THE INFLUENCE OF THE CUTTING PARAMETERS AT THE TOOL LIFE WHEN TURNING ADI UNDER ROUGHING CONDITIONS

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Abstract. *ADI has proven to be a very interesting material for many engineering applications but very few researches had been carried on about its machinability. It has been said that ADI machinability is very poor and this can strongly jeopardize its application. But it is known that the machinability of a material can be improved a lot changing some cutting parameters as the cutting speed, the feed rate and the depth of cut. In this meaning, three values of each parameter were tested using a tool designed for roughing turning cast irons. These tests were performed with three grades of ADI (grades 2, 3 and 4, according to the old ASTM 897-90) and also with the as-cast iron, as a reference condition. Besides of the impact of these changes at the tool-life, the tool wear behavior was also monitored according to ISO 3685 and the main damages found at the tool edge were analyzed. A suggestion of a map of cutting parameters was plotted for roughing conditions using carbide tools. The Quick Stop analysis of some chips obtained in these tests could clarify the influence of these cutting parameters at the chip formation process and when the phenomenon of BUE occurs.*

Keywords*: Austempered Ductile Iron, Cutting Parameters, Quick Stop*

1. INTRODUCTION

Throughout the last three decades, Austempered Ductile Iron (ADI) has been rapidly adopted and exploited worldwide for manufacturing primarily automotive products. It was first commercially applied in 1972 and by the mid 1970's was employed in Chinese military trucks and commercial truck applications among European industries. Towards the end of the 70's ADI had been used for light cars and trucks and was favorably looked upon by the US automotive industries. At the turn of the last century, the worldwide consumption of ADI was estimated at 150,000 tons per year, with a projection forecast of 20% annual growth (Tartera, 1986; Hayrynen, 2002).

ADI exhibits remarkable properties, such as high toughness, relatively light weight, good heat conductivity and good vibration damping, as well as a high level of ductility and wear resistance (Keough, 1991). These useful mechanical properties are arrived at via a unique process of heat treatment that provides designers with further manufacturing flexibility and effective cost reduction compared to comparative forged steel components. ADI is continuously being incorporated into the ferrous application market (Kovacs, 1987; Cakir, 2005).

In contrast to conventional "as cast" ductile irons, ADI gains its mechanical properties by the heat treatment process and not by a specific alloy combination. Thus, the only condition for obtaining a desirable ADI component is a good quality ductile iron material (Hayrynen, 2002).

Regarding mechanical properties, Kovacs (1987) reported that among many beneficial features, ADI has the advantage of offering manufacturing flexibility presenting the designer the option to alter significantly the casting mechanical properties by applying various modes of heat treatment.

The microstructure of ADI was first called bainite as in steels, however, later on work carried out by Kovacs and Hayrynen showed that the microstructures of steel and ADI are not the same. They stated that the structure of ADI is an ausferritic structure composed of ferrite plus carbon-enriched austenite. This finding was also supported by other researchers.

When a steel part is replaced with ductile iron, better machinability is considered to be the most important gain. Although there is no definite information in the published literature that ductile iron has better machinability than steels, data obtained from manufacturers like General Motors shows that parts manufactured from ductile iron leads to improvement in tool life by 20–900% when compared to the heat treated forged steels (Katuku *et al.*, 2009; Klopper, 2007).

It can be reckoned that ADI poses certain problems during machining due to its enhanced strength and wear resistance when compared to the other types of cast iron. It was previously reported that unreacted (or untransformed) retained austenite can decrease the machinability of ADI due to stress induced transformation to martensite during machining. However, the softer grades of ADI's machinability is same as or better than that of steels which is similar to ADI in strength (Ahmadabadi, 1997; Daber *et al.* 2008; Garin *et al.* 2003).

Machining of ADI in its austempered condition is highly desirable because it can yield the tight tolerances and surface finishes generally required, save machining time and thus reduce costs. In depth fundamental understanding of interactions involved in this particular machining of ADI in its austempered condition should show the way to the optimum cutting tool material and or coating as well as optimum machining parameters (productive cutting speeds and feed rates, etc.). These outcomes would be among the last obstacles to be overcome before intensifying the use of this material in the automotive industry.

