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Superficial integrity analysis in a super duplex stainless steel after turning

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ABSTRACT

Purpose: Purpose of this paper was to study the main effects of the turning in the superficial integrity of the duplex stainless steel ASTM A890-Gr6A.

Design/methodology/approach: The focus of the work was the finishing operations and a complete factorial planning was used, with 2 levels and 5 factors. The tests were conducted on a turning center with carbide tools and the main entrances variables were: tool material class, feed rate, cutting depth, cutting speed and cutting fluid utilization. The answers analyzed were: micro structural analysis by optical microscopy and x-ray diffraction, cutting forces measurements by a piezoelectric dynamometer, surface roughness, residual stress by x-ray diffraction technique and the micro-hardness measurements.

Findings: The results do not showed any changes in the micro structural of the material, even when the greater cutting parameters were used. All the other answers were correlated with the cutting parameters and its better combination was founded for the best superficial integrity. The smaller feed rate (0.1 mm/v), smaller cutting speed (110 m/min) and the greater cutting depth (0.5 mm) provided the smaller values for the tensile residual stress, the smaller surface roughness and the greater micro-hardness.

Research limitations/implications: The correlation between all the answers was very difficult to analyze because there was great interaction between the factors, but for some data group it was possible.

Originality/value: The paper contribute for the study of the super duplex stainless steel, considering that no one researches was founded for the studied topics in this material in witch presents different behavior in machining when compared with another stainless steels.

Keywords: Machining; Turning; Super duplex stainless steel; Residual stress

1. Introduction

At least one in each five machining operations is turning [1]. This process also in one of the most used in the industry, with 40% of the total time expensed in machining and 30% with relation to the operation number when compared with other processes [2]. So, is visible the importance of him in the day-by-day of the industries and becomes necessary the continuous improvement of it's quality and the number of specific information that cannot be gotten during the continuous machining process. The turning also is very used in the pumps industry, that is one of the main users of the material to be studied in this work.

The super-duplex stainless steel presents characteristics of the ferritic and austenitic stainless steels in just one material and in this form it possess greater mechanic and corrosion resistance than the conventional austenitic stainless steel. It's characterized by a mixture structure in approximately equal parts of austenite and ferrite. The DSS with relationship to the austenitic steels stainless steel, presents several advantages, being the mayor ones: larger resistance to the corrosion under clorets tension, larger resistance to the pitting corrosion and in general twice strength limit than an austenitic, with just half of the amount of nickel present in the austenitics, being less sensitive at the high cost of this element [3-4].

The machining of stainless steels cannot be totally generalized. Due to the great variety, the machining can be worse, or better, in agreement with the microstructure, hardness and content league of elements, being known that the microstructure affects the machining in larger scale than the hardness.

The difficulties in the machining of super duplex stainless steel tend to increase, and the machining of this material frequently is compared with its PRE (Pitting resistance equivalent) [5]. Due to the great amount of austenite, nitrogen and alloy elements, it's machining tends to decrease quickly.

The superficial integrity is a measure of the quality of the machined surfaces, interpreted in function of elements that describe the structure of the surface and the substratum of the material. Generally it is defined by the metallurgic, chemical and topological properties of the surfaces, as surface roughness, microstructure, micro-hardness variations and changes in the residual stresses [6-7].

To accomplish the established objectives of this work, some tests were made buy a factorial design and the mainly analyzed answers were: surface roughness, cutting forces, residual stress and micro-hardness variation. The objective of this work is to characterize the main effects caused in the material surface by the machining through the turning operation and to establish correlations between the cutting parameters and it's consequences, since the adequate choice of the cutting parameters is basic to get products with the superficial qualities required [8-9].

2. Experimental procedure

The tests were conducted in a turning center OKUMA LB300, and the used cutting fluid used was the Castrol PS04002 with 6% of emulsion in water in abundance.

The Figure 1 shows an example for the used specimens.

