RESIDUAL STRESSES IN THE SAE 52100 STEEL AFTER HEAT TREATMENT AND TURNING

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Abstract. *The present work has as objective to analyze the effect of the heat treatments on the SAE 52100 steel, from bearing cone parts. The residual stresses have significantly contribution in the useful life of the pieces submitted under dynamic forces. Machining processes introduce residual stresses that added to the others generated by the heat treatments can cause an aggravation on the behavior fatigue part. To characterize the profile of these generated residual stresses during the process of heat treatment on these parts, the machining processes is an important starting point to develop products with better performances. Heat treatments of annealing, normalizing, quenching and quenching and tempering had been executed. The residual stresses had been measured before and after the turning process, using the incremental hole drilling (IHD) technique and the results were analyzed by the integral method. The results demonstrate that the machining generates big changes in the residual stresses profile and the previously heat treatment have great importance in the process.*

Keywords: *machining; turning; heat treatment; residual stresses*

1. INTRODUCTION

Precision hard turning has attracted great interest since 1970s because it potentially provides an alternative to conventional grinding in machining high precision, high hardness components. This technology significantly reduces the production time, tooling costs and the capital investment for low volume finishing applications, such as dies, gears, shafts and bearings. In particular, it can often cut manufacturing costs, decrease production time, and improve overall product quality. (Rech, et al., 2008).

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The residual stresses in the machined surface considerably influence the service quality of the component including fatigue life, tribological properties, and distortion (Thiele et al., 2000). It is believed that compressive subsurface residual stresses are more favorable for rolling contact fatigue life than tensile residual stresses. Furthermore, machining of hardened components such as shafts, roller bearing and other mechanical components is usually done in a finishing operation. The residual stresses, whether compressive or tensile, left behind by the machining process remain in the final product. Therefore, it is important that the effect of the finishing process on the subsurface residual stress profile be predicted and that the machining parameters optimally selected to induce favorable residual stresses (Hua et al., 2006).

As studied by Guo and Warren, 2008 the formation sequence of fatigue cracks is different for the turned and ground surfaces. The basic difference is that an initial main crack form in the subsurface for turned samples, while an initial branching crack could start from ground surfaces and joins with the subsurface main crack and the turned finished has several advantages in the life of the component under fatigue efforts.

So, it is very critical to find a fast and precise solution to predict residual stresses in a machined component given the process parameters and material properties (Ulutan et al., 2007). Since the pioneering works in 1950s, a substantial amount of experimental work has accumulated regarding the development of residual stresses as a function of cutting parameters and the properties of the tool and the workpiece. The effects of feed rate, depth of cut, cutting speed, coolant, shape of the cutting edge, tool wear, tool coating, and workpiece hardness on residual stresses can be investigated separately, where residual stresses are measured after a carefully controlled machining process using a variety of techniques ranging from X-ray diffraction to hole drilling and deflection-etching (Valdez, 2008). Various materials including steel, ceramics and composites have been subjected to similar measurements.

Steels have been used since the Iron Age and their importance in the development of industry has been enormous. Steels are the most important alloys utilized as structural material. They are straightforwardly related to engineering. The microstructure of most steels is well known by now as well as the effects of the heat treatments in changing their mechanical properties. For instance, the hardness of the AISI 5150 steel could vary from ~ 20 to 60 HRC depending on its heat treatment. The differences in mechanical properties of given steel are the result of different microstructures formed during cooling. This statement generally means that the highest hardness in the iron–carbon systems is obtained due to a diffusion less transformation called martensite formation and the lowest hardness is obtained due to a diffusion transformation, which causes the ferrite and/or pearlite formation by a eutectoid reaction. Both martensite obtained during rapid cooling and ferrite-pearlite obtained during slow cooling or near the equilibrium, come from austenite. Therefore, both the steel microstructure and the steel mechanical properties are related to steel thermal history (Machado, 2006).

