

## Experimental Study of the Influence of Selected Technological Casting Parameters on Structure and Mechanical Properties of Steel Castings

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The aim of the work was to assess influence of technological parameters of casting on thickness and continuity of decarburized layer of castings and their mechanical characteristics in order to suggest adjustment in the production process according to discovered results. The samples for experimental work were taken from one type of casting made from steel 42CrMo4. The thickness of decarburized layer was examined on the samples cast at different temperatures of ceramic mould and at different temperatures of casting. Influence of the wall thickness of the casting was also evaluated. It was observed that changing temperature of the ceramic mould does not cause a significant change in the decarburized surface area of the casting. The influence of the casting temperature of the metal and the shape of the casting is more pronounced in the formation of the decarburized surface layer. As the casting temperature rises, the thickness of the decarburized surface layer of the casting increases. With the increasing wall thickness of the casting, the surface decarburization layer also gets thicker.

**Keywords:** alloy, casting, ceramic form, decarburized layer

### 1 Introduction

Decarburization is a reduction of the carbon content in steel that happens during heating when the steel is exposed to gases like CO<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub> and H<sub>2</sub>O. The carbon on the steel surface reacts with these gases and produces CO and CO<sub>2</sub> in an oxidizing atmosphere or CH<sub>4</sub> in a hydrogen atmosphere [1]. It typically occurs when steel is heated above the lower limit of its recrystallization temperature, usually around 700 °C. Effect of decarburization can be both beneficial and harmful depending on material and its application [2]. Decarburization as thermochemical treatment is used to improve the properties of metals in which carbon is an unwanted impurity. Unwanted effect of decarburization can occur in non-optimally controlled heat treatment processes that negatively alters mechanical properties of the component surface. The carbon reduction results in a loss of tensile strength, hardness and fatigue strength. Depth of decarburized surface layer depends on the duration and temperature of heating [3]. Decarburization can occur prior to heat treatment for example it can be observed in castings, forgings medium-carbon steels derived from hot-rolled

bar stock [4]. Decarburization can either be machined off or be reversed during heat treatment with a carbon restoration [5].

### 2 Material and methods

Steel 42CrMo4 is an alloy steel for quenching and tempering. It is characterized by a high strength, an interesting fatigue behaviour and good machinability [6]. Therefore it is frequently used material for high-strength machine parts, automotive driving elements, hydraulic motors, hydraulic cylinders etc. In table 1 is chemical composition of steel 42CrMo4. During lost-wax casting into a self-supporting ceramic mould and subsequent cooling in an uncontrolled ambient atmosphere, the undesirable phenomenon of decarburization of the surface area of the casting occurs, due to the carbon content in this alloy [7]. Therefore the structure of the surface of the 42CrMo4 castings is not homogeneous. Due to the decarburization an undesired layer of pure ferrite is formed on the surface of the castings.

**Tab. 1** Chemical composition of steel 42CrMo4 (wt. %)

C	Si	Mn	Cr	Mo	P	S
0.38 ÷ 0.45	0.15 ÷ 0.4	0.5 ÷ 0.9	0.9 ÷ 1.2	0.15 ÷ 0.3	≤ 0.032	≤ 0.035

The method of lost-wax casting into a self-supporting ceramic mould is unconventional casting method. Its share of the world's total casting production is not

large, but this casting method finds application especially in areas requiring high quality castings [8]. The main focus is on mechanical properties and dimensional and geometrical accuracy of the castings without

subsequent machining. Nearly 75% of current production of precision castings is required not to have a continuous decarburized layer [9]. For quality castings exposed to higher degree of mechanical stress, the requirement is to remove this layer by carbon saturation, followed by heat treatment. Carbon saturation is a slow diffusion process that must be performed in a controlled furnace atmosphere at high temperature [10], which is reflected in the final price of the casting. The decarburized layer of castings operating under lower mechanical load is not removed. This work deals with the influence of individual casting parameters on the thickness of the decarburized layer in the final casting. The decarburized layer consists of ferrite and forms so-called ferritic envelope [11]. The aim is to optimize the casting parameters, so the thickness of the ferritic envelope is minimized, in order to minimize the cost of its removal and also to observe the influence of the decarburized layer thickness on the mechanical properties of the casting, which would lead to the improvement of the mechanical properties of the castings which are not subjected to re-carburization [12].

