

Comparison of Austempering and Quench-and-Tempering Processes for Carburized Automotive Steels

Andrew D. Clark, Derek O. Northwood and Randy J. Bowers
University of Windsor

Xichen Sun and Peter Bauerle
Chrysler Group LLC

ABSTRACT

Carburized parts often see use in powertrain components for the automotive industry. These parts are commonly quenched and tempered after the carburizing process. The present study compared the austempering heat treatment to the traditional quench-and-temper process for carburized parts. Samples were produced from SAE 8620, 4320, and 8822 steels and heat treated across a range of conditions for austempering and for quench-and-tempering. Distortion was examined through the use of Navy C-Ring samples. Microstructure, hardness, and Charpy toughness were also examined. X-ray diffraction was used to compare the residual stress found in the case of the components after the quench-and-temper and the austempering heat treatments. Austempering samples showed less distortion and higher compressive residual stresses, while maintaining comparable hardness values in both case and core. Toughness measurements were also comparable between both processes.

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INTRODUCTION

Case carburized steels are often used in the automotive industry for powertrain components such as gears, camshafts, and roller bearings. Commonly these steels are gas carburized, in a process known as the boost/diffuse method, in which the component is placed in a high carbon potential atmosphere to allow carbon diffusion into the case. The carbon potential is then lowered to a value more consistent with the desired weight percent for the case [1]. Most often carburizing takes place between 1550 °F and 1750 °F (843 °C and 954 °C) [1,2]. Oil quenching usually follows the process, forming martensite in both the case and core of the component. After quenching a tempering process is typically used to increase ductility and reduce brittleness [3].

Carburizing offers the advantage of increasing the carbon content on the surface of a material, which can allow for additional wear resistance and strength [4]. It maintains a lower carbon martensitic core within the component, which provides improved toughness and ductility. Carburizing can be combined with austempering to produce bainite at the surface of a component. The increase in carbon content in the carburized case lowers the martensite start temperature [2]

and allows the bainite lines of the time-temperature-transformation (TTT) curve to be crossed [5].

Phase transformations and thermal expansion during heat treatment and cooling from the austenite region result in distortion of the produced component. Distortion is a concern in the production of powertrain components because changes in dimensions during heat treatment must be corrected post heat treatment. The grinding and readjustment of the parts can compromise the mechanical properties of the carburized layer, as well as reduce the fatigue strength of a part [6,7]. Grum has shown that the transformation of austenite to bainite during austempering results in a smaller volume change than the transformation to martensite during quenching [8].

Along with distortion, the heat treatment process forms residual stresses within the component. Austempering can create large residual compressive stresses on the surface of a carburized part [9]. Compressive stresses are beneficial in fatigue as they deter the formation and growth of surface cracks [10,11].

Examination of alternative heat treatments can allow for lower distortion and post heat treatment costs without sacrificing, and potentially improving, mechanical properties.

The purpose of this study was to compare the austempering heat treatment process with the currently used quench-and-temper process for carburized parts.

EXPERIMENTAL DETAILS

Three grades of steel were used in this experiment, SAE 8620, 8822, and 4320. Their compositions are shown in [Table 1](#). Initial samples were cast as bars, and then carburized at 1650 °F (899 °C) for 5 hours at a carbon potential of 0.9. Samples then underwent either 1) an oil quench-and-temper for one hour at either 650 °F or 750 °F (343 °C or 398 °C), or 2) austempering for 30, 60, 120, or 240 minutes at 500 °F, 550 °F, or 580 °F (260 °C, 287 °C, or 304 °C) for a total of 12 austempering conditions. The microstructures of both the core and carburized case were examined for all samples. Austempering parameters that produced a minimum of fifty percent bainite in the case were selected for further testing. These parameters are shown [Table 2](#), along with the quench-and-temper parameters.

Table 1. Chemical compositions of SAE 8822, 8620 and 4320 steels

Steel	8620	4320	8822
C	0.2	0.19	0.22
Mn	0.91	0.64	0.96
Si	0.23	0.2	0.17
Cr	0.5	0.47	0.56
Ni	0.56	1.74	0.34
Mo	0.16	0.22	0.33

Distortion analysis was done using Navy C-Ring samples. Two C-Rings were produced and heat treated for each condition. A coordinate measurement machine (CMM) was used to dimension the samples. Size distortion was determined by measuring the change in outer diameter (OD), inner diameter (ID), thickness, and gap width. Shape distortion was measured in terms of flatness, cylindricity, and roundness. Measurements were made before carburizing, and after the heat treatment processes to allow measurement of the effect of the different processes. A schematic for the measurement points on a C-Ring are shown in [Figure 1](#).

Table 2. Heat treatment temperature and time conditions for austempering and quench-and-tempering

Austempered Samples		
Austemper Temperature (°F)	Time (h)	ID
500	2	500/2
500	4	500/4
550	2	550/2
550	4	550/4
580	1	580/1
580	2	580/2
580	4	580/4
Quenched-and-Tempered samples		
Tempering Temperature (°F)	Time (h)	ID
650	1	QT650/1
750	1	QT750/1

Rockwell C hardness testing was performed in accordance with ASTM E18 [13]. Five measurements were made on both the core and case of all samples using a Brale indenter with a 150 kg load.