The objective of this work is to study the influence of the heat treatment in the residual stresses of the AISI 52100 steel and its consequences in the turning of the pieces.

2. EXPERIMENTAL PROCEDURE

The specimen model used is illustrated in Figure 1. It's a conical bearing part.

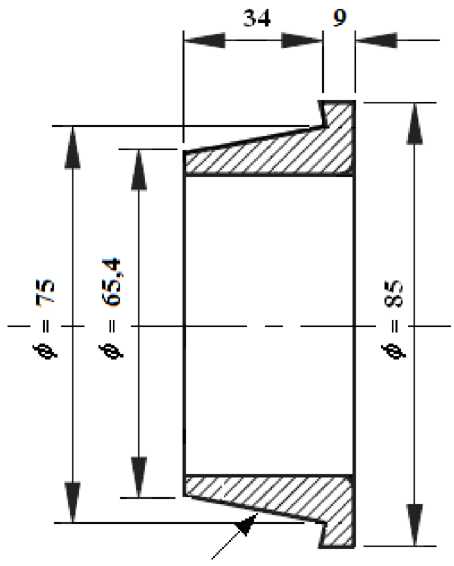


Figure 1 - Conical bearing part used in the tests

The main chemical composition of AISI 52100 are: C: 0.9-1.05, Si: 0.5-0.7, Mn: 1-1.2, Cr: 1.5-1.55, P: <0.025, S: <0.025, Ni: <0.3, Cu: <0,3.

The Table 1 shows the heat treatment used in the specimens. The Lindberg 56962 (heated vacuum furnace) was used.

Table 1 – Heat treatments

Heat treatment	Procedure
Annealing	Temperature: 800 °C; Time: 1,5 h; Cooling: inside the oven (45 h).
Normalizing	Temperature: 800 °C; Time: 1,5 h; Cooling: air (ambient temperature ≈ 28 ºC).
Quenching and tempering	*Quenching:* Temperature: 800 °C; Time: 1,5 h; Cooling in oil without heating (20 ºC); Agitation: 1,5 m/s. *Tempering.* Temperature: 500 °C; Time: 1 h; Cooling in the air (ambient temperature ≈ 28 ºC)..
Quenching	Temperature: 800 °C; Time: 1,5 h; Cooling: water (20 °C); Agitation: 1,5 m/s.

The hardness measurements were conducted by a microhardness tester 4M, Wilson Mechanical Instrument Co. Inc.

The turning process was conducted using:

- ✓ Tool: VBGW 160404 S01020F – 7025 // Sandvik Coromant

- ✓ Tool holder: MVJBR 2020K16 // Sandvik Coromant
- ✓ Lathe: CNC Universal Centur 30D // Romi
- ✓ Cutting parameters: Cutting speed (v_c): 220 m/min ; Feed rate (f): 0,1 mm/rot ; Cutting depth (a_p) : 0,075 mm

An optical microscopy model DM LM, from Leyca and a camera model XC XT50CE, from Sony were used in the metallographic analysis. For the chemical attack the samples was used Nital 3%.

The residual stresses measurements were conducted using:

- ✓ Strain-gages rosette: CEA-13-062UL-120 // Vishay
- ✓ Inverted conical milling – Carbide: FG 39 // KG Sorensen
- ✓ Pneumatic milling – High speed: RS 200 // Vishay
- ✓ Digital micro strain meter: P3 // Vishay
- ✓ Software for residual stresses analysis: H-drill (Integral method) // Vishay

The complete equipment for the residual stresses measurements is illustrated in the Figure 2.

Figure 2 – Complete equipment for residual stresses measurements with the bearing cone parts.

3. RESULTS AND DISCUSSION

The obtained values for the hardness measurements are showed in the Figure 3.

