EFFECT OF AUSTEMPERING PARAMETERS ON THE MICROSTRUCTURE, MECHANICAL PROPERTIES, AND MACHINABILITY OF AUSTEMPERED DUCTILE IRON

By

Mostafa Ahmed Abdel Hamed Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In

<Metallurgical Engineering>

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Key Words: Ductile iron, austempering heat treatment, microstructure, mechanical properties, machinability, retained austenite, strain hardening.

Summary:

When ADI was introduced to be used for engineering applications, there were many problems experienced in trying to machine it.

The first point of this research aims at Producing ADI samples with different microstructures and hardness levels. Heat treatment procedures will cover novel techniques (two-step austempering). This study will cover the effect of alloying element as well as influences the austempering temperature on the mechanical properties and wear behaviour of austempered ductile iron. The second point designed to measure the machinability of different ADI grades and determine the optimum machinability parameters such as cutting speed, feed rate, and depth of cut using taguchi method. Finally, point three designed to study the phase transformation during machining different grades of ADI at different machining trials. Also perform a quantitative analysis of the change in the volume fraction of retained austenite and martensite produce during different machining trials by using XRD and heat tinting techniques.

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Table of Contents

List of Tables

List of Figures

Nomenclature

γ_{HC}	Rich carbon austenite
V_{γ}	Volume fraction of austenite
OA	Orthogonal array
S/N	Signal to noise ratio
DOF	Degree of Freedom
ANOVA	Analysis of Variance
V_C	Cutting speed, m/min
f	Feed rate, mm/rev
a_c	Depth of cut, mm

Abstract

The austempering process of the ductile irons was able to generate materials with unique combination of strength, abrasion resistance, as well as toughness This unique properties make ADI finding a new applications in many engineering fields like; automotive, agricultural, earthmoving, mining, construction as well as military applications.

When ADI was introduced to be used for engineering applications, there were many problems experienced in trying to machine it. The hardest grades of ADI give a hardness of ~50 HRC which would represent a serious problem for any high volume machining operation. The reduced hardness of the lower grades of ADI (300-350 BHN) does not mean better machinability. When subjecting those grades to considerable strains, associated with machining, the high content of retained austenite, which may reach up to 40-43% would transform by TRIP effect to martensite leading to drastic reduction in machinability compared to steels of equivalent hardness.

The first point of this research aims at Producing ADI samples with different microstructures and hardness levels. Various structures will be produced by changing the austempering temperature and using the alloying elements such as Cu and Mo. Heat treatment procedures will cover novel techniques (two-step austempering). This study will cover the effect of alloying element as well as influences the austempering temperature on the mechanical properties and wear behaviour of austempered ductile iron. The second point designed to measure the machinability of different ADI grades and determine the optimum machinability parameters such as cutting speed, feed rate, and depth of cut using taguchi method. Finally, point three designed to study the phase transformation during machining different grades of ADI at different machining trials. Also perform a quantitative analysis of the change in the volume fraction of retained austenite and martensite produce during different machining trials by using XRD and heat tinting techniques and we will try to link this quantitative analysis with the results obtained from machinability measurements.

The machinability experiments results show that depth of cut is the main machining parameters which control and determine the measured cutting force values. The highest cutting force values recorded at high depth of cut at 1.5:2 mm. The optimum machining parameters obtained at depth of cut (0.5:1 mm)

The XRD analysis shows that ADI -375 has a 32.5% retained austenite which transforms to martensite during machining, so this grade shows the same cutting force values of the harder grade of ADI (275). In two-step ADI grade, the cutting forces F_c values are continuously increased when depth of cut changed from 0.5 mm to 1.5 mm but a great decrease with 17.6 % is observed when depth of cut increased from 1.5 mm to 2 mm.

The machinability results proved that IADI has the lowest cutting force values which are decreased by ~ 30:35 % at lower depth (0.5-1 mm) of cut and decreased by ~ 15:20% at higher depth of cut (1.5-2 mm) than other ADI grades introduced in this research.

Chapter 1 :Introduction

In the last 20 years, the dream material, the austempered ductile iron (ADI) with its unique combination of strength, abrasion resistance, toughness, fatigue resistance and machinability has been finding new applications in automotive, agricultural, earthmoving, mining, construction as well as military applications.

Since the announcement of the first production of ADI in the last century, the research started in many industrialized countries, which provided sound products of this dream material in many region in the world during the 1990's and beyond. By the turn of the century, the ADI market had begun to rapidly accelerate from a modest beginning in the early 1970's to an estimated worldwide production level of 125,000 tons in 2005. This growth is expected to continue with the annual world production of ADI reaching 500,000 tons by the end of this year 2013.

The attractive properties of ADI return to its distinct and unique microstructure, which consists of acicular ferrite with enriched carbon austenite (ausferrite). The austempering transformation in ADI can be performed in two-stage reaction:

Stage I Reaction: $\gamma_c \rightarrow \alpha + \gamma_{HC}$ (toughening)

Stage II Reaction: $\gamma_{HC} \rightarrow \alpha + \varepsilon$ - carbides (embitterment)

When ADI was introduced to be used for engineering applications, there were many problems experienced in trying to machine it. The hardest grades of ADI give a hardness of ~50 HRC which would represent a serious problem for any high volume machining operation. The reduced hardness of the lower grades of ADI (300-350 BHN) does not mean better machinability. When subjecting those grades to considerable strains, associated with machining, the high content of retained austenite, which may reach up to 40-43% would transform by TRIP effect to martensite leading to drastic reduction in machinability compared to steels of equivalent hardness.

Therefore, this research objective has been divided into 3 points. The first point aims at Producing ADI samples with different microstructures and hardness levels. Various structures will be produced by changing the austempering temperature and using the alloying elements such as Cu and Mo. Heat treatment procedures will cover novel techniques (two-step austempering). This study will cover the effect of alloying element as well as influences the austempering temperature on the mechanical properties and wear behaviour of austempered ductile iron. The second point designed to measure the machinability of different ADI grades and determine the optimum machinability parameters such as cutting speed, feed rate, and depth of cut using taguchi method. Finally, point three designed to study the phase transformation during machining different grades of ADI at different machining trials. Also perform a quantitative analysis of the change in the volume fraction of retained austenite and martensite produce during different machining trials by using XRD and heat tinting techniques and we will try to link this quantitative analysis with the results obtained from machinability measurements.