After this study, it is expected to know and to understand the tool wear behavior and to give some helpful information to tool manufacturers aiming to develop specific tool geometry to improve its resistance when machining ADI.

2. EXPERIMENTAL EQUIPMENT, MATERIALS AND PROCEDURE

This material was standardized into five groups materials in ASTM 897-90, after Hayrynen's effort. These five groups are better known as ADI grades and are numbered from 1 to 5. Nowadays, the ASTM 897M-06 classifies this material in six different groups, according to its mechanical properties and covers the various strength levels, as shown in Tab. 1, relating the new groups with the previous namely grade number.

Table 1. Mechanical property requirements of grades (SI Units).

Grade	750/500 /11	900/650 /09	1050/750 /07	1200/850 /04	1400/1100 /02	1600/1300 /01
namely grade number	---	1	2	3	4	5
Tensile strength, min, MPa	750	900	1050	1200	1400	1600
Yield strength, min, MPa	500	650	750	850	1100	1300
Elongation in 50 mm, min, %	11	09	07	04	02	01
Impact energy, J(1)	110	100	80	60	35	20
Typical hardness, HBW, kg/mm^2(2)	241-302	269-341	302-375	341-444	388-477	402-512

(1) : Unnotched charpy bars tested at 22 ± 4°C.
(2) : Hardness is not mandatory and is shown for information only.

To carry out these experiments 4 different materials were tested. An as-cast ductile iron (DI), which one was the basis to obtain the ADI's, and three (3) different types of ADI, named here by grade two (G2), grade three (G3) and grade four (G4). These materials were provided all in billets (600 X D150 mm).

The turning center used for these experiments is installed at CCM/ITA. This machine-tool has an available capacity of 11 kW with maximum velocity of 4000 rpm and maximum feed speed of 30 m/min.

Using an optical microscope, the initial conditions of the cutting tools as well as the angles, which define their geometry, were verified. Any defect observed at the edge, flank or face of the tool was enough to consider this tool unavailable to the tests. To improve the reliability of results, three (3) tools were used in each condition.

It was used interchangeable inserts in many ISO specifications. These inserts have edge angle of 80º, side cutting edge angle of 7º and radius peak of 1.6 and 0.4 mm. The support used for all the experiments has the specification of DWLNL 2020K 08.

2.1. Procedure

For tool wear measurement, analyses and photographies were obtained through an universal microscope for subsequent measurement and projection. A Wild M3C type S microscope by Herrbrugg Switzerland, with magnification capacity of 6.4, 16, 25 and 40X, and the software Leica Qwin Pro were used to measure the inserts wear.

The tool support was always kept in the same position. Only the interchangeable insert was removed to allow the measurement of the tool wear. Before its replacement, the cleaning of the seat was guaranteed with a jet of compressed air, thereby ensuring adequate positioning of the insert.

For tool efforts measurement, data of the effective spindle power were acquired through a CP5611 plate and recorded by a routine of the software Labview for data acquisition in a computer.

The machine-tool dynamic characteristic evaluation was performed using acquisition in real time via OPI (Operator Panel Interface). This interface port was connected to a PCI plate through a MPI cable. Most part of the information available in HMI (Human Machine Interface), became available in a personal computer (PC), using a communication converter CNC-PC.

For this converter, already in the DDE (Dynamic Data Exchange) format, a routine developed at Labview application package was used, which can be used as entrance to monitor and collect the data. The routine provides and stores data in text file format that can be moved to be analyzed in different softwares (graphic plots, tables, etc.).

Turning tests were conducted with the objective of raise comparative information among materials. The following tests were performed: power consuming acquisition during cutting of each material; tool life tests, by monitoring of flank wear (VB).

Although the most common is to show graphics of the cutting forces against one specific cutting condition, in these tests the parameter presented is the "consumed power", in terms of a percentage of the available lathe capacity (11 kW). This was performed like this because of the available conditions to compare the cutting forces in real time during the experiments.

