

The Effects of Pre Rough Machine Processing on Dimensional Distortion During Carburizing

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

A study was conducted to isolate the influence of pre-rough machine processing on final dimensional distortion. Methods are discussed to aid process development and minimize dimensional change during carburizing. The study examined the distortion during carburizing between five possible raw material starting conditions. Coupons were used and manufactured from each population of material processing. All coupons were carburized and hardened at the same time. Dimensions were made before and after carburizing using a scanning coordinate measurement machine. The results show that dimensional distortion during carburizing increases with mechanical and thermal processing.

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Introduction

This paper presents the methods and results of an empirical study that was conducted to aid process development of a carburized aerospace gear. The objective of the study was to determine the contribution of premachining material processing on dimensional distortion during carburizing. Five possible raw material starting conditions were evaluated. The five prerough machining conditions studied were: (i) normalized AMS6265 barstock, (ii) hardened and tempered (core-treated) AMS6265 barstock at 1725_F, (iii) hardened and tempered (core-treated) AMS6265 barstock at 1550_F, (iv) normalized AMS6260 forging, and (v) hardened and tempered (core-treated) AMS6260 forging at 1725_F.

Cost, time, and lurking variables were minimized by use of a standard distortion coupon in place of actual aerospace gears. The coupon design is shown in Figure 2. French (1930) used this type of coupon to study dimensional distortion during repeated quenching. French's coupon was scaled as necessary for use in this study. The diametrical changes of the coupon indicate the volume changes during hardening. The width of the slot reflects the magnitude of internal stresses set up by the volumetric changes (French, 1930). French (1930) shows that dimensional distortion increased as the number of quench cycles increased. The distortion coupon gap width increased with each quench cycle, thus indicating that residual stresses were increasing with each thermal cycle.

The hypothesis is that dimensional distortion increases as thermal and mechanical processing of the raw material increases prior to machining. The implication is that dimensional distortion can be influenced before the raw material enters the machining process.

Precarburizing process variables and their influence on dimensional distortion were studied previously. The Instrumented Factory (INFAC) (1994) studied the effects of processing variables prior to

carburizing. The INFAC study evaluated residual stresses induced by turning and hobbing and their contribution to dimensional distortion. Mechanical and thermal processing of the raw material, however, was not included in the study.

Background and Literature Review

A dedicated manufacturing cell to produce small aerospace gears was designed and implemented. The design of the manufacturing cell and process was to minimize lead time and cost. The shaping process was used to generate the spline and gear teeth. The resultant gear and spline surface integrity produced by the newly designed process was deemed unacceptable due to machining tears that would not clean up during gear grinding. An example of the post-shaped tooth surface is shown in Figure 1.

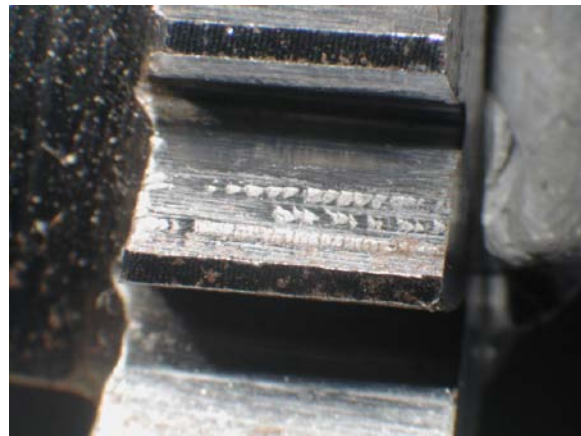


Figure 1. Gear tooth surface, post shaping (Evard, 2005)

Surface integrity is the description and control of the many possible alterations produced in a surface layer during manufacturing. Surface integrity can be evaluated based on a minimum data set. The data set is composed of surface texture, macrostructure, microstructure, and microhardness alterations (MRA,1980). The data set of macrostructure will include surface imperfections such as pits, tears, and/or laps.

The raw material selected for use in the new manufacturing cell was normalized bar stock, which was within the engineering requirements of the finished gear. The soft normalized bar stock was viewed as a good choice for machinability. Many literature sources supported this conclusion. Mott (1985) defined machinability as being related to the ease with which a material can be machined with reasonable tool life. Verzahntechnik Lorenz (1980) and Cluff (1992) indirectly used a similar definition stating that machinability (reasonable tool life) decreases as material hardness increases. The two key terms are "ease of material removal" and "reasonable tool life." An indication of expected surface integrity is not present using these definitions of machinability.

Material hardness can be used as a machinability indicator due to the close relationship between hardness and microstructure (Mullins, 1990). However, hardness is an accurate representation of machinability only for similar microstructures. Mullins (1990) states that a tempered martensite matrix will exhibit superior machinability to a pearlite matrix of similar hardness. Woldman (1937) studied microstructure and machinability and noted that a microstructure selected for long tool life would not necessarily produce good surface integrity.

Based on literature and experience, a tempered martensitic microstructure was desired to produce the required surface integrity. The addition of the hardening and tempering operation was viewed as a risk to changing the dimensional distortion during carburizing and hardening.

A great amount of manufacturing development had been done implementing the new cell. The dimensional distortion during carburizing and hardening had been established and had been determined acceptable and manageable. The addition of a hardening and tempering operation prior to rough machining was viewed as an addition to cost, lead time, and risk of increased dimensional distortion during carburizing. Increased dimensional distortion would then require more process development time and cost.

Problem Statement

Common ground: Aerospace power transmission components must be manufactured to the highest quality standard while minimizing cost of nonquality.