The thickness of the layer is measured using an optical microscope with a scale in the ocular. The thickness of the layer may not be uniform and this fact should be considered when selecting sampling points. It must be ensured that samples represent the whole product. The samples should be taken transversely to the surface of the product. Another way to determine the depth of the layer is to use image analysing computer programs in combination with microscope, which allows faster and more accurate measurements. To evaluate the measurement, it is necessary to ensure a sufficient number of measured values that should be obtained from the entire available sample length. The magnification should be chosen depending on the material, the method of surface treatment and the depth of the layer. A sufficient number of measurements should be made to calculate average value of the decarburized layer thickness [13].

### 3 Experimental part

The aim of the work was to evaluate the influence of selected technological parameters of casting on the thickness and continuity of the decarburized layer in the castings and to optimize the production process based on the obtained results.

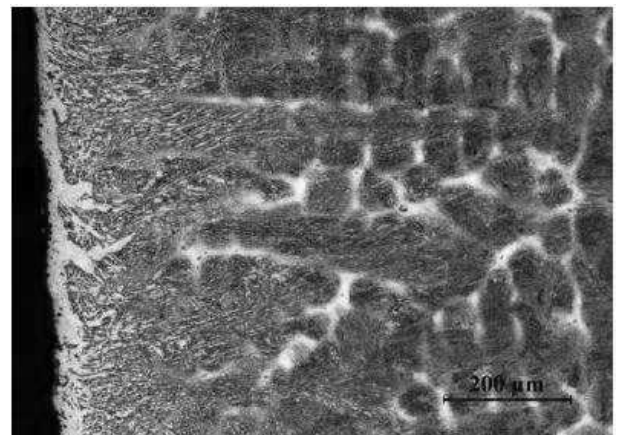
Technological parameters:

- the influence of the temperature of the ceramic mould,
- the influence of casting temperature,
- the influence of geometry of the casting,
- the influence of decarburized layer on mechanical properties.

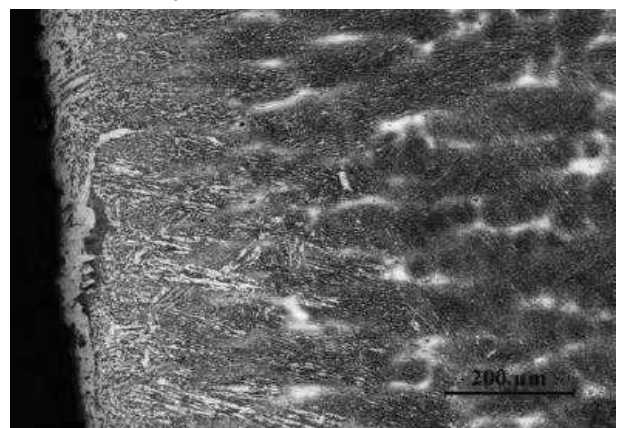
Samples for experiment were prepared from one type of castings made of steel 42CrMo4. The thickness of the decarburized layer was evaluated by metallographic analysis. Evaluation was mainly focused on the area just below the surface of the samples. The cores of all examined samples had same structure with a dendritic character.

#### The influence of the temperature of the ceramic mould

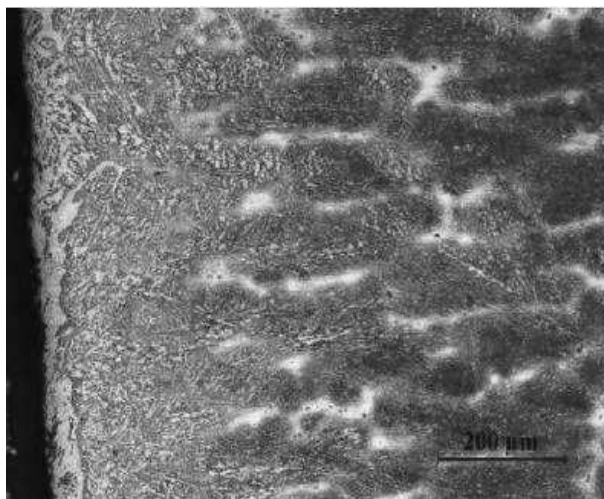
The casting temperature was  $1600 \pm 10^\circ\text{C}$  and the ceramic moulds were annealed at temperatures from 1050 to 1250 °C. Two samples with the same wall thickness were made from each casting cast at these various temperatures of the ceramic mould. The decarburized layer thickness was evaluated from several parts of the sample using 100× magnifications. The average value was calculated from the measured layer thickness values. It was found out that the thickness of the decarburized layer at different temperatures of the annealed ceramic mould was uneven and layer was discontinuous. There were no significant changes in decarburization at individual temperatures. The local thickness was up to 0.158 mm. We can see a local decarburized layer formed by ferrite in Fig. 1, 2 and 3.



