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CUTTING PARAMETERS INFLUENCE ANALYSIS ON RESIDUAL STRESS GENERATION IN IRON TURNING OPERATION CAST NODULAR AUSTEMPERED

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Abstract. *The austempered nodular cast iron (ADI) is a modern cast iron class. Residual stresses are stresses that remain in a component even when it is free from external forces or temperature gradients. The machining process is a source of residual stress generated in the material. The machining ADI presents a difficulty to be a hardened material besides the transformation of austenite into martensite during the machining process, the residual stresses generated during processing. In this sense, it was decided to conduct this research in order to study the effects of cutting parameters in the generation of residual stresses after ADI's turning operation. It was used factorial design randomized by levels and fixed effect model for analyzing the results of experiments. The turning tests were performed in the center of turning Romi GL 240M, with carbide tools k group. For analysis of residual stress were performed micro hardness tests of Ultra Micro Hardness Tester DUH-211S. The results indicated that the ADI of turning caused the generation of residual tensile stress, control all the variables except for variable length machining.*

Keywords: *Turning; Nodular cast iron austempered, Residual Stress, Cutting Parameters;*

1. INTRODUCTION

This research aims to investigate the influence of cutting parameters in the generation of residual stresses in turning operation of Austempered Ductile Iron (ADI). The ADI is a modern cast iron class obtained by austempering treatment performed in a nodular cast iron (Dias, 2006).

The ADI heat treatment consists of heating the part to the austenitizing temperature between 825-950 ° C and remained at this temperature for 1 to 3 hours. Then the piece is cooled rapidly to the desired austempering temperature usually between 230 to 400 ° C for a time between 0.5 to 4 hours. After the part is cooled to ambient temperature before the start of bainite reaction. Figure 1 illustrates the cycle austenitizing and austempering performed for treatment of nodular cast iron.

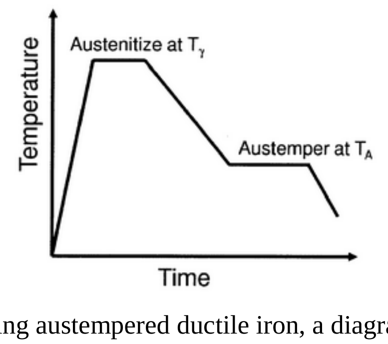

Figure 1- heat treatment cycle for obtaining austempered ductile iron, a diagram superimposed on time, temperature, transformation (TTT). (Adapted DIAS, 2006).

The structure formed after heat treatment, austempering is commonly called ausferrita which consists of acicular ferrite, denoted by α and stabilized austenite due to the high carbon content, denoted by γ High C (KLOCKE et al., 2010).

The nodular cast iron has several properties that give it a standout in the cast iron classes. According to Franco (2010) nodular cast iron has high mechanical strength, higher than that of carbon steel and forgings, lower ductility of steel, but much higher than the other cast irons classes. For Meena and Mansori (2011) these properties conferred to nodular cast iron after austempering are causing many previously produced pieces for forged steel and other iron grades are produced in ADI.

The production of this material intended to parts used in construction machinery in general: the railway industry as wheels of locomotives, wagons, brake shoes couplings; wear parts for mining machinery; in agriculture, earthmoving equipment, automotive industry in the manufacture of parts such as suspension, crankshafts, camshaft valves, connecting rods, gears, suspension system components and supports truck springs.

Figure 2 illustrates crown, pinion and crankshafts produced nodular cast iron Austempered (SORELMETAL, 2002).

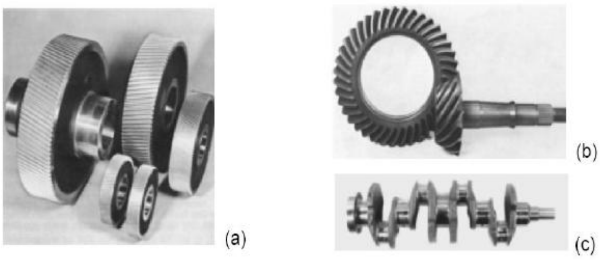

Figure 2 - Examples of parts: (a) gear in ADI, (b) crown and pinion of General Motors and (c) turbo engine crankshaft Ford (SORELMETAL, 2002).

