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# Heat Treatment of Metals: Distortion in Case Carburised Components - the Steelmaker's View

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## Heat Treatment of Metals: Distortion in Case Carburised Components - the Steelmaker's View

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Distortion resulting from heat treatment has a significant effect upon final component costs. Most of the factors which influence distortion behaviour arise during the machining and heat treatment processes and are therefore outside the control of the steelmaker. One important factor which is under the jurisdiction 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

This Paper was presented prior to the formation of Corus plc following the merger of British Steel and Koninklijke Hoogovens. Corus Engineering Steels is the new name of British Steel Engineering Steels referred to throughout the text of this paper.

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## Introduction

The automotive industry requires that engineering steels are made to greater levels of consistency in order to attain improved consistency of properties and processing response. The objective 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.

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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 the furnace;
- quenching - medium, temperature, flow, jiggling, etc;
- hardenability;
- as-cast shape;
- macrostructure.

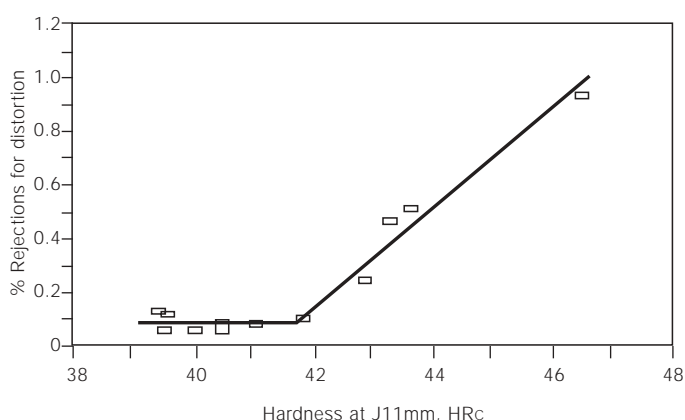
Of the above factors, the steelmaker has influence over only the last three: hardenability, as-cast shape and macrostructure. The remainder of this paper is therefore concerned with these subjects.

### 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. <sup>(1)</sup>

British Steel Engineering Steels employs this understanding during secondary steelmaking operations to achieve a very close control of composition and hence hardenability. <sup>(2)</sup> 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. <sup>(3)</sup>

**Fig. 1** Influence of hardenability upon rejections for distortion of gears in a 27MC5 carbonitriding steel



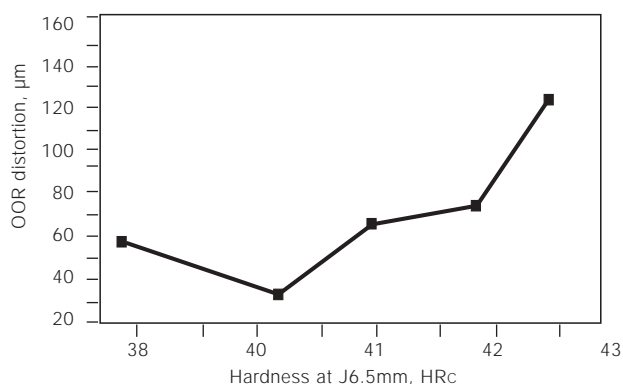
Practical examples of how hardenability influences distortion have been reported in published work <sup>(4, 5)</sup> and one, in gears in 27MC5 carbonitriding grade, was given by Rezel. <sup>(6)</sup> Fig. 1, from Rezel's work, shows percentage rejections for distortion against the hardness value at 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 due to 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 20MnCrS5 type carburising steel to a very restricted hardenability range in order to control distortion in a car final drive gear. The gear is made as a ring- shaped forging which is machined and carburised.

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Measurements of out-of-roundness (OOR) or ovality after heat treatment are plotted against the hardness value at the J6.5(mm) position on a Jominy hardenability test in Fig.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 specified. This compares with a typical 20MnCrS5 restricted range of 6HRc at this position and can only be achieved by precise control of composition during steelmaking.

**Fig. 2** Influence of hardenability upon distortion in a 27MnCr5 final drive gear



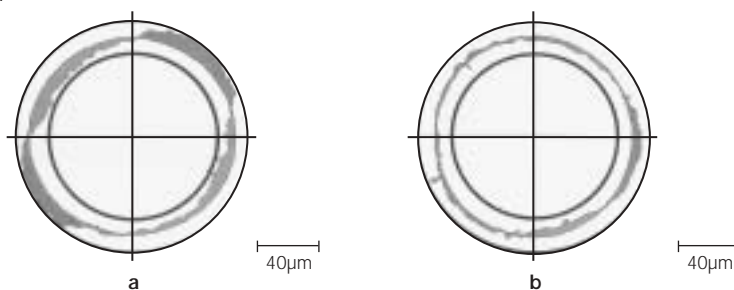
The above examples show that, by working to controlled hardenability limits, the steelmaker can assist in the process of distortion control.

