# Starting Recommendations for Turning Austempered Ductile Iron (ADI)

Studies were conducted to assess the machinability of ADI in turning operations. These experiments focused on varying the cutting speeds when machining various grades of ADI (Grade 1 ADI, Grade 2 ADI and Grade 3 ADI). 100-70-03 ductile iron was also machined at several cutting speeds as the reference material. The effects of different cutting speeds on the tool life when turning ADI were analyzed to provide starting recommendations for turning ADI.

The recommended turning parameters for ADI (**Table 1**) were generated using the Taylor tool life equations with an expected tool life of 15 minutes and depth of cut of 0.060 in (1.5 mm). These recommendations were also compared with the recommended turning parameters for different grades of ductile iron based on a cutting depth of 0.100 in (0.25 mm).

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

| | Feed rate (in/rev) *(mm/rev)* | | | |
|---|---|---|---|---|
| | 0.008 *0.2* | **0.012** *0.3* | 0.016 *0.4* | 0.024 *0.6* |
| **Material** | **Cutting speed (ft/min) *(m/mm)*** | | | |
| ***Grade 1 ADI*** | | **590** 180 | | |
| ***Grade 2 ADI*** | | **535** *165* | | |
| ***Grade 3 ADI*** | | **360** *110* | | |
| *For comparison:* | | | | |
| **A536 60-40-18** | 1280 *390* | | 1115 *340* | 1035 *315* |
| **A536 80-55-06** | 1115 *340* | | 985 *300* | 900 *275* |
| **A536 100-70-03** | 950 *290* | | 840 *255* | 770 *235* |
| **A536 120-90-02** | 790 *240* | | 690 *210* | 640 *195* |

*ADI recommendations are based on the use of SECO CNMG120408-M5, TK 2001 as the inserts and QuakerCool 7020-CG for the coolant.

## Research Study Details

The turning experiments (**Figure 1**) were performed on the workpiece in the shape of a hollow cylinder with an outside diameter of 6.85 in (174 mm) and an inside diameter of 4.5 in (114 mm) using an HAAS ST-20 CNC Lathe. The workpiece was secured from the inside using step jaws on the chuck and tailstock on the opposite end to provide improved support.

Before placement in an instrumented CNC Lathe for the turning studies, the casting was prepared using a conventional lathe to establish the datum. The casting scale of the workpiece was removed prior to testing.

Different cutting speed configurations with a constant feed rate of 0.012 in/rev (0.30 mm/rev) and depth of cut of 0.060 in (1.5 mm) were investigated per work material with three replications per condition to establish the relationship between cutting speed and tool life. Grade 1 ADI and Grade 2 ADI were turned at cutting speeds of 375, 500, 750 and 1000 ft/min (114, 152, 228 and 305 m/min) while Grade 3 ADI was machined at a lower range of cutting speeds: 250, 300, 375, 400 and 500 ft/min (76, 91, 114, 122 and 152 m/min). As a reference, 100-70-03 ductile iron was tested at cutting speeds of 500, 750 and 1000 ft/min (152, 228 and 305 m/min).

**Figure 1: The setup for the turning experiment is shown.**

## Tool Life

A linear relationship between the tool life and cutting speed, also called Taylor tool life equation, was established based on the experimental data. Taylor tool life equations for different grades of ADI derived from the linear regression model are presented in **Table 2**, and the initial recommendations to turn ADI are shown in **Table 3**. Given a specific production rate, these equations will allow machine shops to predict the tool life for the cutting speed used to meet their demand requirements. These relationships can also be used to approximate the starting cutting speed for a desirable tool life.

**Table 2: Taylor tool life equations for ADI and 100-70-03 DI.**

| Material | Taylor Tool Life Equation |
|---|---|
| V (ft/min) – T (min) | |
| A536 100-70-03 | $V\,T^{0.25} = 1508$ |
| Grade 1 ADI | $V\,T^{0.37} = 1610$ |
| Grade 2 ADI | $V\,T^{0.32} = 1274$ |
| Grade 3 ADI | $V\,T^{0.26} = 727$ |

**Table 3: ADI turning parameters for various expected tool life.**

| **Tool Life (min)** **T = 15 min** | **Cutting speed (ft/min)** **f = 0.012 in/rev – d = 0.060 in** *Cutting speed (m/min)* *f = 0.30 mm/rev – d = 1.5 mm* | | |
|---|---|---|---|
| | **Grade 1 ADI** | **Grade 2 ADI** | **Grade 3 ADI** |
| **2T** | **455** *140* | **430** *130* | **300** *90* |
| **T + 5** | **530** *160* | **500** *150* | **335** *100* |
| **T** | **585** *175* | **550** *165* | **360** *110* |
| **T – 5** | **680** *205* | **625** *190* | **400** *120* |
| **0.5T** | **760** *230* | **685** *210* | **430** *130* |

Similar wear measurements on the major and minor flank faces can be expected when turning ADI with coated carbide tools. In the case of ceramic inserts, a higher wear rate on the minor flank face is anticipated [1]. In addition to flank wear, crater wear occurs on the tool used to machine ADI. The existence of crater wear is the primary reason for the lower machinability of ADI in comparison to as-cast ductile iron and Q&T steels with similar bulk hardness. This crater wear formed very close to the cutting edge causes initial breakage along the cutting edge and potential catastrophic failure. Instead of the as-cast material or steel with similar hardness, the machinability of ADI is more similar to that of TRIP materials such as Hadfield steel and austenitic stainless steel. Adhesive wear, in addition to abrasive wear, is mainly responsible for tool failure when turning ADI at a low cutting speed. On the other end, diffusion wear and accelerated tool oxidation limit tool life at high cutting speeds.