Destabilizing condition: Gear tooth surfaces inconsistently have poor surface integrity ("tears") present after finish flank grinding. The surface defects are produced during the semi-finishing, prehardening, operation. These gears are then deviated, reworked, and/or scrapped.

Contributing factors: Aerospace gears are expensive and have long lead times. A study of many variables is not always practical using actual gears.

Problem: The shaping machine used in the manufacturing cell has limited cutting parameters. Literature suggests that hardening and tempering the material prior to any machining will improve the surface integrity during shaping. The material structure is then martensitic and hardness ranges from Rc 25 to Rc 32. However, literature also suggests that this fix could negatively influence dimensional distortion during hardening.

Solution: Material samples made of different microstructure and hardness will be fabricated and tested. Paired data studies statistically analyzing dimensional distortion will be performed on coupons of similar size and process.

Assumptions

The material samples are assumed to fully represent their population. For example, a group of normalized material samples is assumed to represent all normalized material.

The change in coupon gap width is assumed to represent the relative dimensional distortion of an actual gear.

Methods & Procedures

This section contains the details of coupon manufacturing and processing. Standard distortion coupons were manufactured for each population as shown in Figure 2. The dimensions of the coupon are proportional to the gear being developed and are shown in Figure 3.



Figure 2. Distortion coupon, GR-0010

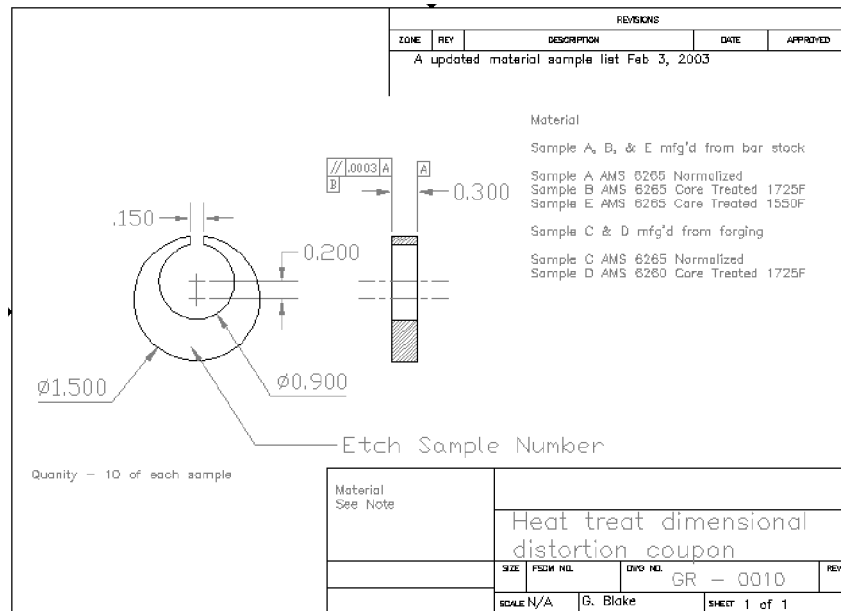


Figure 3. Detailed Specimen Drawing (units = inches)

The coupons from each population were machined, stress relieved, carburized, and hardened together. The coupons were randomly located in the carburization furnace and quench basket. A summary of the populations is shown in Table 1. A sample size of ten was used with one additional sample used for metallurgical evaluation. The letter designation will be used from this point on to identify the population.

The raw material requiring hardening and tempering was heat treated in-house as listed in Table 2 and Table 3 prior to any machining. The normalizing process was done per the AMS specification prior to receiving the material. The manufacturing and inspection stages of the coupons are listed in Table 4. The coupons were carburized and hardened using a cycle common to the actual gear (see Table 5).

Table 1. Specimen populations

<u>Material</u>	<u>Form</u>	<u>Pre-machining Heat Treatment</u>	<u>Quantity</u>	<u>Expected Structure</u>	<u>Identification</u>
AMS6265	Barstock	Normalized	10*	Pearlite in Ferrite Matrix	A
AMS6265	Barstock	Normalized + Harden @1725F	10*	Pearlite in Ferrite Matrix	B
AMS6260	Forging	Normalized	10*	Pearlite in Ferrite Matrix	C
AMS6260	Forging	Normalized + Harden @1725F	10*	Tempered Marten-site	D
AMS6265	Barstock	Normalized + Harden @1550F	10*	Tempered Marten-site	E

*One additional specimen was manufactured for metallurgical evaluation

**Table 2. Hardening and tempering process
@1725F**

<u>Operation</u>	<u>Operation Description</u>
10	Load
20	Core Harden
	Temperature 1725 F
	Time @ Temp: 1 hour min.
	Atmosphere: Endogas
	Quench in 110 - 190 F oil
	to 200 F max. part temperature
25	Wash
30	Load
40	Temper to BHN 258-301
	Temp. (ref.) 980F
	Time @ temp: 2 hours min.
50	Unload
60	Clean
69	Inspect

**Table 3. Hardening and tempering process
@1550F**

<u>Operation</u>	<u>Operation Description</u>
10	Load
20	Core Harden
	Temperature 1550 F
	Time @ Temp: 1 hour min.
	Atmosphere: Endogas
	Quench in 110- 190 F oil
	To 200 F max. part temperature
25	Wash
30	Load
40	Temper to BHN 258-301
	Temp. (ref.) 980F
	Time @ temp: 2 hours min.
50	Unload
60	Clean
69	Inspect