*Fig. 1 The thickness of the decarburized layer at temperature of the ceramic mould 1050°C*



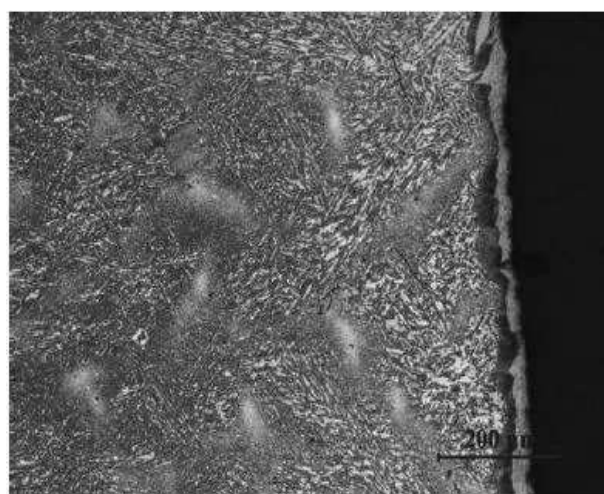
*Fig. 2 The thickness of the decarburized layer at temperature of the ceramic mould 1150°C*



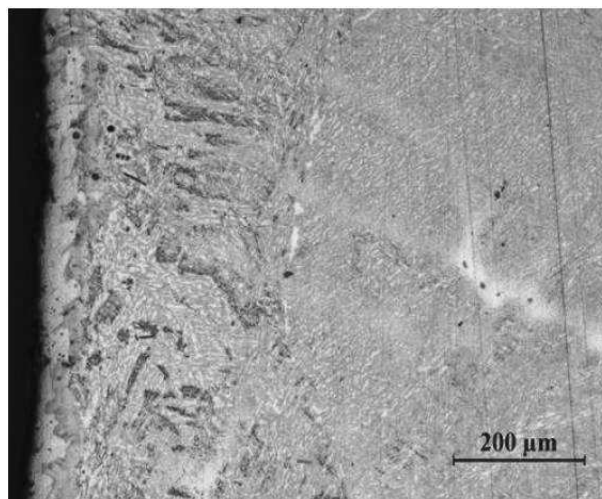
**Fig. 3** The thickness of the decarburized layer at temperature of the ceramic mould 1250°C

### The influence of casting temperature

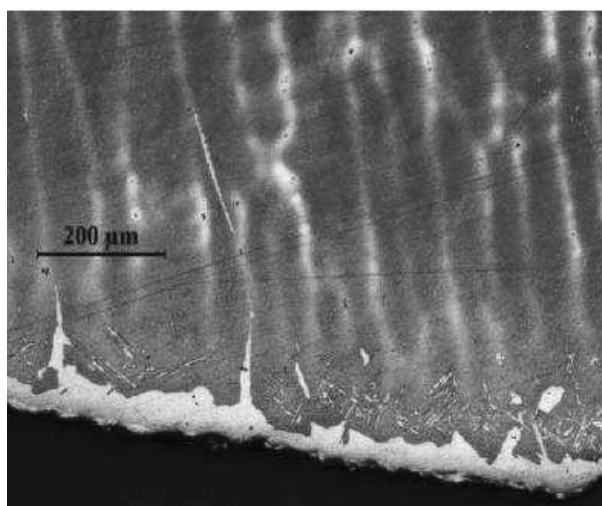
Samples for evaluation of the influence of casting temperature on the thickness of the decarburized layer were prepared from castings cast at different casting temperatures into ceramic moulds annealed at temperature 1050° C. The casting temperature varied from 1590 to 1690°C. For each casting temperature, 2 samples with the same wall thickness were evaluated using 100× magnifications. The average value of the decarburized layer thickness was calculated. It was found out that with the rising casting temperature the thickness of the decarburized layer increases. In addition to the decarburized layer, the transition region can be seen in the Fig. 4, 5 and in the Fig. 5 is grey oxide phase. The thickness of the decarburized layer varied from 0.095 to 0.161 mm. At a casting temperature of 1690°C (Fig. 6), the continuous decarburized layer was the most pronounced. It was formed by pure ferrite, and the transition region completely disappeared.