**Chip Formation**

Discontinuous, segmented chips should be expected when turning ADI. Increased length (continuousness) of chips can be anticipated:

(1) with increased tool wear [2]

(2) at a very low cutting speed when built-up-edge (BUE) occurs

(3) with increased feed rates [3]

An increase in chip thickness and width can be obtained by increasing the feed rate and depth of cut respectively. The chips also tend to become flatter with these parameter selections [3]. Based on this observation, short-segmented, wide chips are desirable for longer tool life.

**Surface Finish**

A sufficient cutting speed is required to avoid the built-up-edge effect. Grade 1 and Grade 2 ADI must be turned at a cutting speed higher than 375 ft/min (114 m/min), and a cutting speed higher than 250 ft/min (76 m/min) must be used for Grade 3 ADI. By combining the tool life and surface finish as two main criteria, a range of cutting speeds was established for 100-70-03 ductile iron and each grade of ADI (**Figure 2**). While increased cutting speed improves surface finish, increased feed rates result in deterioration of surface finish. The effect of depth of cut on the surface roughness is still unclear. Akdemir claimed that small depth of cut is desirable for improving surface finish [4], but Parhad found that small depth of cut results in strain hardening and deeper cut improves the surface finish due to thermal softening [5].

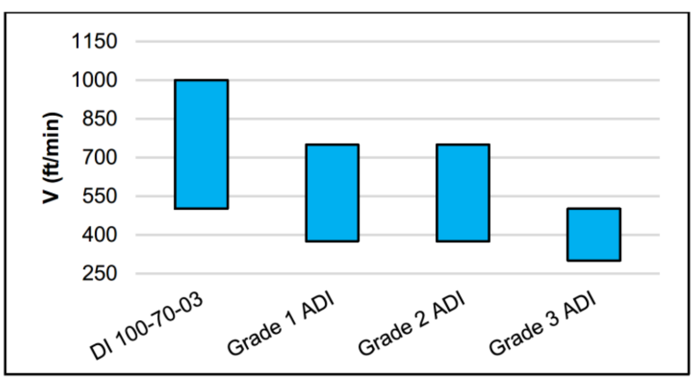


**Figure 2: A range of turning parameters for 100-70-03 ductile iron and ADI was established using tool life and surface finish.**

**Cutting Forces**

A higher cutting force is expected when machining ADI compared to conventional ductile iron. Klocke reported that a significantly lower cutting force was obtained when machining ADI than Q&T steel with similar strength; especially with a greater chip thickness [2]. Furthermore, an increased cutting force should be expected with decreased austempering temperature (higher ADI grade) due to a lower volume of austenite and increased hardness.

Cutting force is expected to decrease with increased cutting speed due to an increased temperature and; thus, thermal softening. A high cutting force might also occur at a "low" cutting speed. The use of low cutting speed when machining ADI resulted in a formation of BUE, which caused a greater effective rake and a decreased shear angle; thus, higher cutting force was required.

**Cutting Tool and Conditions**

Coolant is recommended to minimize flank wear on both major and minor flank faces and crater wear. When turning all grades of ADI with coated carbide tools, an appropriate cutting speed should be chosen to minimize the BUE formation. The combined use of high feed rates and deep cuts are important to minimize the work-hardening effect. Grade 1 ADI can be turned using a cutting speed 25% lower than that recommended for 100-70-03 ductile iron.

In the case of ceramic tools, neither PCBN nor $Si_3N_4$ ceramic should be used when machining ADI. These ceramic tools are more expensive than carbide tooling options, but do not provide any additional benefits in terms of increased tool life. $Al_2O_3$ can be used when ceramic tools are selected. As can be seen from **Figure 3**, a cutting speed of 850 ft/min (260 m/min) can be used to obtain an estimated tool life of 15 min [2]. No coolant should be used when machining ADI with a ceramic tool. Success has also been reported with a $TiCN+Al_2O_3$-coated carbide insert with chamfered cutting edge and positive effective rake angle [6].

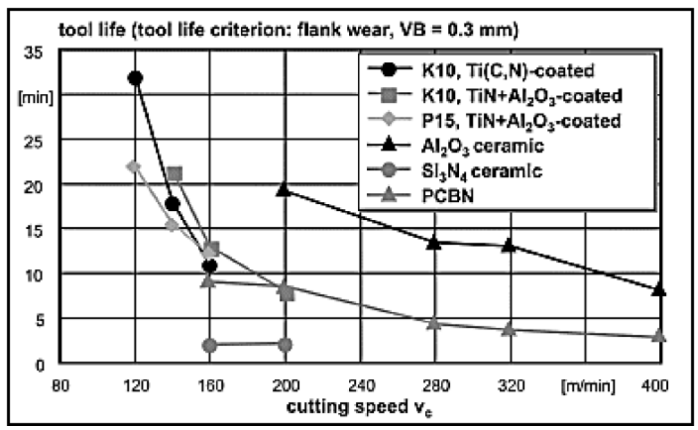


**Figure 3: The effect of cutting speed on tool life is shown when turning ADI using ceramics and no coolant [2].**

**References**


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