Starting Recommendations for Milling Austempered Ductile Iron (ADI)

A series of face milling experiments were conducted to evaluate the machinability of ADI. The results of these experiments were expected to show how different grades of ADI (GR 900 ADI, GR 1050 ADI, and GR 1200 ADI) affect the milling performance. AISI 4340 with hardness similar to that of GR 1050 ADI was used as the reference material. The effects of different milling parameters on the tool life when machining ADI were analyzed to provide starting recommendations for milling ADI. The recommended milling parameters for ADI (**Table 1**) were generated using the modified Taylor tool life equations with expected tool life of 20 minutes and depth of cut of 0.039 in (1 mm). Note that the recommended cutting speed for GR 1050 ADI was interpolated. In addition, with increased feed rate, the range of recommended cutting speed became wider. This indicates that more trial and error should be done when a higher feed rate is to be used.

Table 1: Recommended initial milling parameters for different grades of ADI.

	Feed (in/tooth)			
	0.003	0.006	0.010	0.014
Material	**Cutting speed (ft/min)**			
A536 60-40-18		870	740	660
A536 80-55-06		760	650	580
GR 900 ADI	***805***	***730***	***675***	***640***
GR 1050 ADI	***750***	***690***	***645***	***615***
A536 100-70-03		640	550	490
GR 1200 ADI	***550***	***535***	***525***	
A536 120-90-02		530	455	

	Feed (mm/tooth)			
	0.08	0.15	0.25	0.36
Material	**Cutting speed (m/min)**			
A536 60-40-18		265	226	201
A536 80-55-06		232	198	177
GR 900 ADI	***250***	***225***	***205***	***190***
GR 1050 ADI	***220***	***200***	***190***	***180***
A536 100-70-03		195	168	149
GR 1200 ADI	***165***	***160***	***160***	
A536 120-90-02		162	139	

* Recommendations are based on the use of SECO Double Octomill 220.48-09S R220.48-03.00-09-06SA as the tool holder, SECO ONMU090520ANTN-M14 MK2050 as the inserts and QuakerCool 7020-CG for the coolant.

Research Study Details

The face milling experiments (**Figure 1**) were carried out using a 3-insert configuration. The experiments were performed on a HAAS VF-2 vertical CNC Mill with the use of a large modular vise to support the workpiece (305x151x25 mm). The casting scale of the workpiece was removed prior to testing because the scale is not of main interest.

Figure 1: The setup for the milling experiment is shown.

The tool life experiments were conducted according to ISO 8688. Five cutting speed configurations with a constant feed rate of 0.003 in/tooth and depth of cut of 0.039 in. were investigated per work material with three replications per condition to establish the relationship between cutting speed and tool life. GR 900 ADI and GR 1050 ADI were milled at a cutting speed of 787, 984, 1181, 1378 and 1575 ft/min while GR 1200 was milled at a lower range of cutting speed: 394, 591, 787, 984 and 1181 ft/min. AISI 4340, however, was tested only at a cutting speed of 1181 and 1575 ft/min. Useful tool life was defined as the time when the inserts reached maximum flank wear penetration (VB_{max}) measured from the uniform wear of 0.3 mm (average wear across all teeth) or localized wear of 0.5 mm (on any individual tooth). Wear land measurements were taken over intervals corresponding to constant volume of material removed (e.g., after each pass) using a Nikon SMZ800 stereoscope.

Additional testing with different feed rates and depth of cuts was performed to analyze the effects of these cutting parameters on tool life. Milling experiments were performed on GR 900 ADI and GR 1200 ADI with the following parameters: a cutting speed of 984 ft/min, a feed rate of 0.004 in/tooth, a depth of cut of 0.039 in. and a cutting speed of 984 ft/min, a feed rate of 0.003 in/tooth and a depth of cut of 0.055 in.

Since cutting speed is considered the main contribution to tool life, the first-stage of the experiment was done by varying the cutting speed at a constant feed rate of 0.003 in/tooth and a constant depth of cut of 0.039 in. A representation of tool wear progression as a function of cutting time at different cutting speeds is shown in **Figure 2(a)**. This figure shows the expected behavior for the most cost-effective machining operations. A rapid increase in the wear rate was observed at the beginning of cutting, which was then followed by a steady state condition and another rapid wear rate towards the end. After the wear progression plots of the tool used to mill ADI and AISI 4340 were generated, the tool life corresponding to various cutting speeds and a constant feed rate and depth of cut were estimated and plotted as a function of cutting speed as shown in **Figure 2(b)**.