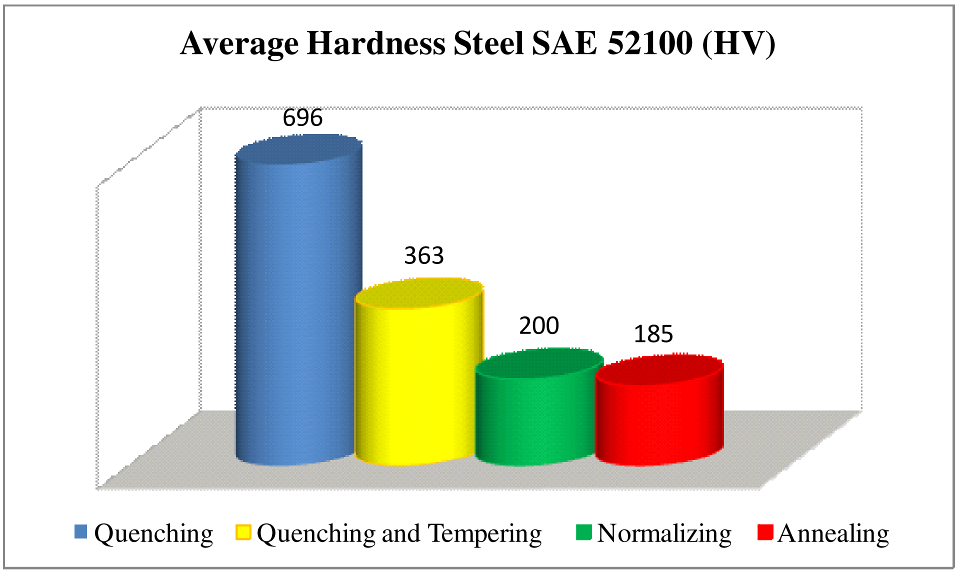


Figure 3 - Hardness of the specimens in scale HV.

The Figure 4 shows metallographic analysis in the surface of the pieces after the heat treatment and turning**.**

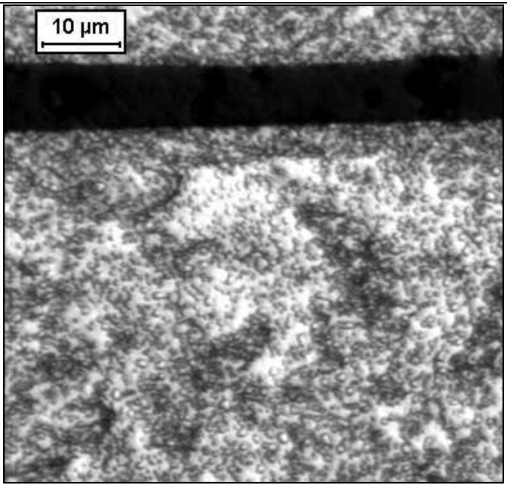
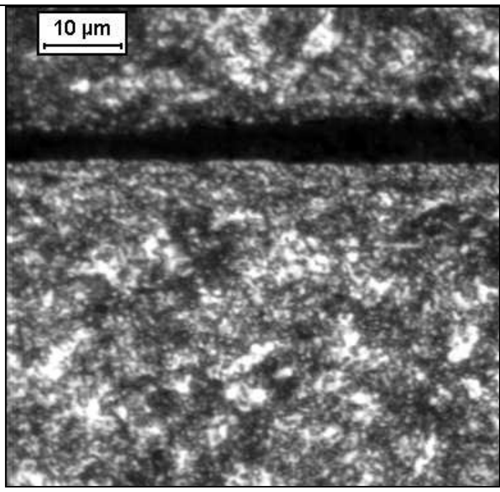
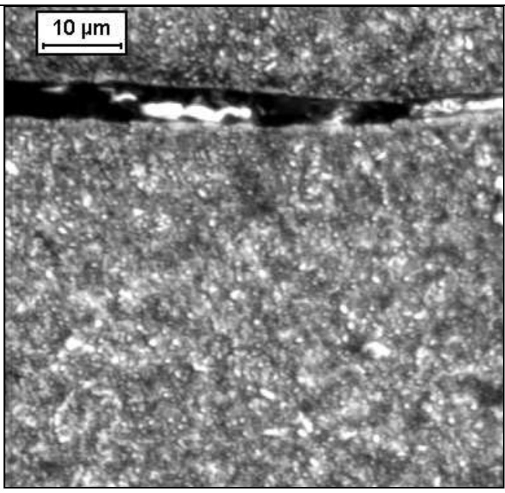
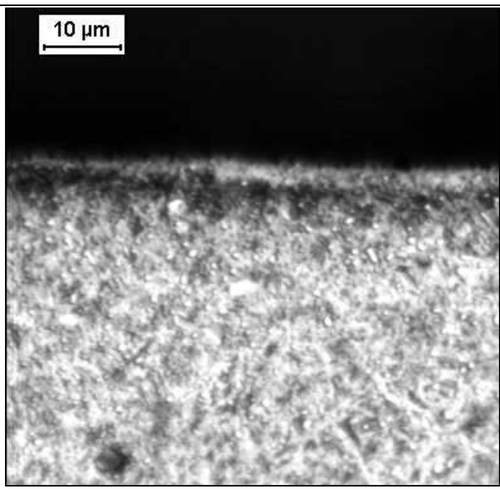
	