For turning tests, the length/diameter ratio of test specimens should be enough to avoid machining vibrations. At the end of each test, this ratio should not exceed the value of 10. Aiming a good use of material during the tests, the sample dimensions were defined as 300 mm in length, and diameters of 145 and 73 mm at the beginning and at the end of the experiment, respectively.

With these dimensions, the new test specimen can yet be handled without the necessity of auxiliary equipments during loading and unloading of the machine. The test specimens were pre-machined to remove the rough surface generated in the foundry (iron scales).

The metal working fluid used for all tests was a commercial emulsion directed to the cutting tool, with concentration of 7.9% and pH of 8.6.

Measurements of wear were made under regular intervals of time, being carried out every minute for each variation of level of wear and every three (3) minutes in stabilization points of the cutting edge. The objective of so many measurements, since a series of standard numbers could be used instead, was to verify the variation in levels of stabilization of the edge, and verify the behavior of cutting through the inclination of tools edge wear curves, to assess the repeatability of tests.

3. RESULTS

3.1. Behavior for different feed rates

In this test it was studied the tool life behavior and the consumed power versus machined volume, during lathe operations in roughing conditions. The condition to consider the test finished was the flank wear of VB = 0,3 mm or its breakage, according to ISO 3685. Three values of feed rate tested were: 0, 10 mm/rev; 0,15 mm/rev and 0,20 mm/rev.

The cutting conditions were chosen according to previous studies and research data, and they were: cutting speed of v_c = 60m/min and depth of cut of a_p = 1,5 mm. The tool used was the KR 3205, for cast iron roughing. The obtained results for "tool life" are presented in Fig. 1 and the results for "power consumption" are presented in Fig. 2.

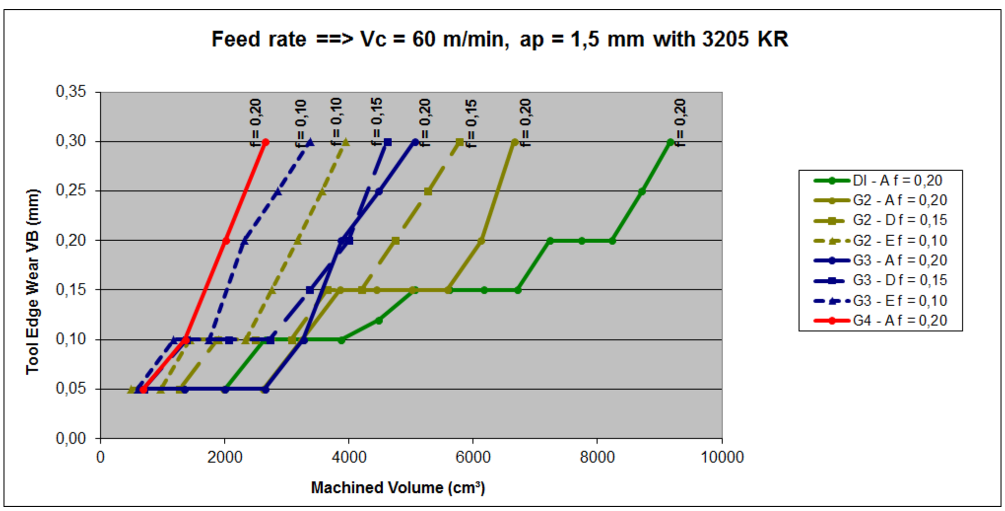

Figure 1. Tool life for different feed rates versus Machined Volume.

If the results were plotted against "machine time", it would be only possible to notice the common expected behavior of tool life when comparing the machinability of these materials: DI > G2 > G3 > G4. To have an attractive result in terms of productivity, one should look at the results presented at Fig. 1, where the Tool Life is plotted against the removed material (Machined Volume).

Looking at each material, it is possible to notice that greater feed rates allow greater material removal with greater tool life. This is an interesting result for roughing operations once it allows increase in the productivity with lower tool investments. Another interesting result obtained during these tests is that the use of greater feed rates when machining

ADI G3 allows better results for tool life either comparing with ADI G2 with lower feed rates. This is an important result once that it shows that investigations on cutting parameters can improve the productivity performance of one material.

