EFFECT OF CARBURIZED STEEL HARDNESS ON THE SURFACE ROUGHNESS AND RESIDUAL STRESSES AFTER MANUFACTURING OPERATIONS

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Abstract. *Many factors affect residual stresses magnitude in case hardened steel. Since surface treatments can introduce compressive stresses on materials surface, they are an important group of manufacturing operations, specially to improve fatigue resistance. On the other hand, if the manufacturing process increaeses surface roughness, it also implies in negative variations of fatigue life. This paper studies the residual stresses and surface roughness variations after shot peening and subzero treatment apllied to carburized and quenched AISI P20 tool steel. In order to analyze the effect of carbon content, specimens were carburized in the same batch, followed by different grinding operations, resulting on two sizes of hardened layer: 0.1 and 1.0 mm. The surface roughness was analyzed using the* R_z *parameter. The residual stresses were measured by X-ray diffraction. The variation of superficial hardness from 800 to 650 HV increased twice the compressive residual stresses. Additionally, in the softer specimen a smaller* R_z *value was found after shot peening.*

Keywords*: tool steel, carburizing, shot peening, surface roughness, residual stress.*

1. INTRODUCTION

It is well-known that in most cases a fatigue crack initiates at the surface (Schijve, 2003). Thus, when surface treatments are able to introduce compressive residual stresses, a fatigue life improvement is expected. A combination of thermo-chemical and mechanical surface treatments can result in a synergistic effect on the residual stress. For instance, Batista et al. (2000) found for AISI 4130 steel a compressive stress peak of 500 MPa when gears were carbonitrided. After a sequence of carbonitriding and shot peening, the maximum residual stress at surface was increased to 1200 MPa.

This sequence of treatments also affects the surface roughness. In order to avoid a possible reduction in fatigue life, the average surface roughness should be minimized. Then, an optimization of processing variables that lead to a combination between the maximum residual compressive stresses and the minimum surface roughness is expected (Macodiyo and Soyama, 2006).

Although the shot peening parameters could be investigated, such as air pressure, distance from target surface, and even the working temperature (Harada et al., 2007), the initial hardness of previous treated steel can have an important role to the subsequent effect of shot peening on the surface roughness. It was expected that the lower the hardness, the higher the average roughness after shot peening (Grinspan and Gnanamoorthy, 2006).

Widmark and Melander (1999) investigated how the order of process, grinding and case hardening, influences the surface roughness and residual stresses of carburized steels. They 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 this difference did not affect the minimum lubricant thickness in a rolling contact fatigue test, and consequently, the component life practically did not change with the R_z variation. Also, the residual stresses profile was not affected when the case hardening was performed before grinding. The surface hardness of materials studied by Widmark and Melander was not affected by the processing variables, thus, it could be explored.

Therefore, 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 subsequent shot peening. The variation of surface hardness is achieved with different grinding process before the shot peening, which allows obtaining different hardened case depths associated to different carbon contents.

2. EXPERIMENTS AND ANALYSIS

This investigation was developed according to the flow chart presented in Fig. 1.