(a). Annealed piece. Magnification 500x	(b). Normalized piece. Magnification 500x
	
(c). Quenched piece (oil) and tempered. Magnification 500x	(d). Quenched piece (water). Magnification 500x

Figure 4. Microstructure of different heat treatments and turning.

In according with the Figures it can be observed:

- ✓ Figure 4(a) – Annealed piece: spheroid microstructure, formed by ferrite and spheroid carbide.
- ✓ Figure 4(b) – Normalized piece: spheroid microstructure, with perlitic regions and carbide in the boundary grain.
- ✓ Figure 4(c) – Quenched and tempered piece: microstructure formed by tempered martensite and primary chromium carbide.
- ✓ Figure 4(d) – Quenched piece: microstructure formed by martensite and primary chromium carbide.

On the annealed, normalized and quenched/tempered pieces there were no differences in the microstructure between the surface and the middle of the piece. After the machining, the presence of white layers were not observed, because only new tools were used (without wear) with less friction, low cutting forces and smaller temperatures, not causing changes in the microstructure.

In the quenched piece a dark layer was observed. The martensitic microstructure is metastable, that means, the microstructure can change with the heating. During the machining, the temperature of the piece can reach at high values but for a small time. In this case it was sufficient to cause tempering in the region. A quenched and tempered steel is more susceptible at chemical attack when comparing with a quenched steel, that explain the darkness in the surface.

The small white points observed in the microstructure are primary chromium carbide, and their appearance is justified by the high carbon content of steel and the presence of chrome that contribute with a significant way in the wear resistance of the quenched/tempered material.

The Figure 5 shows the residual stresses measurements for the annealed piece. Was observed that the turning introduce high plastic deformation by mechanical effects on the surface of the work piece. After the turning, the compression residual stresses in the surface almost duplicated the valor initial, and the values tend to zero in the bulk, to approximate 0,2 mm above the surface.