According Shaw (2005), the turning process may be defined as the removal of material from a rotating workpiece by the use of fixed cutting tools in a single region. The tool removes workpiece material through the shearing process, which possesses high rates of deformation, high temperatures.

For Trent and Wright (2000) turning machining operation is most commonly used in metal cutting. In the workpiece and the tool are two factors that determine the final material result of a turning process, cutting parameters and the geometry of the cutting edge.

Among the cutting parameters can quote the cutting speed (Vc), advance (f), the feed rate (Vf) and cutting depth (ap), as the main parameters of entry of a turning process.

Diniz (2008) sets the speed of cutting (Vc) and the resulting instantaneous tangential speed of tool rotation around the piece.

The advance (f) is the path of advancement at every turn (mm / rev). The feed rate (VF) is the advancement of the product by rotation of the tool and its unit is mm / min.

The depth of cut (ap) is the tool penetration width in relation to the piece, measured perpendicular to the work plan being given in mm.

Residual stresses are stresses that remain in a component even when it is free from external forces or temperature gradients. These residual stresses may be provided from a process or manufacturing stresses to which it was subjected are classified as mechanical, thermal or chemical origin.

The machining process is a source of residual stress generated in the material. Research indicated that the main influences on the generation of residual stresses in machining processes cutting parameters, material and tool geometry and nature of the machined material.

Residual stresses can affect the mechanical properties of the material and its structure causing structural defects, decreasing the corrosion behavior (in case of residual elastic tension) but it can have beneficial effects such as increasing the fatigue limit, in the case of compressive surface stresses (Medeiros, 2003).

Residual stresses can be classified into tensile and compressive stresses can be as illustrated in Figure 3. The tensile stresses can facilitate nucleation of cracking leading to failure due to mechanical fatigue, when subjected to cyclic mechanical stress. However, compressive stresses are beneficial because they tend to disrupt the propagation of existing cracks in the material (Bianch et. Al., 2000).

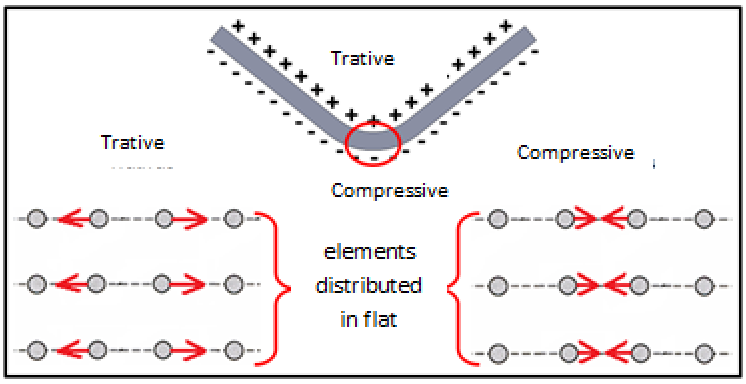

Figure 3 - Nature of residual stress: tensile and compressive.

The machining process may result in residual stresses in material due to plastic deformation of the surface layer, the mechanical action of the tool and local heating during machining, and this temperature can take very high values leading to the transformation of some alloy phase. Cullity (2001) instructs that the final distribution of residual stresses in a machining process depends on heating rate and tool characteristics.

According to Agrawal and Joshi (2013) the machining process causes an undesirable induction of residual stresses in the machined surfaces. Stress can directly affect the fatigue life, resistance to component corrosion.

The geometry of the cutting edge exerts great influence on the generation of residual stress. In general chamfered and rounded cutting edge is the best condition for generation of compressive residual stress (HUA et. Al .; 2006).

According Javidi et. al. (2008) advancing (f) is the machining parameter that most influences the generation of compressive residual stresses.