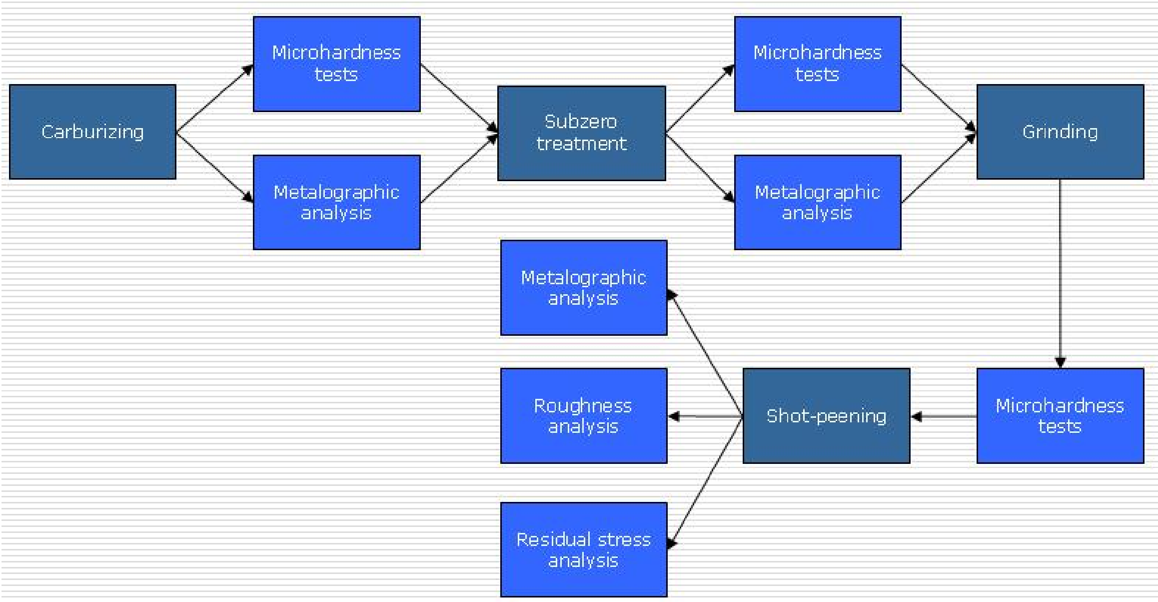

Figure 1. Methodology flow chart.

2.1. Specimens preparation

The specimens were taken from a P20 steel blank by machining and grinding. Their dimensions are presented in Fig.2 and P20 nominal chemical composition is shown in Tab. 1. Cross-sections of the specimens were used for the hardness and metallographic analysis indicated in the methodology flow chart (Fig. 1).

Table 1. Nominal chemical composition of P20 steel.

	C	Si	Mn	Cr	Mo
% mass	0.35	0.65	0.80	1.70	0.40

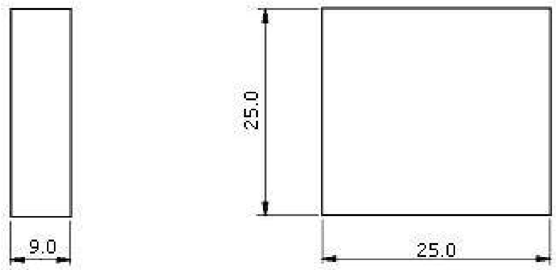

Figure 2. Dimensions (in millimeters) of the specimens after machining and grinding.

2.2. Carburizing

The P20 specimens were gas carburized in order to reach superficial carbon content between 1.0 and 1.2%. It was intended to produce a hardened layer of 1 mm with hardness higher than 550 HV after carburizing and quenching. The carburizing was conducted at 930ºC for 8.5 hours followed by cooling in the furnace atmosphere. For quenching the specimens were austenitized at 860°C and oil-quenched. Tempering was performed for 2 hours at 200ºC. After the complete cooling, the specimens were submitted to the subzero treatment in liquid nitrogen for 10 min at -196ºC, as a means to transform the retained austenite to martensite. After subzero treatment, another tempering was carried out for 1 hour at 180°C.

Vickers microhardness was used to evaluate the case hardness. In order to obtain the hardness profiles, 30 to 50 indentations were made from the surface downward to the core. The applied load was 4.9 N (500 gf).

Figure 3 presents the effect of subzero treatment on the hardness profile of carburized and quenched specimens. The hardness profiles are different from the surface up to around the depth of 0.7 mm. Before the subzero treatment, the surface hardness was approximately 630 HV and the hardness peak was found in the subsurface, which is undesired after the carburizing. The subzero treatment promoted an increase of surface hardness to 800 HV.