### As-Cast Shape

The effect of the as-cast shape upon distortion in car crownwheels in 16MnCr5 grade was reported by Seger.<sup>(7)</sup> 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.

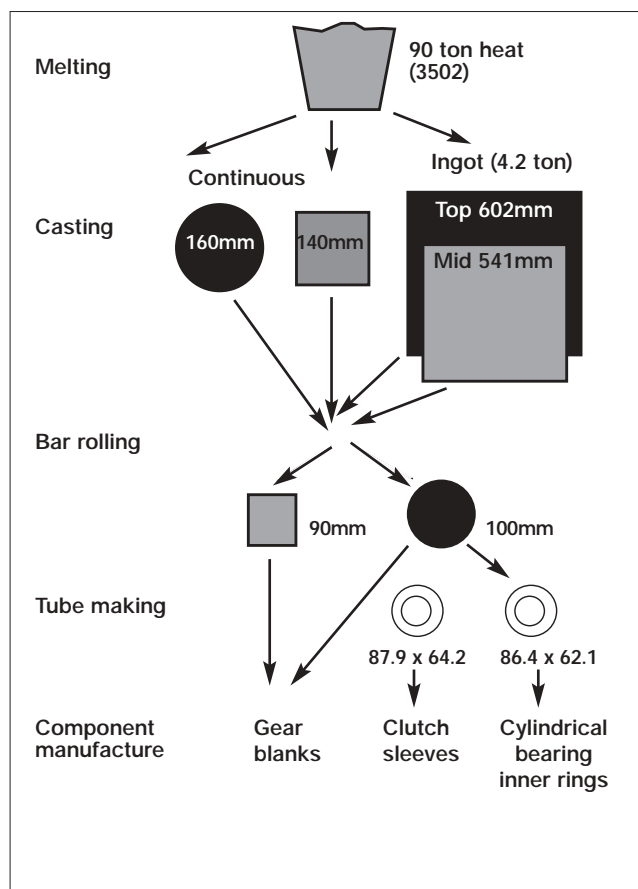
This was further investigated by Gunnarson<sup>(8)</sup> who demonstrated that the use of a continuously-cast round section, in place of a section rolled from non-square continuously-cast bloom, gave a reduction in ovality on large truck crownwheels. Fig. 3 shows schematically the differences in out-of-roundness distortion between two crownwheels produced from continuously-cast bloom, rolled to 120mm square, and 140mm-diameter 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.

**Fig. 3** Distortion in crownwheels from: (a) continuously-cast rectangular bloom, 120mm square; (b) continuously-cast round, 140mm diameter. Measurements of out-of-roundness from Gunnarson<sup>(8)</sup>



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Fig. 4 Steel manufacturing route for cast shape/distortion project



Other published work <sup>(9)</sup> 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 involving BSES, Ovako Steel, Volvo and SKF. <sup>(10)</sup> The cast shapes were produced from one heat, to eliminate any hardenability variations, as shown in Fig.4.

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 (on the following page).

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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 sections have been realised;
- rolled 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.

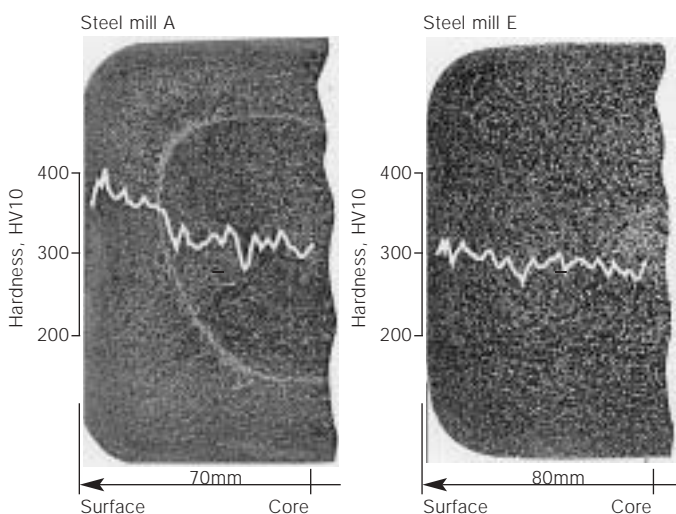
**Table 1** Investigations into the effect of as-cast shape upon distortion