Charpy toughness testing was used to determine the energy absorbed during fracture. Three tests were performed for each condition for each material. Fracture surfaces were observed using scanning electron microscopy (SEM). The Microstructure was documented for both the case and core of all samples using optical microscopy. Samples were prepared by using silicon carbide paper, followed by 9-micron diamond and then a 1-micron and 0.05-micron alumina polish. An initial etch was done using a 2% nital solution, followed by repolishing with 0.05-micron alumina, before final etching with 2% nital.

Residual stress testing was performed on the 4320 steel samples by X-ray diffraction, in which lattice spacings are measured and compared to an unstressed sample often prepared using metal powder that has been annealed to relieve stress [12]. X-ray diffraction was performed by a certified lab, on a machine calibrated to within 1 ksi in accordance with ASTM E915 [14]. Residual stress measurements for both hoop stress about the outer diameter and axial stress were taken. A C-ring ready for residual stress testing is documented in [Figure 2](#).

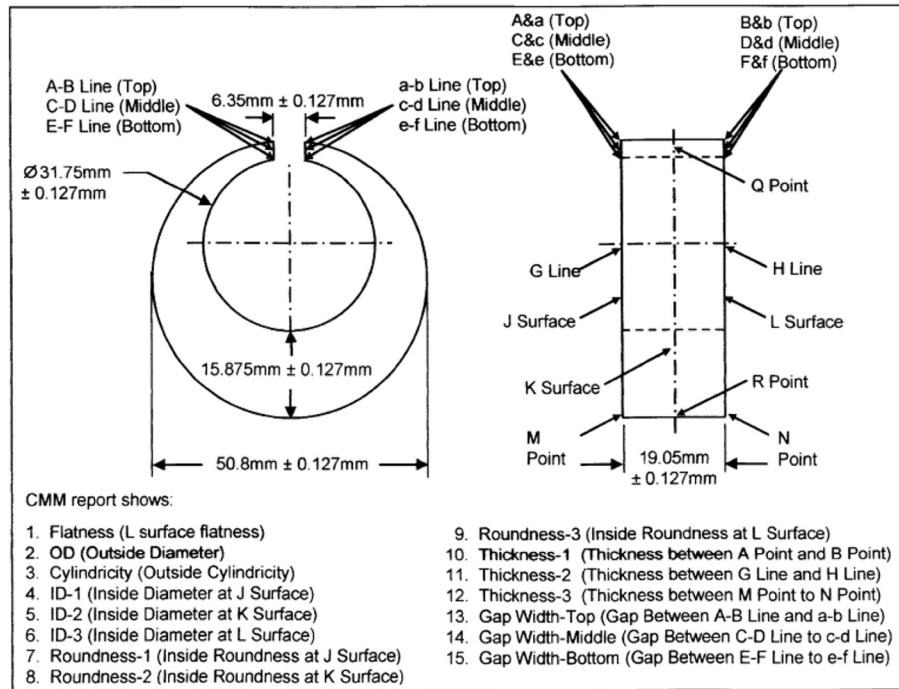


Figure 1. Dimensions and measurement locations for C-Ring specimen.

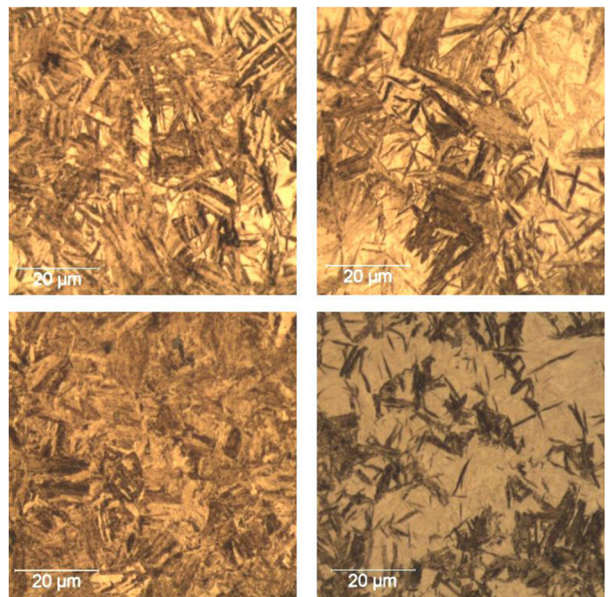


Figure 2. Navy C-Ring ready for residual stress testing

Results

Microstructural analysis revealed varying amounts of bainite in the cases of the austempered samples; the core microstructures for the austempered samples were martensite. Both the case and core microstructure of the quench-and-tempered samples were tempered martensite. Case microstructures for a series of austempered samples are shown in Figures 3-6. Figures 3 and 4 demonstrate the effect of composition on the formation of bainite in the case. Both are austempered at 500 °F for 2 hours; Figure 3 is 8620 steel, and Figure 4 is 8822 steel. The 8822 steel shows less bainite formation. Figures 5 and 6 show the effect of time. Both samples are 4320 steel austempered at 550 °F. Figure 5 was austempered for 4 hours and shows a nearly entirely bainitic structure. Figure 6 was austempered for 30 minutes and

shows a mostly martensitic structure with the darker portions being the bainite.



Figures 3-6. Case microstructures showing effect of composition and austempering time on bainite formation in carburized case. Figure 3. Top left: 8620 steel austempered at 500 °F for 2 hours. Figure 4. Top right: 8822 steel austempered at 500 °F for 2 hours. Figure 5. Bottom left: 4320 steel austempered at 550 °F for 4 hours. Figure 6. Bottom right: 4320 steel austempered at 550 °F for 30 minutes.