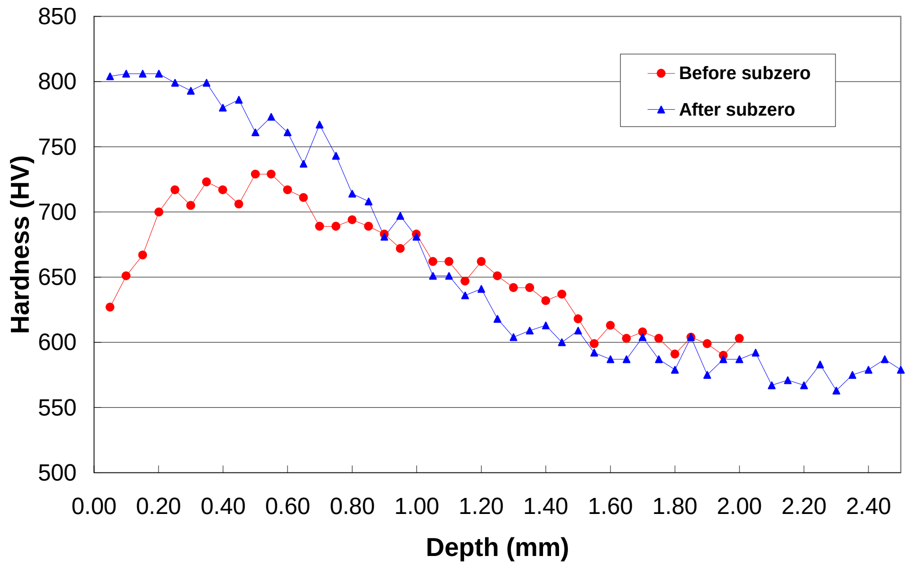

Figure 3. Microhardness profiles before and after subzero treatment.

Analyzing the hardness profiles and microstructures of specimens' surfaces (Figs. 4 and 5); it can be observed that the hardness increase is associated to the elimination of retained austenite. Figure 4 presents the microstructure of carburized and quenched P20 before the subzero treatment, it is possible identify the martensitic microstructure. The lighter region close to the surface indicates the presence of retained austenite.

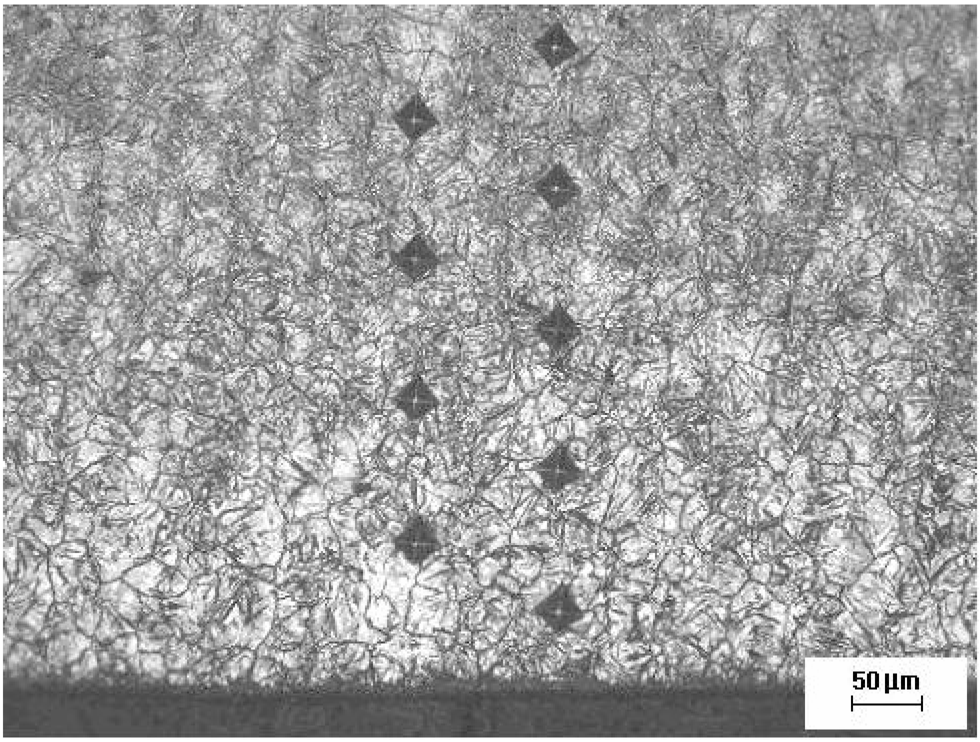

Figure 4. Surface microstructure of carburized and quenched P20 steel before subzero treatment (Nital 2%).

