

THE INFLUENCE OF CERIUM ON THE MICROSTRUCTURE OPTIMIZATION OF 42CrMo4 STEEL

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Abstract

The manufacturing program of the company VÍTKOVICE HEAVY MACHINERY a.s. comprises production of a wide range of structural steels for the high exposed machine parts, such as shafts of wind power stations, turbine shafts, gears, etc. Due to the ever increasing demands of customers to increase the service properties of steel while maintaining the reasonable prices it is necessary to look continuously for ways to improve the offered steel grades. One option is to optimise the microstructure by refinement of grain size and thus to achieve better mechanical properties. It is generally known for achievement of fine-grained microstructure of steels a suitable combination of microalloying elements and thermomechanical processing is used. In addition to standard microalloying elements, such as Al, V, Nb and Ti it is also possible to use cerium inclusions of which serve as good place for heterogeneous nucleation during solidification of steel. In this paper the influence of cerium on optimisation of microstructure of the 42CrMo4 steel was studied. A series of laboratory tests was performed, on the basis of the results of which an operational experiment was proposed and designed.

Keywords: cerium, inclusion, microstructure

1. INTRODUCTION

Low alloy chromium-molybdenum steels belong to the most commonly used steels for high exposed machine parts, such as shafts, spindles, gears, etc. The product portfolio of the company VÍTKOVICE HEAVY MACHINERY a.s. (VHM) contains a wide range of these steels, with a dominant position of the 42CrMo4 steel and modifications thereof. This steel shows after quenching very good strength properties while preserving still sufficient toughness. It has also a very good resistance to wear. The 42CrMoS4 steel exhibits an improved machinability, and the 42CrMo4 steel alloyed with nickel, which is not standardized and is manufactured on the basis customer's demand, shows higher level of brittle fracture properties. Due to the ever increasing requirements of customers it is necessary to continuously look for ways for improvement of the offered grades of chrome-molybdenum steels. One option is to optimise the structure by refinement of grain size and thus by achievement of better mechanical properties. Achievement of fine-grained structure is usually obtained by suitable combination of microalloying elements and thermomechanical processing. Apart from standard microalloying elements it is also possible to use cerium, which has high affinity to oxygen and sulphur and forms oxides, sulphides, oxysulphides of a size of approx. 1 micron, as well as carbides and nitrides [1]. These inclusions reduce the surface tension and the amount of energy required for nucleation during primary crystallisation [2]. Cerium is in steelmaking usually used in the form of mischmetal, which is a mixture of several rare earth metals. Mischmetal is in operational practice used mainly at production of stainless steels. During they use we encounter, however, some problems during casting. It concerns a nozzle clogging, which occurs as a result of compounding of Ce₂O₃ inclusions with Al₂O₃, which leads to formation of clusters larger than 20 microns. The use of cerium added to the steel greatly varies according to various literature sources, ranging from several percent

to 78 % [3]. The applicability depends on the degree of deoxidation of steel, on the selected technology and on the method of addition of this alloying elements into steel [4].

The influence of cerium on microstructure of the 42CrMo4 steel was investigated with use of laboratory tests at the VSB-TU Ostrava. On the basis of the obtained results an industrial scale experiment in the VHM was then proposed and designed.

2. LABORATORY EXPERIMENT

The laboratory experiment was realised at the VSB-TU Ostrava, Department of non-ferrous metals, refining and recycling. The test segments were taken from the 42CrMo4 steel, which had been forged into the form of bar on 120 MN forging machine in VHM. Chemical composition of the 42CrMo4 steel and filled profile with cerium (mischmetal) is shown in **Table 1** or in **Table 2**.

Table 1 Chemical composition of the 42CrMo4 steel [mass %]

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	Al
0.41	0.72	0.26	0.006	0.001	0.16	0.17	1.00	0.17	0.024

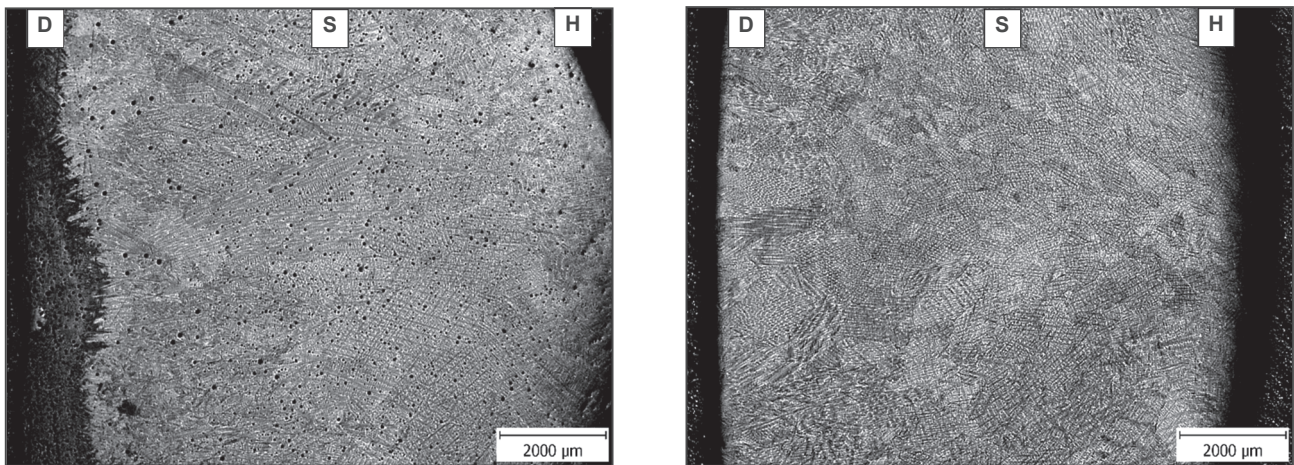
Table 2 Chemical composition of the filled profile with cerium [mass %]