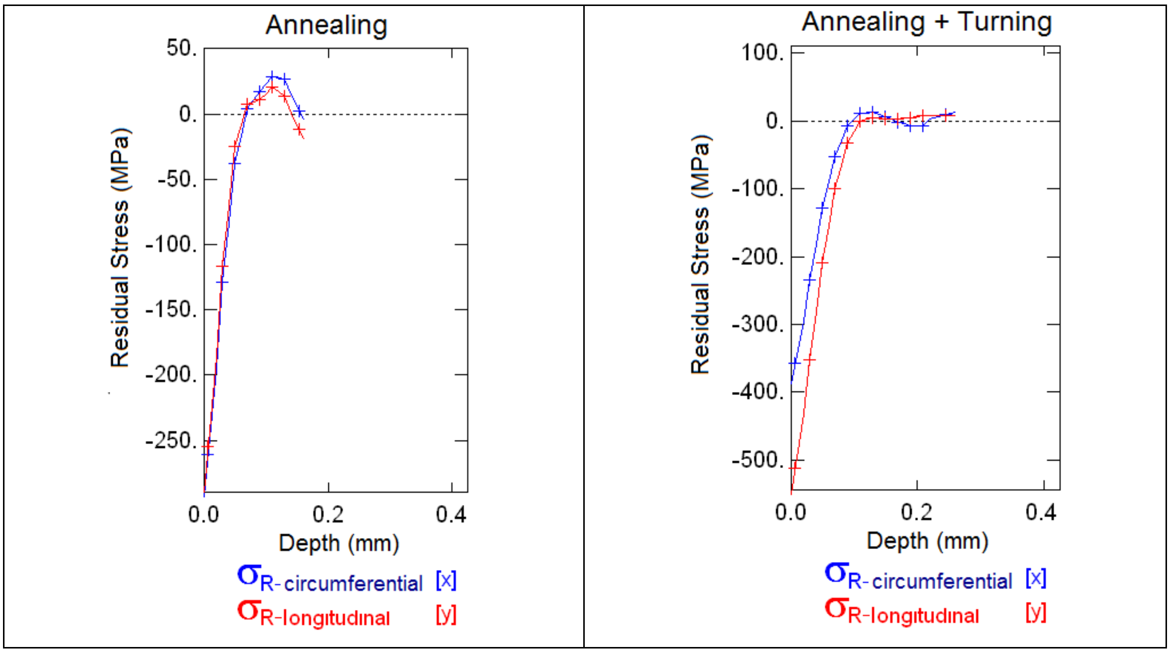


Figure 5. Residual stress measurements for the annealed piece

The Figure 6 shows the residual stresses measurements for the normalized piece. In this case the values before the turning process is different than the last results, due to microstructures. Smaller compressive residual stresses were founded in the surface and traction values in the sub-surface. After the turning, high values of compressive residual stresses were founded in the surface and sub-surface, this because to mechanical action of tool in the work piece.