**Fig. 4** The thickness of the decarburized layer (up to 0.095 mm) at casting temperature 1590°C

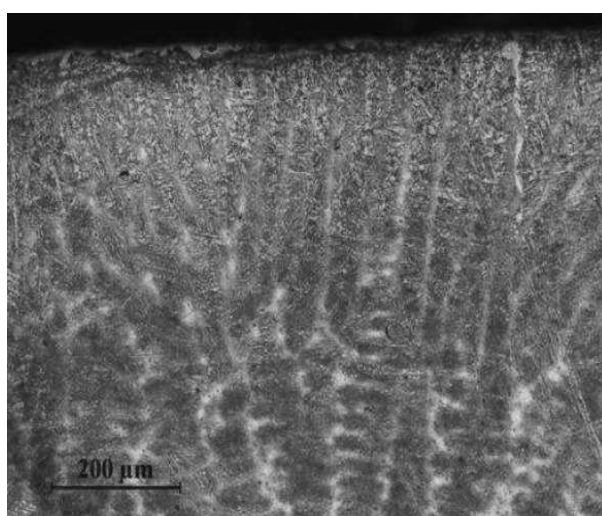


**Fig. 5** The thickness of the decarburized layer (up to 0.131 mm) at casting temperature 1610°C

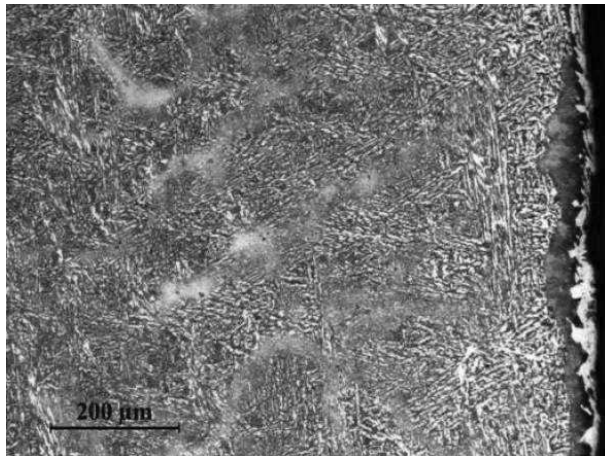


**Fig. 6** The thickness of the decarburized layer (up to 0.161 mm) at casting temperature 1690°C

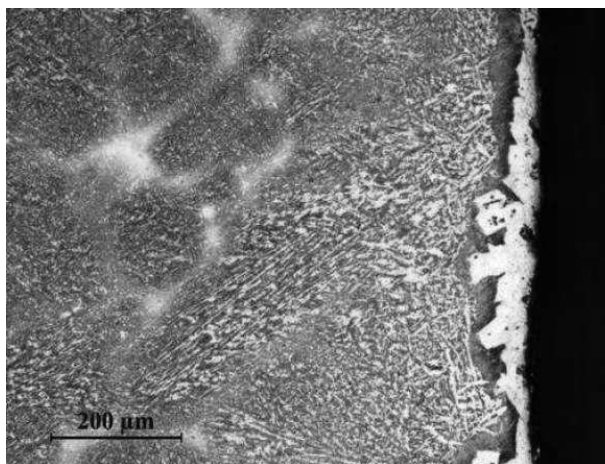
### The influence of geometry of the casting