For the cutting depth (ap) and the cutting speed there is no consensus about its influence on the generation of residual stresses. Dahlman et. al. (2004) in his research found no influence of cutting depth in the generation of residual stress, as Bordinassi (2006) in its survey reported that the cutting depth influenced the generation of residual stress. In surveys conducted in turning operation of hardened steels, Rech and Moisan (2003), reported strong influence of the cutting speed in the generation of residual stress compression, as Gunnberg et al. (2006) reports that the cutting speed influenced generating residual tensile stresses in your search.

There are several qualitative and quantitative techniques for analyzing residual stresses. The indentation test method has been used to measure residual stress. In pyramidal penetrator (indenter Vickers) hardness of crystalline materials generally increases with decreasing depth of penetration (SWADENERA; Georgea; Pharm, 2002). It is expected that a deformed material subjected to a hardness test presents a result different from a result of the test in a non-deformed material. If the nature of the residual stresses on the surface are tensile, the test will present a lower value for the surface hardness compared to the non deformed material. Otherwise, with compressive residual stresses on the surface, the penetration will be more difficult and the test result will present higher values (Bocciarelli and Maier, 2006).

2. DEVELOPMENT

2.1 Materials and Methods

The experimental procedures were performed in Manufacturing Processes Laboratory for Machining of the Federal University of São João del Rei. It was used nodular cast iron with the chemical composition shown in Tab. 1, the same being subjected to austempering heat treatment.

Table 1. Chemical composition (mass%) of austempered ductile iron used in the tests (Dias, 2006).

C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Ti	Sn	Al	Mg	Fe int	Fe %
3,7436	2,5985	0,1316	0,0848	0,1045	0,6021	0,0120	0,0000	0,6310	0,0227	0,0000	0,1096	0,0465	6,3949	92,1050

To characterize the nodular cast iron Austempered as its main mechanical properties were performed the hardness test and tensile following ASTM A536 / 84 in specimens without suffering the machining process. The samples were prepared according to Fig. 4

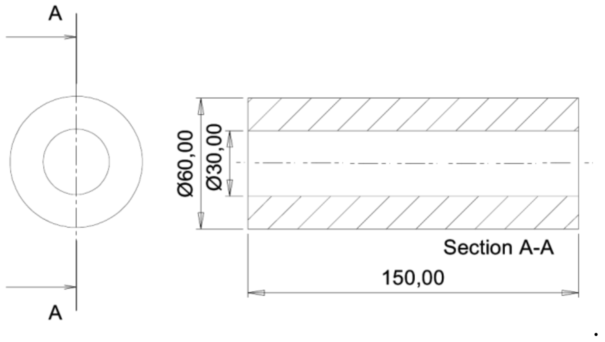

Figure 4. size of gross smelter specimen

For the realization of cylindrical turning tests, we used a lathe ROMI GL 240M with longitudinal and transversal fast forward speed of 30 m / me maximum power of 15 kW spindle, maximum speed of 6000 rpm and CNC Fanuc Hi TD, as shown in Fig. 5.

Figure 5. lathe Romi GL 240.

For turning tests were used carbide inserts from Sandvik K class with basic geometry CNMG 1208 - KR, PCLNL-2020K12 toolholder which has χr angle position equal to 95, γo draft angles and edge of the slope cutting λs both equal to -6º.

The micro hardness tests were performed in the Ultra Micro Hardness Tester DUH-211S Dynamic Ultra Micro Hardness Tester Shimadzu with maximum force of 500 mN, the laboratory UFSJ, as shown in Figure 6. For the tests we used minimum force of 1.96 mN, reading speed of 1.0 mN / sec, and tip angle of the indenter 0,070º.

Figure 6 - Ultra Micro Hardness Tester DUH-211S

In this test a diamond indenter with pyramidal geometry, is forced against the surface of the specimen. The resulting print is observed under a microscope and measured. This measurement is then converted into a number Vickers hardness index (HV).

In this study we used a factorial design. The same is used when there is interest in an experiment to determine the influence of various factors on the response variable.

In the factorial design all possible combinations of the factor levels are analyzed, evaluating both the influence of factors on the response variable, as the influence of the interaction between them in the response variable.

