

The share of non-metallic inclusions in high-grade steel for machine parts

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Abstract

The aim of this work was to compare the differences in the purity steel in the dimensions of inclusion particles as dependent on various steel production processes. The experimental material consisted of semi-finished products of high-grade, medium-carbon constructional steel with: manganese, chromium, nickel, molybdenum and boron. The impurity content of steel was low as phosphorus and sulphur levels did not exceed 0.025%. The experimental material consisted of steel products obtained in three metallurgical processes: electric, electric with argon refining and oxygen converter with vacuum degassing of steel. Billet samples were collected to determine: chemical composition, relative volume of non-metallic inclusions, dimensions of impurities. The results were processed and presented in graphic form.

Keywords: Steel, Non-metallic inclusions, Metallography, Structure

1. Introduction

Rapid technological progress and the demand for highly reliable machines and devices spur research investigating the strength of structural materials. Improve the fatigue life of steels, an effective measure is to decrease the volume fraction and the size of nonmetallic inclusion in steels. Commercial iron alloys contain sulfur and oxygen, and those elements form solutions in liquid metal. The physical and chemical reactions that occur in the process of steel melting and solidification produce non-metallic compounds and phases, referred to as inclusions. The quantity of non-metallic inclusions is correlated with the content of admixtures in the alloy, while their phase composition and structure, in particular shape, dimensions and dispersion, are determined by the course of metallurgical processes [1-6]. According to Kocańda, if evenly distributed, non-metallic

inclusions larger than 5 μm may affect the fatigue strength of steel [7, 8].

Non-metallic inclusions may be introduced to liquid steel from the outside, usually with charge material, or they may be produced in the metallurgical process [9]. Non-metallic inclusions in steel may be classified into two groups [10]:

- endogenous – including sulfides, oxides and silicates produced in liquid steel during the metallurgical process,
- exogenous – mostly particles of refractory lining material in furnaces, tapping spouts and ladles which penetrate liquid steel from the outside.

However, structural defects, such as non-metallic inclusions, are also responsible for the performance of this material when it is submitted to mechanical stress. distribution of non-metallic inclusions in steel and their quality is determined by various factors, including charge quality, process regime, furnace type and out-of-furnace processing. Alloy additives introduced during out-of-furnace processing have a more supportive reaction

environment than inside the furnace, and the above improves charge yield [11-18]. Since the morphology of non-metallic inclusions is determined by the course of the metallurgical process, this study set out to test materials produced with the involvement of various methods.

2. Aim of the study and methods

The aim of this study was to determine the share of non-metallic inclusions in high-grade, medium-carbon steel for casting machine parts during various steel making processes. The morphology of inclusions is largely determined by the metallurgical process in all three experimental series and similar quantities of melted steel. For this reason, the analysis involved semi-finished products manufactured with the use of various technological processes. The experimental material consisted of steel products obtained in three metallurgical processes: electric (E), electric with argon refining (EA) and oxygen conversion (KP).

Every analyzed metallurgical technology was represented by seven heats. A total of 95 sections were sampled from each billet. Five sections were analyzed to determine the chemical composition and the impurities content of steel, and the remaining sections were used for metallographic analyses. The applied materials and methods are described in detail in paper [3].

3. The results of investigations and their analysis

The objective of metallographic analyses was to determine the quantity and dimensions of non-metallic phases in steel and the alloy's microscopic structure. Heat-processed sections were used to form metallographic specimens whose surface had a perpendicular orientation to the working direction. Sample particles produced by the analysis are presented in Figures 1 and 2.

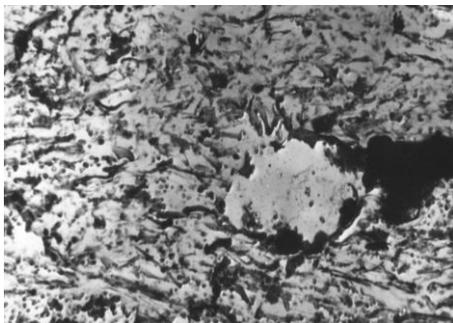


Fig. 1. The steel structure with Al_2O_3 and (SiO_2-CaO) deformed by plastic working, mag. 10 000 x

The composition of non-metallic inclusions is shown in Figures 3 and 4. The lowest sulfur content ($110 \cdot 10^{-3} \%$) was noted in heats from an electric furnace with desulfurization (E). Higher quantities of the analyzed element ($116 \cdot 10^{-3} \%$) were

observed in steel melted in an electric furnace with desulfurization and argon refining (EA). The lowest sulfur levels ($131 \cdot 10^{-3} \%$) were determined in vacuum degassed steel melted in a converter (KP). Similar oxygen levels ($5 \cdot 10^{-3} \%$) were reported in heats melted in an electric furnace (E) and (EA) regardless of the out-of-furnace processing method. The oxygen content of vacuum degassed steel melted in a converter (KP) was much lower, reaching ($2.63 \cdot 10^{-3} \%$).



