Distortion in Case Carburized Components –
The Steelmakers View

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1. Abstract

Distortion of components during heat treatment has a significant effect upon final component costs. The factors which influence distortion behaviour occur during the machining and heat treatment processes and are therefore outside the control of the steelmaker. One important factor which is under the control of the steelmaker is hardenability - Consistent hardenability performance can have a significant effect in reducing the variability in distortion. In a number of instances it has been shown that the macrostructure and as-cast shape of the steel can also influence distortion. Other downstream processing effects such as forging may also be influential in these circumstances.

This paper gives examples of some of the experiences of British Steel Engineering Steels with customers and end users, and refers to relevant published work.

2. Introduction

The automotive industry requires that engineering steels are made to greater levels of consistency to meet improved consistency of properties and processing response. This is to ensure that cost and performance targets are met in the final product.

A prime example of this is in the control of distortion during heat treatment.

As a result of non-uniform heat transfer and volume changes on transformation, a change in shape or distortion will always occur when ferrous components are heat treated. If this change in shape can be controlled and made consistent, corrections can be made in the machining processes so that the components distort into “true” on heat treatment. Where this is not possible, product costs are increased as a result of scrap losses, rectification and extra process steps such as hard machining after heat treatment. Controlled and consistent distortion from cast to cast and batch to batch therefore enables component costs to be reduced.

NVH (noise, vibration and harshness) is becoming of increasing importance in the automotive industry. The control of distortion to give correct mating of rotating components such as gears and shafts has a major influence upon NVH performance.

Most of the examples given in this paper are automotive transmission components which are carburised.

A wide variety of factors influence distortion behaviour and can be broadly summarised as follows:

- Component shape.
- Steel type.
- Microstructure and residual stresses prior to heat treatment.
- Reheating and carburising conditions.
- Stacking and support in furnace.
- Quenching - Medium, temperature, flow, jigging, etc.
- Hardenability.
- As-cast shape.
- Macrostructure

Of the above factors, the steelmaker has influence over only the last three, hardenability, as-cast shape and macrostructure.

The remainder of the paper is therefore concerned with these subjects.

3. Hardenability

The hardenability of steel depends upon composition and austenitic grain size. This relationship has been understood for some time. More recently the relationship has been developed to enable the accurate prediction of hardenability based upon composition (1). British Steel Engineering Steels employs this understanding during secondary steelmaking operations to achieve a very close control of composition and hence hardenability (2). Cast to cast variation in hardenability is minimised which is vital to the steel user as it has a major influence upon the component properties and the distortion which occurs during heat treatment. The relationship with distortion has been clearly demonstrated (3).
Practical examples of how hardenability influences distortion have been reported in published work (4, 5) and one example for gears in 27MC5 carbonitriding grade as shown below, was given by Rezel (6).

The gear is made as a ring-shaped forging which is machined and carburised. Measurements of out of roundness (OOR) or ovality after heat treatment are plotted against the hardness value at the

![% Rejections for Distortion](image)

**Figure 1 Influence of Hardenability upon Rejections for Distortion**

Figure 1 shows % rejections for distortion against the hardness value at the J11 (mm) Jominy position. It can be seen that as the J11 value exceeds 42HRC, the rejections for distortion increase significantly. In order to meet the required properties and avoid excessive losses for distortion, a restricted hardenability of 37/43 or 38/42HRC at J11 is specified for measured and calculated Jominy results respectively.

Recently, British Steel Engineering Steels was asked to produce a 20MnCr5 type carburising steel to a very restricted hardenability range to control distortion in a car final drive gear.

![O.O.R Distortion 1/100mm](image)

**Figure 2 Influence of Hardenability upon Distortion in a 20MnCr5 Final Drive Gear**

J6.5(mm) position on a Jominy hardenability test in Figure 2. It can be seen that as the hardness exceeds 41HRC there is an increase in OOR distortion. A minimum hardness of 38HRC is required at the J6.5 Jominy position in order to meet the design properties of the gear and therefore a hardness range of 38/41HRC is required. This compares to a typical 20MnCr5 restricted range of 6HRC at this position and can only be achieved by precise control of composition during steelmaking.
The above examples show that by working to controlled hardenability limits, the steelmaker can assist in the process of distortion control.

4. As-Cast Shape

The effect of the as-cast shape upon distortion in car crownwheels in 16MnCr5 grade was reported by Seger (7). In this case, the use of a non-square continuously cast slab section in place of the normal continuously cast square section gave rise to an excessively oval shape in the crownwheels after heat treatment.

This was further investigated by Gunnarson (8) who demonstrated that the use of a continuously cast round section in place of a section rolled from non-square continuously cast bloom gave a reduction in ovality on large truck crownwheels. Figures 3a and 3b show schematically the differences in out of roundness distortion between two crownwheels produced from continuously cast bloom rolled to 120mm sq and 140mm dia continuously cast round billet. Fourier analysis of the measurements showed a difference of 20μm in extreme cases. Improvements in flatness were also seen from the use of a round section.

Figure 3b Distortion in Crownwheels from Continuously Cast Round, 140mm dia

Other published work (9) showed an influence of as-cast shape in epicyclic annulus gears.

An attempt to investigate the effect of as-cast shape, continuously cast round and square and square ingot was made in a collaborative project with BSES, Ovako Steel, Volvo and SKF (10). The cast shapes were produced from one heat to eliminate any hardenability variations as shown below:

Figure 3a Distortion in Crownwheels from Continuously Cast Rectangular Bloom, 120mm sq

Figure 4 Steel Manufacturing Route for Cast Shape/Distortion Project
Components were produced from the various combinations of cast and rolled shapes in the form of gear blanks, bearing rings and gearbox clutch sleeves. Extensive measurements were carried out before and after heat treatment on each of the components. As-cast shape did not have an influence upon heat treatment distortion in any of the components.