Ce	Si	Cr	C
12.23	21.5	31.18	0.1

For the experiment, the samples with the weight of approx. 20 g were prepared and they were together with addition of mishmetal (MM) containing cerium melted in a plasma furnace. Additions of mishmetal of cerium were selected as follows: 0.05 mass % of MM (0.006 mass % of Ce), 0.5 mass % of MM (0.061 mass % of Ce), 1 mass % of MM (0.122 mass % of Ce). The furnace operates by zone melting. Material is located in the copper, water-cooled mould, which is entrained by screw under the stationary plasma torch. At this method of melting the temperature of the plasma reaches up to 6500 K. The great advantage of this furnace is almost hundred percent utilisation of alloying additives as a result of exploiting the benefits of an inert atmosphere in the melting space. Used plasma gas was argon gas with purity 4N6. The samples of steel were twice melted and they were subjected to the same heat treatment mode, which is applied in the VHM to forgings made of these steels.

Metallographic analysis was performed using the Olympus IX70 light microscope. It can be stated that in the samples with the addition of cerium no defects of the type voids and blow holes were detected (**Fig. 1b**), in contrast to the samples not containing cerium (**Fig. 1a**). The samples with the contents of cerium of already 0.0061 mass % (**Fig. 2b**) also showed a finer microstructure in comparison with the samples that did not contain the addition of cerium (**Fig. 2a**).

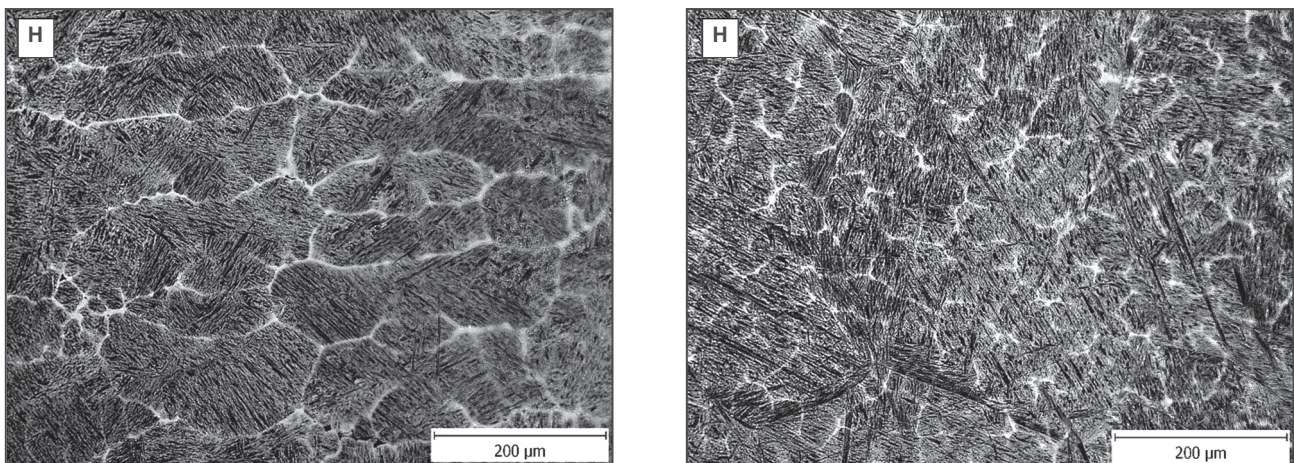
Microanalysis of non-metallic inclusions was performed with use of a JEOL 6490LV scanning electron microscope, equipped with the energy dispersive analyser Inca x-act. Mainly cerium oxide inclusions, the size of which was approx. 1 micron, were detected.



a) 0 mass % of Ce

b) 0.0061 mass % of Ce

Fig. 1 Comparison of macrostructure of laboratory samples of the 42CrMo4 steel



a) 0 mass % of Ce

b) 0.0061 mass % of Ce

Fig. 2 Comparison of microstructure of laboratory samples of the 42CrMo4 steel

Table 3 Chemical composition of the experimental heat of the 42CrMo4 steel [mass %]

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	Al	Ce
0.40	0.77	0.22	0.007	0.003	0.16	0.19	1.03	0.16	0.015	0.04

3. OPERATIONAL EXPERIMENT

The operational experiment was designed on the basis of the literary analysis of the given issue and results of the laboratory experiment. The aim was to verify the possibility of using cerium additives for improving internal quality of the steel 42CrMo4 in conditions of the VHM. Chemical composition of the heat of produced steel is given in **Table 3**. Alloying with cerium was carried out with use of filled profile, see **Table 2**. Cerium was added to the steel, after completion of its vacuum treatment and was added as alloying element to the amount of 0.06 mass %.

