Heat Treatment of Some Temperature-Resistant Carburizing Steels

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The heat treatment of some Mo-Cr-V secondary hardening carburizing steels was investigated. The compositions selected for study were chosen because 1) they can be readily softened by annealing, and 2) they do not require excessively high temperatures for carburizing. Both of these characteristics are desired for ease of manufacturing.

After carburizing these steels at 955°C and oil quenching, the as-quenched core hardness is retained with little change for tempering temperatures up to 600°C, but the case hardness decreases slowly with increasing tempering temperature, reaching values of 52-54 Rc after tempering at 550°C. The case depths, case carbon content, retained austenite content and residual stress resulting from carburizing the experimental alloys were compared with the same properties measured on SAE 8620 steel. It was found that the surface oxides which form on V-bearing steels during heat treatment in endothermic gas-base carburizing atmospheres interfere with carburizing. For this reason, steels with 0.15 wt. pct. V or less are preferred for carburizing.

Because of their enhanced resistance to softening at elevated temperatures compared to conventional carburizing steels, carburized secondary hardening steels should provide improved resistance to surface damage under conditions of marginal lubrication.

INTRODUCTION

The low carbon steels employed in the automotive industry for carburized parts such as gears and bearings are selected primarily on the basis of hardenability. None of the usual grades of carburizing steels are notably superior to the others with respect to properties at elevated temperatures. The quantities and types of alloying elements needed for purposes of enhancing hardenability do not change in any fundamental way the reactions which occur during tempering. Hot work tool steels (H series) or high speed steels (M and W series), on the other hand, undergo secondary hardening reactions during tempering, so the strength of these alloys is maintained to temperatures of about 600°C.

In recent years efforts have been made to develop carburizing steels with secondary hardening characteristics for bearings which see service at elevated temperatures, for helicopter gearing, and for oil well drilling applications. Some of the alloys proposed are low carbon versions of tool steels, e.g., VACO X-2, and require high temperatures to form austenite. Others, such as CBS 600, can be austenitized at lower temperatures, but do not contain sufficient amounts of Cr, W, Mo or V to exhibit substantial secondary hardening. Another alloy, Pyrowear 53 (EX-00053), utilizes precipitation of Cu as well as alloy carbides for secondary hardening. Table I lists the compositions of some of the alloys which have been investigated.

Trends in the automotive industry toward improved engine and powertrain performance suggest that a role for secondary hardening steels may develop. Even though ambient operating temperatures are governed by the thermal stability of the lubricant, surface temperatures of...
Composition of Some High Temperature Carburizing Steels

<table>
<thead>
<tr>
<th>Alloy</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>W</th>
<th>Mo</th>
<th>V</th>
<th>Other</th>
<th>Reference</th>
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<tbody>
<tr>
<td>CBS 600</td>
<td>0.19</td>
<td>0.60</td>
<td>1.1</td>
<td>1.5</td>
<td></td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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<tr>
<td>CBS 1000M</td>
<td>0.13</td>
<td>0.50</td>
<td>0.5</td>
<td>0.5</td>
<td>3.0</td>
<td>4.5</td>
<td>0.35</td>
<td>4.8</td>
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<td>1-3</td>
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<tr>
<td>VASCO X-2</td>
<td>0.24*</td>
<td>0.32</td>
<td>0.88</td>
<td>4.92</td>
<td>1.38</td>
<td>1.43</td>
<td>0.45</td>
<td>4.8</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Pyrowear53</td>
<td>0.10</td>
<td>0.35</td>
<td>1.0</td>
<td>1.0</td>
<td>2.00</td>
<td>3.25</td>
<td>0.10</td>
<td>2.0 Cu</td>
<td>7,8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.50</td>
<td>1.0</td>
<td>1-</td>
<td>0-</td>
<td>2.2-</td>
<td>0-</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Also lower carbon versions

parts in sliding contact under conditions of marginal lubrication can become very high. Present carburizing steels soften rapidly as the temperature rises about 300°C. Thus, each excursion at the wear surface above 300°C renders the surface less capable of resisting subsequent excursions as well as "normal" service conditions. Therefore, improved durability would be expected from steels which resist softening, even at ambient operating temperatures below 300°C, whenever the lubrication is marginal.

The types of steels useful to the automotive industry must be amenable to low cost modes of manufacturing and the high production volumes characteristic of the industry. Two principal requirements are: 1) steels must be capable of being softened for ease of fabrication into parts by forming or machining, and 2) steels must be readily heat treatable by methods and equipment commonly employed in the industry. The main implication of this last condition is that heat treatment temperatures cannot be too high.

This paper describes the results of some processing experiments on alloys which were designed to meet these objectives. The alloys considered contain 0.2 wt pct carbon, 2 - 2.9 wt pct Mo, 0.6 wt pct Cr and varying amounts of vanadium. In choosing this composition, the following factors were considered:

1. The alloys are designed to be carburized at 920-960°C in conventional sealed quench carburizing furnaces using an endothermic gas-base atmosphere. Quenching is in oil at 55-65°C, and a single tempering operation is employed. Higher carburizing temperatures are avoided because a) maintenance costs on furnaces and furnace fixtures increase rapidly with temperatures much above this range, and b) carbon potential control of furnace atmospheres becomes more difficult the higher the furnace temperature.

2. The principal alloying element chosen was molybdenum. At 950°C, alloys with 0.2-1.0 wt pct carbon and about 2 wt pct Mo should be fully austenitic. Thus a low carbon steel with this Mo content can be carburized without forming carbides in the case. The total alloy content of the steels prepared was chosen to be somewhat higher than the solubility limit, so that some carbides remain undissolved during heat treatment, to aid in maintaining a fine austenite grain size in both the high carbon case and low carbon core.

3. A small amount of chromium (0.6 wt pct) was added to increase the atom fraction of carbide forming elements. Chromium can substitute for molybdenum in M₂C carbides. Higher chromium contents were avoided because a) the carbon solubility in austenite at 950°C drops rapidly as the Cr content increases, and b) formation of chromium oxides at the surface during carburizing can interfere with carbon penetration.

4. Alloys with 0, 0.15, 0.30 and 0.45 wt pct V were prepared with Mo contents diminishing as the V contents increased, maintaining the total atom fraction of carbide forming elements approximately constant. It was expected that 0.15 wt pct V would be in solution in a high carbon case and that as much as 0.45 wt pct might be soluble in the low carbon core at 950°C. Vanadium can substitute for Mo in M₂C carbides, but it is also likely that V₄C₃ will precipitate during tempering in the V-bearing alloys. The feasibility of substituting some V₄C₃ precipitation for M₂C precipitation is of interest because a) a greater volume fraction of carbide results from a given atom fraction of alloying element when V₄C₃ rather than M₂C is the precipitate, and b) the fine dispersions of V₄C₃ responsible for secondary hardening have better stability at 600°C than the M₂C precipitate. Higher V contents cannot be usefully employed unless the austenitizing temperature is raised.

5. Manganese and nickel, which are commonly used to improve the hardenability of carburizing steels, were omitted except for a small Mn addition to prevent hot shortness. Both Mn and Ni tend to lower the Ar₁ temperature, making it more difficult to coarsen carbides during annealing. The silicon content was kept low also, to make it easier to achieve low hardness after annealing. The Cr and Mo additions were expected to confer ample hardenability for small, oil-quenched parts.