**Fig. 7** The thickness of the decarburized layer (up to 0.015 mm) - wall thickness of the casting 1.8 ÷ 2.0 mm



**Fig. 8** The thickness of the decarburized layer (up to 0.058 mm) - wall thickness of the casting 7.0 mm



**Fig. 9** The thickness of the decarburized layer (up to 0.162 mm) - wall thickness of the casting 25.0 mm

**Tab. 2** Evaluation of mechanical properties

Average values	Casting temperature [°C]		
	1590	1610	1650
The thickness of the decarburized layer [mm]	0.095	0.131	0.149
Strength Rm [MPa]	684.657	718.354	766.945
Ductility A [%]	8.13	8.80	9.13
Contraction Z [%]	2.61	4.04	5.70

## 4 Results and discussion

Based on the performed experiments, it can be concluded that the temperature of the ceramic mould during casting has the smallest influence on the decarburized layer. With a change in the temperature of the ceramic mould, virtually no change in the decarburized surface area of the casting was noted. This minimal influence of the ceramic mould temperature is due to the fact that the self-supporting ceramic moulds are only 8 to 12 mm thick (which is significantly less compared to the thickness of the sand moulds) and they are preheated to about 2/3 of the metal casting temperature. Thus, the influence of the temperature of the metal and the shape of the casting is more pronounced

Samples for evaluation of the decarburized layer thickness depending on the casting geometry were taken from one type of the casting which had walls with different thickness. The casting temperature was 1610°C and the ceramic moulds were annealed at 1050°C. Two samples were prepared for each wall thickness of the casting.

The thickness of decarburized layer was measured at multiple locations of each sample at 100× magnification. Average values of the decarburized layer thickness were calculated. The thickness of the decarburized layer depending on the casting wall thicknesses can be seen in Fig. 7, 8 and 9.

### The influence of decarburized layer on mechanical properties

To evaluate the impact of the decarburized layer thickness on the mechanical properties, we prepared tensile rods with special shape which were cast at 1590, 1610 and 1650°C. Five samples were cast at each temperature. After casting, a visual inspection was carried out on the testing rods mainly in the tear section for detection of casting defects and ceramic impurities. Average values of strength, ductility and contraction obtained from the static tensile test are listed in the Table 2. The strength increases with increasing temperature, which can be caused by higher hardening of the samples during casting as they were cooled from higher temperature. The decarburized layer, which is larger at higher temperatures, thus has no effect on the resulting strength of the raw castings.

in the formation of the decarburized surface layer. As the casting temperature rises, the thickness of the decarburized surface layer of the casting also increases. However, the progression of decarburization formation is not great with increasing temperature. The geometry of the casting has a significant influence on the thickness of the decarburized layer. As the casting thickness increases, the surface decarburization layer also increases. The steel 42CrMo4 is used for quality heat treated castings, so a continuous decarburization layer on the surface of the raw castings is unwanted. For this reason, before the heat treatment, the surface of the castings is saturated with carbon to remove the ferritic envelope. Carbon surface saturation is a di-

ffusion process and it is necessary to increase the temperature depending on the thickness of the decarburized layer, therefore this operation significantly affects cost of the casting. The thinner the decarburized layer on the raw castings is, the lower the production cost is. Based on the experiments carried out, the following technological recommendation can be made for the casting production process: it is preferable to heat the casting mould at higher temperature and to reduce the casting temperature. In the casting practice the empirical rule applies that by increasing the ceramic mould temperature by 100°C it is possible to reduce the casting temperature by 20°C. This creates possibility for limiting the formation of decarburized layer on the casting surface and thereby reducing production costs.

## 5 Conclusions

Surface decarburization is characterised by decrease of carbon content and subsequent change in and structure of the steel surface. In complete decarburization, the top layer of steel consists mainly of ferrite materials, while partial decarburization presents a combination of materials. Decarburization can be either harmful or beneficial, based on the application of the final product. The unwanted decarburization of the surface of the steel casting mainly occurs during the heat treatment due to the reaction of carbon with gases in ambient atmosphere at elevated temperatures. When considered a defect, material testing can be useful to determine whether carbon loss levels are acceptable. Microscopy is one of the techniques used to determine carbon loss and thickness of the decarburized surface layer. Inadmissible decarburization of the casting surface is associated with an unsatisfactory structure, which can cause lower hardness and strength of the surface layers, so that the casting does not meet the functional requirements.

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