BSES has been involved in discussions and investigations with a number of other component producers and a summary of this experience, along with some published work is given in Table 1 below.

Roll shape has had an influence in some cases, but not all.

On a worldwide basis, large tonnages of steel for carburised components are regularly produced in the form of non-square continuously cast bloom without distortion problems being experienced. This includes crownwheels and other critical components. Placed in this context, it has to be concluded that as-cast shape is a relatively minor influencing factor in heat treatment distortion.

<table>
<thead>
<tr>
<th>SOURCE IF PUBLISHED</th>
<th>COMPONENT</th>
<th>GRADE</th>
<th>CAST/RolLED SHAPE</th>
<th>COMPONENT SECTION</th>
<th>FIXTURE QUENCHED</th>
<th>BENEICIAL INFLUENCE OF CAST SHAPE</th>
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<tbody>
<tr>
<td>Seger (7)</td>
<td>Crownwheel</td>
<td>16MnCr5</td>
<td>CC Slab and CC Sq → 70mm Sq</td>
<td>25mm+</td>
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<td>Yes</td>
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<td>Gunnarson (8)</td>
<td>Crownwheel</td>
<td>INiCr</td>
<td>CC 140mm dia, CC Rectangle → 120mm Sq</td>
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<td>Yes</td>
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<td>Thoden (9)</td>
<td>Gearbox Clutch Sleeve</td>
<td>20MoCr4</td>
<td>CC 325mm dia, CC Rectangle → 80mm Sq</td>
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<td>BSES (10)</td>
<td>Gear Blank</td>
<td>INiCr</td>
<td>CC 140mm Sq, CC 160mm dia, Ingot → 100mm dia, 90mm Sq</td>
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<td>Gearbox Clutch Sleeve</td>
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<td>Bearing Ring</td>
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<td>SAE 52100</td>
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<td>SAE 52100</td>
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<td>50mm</td>
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<td>16MnCr5</td>
<td>CC 325mm dia, 300mm Sq → 65/70mm Sq</td>
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Table 1 Investigations into the Effect of As-Cast Shape Upon Distortion

From Table 1, it can be seen that as-cast shape appears to have had an influence upon distortion of crownwheels and epicyclic gear annulus components, made from carburising steels. There are some contradictory results.

Where as-cast shape has been influential the following circumstances apply:
Relatively large section size.
Fixture or press quenching is applied.

The following comments can be made in these cases:
Square or round have given benefits over non-square cast sections.
No significant differences between round and square as-cast section have been realised.

5. Variations in Macrostructure and Hardenability

An extreme example of how the macrostructure of steel can influence component properties has been reported by Hock et al (13). In this case, the use of badly-applied electromagnetic stirring below the mould during continuous casting can give rise to a phenomenon known as "white band". This is shown in Figure 5a.
The negative and positive segregation effects associated with the white band give rise to significant variations in the hardness across a heat treated billet slice compared to a section free of white band, as in Figure 5a. Jominy test pieces taken across the billet show a significant difference at the position corresponding to the white band (Figure 5b). In addition to the potential for "softspots" should the white band be present at the final component surface, the difference in hardenability is also a potential for variation in distortion behaviour.

This is an extreme example of variability in the macrostructure. Most steelmakers producing engineering steels have a good control of this feature but there is inevitably a difference in macrostructures from steelmaker to steelmaker, reflecting differences in plant and processes. Following the casting and rolling of the steel to billet or bar, components are produced by forging and/or machining processes. It is the remnant macrostructure or "grainflow" in these components prior to heat treatment which can be important.
Added to the variation in macrostructure across products from different steelmakers is a variation in measured Jominy hardenability - The Jominy hardenability test can be subject to numerous variables in sampling preparation and testing (14). Whilst most steelmakers achieve a good consistency of hardenability performance based upon their own results, significant differences have been shown to exist from steelmaker to steelmaker against the same nominal specification (6, 13).

In order to overcome potential problems from changes in macrostructure and hardenability testing, particularly those of distortion, some end users (13, 15, 16) source individual or families of components against one consistent supply chain - The same steelmaker, forger and machinist using the same consistent process routes. This is known as “monosourcing” and is claimed to have significant benefits in the control of distortion.

Monosourcing is worthy of further study and application for mass-produced carburised components in the automotive industry.

6. Summary and Conclusions

1. Many of the factors which influence heat treatment distortion are outside the control of the steelmaker.
2. Of those factors which the steelmaker does control, hardenability is the most important. A consistent hardenability is necessary to assist consistent distortion behaviour on heat treatment.
3. As-cast shape has been shown to have an influence upon heat treatment distortion in a limited number of cases.
4. The monosourcing of components to reduce variations due to steelmaking, forging and machining operations upon distortion behaviour is applied by some producers of mass-produced parts. This is worthy of further investigation and application.

7. Acknowledgements

The author is grateful to Messrs. Gunnarson and Ravenshorst of Volvo AB, Gothenberg, Sweden and Messrs. Beck and Hock of ZF Friedrichshafen, Germany for useful and informative discussions on this subject.

8. References

4. H. Mallener, “Changes in Dimensions and Shape During Case Hardening”, AWT Meeting on “Case Hardening”, hosted by AWT, Darmstadt, Germany. 12-14th April 1989 (in German).

