



# The occurrence of quenching cracks in high-carbon tool steel depending on the austenitizing temperature

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## ABSTRACT

Heat treatment has the greatest impact on the microstructure and properties, as well as the residual stresses and dimensional control of steel. Most of the problems that occur in heat-treated parts are attributed to improper heat-treatment practices, deficiency in the used grade of steel, poor part design or part defects. Inappropriate heat-treatment practices include overheating, burning, non-uniform heating, incorrectly selected austenitizing temperature and improper quenching. The formation of cracks during and after the quenching of austenitized steels is a major problem. As the carbon content of steel increases, the tendency to crack increases too. The tendency for quench cracking is also increased with higher austenitizing temperatures.

The aims of the research were to determine the cause of the cracks in high-carbon tool steel and to analyze the influence of the austenitizing temperature on the occurrence and propagation of quenching cracks. The results show that the main cause of quenching cracks is a too high austenitizing temperature caused by poor temperature control. A temperature that is too high leads to excessive austenite grain growth, distinctive grain boundaries with coarser martensite and the presence of retained austenite. On the other hand, the best properties and the absence of quenching cracks occur when C85S steel is quenched from a temperature below the  $A_{cm}$  temperature.

## 1. Introduction

Heat treatment has the greatest impact on the microstructure and properties, but also on the residual stresses and dimensional control, of steel. Most of the problems that occur in heat-treated parts are attributed to applying the wrong heat treatment, incorrect steel grades, poor part design or part defects. Inappropriate heat-treatment practices include overheating, burning, non-uniform heating, the wrong austenitizing temperature and improper quenching. Anything that produces excessive quenching stress can result in cracking. Quench cracking is mostly intergranular, and its formation may be related to some of the factors that also cause intergranular fracture in overheated and burned steels [1].

Overheating is a phenomenon that occurs when low-alloy steels are preheated to high temperature (usually  $> 1200\text{ }^{\circ}\text{C}$ ) prior to hot working, e.g., forging, for a longer period, which leads to the solution of MnS particles in austenite during heating or reheating at high temperatures. It increases with temperature, and its subsequent re-precipitation during cooling occurs at intermediate rates in the form of very fine arrays of  $\alpha$ -MnS particles on the austenite grain boundaries. On subsequent heat treatment, the intergranular network of sulphides can provide a preferential, lower-energy fracture path in contrast to a normal transgranular fracture path. This

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leads to a deterioration of the room-temperature mechanical properties (particularly the ductility, impact strength and toughness) [1–3]. Linked to the reduced mechanical properties is the appearance of intergranular matte facets on the normal ductile fracture surface of an impact specimen. Overheating is a reversible process that has also been noticed in the heat-affected zones of welds, heavily ground parts and steel castings (due to a variation in the pouring temperature and the effectiveness of the proprietary grain inoculants applied to the mold surface) [4].

Burning is a phenomenon that occurs at a higher temperature than overheating when a low-alloy steel is preheated at too high a temperature ( $> 1400\text{ }^{\circ}\text{C}$ ). At these temperatures local melting occurs at the austenite grain boundaries as a result of the segregation of phosphorus, sulphur and carbon [5]. During cooling, initially dendritic sulphides (type II-MnS) form within the phosphorus-rich austenite grain boundary, which then transforms to ferrite. This results in excessively weak boundaries. Subsequent heat treatment provides a very poor impact strength and an almost completely intergranular fracture surface after impact failure. If burning occurs during forging, the forging will often break during cooling or subsequent heat treatment [4]. The major problem of the overheating and burning phenomena, although usually occurring during forging or rolling, is that they might not be observed until after the heat treatment.