The material was the super duplex stainless steel ASTM A890GR6A (0.02 C, 24.8 Cr, 7.49 Ni, 0.65 Mn, 0.8 Si, 3.37 Mo, 0.006 S, 0.025 P, 0.8 Cu, 0.059 Zr, 0.79 W, 0.24 N, <0.001 Nb, <0.001 Al, 0.044 Co, 0.03 V, 0.006 Ti, 0.0009 Pb, 0.082 Sn, Fe).

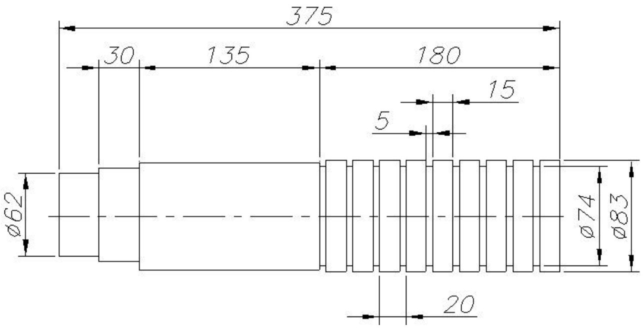

Fig. 1. An example of a specimen used

After the casting made especially for this work with dimensions ∅90x400mm, the material was annealed.

The used design of experiments was the complete factorial, with 2 levels and 5 factors and 2 replicates. This design was used because it's the unique that can study the interactions between the factors. The used cutting parameters were: cutting speed (110 and 150 m/min), feed rate (0.1 and 0.2 mm/r) and cutting depth (0.25 and 0.5 mm).

Every one of the used insert carbide tools doesn't have been utilized for more than 2 segments of the specimen and in this way, was considered, that only new tools were used on the work. The inserts carbides used were: VNMG 160404-MF–1025 with PVD TiAlN coating and VNMG 160404-MF–2015 with CVD TiCN-Al2O3-TiN coating.

For the cutting measurements the mainly used instruments were: piezoelectric dynamometer with a PCB Piezotronics cell, model 260A01, software Catman release 3.1, signal conditioning Spyder 8 from Hottinger Baldwin Messtechnik (HBM) and a personal computer.

For the surface roughness measurements: Roughness surface tester Mitutoyo Surftest SJ201.

The residual stress measurements were made by x-ray difractometer RIGAKU – DMAX Rint 2000.

The investigation on precipitated phases was made by x-ray difractometer RIGAKU, model Multiflex and optical microscopy Olympus BX60MFS, with digital camera Sony CCD-IRIS.

The micro-hardness measurements were conducted by micro-hardness tester HMV – Shimadzu (HMV-2 344-04152-02), with 50g of load, during 15s for all the measurements. The KOH etch by electrolytic immersion during 50 s with 2 V was used for distinguishes the both phases before the micro-hardness measurements.

For the optical metallographic analysis more 2 etches were made to study the precipitation phases on the material: Oxalic 10%, and modified Behara.

3. Results and discussion

The optical metallographic analysis does not show any change in the microstructure of the material in any one of the 3 etches conducted. In the same way, the x-ray diffraction also reveals that the cutting parameters used don't affected the surface and the substrate of the material.

The surface roughness analysis show great influence of feed rate on the analysis, as expected, considering that the roughness is geometrical dependent of this parameter. The cutting depth practically does not make influence on the roughness. The cutting fluid when used, improves the tribological phenomenon in the machining by the cutting lubrification and better roughness values were obtained. Bigger cutting speed decreases the tendency of BUE formation (critical in this material), and decreases the tool-piece contact area, decreasing in this way the deformations and consequently the surface roughness [10].