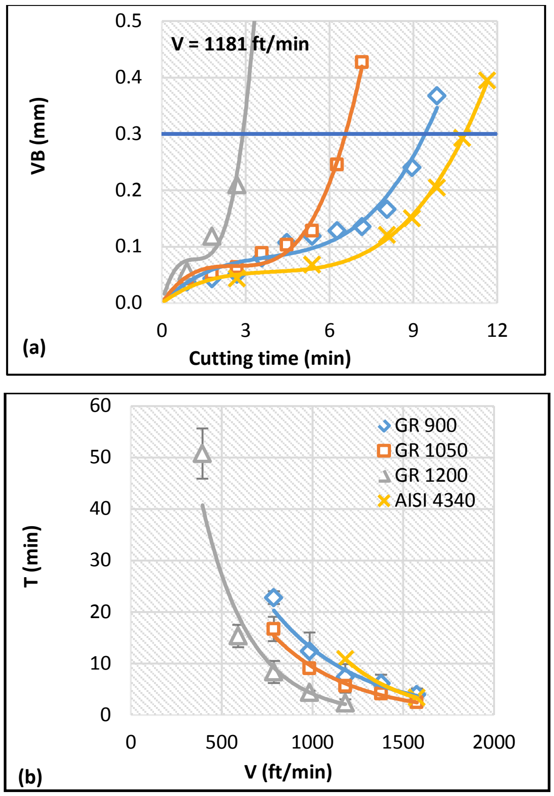

Figure 2: (a) Tool wear behavior during machining of ADI and AISI 4340 at cutting speed of 1181 ft/min; (b) The effect of cutting speed on tool life in different ADI grades and AISI 4340.

Although GR 1050 ADI and AISI 4340 had a similar hardness, a shorter tool life was obtained when the tool was used to mill GR 1050 ADI for the same milling parameters. The difference in microstructure between ADI and steel likely influenced the tool wear.

A linear relationship between the tool life and cutting speed (**Figure 3**) exists when these data points are plotted in a log-log coordinate. This relationship was used to establish a Taylor tool life equation. Taylor tool life equations for different grades of ADI and AISI 4340 are derived from the linear regression model presented in **Table 2**. These equations can be used to approximate the starting cutting speed for a desirable tool life. The importance of establishing this relationship is the ability to fulfill the different preferences from machine shops (i.e. productivity vs. cost).

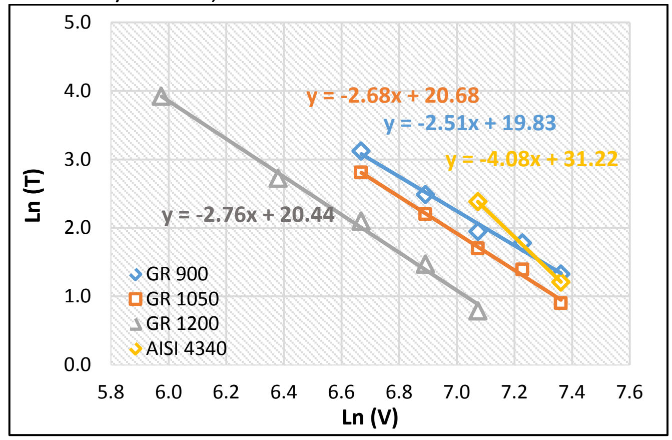

Figure 3: The effect of cutting speed on tool life in ADI and AISI 4340 (T = tool life - min; V = cutting speed – ft/min).

Table 2: Taylor tool life equations for ADI and AISI 4340.

Material	Taylor Tool Life Equation
V (ft/min) – T (min)	
GR 900 ADI	$V\,T^{0.40} = 2681$
GR 1050 ADI	$V\,T^{0.37} = 2246$
GR 1200 ADI	$V\,T^{0.36} = 1627$
AISI 4340	$V\,T^{0.25} = 2119$

When the cutting speed was reduced from 1378 ft/min to 984 ft/min while milling GR 900 ADI, a significant improvement in tool life was observed. This, however, resulted in a reduction in the rate at which material was removed. In order to maintain the material removal rate (MRR), another experiment with a higher feed rate and deeper cut were conducted.

It was determined that the tool life decreased with increasing feed rate, but slightly increased with increasing depth of cut at a constant cutting speed for both GR 900 ADI and GR 1200 ADI. By using a cutting speed of 984 ft/min, feed rate of 0.003 in/tooth and increasing the depth of cut to 0.055 in, the tool life increased without sacrificing the MRR. This observation is in agreement with the recommendation on machining ADI at a deeper cut. Although this behavior is desirable, it should be noted that this was observed on the testing range of depth of cut of 0.039-0.055 in. The effect of depth of cut on tool life outside this range should be further validated. Modified Taylor tool life equations (**Table 3**) were derived from multiple regression analysis.

Table 3: Modified Taylor tool life equations for ADI.

Material	Modified Taylor Tool Life Equation
V (ft/min) – T (min) – f (in./rev) – d (in.)	
GR 900 ADI	$V\,T^{0.40} f^{0.16} d^{-0.08} = 1680$
GR 1200 ADI	$V\,T^{0.38} f^{0.04} d^{-0.11} = 2145$

Reference: The Pennsylvania State University