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The Influence of Strain Induced Martensitic Transformation on Machinability of (ADI)

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Abstract

This work discusses the machinability properties of different ADI grades measured in terms of the cutting force experienced during machining under different machining conditions of cutting depth and cutting speeds.

Four different grades of ADI with different microstructures and hardness levels were subjected to machinability tests by measuring the turning cutting force using three-dimensional force dynamometer with different machining parameters.

The influence of machining parameters on the cutting force was investigated and correlated to the strain induced martensitic transformation from retained austenite during machining.

Keywords: *austempered ductile iron (ADI), TRIP Phenomenon, machinability, cutting force.*

1. Introduction

The recently found wide spectrum of applications is related to ADI's unique combination of mechanical and physical properties [1-2]. However, the serious problems experienced during machining are still limiting its volume production.

The hard grades of ADI would represent a real challenge for high volume machining operations, whereas the soft grades does not represent better machining options due to high retained austenite content, which would transform to martensite by TRIP mechanisms as a result of excessive strains associated with machining [3-5].

In this study, the machinability properties of four grades of ADI in terms of cutting force are evaluated. The interaction between different machining parameters like depth of cut and cutting speed is discussed and correlated to the TRIP phenomenon.

2. Experimental Work

Ductile iron was melted in medium frequency 100 Kg capacity induction furnace. The chemical composition of the D.I bars is shown in table 1.

Table 1. Chemical Composition of D.I bars

C	Si	Mn	P	S	Mo	Cu	Fe
3.68	2.52	0.28	0.0128	0.0139	0.3	0.6	Bal

The base ductile iron (D.I) was subjected to four austempering cycles:-

1. Two conventionally austempered ductile irons *(ADI-275 & ADI-375)* austenitizaed at 900°C and then austempered at 275°C and 375°C for 90 min with fine and coarse ausferritc microstructures, representing hard and soft grades consequently.
2. Two – step austempered ductile iron (ADI-2step), austenitized at 900°C and austemepered at 275°C for 10 min. then at 375°C for 90 min with mixed fine/coarse ausferritic structures.
3. Intercritically austenitized ADI (IADI) at 820°C (where $\gamma + \alpha$ + graphite coexist). The presence of proeutectoid ferrite in the microstructure would contribute to better machinability.

The cutting force during turning was measured by a three-dimensional force dynamometer type 9255B (Kistler, Coherent). The machining parameters varied between 0.5 – 2.0 mm depth of cut and 55 – 180 m/min cutting speed with 0.187 mm/rev feed rate. The martensite content in the microstructure of machined surface was determined using XRD (Rietveld method-MAUD software), and heat tinting techniques

3. Results and Discussion

The retained austenite, martensite content and the hardness of the four investigated ADI grades before machining are shown in Fig. 1.

The maximum cutting force experienced by some ADI alloys at cutting depth of 1.5 mm (Fig. 2) with further decrease of the force with increasing the cutting depth to 2.0 mm suggests that another mechanism plays an important role in formulating the correlation between the machining parameters. With increasing the cutting depth over 1.5 mm, the cutting tool seems to avoid the strain hardened layer and the cutting action proceeds through the deeper unhardened material with a drop in the cutting force.

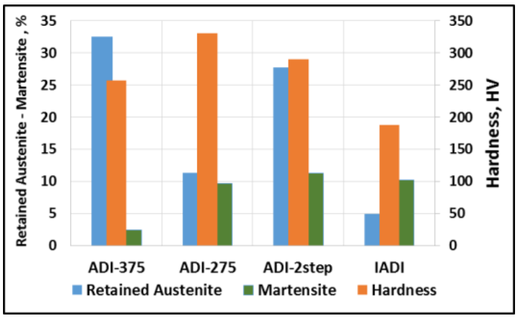

Fig. 1 XRD analysis and hardness of the machinability bars

At higher cutting speeds, the cutting force continues to increase with cutting depth, indicating that the hardened layer is thicker than 2.0 mm due to higher rate of material deformation during machining. With all cutting parameters, the cutting force of IADI was significantly lower than that needed for the other alloys, apparently due to the existence of proeutectoid ferrite in the structure of this grade.

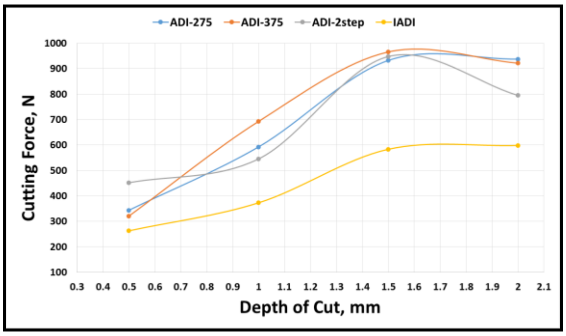

Fig 2 The change in cutting force with depth of cut for different ADI-grades at 55 m/min cutting speed

The increase in cutting force was always associated with a corresponding increase in the martensite content for all investigated alloys. It is interesting to observe that though the ADI-375 and ADI-275 had martensite contents 2.46% and 9.71 % respectively before machining, the two alloys, being subjected to a cutting depth of 2.0 mm had a very similar contents of total martensite (~25%), which is the sum of original content before machining + martensite formed by deformation induced transformation from the retained austenite.

The retained austenite was entirely transformed in ADI-275 and only partially transformed in ADI-375, which indicates that retained austenite formed at higher austempering temperature is more mechanically stable than that formed at lower austempering temperature [6].

The fact that the two alloys reached the same cutting force at 2.0 mm depth of cut confirms that the martensitic transformation due to induced strains is closely related to the machinability behaviour of ADI-alloys. Such correlation is more evident with the ADI-2step alloy (Fig.3), where at 1.5 mm cutting depth, the martensitic content and the force of cutting reached almost the same levels observed in ADI-275 and ADI-375. However, with increasing the cutting depth to 2.0 mm, both martensite content and the cutting force decreased in very similar manner, obviously 2.0 mm depth of cut is deeper than the hardened layer and so, the cutting tool avoids that layer and penetrates deeper in the base metal.

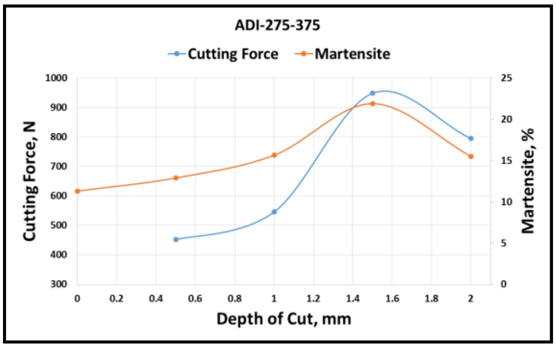

Fig 3 Variation of both martensite content and cutting force with the cutting depth for ADI – 275-375

4. Conclusions

- Retained austenite transformation to martensite through the TRIP effect was found to play a profound role in determining the cutting force and machinability behaviour of ADI-grades.
- The thickness of the hardened layer by martensite formation is a function of different factors, among them are the cutting depth and cutting speed.
- It was found that optimum machinability of different ADI-grades requires different combinations of cutting speed and depth of cutting.

5. References

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