Fig. 2. The steel structure with SiO_2-CaO deformed by plastic working, mag. 10 000 x

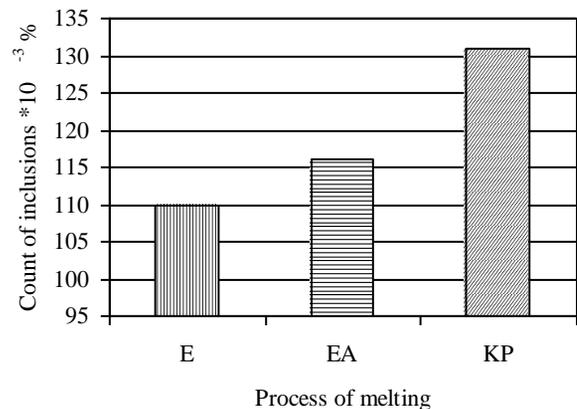


Fig. 3. Sulphur inclusions for each process of melting

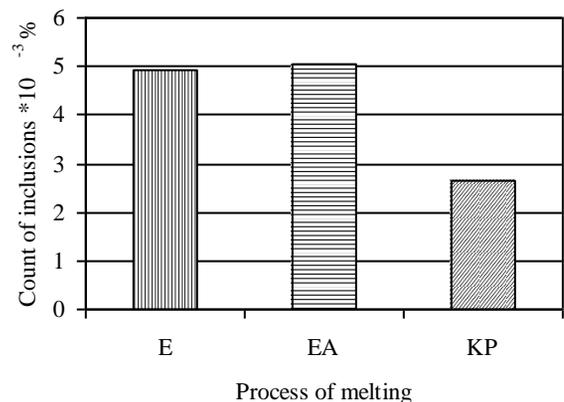


Fig. 4. Oxygen inclusions for each process of melting

The relative volume of non-metallic inclusions within a given size interval is presented in Figure 5. The highest average relative volume of non-metallic inclusions in the $w < 2 \mu\text{m}$ size interval was noted in heats melted in an electric furnace with argon refining (EA). The analyzed parameter was 29% lower in electrically-melted steel (E) and 36% lower in heats melted in a converter (KP). A similar trend was observed in the remaining size intervals. The highest impurities content was noted in respect of the electrical melting method, followed by electrical melting with argon refining, while vacuum degassed heats melted in a converter were marked by the lowest impurities content. Similar change ratios were reported, and the following values were noted for (E) : (EA) : (KP), respectively, in reference to the electrical method (E): for $w \geq 2 \mu\text{m} - 1 : 0.76 : 0.38$; for $w \geq 5 \mu\text{m} - 1 : 0.71 : 0.3$; for $w \geq 10 \mu\text{m} - 1 : 0.7 : 0.3$. A balanced correlation between the impurities content of various melts points to process stability and a set purity ratio for each of the analyzed melting methods.

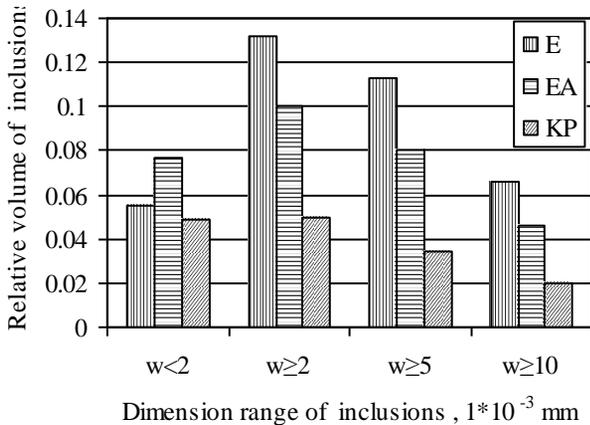


Fig. 5. The relative volume of non-metallic inclusions

The results of impurities analyses have shown that their content is determined by the steel making process. The share of phase compounds in the studied heats is presented in Figure 6. Al_2O_3 inclusions formed the largest group with a 43% share of the population. They were followed by: 13% SiO_2 , 8% MnO , 9% MgO , 10% CaO , 8% FeO and 10% Cr_2O_3 . The above indicates that with the exception of Al_2O_3 , the remaining compounds had a similar share. Excluding Al_2O_3 and CaO , the lowest share of non-metallic inclusions in various phase structures was reported for the converter method (KP). The share of different phases in both electrical methods varied subject to inclusion structure.