The experimental design does not allow the conclusions of a factor effect at different levels be extended to levels not studied in the planning, because it is a fixed effects model.

The turning test was performed in two stages, was initially performed the test with just one pass the test specimens after the test was carried out with other specimens and the same parameters, but with two consecutive machining passes in turning.

The external cylindrical machining tests were carried out dry, with a cutting depth (p) equal to 2 mm. The cutting edge inclination angle (λs = -6 °) and cutting edge position (Xr = 95 °) were also kept constant for all experiments, according to the toolholder used. Table.2 shows the control variables with levels used in the test.

Table 2 - Control variables used in the turning test.

Control variables	Unit	N° Levels	Specification		
Advance (f)	mm/rot	2	0,2		0,3
Cutting speed (Vc)	m/min	2	200		300
Machining length (L)	mm	2	145	100	80
Number of pass (P)	-	2	1		2
Teste specimen (E)	-	2	Machined		Blank

Three replicates were performed to obtain an estimate of the experimental error, it is necessary to determine whether the observed differences in the responses were statistically significant. Replications also allow to obtain a more accurate estimate of the effects of the control variables in the studied answers.

The analysis of micro hardness (HV) was performed on machined test specimens and in no machining specimens, to serve reference allowed so evaluate the micro hardness and therefore residual tension.

The preparation of the samples for the indentation test initially had cutting the nominal area machined in three regions at the beginning of machining to 145 mm from the base (LA) in the middle region of the machining length 110 mm base (LB) and the end of machining length 80 mm of the base (LC). These cuts are illustrated in Fig. 7.

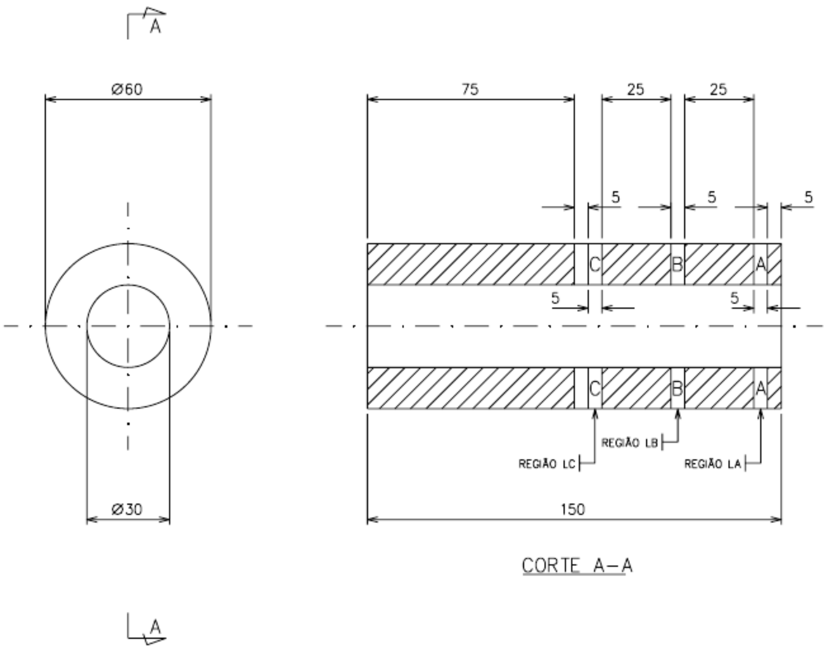

Figure 7 - Test piece for micro hardness testing

The sectioning of the samples for the analysis of micro hardness was through lubrication with cutting disc to preserve the characteristics of the sample. They have been built with epox resin subsequently sanded and polished.

The schematic drawing and the picture of the specimen are shown in Fig 8. The cuts were made in three different regions of the specimen permitino to assess the condition of residual stress therein, that is, whether the machining process generates residual stresses in the different range comprising from start to finish machining.