Two identical ingots 8K27SF were cast from the heat, weighting 23.9 tonnes. In conditions of the VHM's steelworks the standard time of casting of ingots lasts approximately about 14 minutes. Due to limitations of steel reoxidation, and in particular top cerium contained therein, the casting stream was during ingot casting protected by argon. Time of casting of ingots was longer than at the standard production, since after 11 minutes the nozzle got clogged and a significant drop in the casting speed took place.

The first ingot was cooled by controlled cooling and then longitudinally cut out in order to investigate the distribution of cerium in the cross section of the ingot, and in order to verify its influence on the distribution of segregation, particularly of carbon and sulphur.

The samples for chemical composition were taken from the ingot by drilling - in the form of chips. Solid samples with diameter of 27 mm were taken in the form of cores. The cerium was in the ingot cross-section distributed unevenly and its use was 25 - 32.3 %, i.e. comparatively low. The highest content of cerium was found in the ingot bottom. Its contents near the wall was around 0.019 mass %, while in its axis it was 0.017 mass %). The cerium contents progressively drop in direction towards the ingot head, and in the part below the ingot head its contents was 0.015 mass %.

The second ingot was re-forged on 120 MN forging machine into a bar with three different diameters, see **Fig. 3**. The forged piece was then subjected to a standard heat treatment, which is common for the given steel, i.e. quenching and tempering (**Fig. 4**). Samples for metallographic analysis and testing of mechanical properties were taken from all three diameters of the forged piece. The results of analyses and tests will be compared with the test results obtained during standard manufacturing of forged pieces from the 42CrMo4 steel. Dispersion of very small inclusions of cerium in the metallic matrix is expected, as well as fine-grained structure and increase in tensile strength and yield strength.

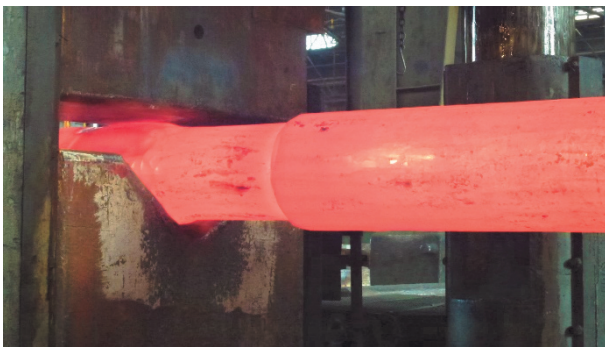


Fig. 3 Forging of the 42CrMo4 steel on the 120 MN forging machine



Fig. 4 Quenching of the 42CrMo4 steel

CONCLUSIONS

The presented paper deals with the influence of cerium on the optimisation of structure of the 42CrMo4 steel. The cerium was added into steel in the form of filled profile, so called mischmetal. Within the frame of laboratory experiment it was added from 0.05 mass % up to 1 mass % (from 0.006 % of Ce up to 0.122 % of Ce). Steel samples and filled profile were twice re-melted in the plasma furnace and they were subjected to the same mode of treatment, which is applied in the VHM to the forged pieces for these steels. Addition of cerium had a positive effect. In the samples with the addition of cerium no defects of the type of voids and shrinkage porosity were observed, unlike the samples without addition of cerium. The samples containing already 0.006 mass % of cerium also manifested a finer microstructure in comparison with the samples, which did not contain an addition of cerium. Refinement of the structure was achieved by inclusions of cerium, which acted as efficient crystallisation nuclei.

On the basis of the findings from the laboratory experiment and study of the professional literature an optional experiment with alloying of cerium into steel was proposed and designed. Two identical ingots 8K27SF were cast. The first ingot was cooled by controlled cooling and then longitudinally cut in order to investigate the distribution of cerium in the cross section of the ingot, and also in order to verify its influence on the distribution of segregations, mainly of carbon and sulphur. The detected use of cerium was comparatively low (around 30 %) and it will therefore be necessary to continue development of technology for adding this element into steel.

The second ingot was the re-forged on the forging machine into a bar with three different diameters. The forged was then subjected to improvement processing. The samples for metallographic analyses and testing of mechanical properties were taken from all three diameters of the forged piece. Analyses and tests will be evaluated in the context of an ongoing project, and verification of the results obtained also with use of other steel grades will be performed.

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