The cutting forces measurements showed that the cutting force was the bigger, followed up by the penetration cutting force and the feed rate cutting force. This is a common comportment in ductile materials, but changing position angle tool and rake angle this order could be affected. The feed rate and the cutting depth were the mainly parameters that influenced the forces, since they are the responsible for the cutting section. The bigger cutting velocities, the smaller feed rate and cutting depth, the dry cutting and the insert class 1025 makes minor forces in it's 3 components. The feed rate and cutting depth influences geometrically the cutting section and its comportment was expected. The bigger cutting speed and the dry cutting, decrease the shear stress, due to decrease in plastic deformation, chip hardness and in the friction coefficient, due to the increase in cutting temperature. The insert class also makes influences in all the cutting forces, due to the changes in tribological contact tool-piece, that the CVD TiCN-Al2O3-TiN coating introduce on this material coating.

The residual stress measurements show that this is a difficult parameter to be analyzed. So many researches had been studied it [11-14], but no one for the super duplex stainless steel. Comparing the results from these authors is not possible to establish good correlations between the works and the cutting parameters used, in many cases, for works almost equals, and can be assumed that small details of the machining makes great differences on the analysis. The Table 1 shows the founded values for the residual stress measurements.

Table 1.
Founded values of residual stress measurements

Test	Cutting speed (m/min)	Feed rate (mm/r)	Cutting depth (mm)	Insert class	Residual stress (MPa)
1	110	0.1	0.25	2015	484,5
2	150	0.1	0.25	2015	417
3	110	0.2	0.25	2015	434,5
4	150	0.2	0.25	2015	222,5
5	110	0.1	0.5	2015	654
6	150	0.1	0.5	2015	299,5
7	110	0.2	0.5	2015	345,5
8	150	0.2	0.5	2015	572
9	110	0.1	0.25	1025	354,3
10	150	0.1	0.25	1025	326,4
11	110	0.2	0.25	1025	560
12	150	0.2	0.25	1025	492,5
13	110	0.1	0.5	1025	281,5
14	150	0.1	0.5	1025	329,5
15	110	0.2	0.5	1025	326
16	150	0.2	0.5	1025	406

The residual stresses generated during the machining were tensile. Also was noted during the interactions data analysis that the cutting speed and the insert class presented interactions with all the other factors. When they were analyzed with any one of the others, the comportment was inversed. When the smaller cutting speed was used, as the other parameters was increased the residual stress value dropped, and when the bigger cutting speed was used, as the other cutting parameters was increased, also the residual stress value gone up. This means that there is an optimum grade of "deformation vs. thermal effect" to be considered in this case. The results also show great importance of the cutting speed that modify the thermal effects on the machining and its variation make greats differences on the residual stress analysis. So for this analysis the combination between the parameters must be observed and not just one parameter. The insert carbide class also makes some differences in the others, because it also presents interaction. Probably the changes in the coatings introduce more or minus thermal effects on the residual stress formation like the cutting speed.

Great values of compression residual stress provides longer life fatigue to the pieces in service, and for the tensile residual stress, how minor is it's values, it's better for the pieces lives. The carbide insert class 1025 provides smaller values of residual stress, so the Figures 2 and 3 show the contour plots for this case.

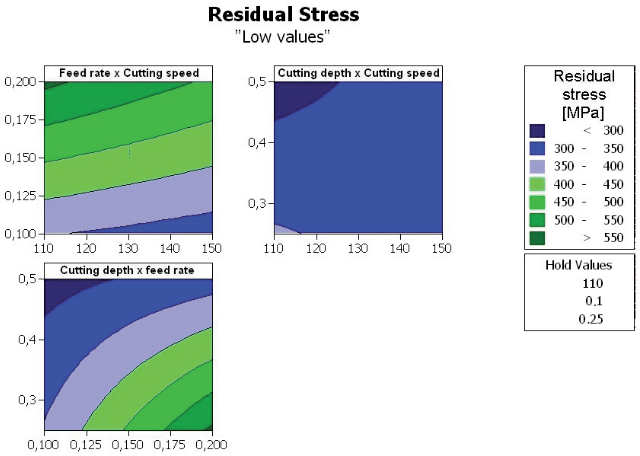

Fig. 2. Contour plot for residual stress (low values)