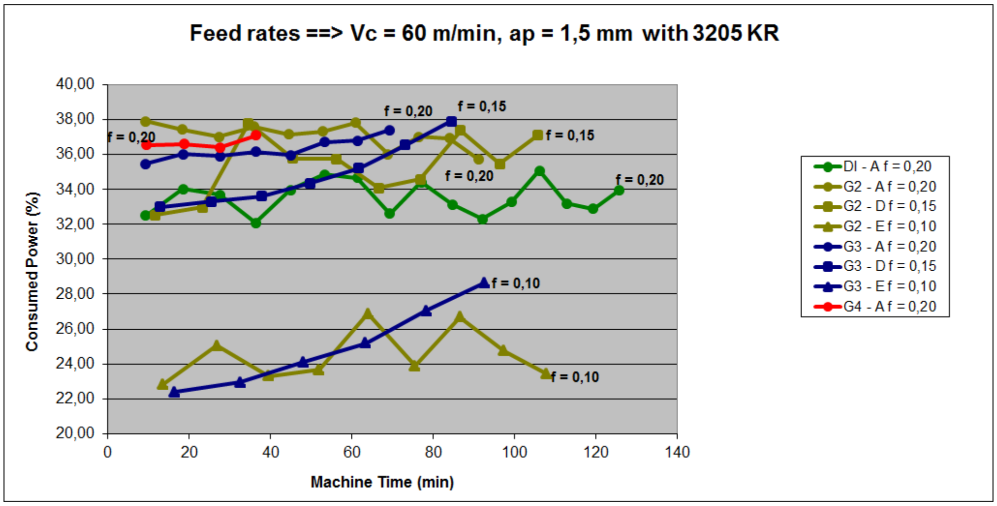

Figure 2. Consumed Power for different feed rates.

The results obtained for Power Consumption give very poor information. It is only possible to notice expected results, lower feed rates allow lower power consumption. This is an expected result once the feed rate has direct relation to the cross section of the chip.

The monitoring of the tool wear behavior allows noticing the mechanisms of abrasion and adhesion. It was possible to notice that for lower feed rates the adhesion mechanism begun to act very soon. In Fig. 3, that is a photo of the first tool passage on ADI G2 with f = 0.10 mm/rev.

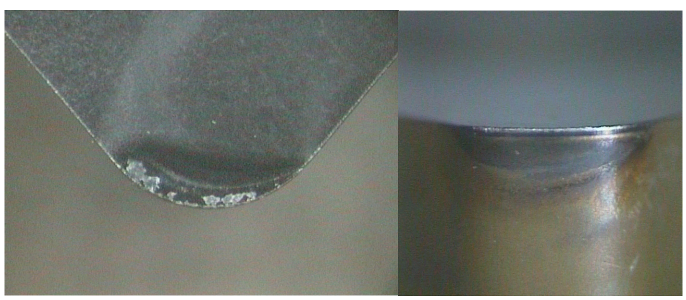

Figure 3. Tool wear on insert KR 3205 when rough turning ADI G2 with low feed rate.

The coating displacement on the tool face with a flank wear so little, is a strong evidence of the intensity of adhesion mechanism when rough machining ADI. This phenomenon can be reduced a lot with investigations on the chip formation mechanisms that will provide more information about the interaction of the chip and the tool face.

3.2. Behavior for different cutting speeds

In this test it was studied the tool life behavior and the consumed versus the machined volume, during lathe operations in roughing conditions. The condition to consider the experiment finished was the flank wear of VB = 0,3 mm or its breakage, according to ISO 3685. Three values of cutting speed were tested: 60 m/min; 80 m/min and 100 m/min.

The cutting conditions were chosen according to previous studies and research data, and they were: feed rate of f = 0.2 mm/rev and depth of cut of a_p = 1,5 mm. The tool used was the KR 3205, for cast iron roughing. The obtained results for “tool life” are presented in Fig. 4 and the results for “power consumption” are presented in Fig. 5.