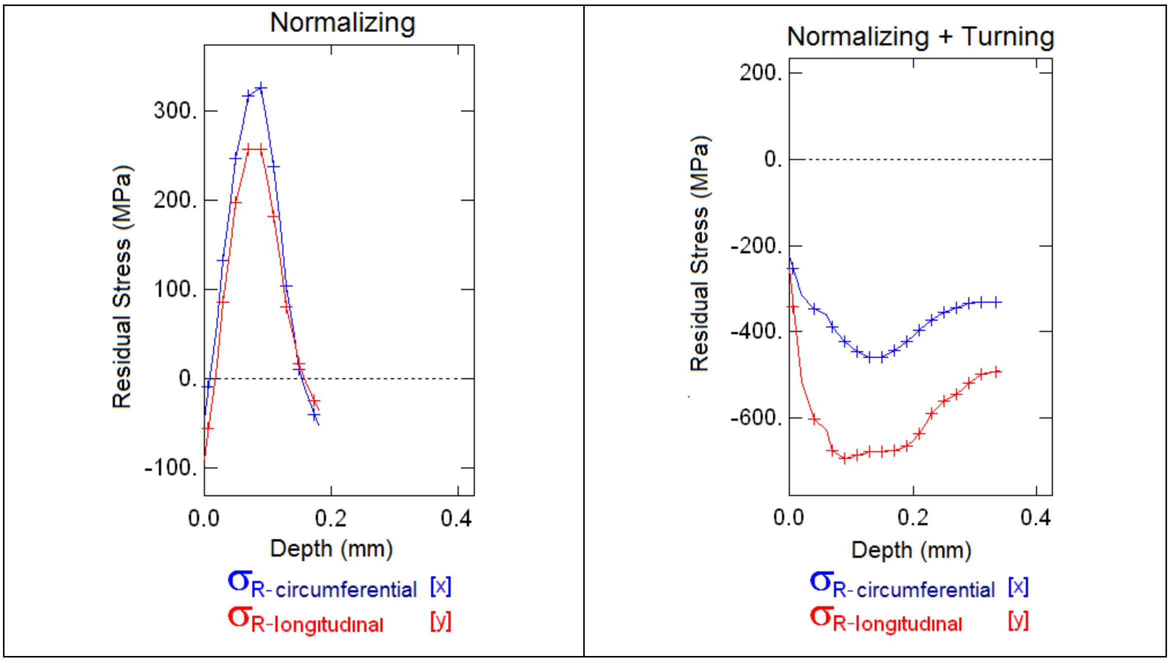


Figure 6. Residual stress measurements for the normalized piece

The Figure 7 shows the residual stresses for the quenched and tempered pieces. Initially were founded in the workpiece traction residual stresses in the surface and compressive values in the sub-surface. After the turning the values of traction residual stresses were inverted, and high compressive residual stresses were measured in the surface. In the bulk the values of compressive residual stresses also increased, and tend to zero from 0,3 mm below the surface.

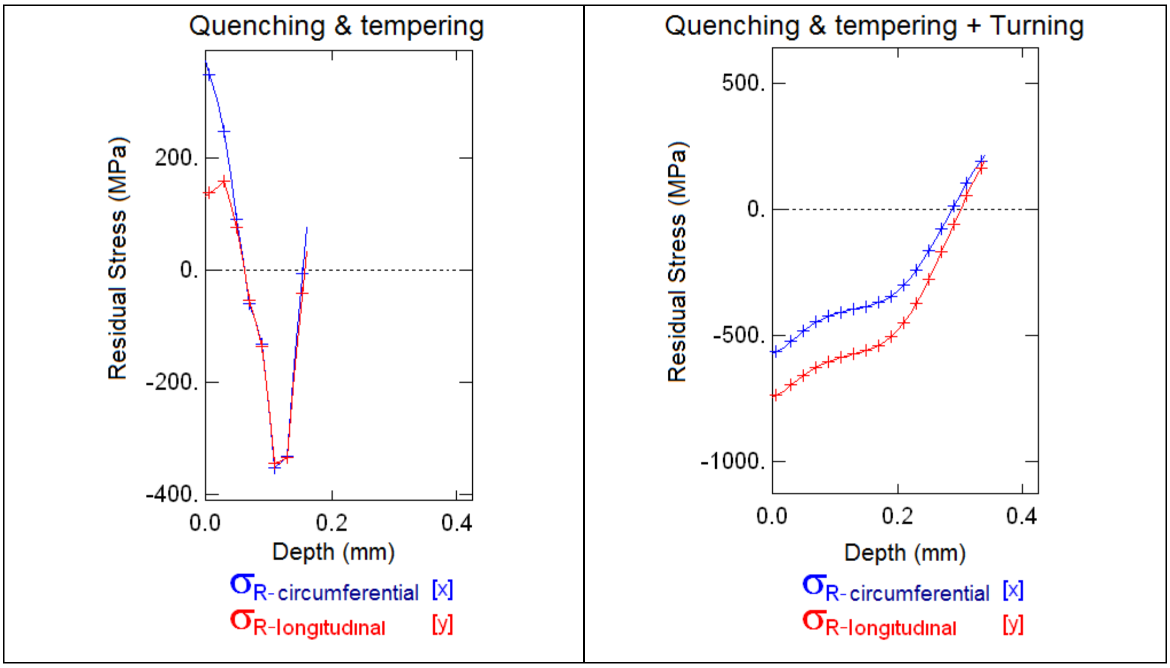


Figure 7. Residual stress measurements for the quenched and tempered piece

The Figure 8 shows the residual stresses for the quenched work piece. In this case, this residual stresses before turning test was similar to previous case. The turning process also introduces residual stresses of compression in the surface of the work piece. Observed that the use of the new tool continues generating compressive residual stresses even at steel with high hardness.