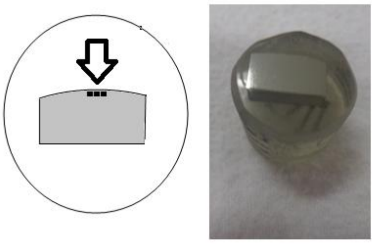

Figure 8 - Sample embedded specimens, sanded and polished for testing indentation

2.2 Analysis of Results

Table 3 shows the ANOVA micro Vickers hardness response variable. For all variables (main effects) the null hypothesis (Ho) was rejected, except for the number of pass length and machining interactions (PXL) and number of passes, machining length and type of test (PXLXE) since was obtained the calculated statistics (Fo) less than the tabulated statistics (Ftab) the α significance level of 5%.One blank line must be included above and below each equation.

Table 3 - ANOVA for analysis on micro hardness indentation test

Source Δ	SQ	GL	MQ	Fcal	Ftab	Decision
Vc	61936	1	61936	79,42	3,94	Rejects HO
P	77247	1	77247	99,05	3,94	Rejects HO
F	47792	1	47792	61,28	3,94	Rejects HO
L	26167	2	13083	16,78	3,09	Rejects HO
E	65762	1	65762	84,32	3,94	Rejects HO
Vc*P	76643	1	76643	98,27	3,94	Rejects HO
Vc*F	75015	1	75015	96,19	3,94	Rejects HO
Vc*L	20623	2	10312	13,22	3,09	Rejects HO
Vc*E	61936	1	61936	79,42	3,94	Rejects HO
P*F	31492	1	31492	40,38	3,94	Rejects HO
P*L	2275	2	1138	1,46	3,09	Accepts HO
P*E	77247	1	77247	99,05	3,94	Rejects HO
F*L	39947	2	19973	25,61	3,09	Rejects HO
F*E	47792	1	47792	61,28	3,94	Rejects HO
L*E	26167	2	13083	16,78	3,09	Rejects HO
Vc*P*F	18624	1	18624	23,88	3,94	Rejects HO
Vc*P*L	37187	2	18593	23,84	3,09	Rejects HO
Vc*F*L	66403	2	33202	42,57	3,09	Rejects HO
Vc*P*E	76643	1	76643	98,27	3,94	Rejects HO
Vc*F*E	75015	1	75015	96,19	3,94	Rejects HO
Vc*L*E	20623	2	10312	13,22	3,09	Rejects HO
P*F*L	39807	2	19903	25,52	3,09	Rejects HO
P*F*E	31492	1	31492	40,38	3,94	Rejects HO
P*L*E	2275	2	1138	1,46	3,09	Accepts HO
F*L*E	39947	2	19973	25,61	3,09	Rejects HO
Vc*P*F*L	11685	2	5843	7,49	3,09	Rejects HO
Vc*P*F*E	18624	1	18624	23,88	3,94	Rejects HO
Vc*P*L*E	37187	2	18593	23,84	3,09	Rejects HO
Vc*F*L*E	66403	2	33202	42,57	3,09	Rejects HO
P*F*L*E	39807	2	19903	25,52	3,09	Rejects HO
Vc*P*F*L*E	11685	2	5843	7,49	3,09	Rejects HO
Error	74870	96	780			
Total	1406322	143				

Figure 9 (A), (B), (C), (D) and (E) illustrates the effect each parameter studied in the micro vickers hardness. One of the most important parameters for analyzing the turning process of nodular cast iron Austempered with the chemical composition of the contained in this paper has generated residual voltage is the analysis of the test parameter (E) shown in Figure 9. This parameter compares the micro Vickers hardness contained in the blank with the specimens after turning.

According to Figure 9 (E), you can check the machining process generated residual tensile stress as the Blank has a greater amount of micro Vickers hardness that the machined test specimens because the penetrator has penetrated easier after machining of material.