Source if published	Component	Grade	Cast/Rolled Shape	Component Section	Fixture Quenched	Beneficial Influence of Cast Shape
Seger <sup>7</sup>	Crownwheel	16McCr5	CC slab and CC square → 70mm square	25mm+	Yes	Yes
Gunnarson <sup>8</sup>	Crownwheel	1NiCr	CC 140mm diameter, CC rectangle → 120mm square	50mm	Yes	Yes
Thoden <sup>9</sup>	Gearbox clutch sleeve	20MoCr4	CC 325mm diameter, CC rectangle → 80mm square	?	Yes	Yes
BSES <sup>10</sup>	Gear blank	1NiCr	CC 140mm square, CC 160mm diameter, ingot → 100m diameter, 90mm square	30mm	No	No
Volvo <sup>10</sup>	Gearbox clutch sleeve	1NiCr	CC 140mm square, CC 160mm diameter, ingot → 100m diameter	<10mm	No	No
SKF <sup>10</sup>	Bearing ring	1NiCr	CC 140mm square, CC 160mm diameter, ingot → 100m diameter, 90mm square	7mm	No	No
Volkmoth <sup>11</sup>	Bearing ring	SAE 52100	CC 325mm diameter, CC rectangle → 100m diameter	7mm	No	No
Zoch <sup>12</sup>	Bearing ring	SAE 52100	CC square, CC rectangle → 50mm square CC 325mm diameter → 45, 55mm diameter	6mm	Yes	No
Internal report	Bearing ring	1NiCr	CC 140mm square, CC 160mm diameter → 38mm diameter	6mm	No	No
" "	Crownwheel	CrMo	CC rectangle ingot → 65mm square	30mm	No	No
" "	Crownwheel	1NiCr	CC 325mm diameter, CC rectangle → 140m diameter CC 140mm diameter	50mm	Yes	No
" "	Crownwheel	16McCr5	CC 325mm diameter, 300mm square → 65/70mm square	25mm+	Yes	No
" "	Epicyclic annulus	MoCr	Ingot CC rectangle → 100mm square	20mm+	Yes	Yes
" "	Epicyclic annulus	1NiCr	Ingot CC rectangle → 100mm square	20mm+	Yes	Yes
" "	Sun gear	1NiCr	CC square, rectangle → 76mm square	25mm	Yes	Yes

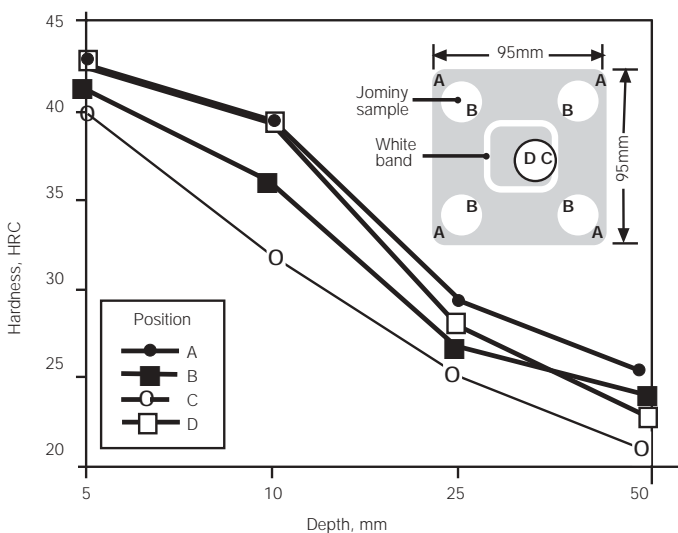
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**Fig 5** (a) Hardness traverses on quenched billet sections from two sources and (b) Jominy hardenability variations across a billet section showing white band (plots A and B are average values).

**Fig 5 (a)**



**Fig 5 (b)**



## 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.<sup>(13)</sup> 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 illustrated in Fig.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 with a section free of white band, as shown in Fig.5a. Jominy test pieces taken across the billet show a significant difference at the position corresponding to the white band (Fig.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 factor 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.

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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.<sup>(14)</sup> 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.<sup>(6, 13)</sup>

In order to overcome potential problems from changes in macrostructure and hardenability testing, particularly those of distortion, some end-users<sup>(13, 15, 16)</sup> 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.

## 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 treat 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 distortion behaviour variations due to steelmaking, forging and machining operations, is applied by some producers of mass-produced parts. This is worthy of further investigation and application.

## Acknowledgements

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