A wrongly selected austenitizing temperature also has an influence on the occurrence of quenching cracks. Higher austenitizing temperatures increase the tendency for quench cracking. The steel austenitizing temperature is a compromise between achieving a rapid solution and the diffusion of carbon in the austenite, and minimizing the grain growth. Fine-grained steel can be heated to a higher temperature for rapid austenitization with little danger of grain growth. However, quenched structures formed from large austenite grains exhibit poor toughness and are crack sensitive [6]. Steels with coarser grain sizes are more prone to cracks than fine-grain steels because the latter possess more grain-boundary area to stop the movements of cracks, which also help to absorb and redistribute the residual stresses. The optimal austenitizing time is determined by dividing the total time in the furnace between heating time (the time necessary to heat the part to the required austenitizing temperature) and transformation time (the time required to produce the desired microstructural transformation or to complete the desired diffusion process). Excessive heating times also result in undesirable grain growth.

Steels with a carbon content greater than the eutectoid concentration are usually austenitized and quenched from a temperature below the  $A_{cm}$  temperature, which results in the presence of undissolved carbides in the microstructure prior to quenching. Austenitizing below the  $A_{cm}$  temperature reduces the amount of retained austenite that often accompanies excessive heating temperatures and the problems of increased distortion. Furthermore, cracking also increases with an increased content of retained austenite. It is very important that the undissolved carbides are in spheroidal dispersed form and not in the form of grain-boundary films that produce a brittle microstructure after tempering [7].

The aims of the research were to determine the cause of the cracks and to analyze the influence of austenitizing temperature on the occurrence and propagation of quenching cracks.

## 2. Materials and methods

### 2.1. Material

The hand-tool material in this research was the high-carbon steel grade C85S. The chemical composition of the investigated steel is given in Table 1 and compared to the nominal composition of the steel grade C85S (1.1269) according to the EN 10132-4-2000.

According to the manufacturer, for C75S and C85S steels the recommended austenitizing temperature (hardening temperature) is  $800\text{--}830\text{ }^{\circ}\text{C}$ , while the hand-tool manufacturer used an austenitizing temperature of  $830\text{ }^{\circ}\text{C}$  in the furnace during production. The manufacturer of the hand tools started to introduce C85S steel as a higher grade of high-carbon tool steel in production, with the aim being to improve the quality of the product and to give customers a lifetime guarantee for the hand tools. The heat-treatment parameters provided by the steel manufacturer did not differ much from the parameters used for C75S steel. Therefore, the hand-tool manufacturer conducted the heat treatment in the same furnace with the same parameters for both steels. Since it is a furnace without a protective atmosphere, the hand tools made from the higher steel grade started to exhibit partial to complete decarburization of the surface. As a result, the heat treatment of the higher-grade steel parts was outsourced and relocated to an external heat-treatment facility. After conducting the heat treatment in a furnace with a protective atmosphere, every hand tool from that batch was found to be cracked.

Fig. 1 shows the heat-treated hand-tool parts from the external heat-treatment facility (quenched from  $830\text{ }^{\circ}\text{C}$  and tempered at  $\vartheta_T = 430\text{ }^{\circ}\text{C}$ ) with clearly visible cracks.

For experimental purposes, new hand-tool batches were made using an identical procedure. The hand tools made from the C85S steel were forged from a temperature of  $\sim 1250\text{ }^{\circ}\text{C}$  and air cooled (Grossmann quench-severity factor  $H = 0.02$ ) to room temperature. After sand blasting, the forged hand tools were normalized at the temperature  $\vartheta_N = 830\text{ }^{\circ}\text{C}$  for 1 h and heat treated at three different

**Table 1**  
Chemical composition (in weight %).

| Element, wt%                   | C       | Si        | Mn      | S         | P          | Cr      | Ni      | Mo      | Al    | Cu   | V    |
|--------------------------------|---------|-----------|---------|-----------|------------|---------|---------|---------|-------|------|------|
| C85S steel                     | 0.87    | 0.23      | 0.30    | 0.009     | 0.014      | 0.30    | 0.10    | 0.04    | 0.024 | 0.14 | 0.10 |
| C85S (1.1269): EN 10132-4-2000 | 0.8–0.9 | 0.15–0.35 | 0.4–0.7 | max 0.025 | max. 0.025 | max 0.4 | max 0.4 | max 0.1 | –     | –    | –    |

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