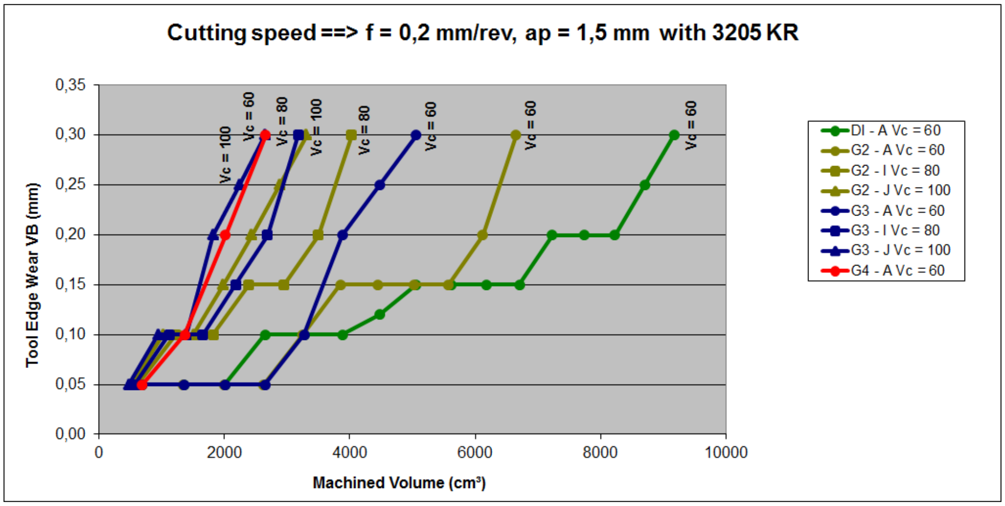

Figure 4. Tool life for different cutting speeds versus Machined Volume.

Similarly to the comments made for the Feed Rate tests, if the results were plotted against "machine time" it would be only possible to show the expected machinability difference between these materials. In Figure 4 are plotted more interesting results in terms of productivity.

Looking at each material, it is possible to notice the influence of the cutting speed on the tool life behavior during roughing conditions. Lower cutting speeds for carbide tools when machining ADI, provides greater tool life. It is once more possible to notice that investigations on cutting parameters can improve a lot the performance of some materials. This is evidenced on the better performance of ADI G3 with v_c = 60 m/min when compared with the performance of ADI G2 with v_c = 100 m/min or either with v_c = 80 m/min.

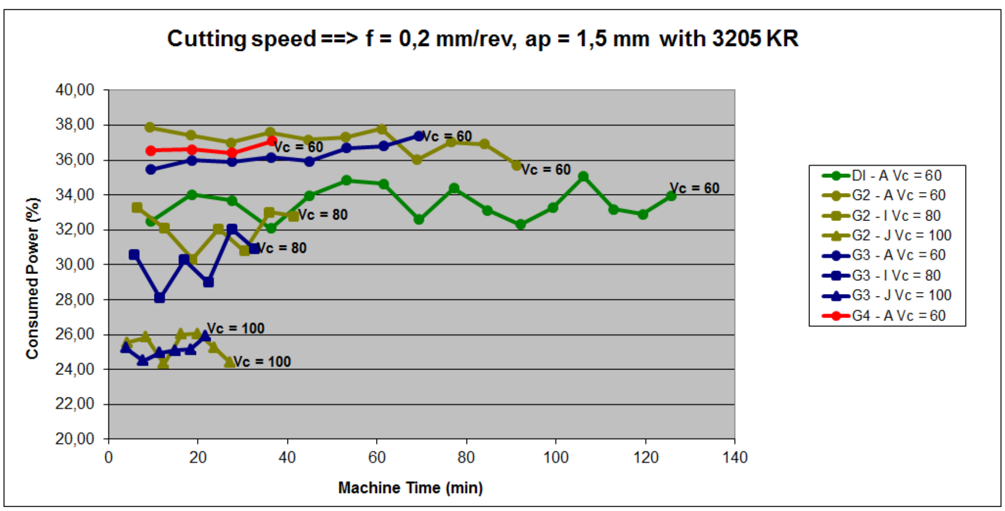

Figure 5. Consumed Power for different cutting speeds.