Figure 5 shows the surface microstructure after the subzero treatment. A reduction on the retained austenite content is remarkable. The precipitation of carbides at the grain boundaries, which indicates the effectiveness of the carburizing treatment to increase the superficial carbon content, and mixed martensite morphologies are also verified.

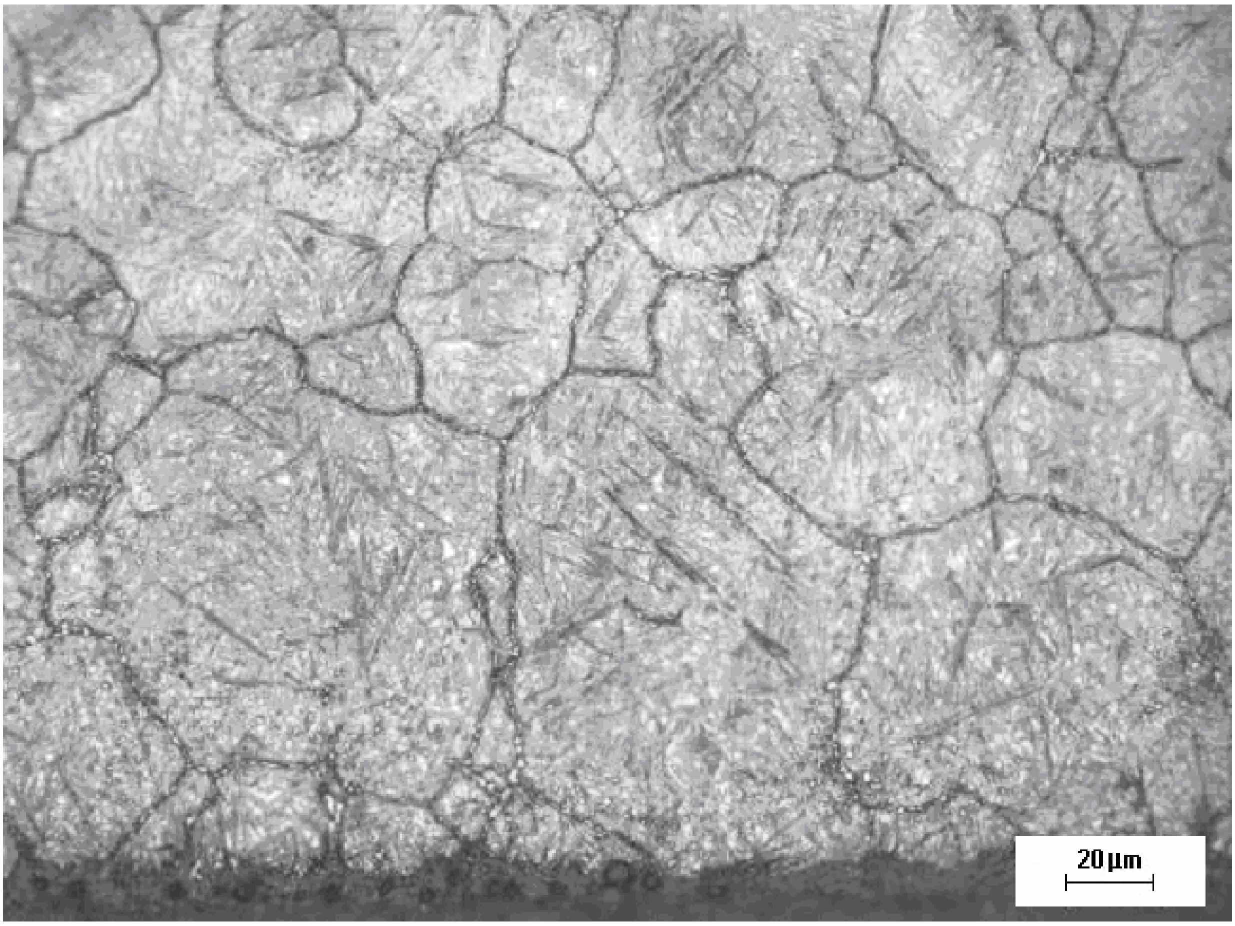

Figure 5. Surface microstructure of carburized and quenched P20 steel after subzero treatment (Nital 10%).

