry, modifying in this way the surface roughness. In this way, if this hypothesis is true, the values of Table 2 could be attributed to the grinding process, instead of the shot-peening one. For comparison, Richardson (1967) measured the hardness of steel with 650 HV after shot-peening and after wear in the field, and the values were 806 and 858 HV, respectively, showing that the cutting process can be able to promote, depends on the case, a larger work hardening than a shot-peening process.

In order to summarize the results of the current investigation, it is presented in Table 4 a comparison with the results reported by Widmark and Melander (1999). It shows that the applied processes could have a beneficial effect on the fatigue life, because a high level of hardening and compressive residual stress were achieved after shot peening, with minor changes in surface roughness, compared with the similar methodology used by Widmark and Melander (1999). Probably, some differences are due to the relatively large amount of removed material during grinding operations in the current investigation.

Table 4. Comparison of main technological parameters obtained in this investigation and by Widmark and Melander (1999)

	This investigation	**Widmark, Melander (1999)**
Vickers hardness of ground specimen	650 HV	700 HV
Increase in hardness after shot peening, %	38	22
Rz parameter after shot peening, μm	3.0	4.3
Residual stress after shot peening, MPa	-790	-520

4. CONCLUSIONS

The superficial hardness of carburized P20 steel presents a little influence on the residual stresses and surface roughness produced by shot peening process. In this investigation hardness reduction from 850 to 650 HV led an increase in compressive residual stress, but the Rz roughness parameter was not affected by the hardness variation, which is beneficial for fatigue life requirements.

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