Figure 5 can show the direct influence of the cutting speed on the Consumed Power. It is clear to notice three different levels of consumed power for the tested cutting speeds. This fact occurs due to the direct relation existing on the cutting speed with the cutting temperature. As high the cutting temperature, more soft became the material, facilitating its removal. There is no significant evidence of differences on power consumption when varying the materials during this experiment.

Once more was observed the soon begin of the adhesion mechanism on the tool face. Already on the first tool passages, it was possible to notice coating displacement and material deposition on the tool face (Fig. 6), either with reduced flank wear. This behavior was much pronounced for higher cutting speeds. This is an expected result once the temperature has direct influence on the diffusion rate, which guides the adhesion mechanism.

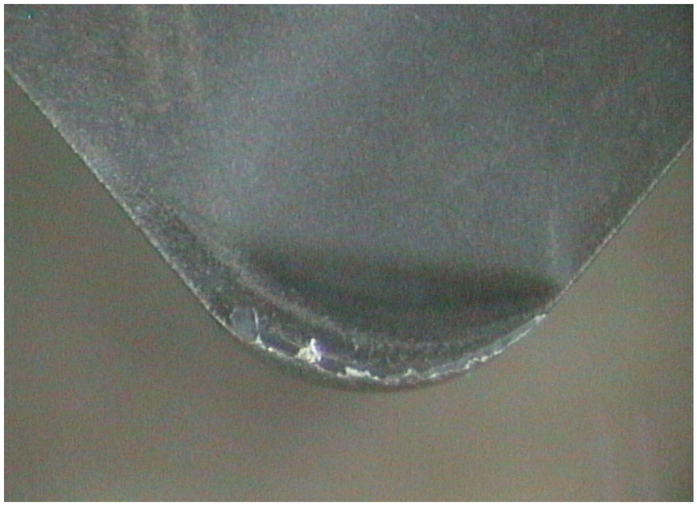

Figure 6. Tool wear on insert KR 3205 when rough turning ADI G2 with high cutting speed.

4. CONCLUSIONS

It can be concluded that as higher the number of the ADI grade, most difficult this material is to be machined. It was proven that the Ductile Iron is much easier to be machined than the tested ADI's. It was also observed that the ADI G4 present an enormous difficulty to be machined, been an alternative that gives very low productivity.

It can be also concluded that ADI G2 is easier to be machined than the ADI G3, considering the tested tools. But it is also possible to say that improvements in cutting parameters can place these two materials in very similar levels of productivity, regarding the obtained results presented here.

With the feed rate tests, it was possible to notice that greater feed rates allow greater material removal with greater tool life. This is an interesting result for roughing operations once it allows increase in the productivity with lower tool investments. Another interesting result obtained during these tests is that the use of greater feed rates when machining ADI G3 allows better results for tool life either comparing with ADI G2 with lower feed rates. This is an important result once that it shows that investigations on cutting parameters can improve the productivity performance of one material.

With the cutting speed tests, it was possible to notice the influence of the cutting speed on the tool life behavior during roughing conditions. Lower cutting speeds for carbide tools when machining ADI, provides greater tool life. It is once more possible to notice that investigations on cutting parameters can improve a lot the performance of some materials. This is evidenced on the better performance of ADI G3 with v_c = 60 m/min when compared with the performance of ADI G2 with v_c = 100 m/min or either with v_c = 80 m/min, once that the expected result is that G3 has worst machinability than G2.

These two results have an important meaning to industrial applications once that G3 is more strength than G2.

Although the tools used in these tests were commercial solutions already available for machining common industrial materials, these tests allowed a better understanding of the tool wear behavior when machining ADI. Now it is possible to recommend some improvements on the cutting parameters in order to make the machining of ADI more profitable.

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