The specimens submitted to the subzero treatment were chosen to analyze the effect of superficial hardness on the surface roughness and residual stresses. The presence of retained austenite could interfere on the subsequent analysis, because the plastic deformation imposed by the shot peening could induce martensitic transformation (Benedetti et al., 2002).

2.3. Grinding

The ground surfaces were obtained in a plane grinding machine, using an aluminum oxide grinding wheel, grade AA-60 K8V. The parameters used in grinding were: an in-feed of 15 μm, and a speed of 30 m/s. The longitudinal and transverse feeds were not controlled. Considering that all specimens were submitted to gas carburizing in the same batch, all carbon profiles should be equal. In order to achieve different superficial carbon contents, the grinding operation was conducted with the purpose of removing different amounts of material from specimens' surfaces. Such amounts of material were determined based on hardness profiles after subzero treatment (Fig. 3). It was decided to apply the shot peening to the specimens with initial hardness of 800HV and 650 HV. Thus, two groups of specimens were created: one set was ground up to depth of 0.1 mm (800 HV) and the other up to 1.0 mm (650 HV). Figure 6 shows the hardness profiles of both specimens groups. In both cases the effects of carburizing on hardness is noticeable.

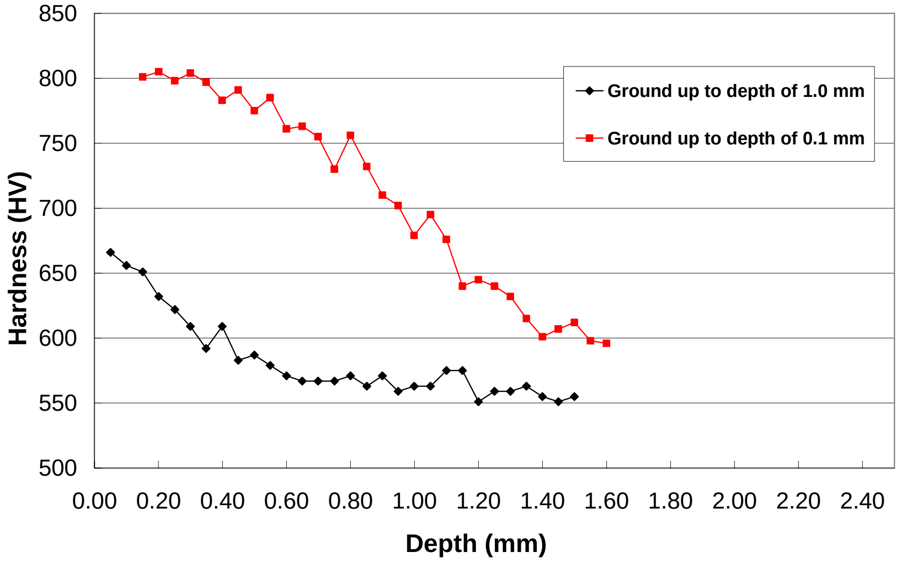

Figure 6. Microhardness profiles after two grinding levels of carburized, quenched and tempered specimens. The values of R_z roughness after grinding were 5.8 and 4.6 μm for specimens ground up to depths of 0.1 mm and 1.0 mm, respectively.

2.4. Shot peening and residual stresses

The shot peening was carried out for 15 minutes in a George Fisher machine, which has two turbines pushing the particles in the specimens while they are rotating in the support device. 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 reveal any incrusted particles on the surfaces. Therefore, it indicates that particles did not penetrate on the surface during shot peening process.

Figure 7 presents the superficial microstructure after shot peening of specimen ground up to depth of 1.0 mm. The microstructure revealed in Fig. 7 perfectly agrees with hardness profiles presented in Fig. 6. Also, the absence of precipitated carbides and mixed martensite morphologies reveals the lower carbon content of the specimen ground up to depth of 1.0 mm.