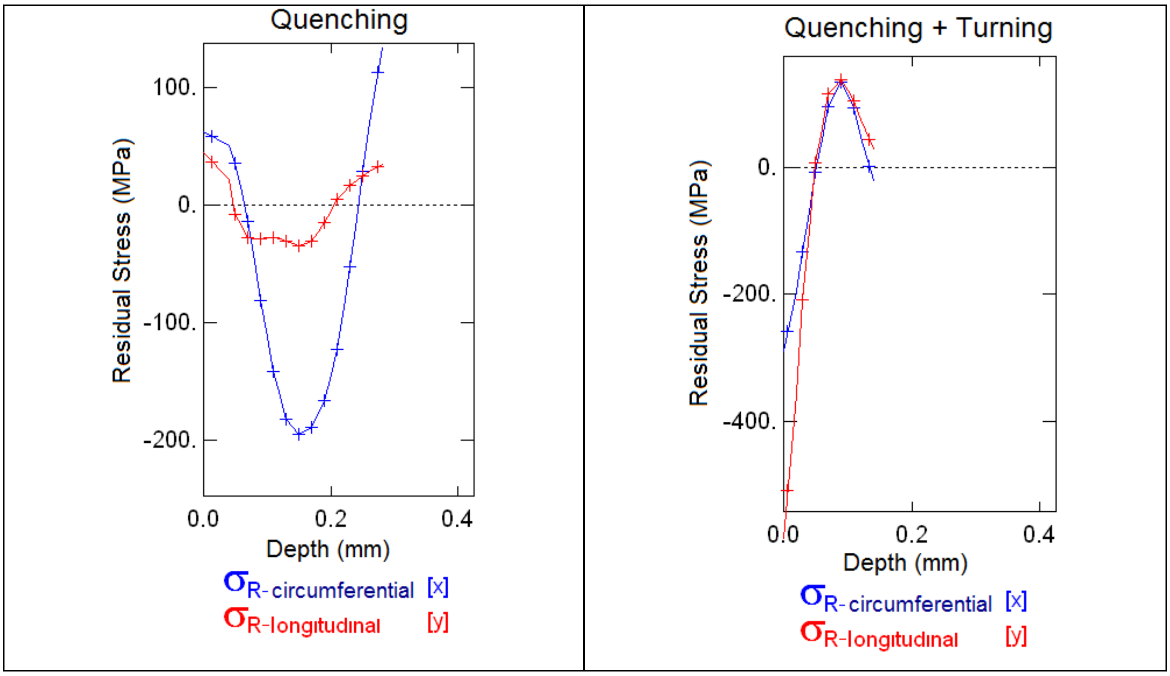


Figure 8. Residual stress measurements for the quenched piece

4. CONCLUSIONS

In all of the cases the turning finish process using new tools always makes positive changes in the surface of workpieces

There are not microstructural changes in the surface after the turning process in the annealed, normalized and quenched/tempered workpieces. In the quenched work piece it was observed a dark layer in the surface, which suggests a tempering in some portion of the microstructure. The white layer formation was not observed.

The workpieces with heat treatment and hardness smaller than 220 HV, originality has residual stress of compression in the surface and quenched and quenched/tempered have residual stresses of traction.

In the hard and ductile materials the turning finish process always increases the residual stresses of compression in the surface and subsurface the workpieces. Also, it was noted a decrease in the residual stresses that tends to zero on the bulk of material.

5. ACKNOWLEDGEMENTS

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