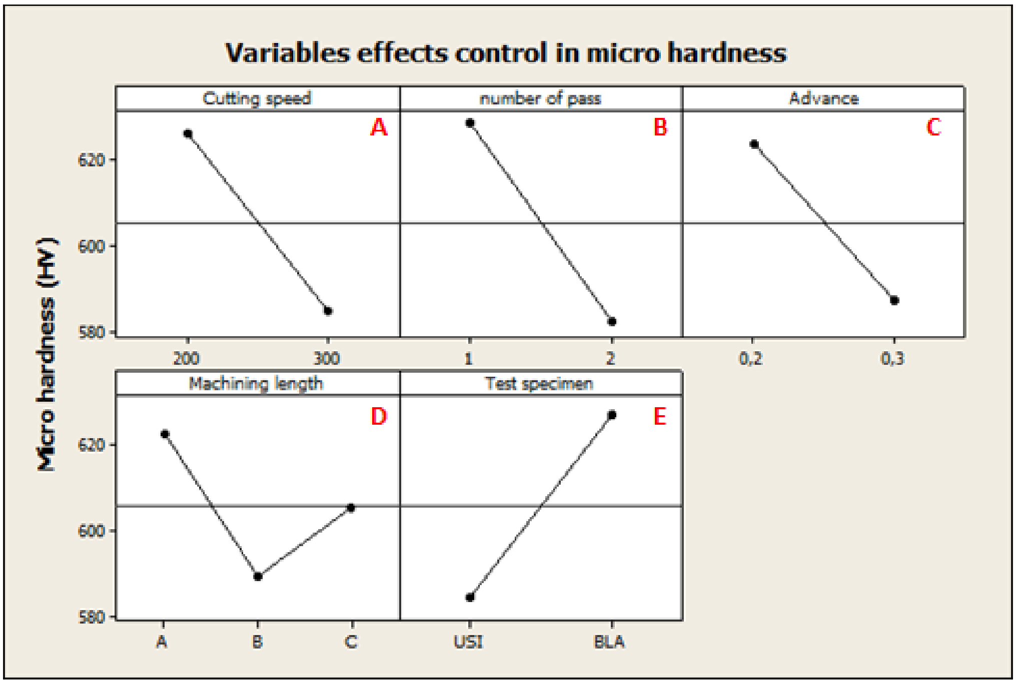

Figure 9 - the control variables Effects on micro Vickers hardness

The cutting speed influenced as micro hardness, and its increase of 200 m / min to 300 m / min resulted in a reduction in the micro hardness, as illustrated in Figure 9 (a). This behavior features a higher intensity of the residual tensile stress at higher cutting speeds resulting in increased strain energy caused by the increase of the cutting speed and therefore the temperature that will result in a higher strain energy.

The reduction micro hardness with increasing feed, illustrated in Figure 9 (c) also indicates an increase in the intensity of the tensile stresses. This increase (in residual stress trative) is also caused by the increase in deformation of the material to increase the advance.

The effect of increasing the cutting speed and feed the residual stress was tensile next generation, and to increase the cutting speed was reduced in the micro hardness of 7.09% and increasing the advance reduction in the micro hardness was 6.20%.

For the second pass also caused a reduction in the micro hardness, as shown in Figure 9 (b). Is reduced indicates the generation of residual tensile stress in the second pass, influenced by the increase in the specific resistance of the material caused due to the first pass.

The length of milling, also influenced the generation of tensile residual stress as shown in Figure 9 (D). It is noticed that the region with greater residual tensile stress was the central (LB), as it showed a lower value of micro Vickers hardness. The initial region (LA) was the one with a lower intensity of residual tensile stress and the final (LC) showed an intensity of residual voltage intermediate traction.

3. CONCLUSIONS

The analysis of the results of austempered ductile iron turning, when the cutting speed change (Vc), the tool advance (f) and the number of passes, it can be concluded that the turning of nodular cast iron Austempered caused the generation of residual tensile stress.

All control variables except for variable length machining (L) caused a reduction in the value of micro hardness when leaving a lower level to the highest, which indicates the generation of residual tensile stress.

The intensity of the tensile residual stress generated during the machining length was significantly different proved to be lower when cutting starts.

If there is interest in reducing the surface tension tensile, so that the resulting stresses acting in one piece is less to be placed in work on trative efforts should opt to use lower cutting speeds and feeds.

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