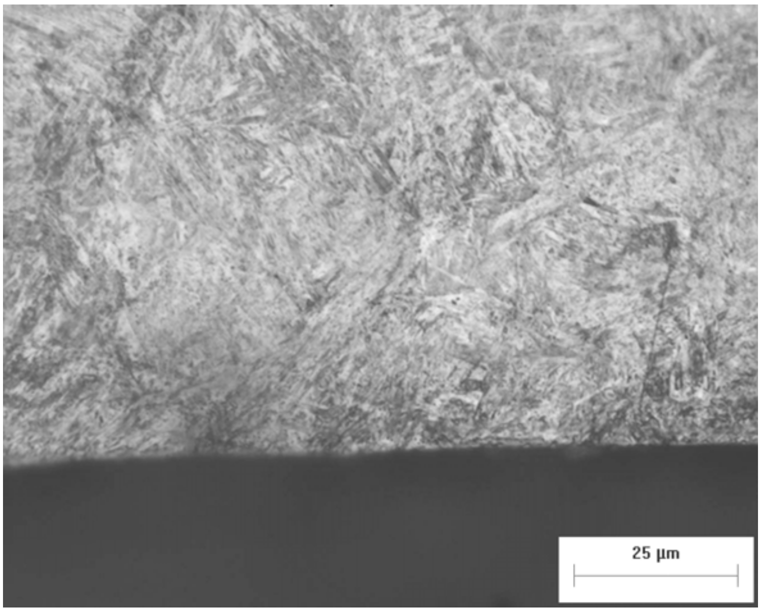

Figure 7. Microstructure of P20 steel ground up to depth of 1.0 mm after shot peening (Nital 10%).

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

Table 2 shows the residual stresses after shot peening for specimens ground up to depths of 0.1 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 (Batista et al., 2000).

Table 2. Residual stresses (MPa) after shot peening for different ground depths (mm).

Ground depth (mm)	Residual stress (MPa)
0.1	- 710 ± 20
1.0	- 1,490 ± 80

A correlation between superficial hardness and residual stress is possible when comparing Tab.2 and Fig.7. The harder specimen (removal of only 0.1 mm by grinding) reached a lower residual stress (-710 MPa) after shot peening. On the other hand, the softer one reached a higher residual stress (-1,490 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.

2.5. Superficial finishing

In order to analyze the superficial finishing after shot peening, the surface roughness was determined by SURTRONIC 25+ equipment. The cut-off was 0.8 mm, resulting in 4 mm of evaluation length. The roughness 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.

Figure 8 presents the filtered roughness profile and the R_z value after shot peening of specimen ground up to depth of 0.1 mm. In the same way, the roughness results of specimen ground up to depth of 1.0 mm are shown in Fig. 9.

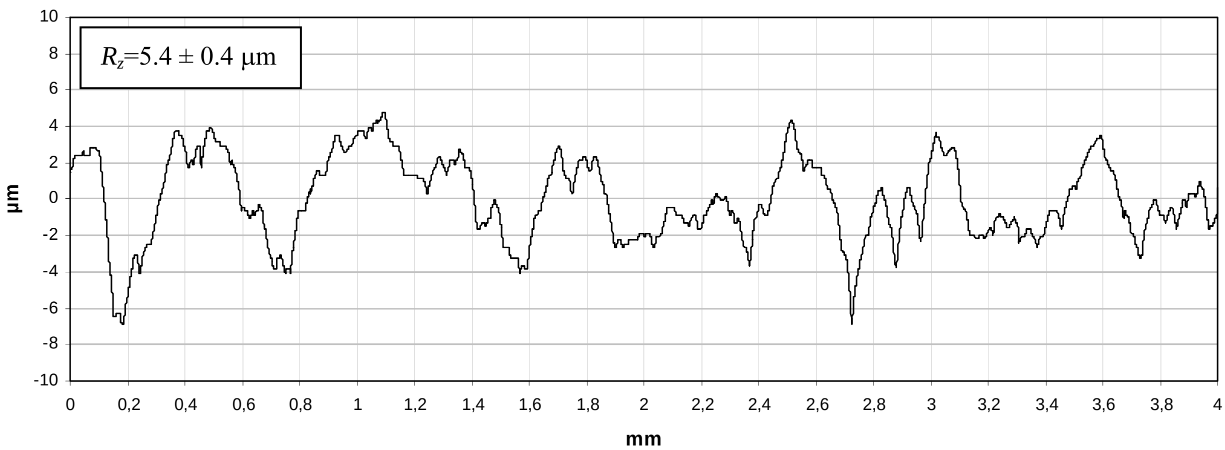

Figure 8. Profile and R_z after shot peening of specimen ground up to depth of 0.1 mm.