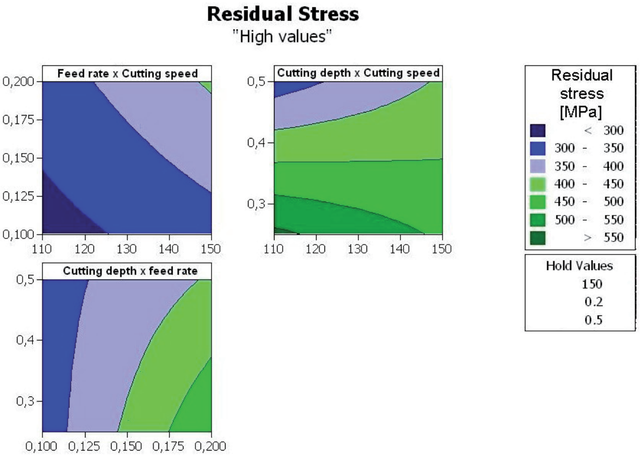

Fig. 3. Contour plot for residual stress (high values)

The micro-hardness measurements showed different values for the austenitic and ferritic phases. The ferritic were the bigger, and for the both, the values were dropped as soon as the measurement distance of the surface bigger. The Figure 4 shows the graphs for one specimen. In most of all the measurements, below the 0.1 mm of depth the values do not change significantly, staying similar to the material center. The deformation process of the austenite occurs by grain contours rearrangement and has a viscous character. Its rearrangement is more time dependent than the slip occurred in the austenitic phases, and for this, its more dependent of the deformation rates imposed on the machining [15].

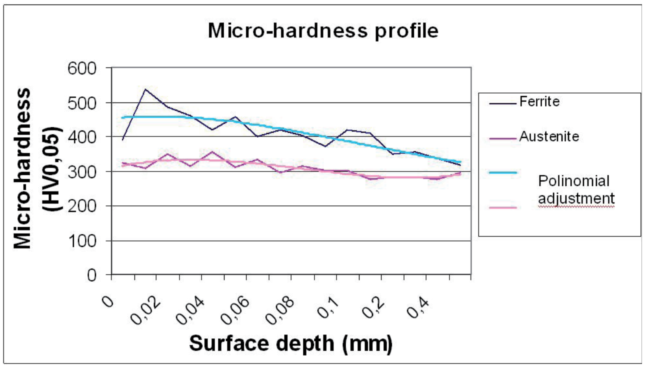

Fig. 4. Micro-hardness example profile for a specimen (cutting speed=150 m/min; feed rate=0.1 mm/r; cutting depth=0.25 mm)

3.1. Correlation between the values

It was very difficult to make correlations between all the answers, because most all of the analyzed plots showed great interactions between the factors. In this sense some factors were eliminated from the analysis to find some possible correlations by the Pearson coefficient. For some parameters group, the correlations between the residual stress, micro-hardness and roughness was possible, but how it was not constant for all the analysis it was not showed here.

The correlations between all the factors were not possible, but throughout some contour plots it was possible to establish tendencies to the machinability of this material. It was possible to find the better parameters to obtain the recommended superficial integrity, that means that, smaller cutting speed (110 m/min), smaller feed rate (0.1 mm/r) and bigger cutting depth (0.5 mm) provides the smaller tensile residual stress, the smaller roughness and the bigger micro-hardness. Also is possible to know each cutting parameters can be selected for a specific characteristic.

4. Conclusions

There was not possible the identification of micro structural changes in any one of the specimens, even when the greater cutting parameters was used.

The tensile residual stress analysis showed a great influence of the cutting speed on its results as well as the insert carbide class.

The same behavior can be observed in the micro-hardness analysis.

Were not possible to establish correlations between all the final answers because there were greats interactions in most all of the then, but the best cutting parameters for a required superficial integrity was identified.

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