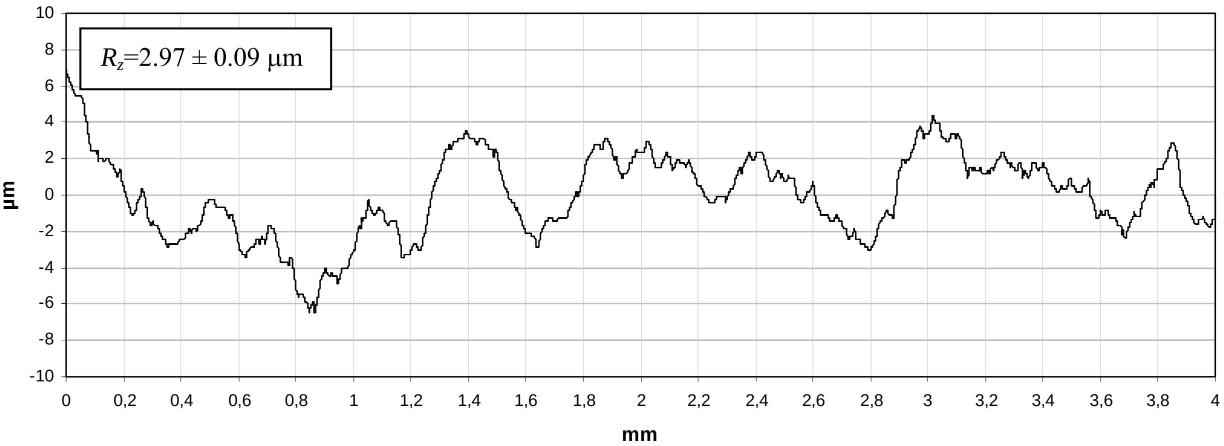

Figure 9. Profile and R_z after shot peening of specimen ground up to depth of 1.0 mm.

The comparison between the roughness profiles presented in Figs. 8 and 9 allows concluding that the specimen ground up to depth of 1.0 mm is smoother than that ground up to 0.1 mm. Thus, a height dependent roughness parameter such as R_z should indicate this difference, and in fact it does.

However, the relationship between R_z values and superficial hardness showed an unexpected behavior: the higher the superficial hardness, the higher the surface roughness. A possible explanation for these results is the superficial finishing previous to the shot peening, which was worse (rougher) than typical roughness after shot peening (1.5-2.0 μm) (Batista et al., 2000). In other words, after grinding process both specimens presented high surface roughness (5.8 μm and 4.6 μm for specimens ground up to depths of 0.1 mm and 1.0 mm, respectively), then shot peening led the softer specimen to achieve a surface roughness closer (2.97 μm) to the typical roughness for this process. On the other hand, the shot peening was not able to impose the same intensity of superficial deformation to the harder specimen, and the remaining roughness was close (5.4 μm) to that after grinding (5.8 μm), which was excessively high, as said before.

3. CONCLUSIONS

The superficial hardness of carburized P20 steel presents a strong influence on the residual stresses and surface roughness produced by shot peening process. In this investigation hardness reduction from 800 to 650 HV led the compressive residual stress to be doubled.

A mechanical component which requires case hardening and shot peening will reach an optimized condition of residual stress and surface roughness when the superficial hardness is as close as possible to lower hardness design limit.

Further investigations should be made regarding the effect of the previous manufacturing process (e.g. grinding) on the typical surface roughness produced by shot peening.

4. ACKNOWLEDGMENTS

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