The average number of inclusions per unit of volume is presented in Figure 7. The highest number of inclusions per unit of volume was noted for the finest fraction at $w < 2 \mu\text{m}$. The number of inclusions reached $44110 \cdot 10^{-3}$ in the electrical method (E), it was 66% higher in method (EA) at $73414 \cdot 10^{-3}$, while 47% more inclusions were determined in method (KP) in comparison with process (E) at $64649 \cdot 10^{-3}$. For the $w \geq 2 \mu\text{m}$ fraction, the highest number of inclusions was observed in method (E), followed by method (EA), while inclusions were least abundant in method (KP). For fraction $w \geq 10 \mu\text{m}$, $109 \cdot 10^{-3}$ inclusions were noted in method (E), $168 \cdot 10^{-3}$ in method (EA) and $61 \cdot 10^{-3}$ in method (KP).

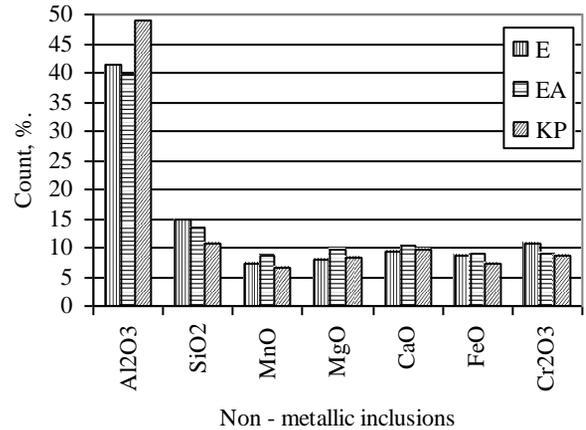


Fig. 6. The share of phase compounds in the studied steel

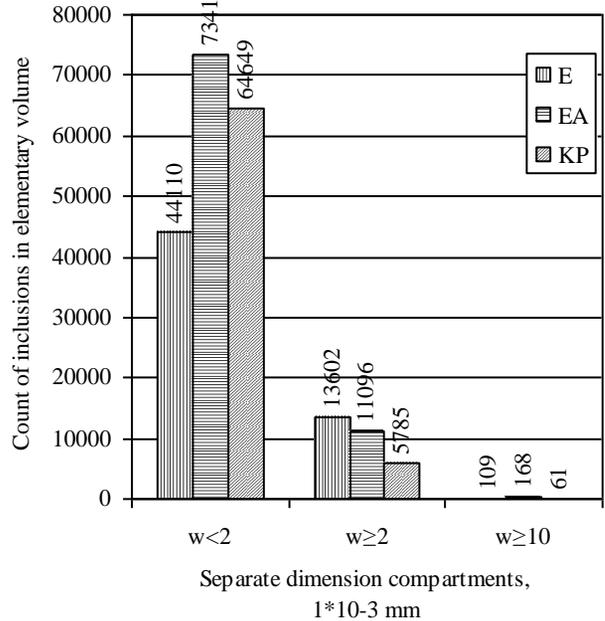


Fig. 7. The average number of inclusions per unit of volume

The metallurgical process significantly affects material purity. The phase structure of inclusions is comparable for all three analyzed processes (Fig. 7). Phase Al_2O_3 , followed by SiO_2 , had the highest share of inclusions. The remaining phases had a lower and nearly equal share. It should be noted that the share of various non-metallic inclusions in steel from different melting processes is expressed in terms of their percentage share of every individual melting method (in each process, the combined shares of impurity inclusions total 100%).

Argon refining did not decrease oxygen content or the relative volume of non-metallic inclusions in steel. The EA method did not affect the phase composition of impurities. An analysis determining the number of inclusions per one volume unit of steel

showed the highest number of inclusions for $w < 2 \mu\text{m}$. In the submicroscopic range, heats melted in an electric furnace with desulfurization (E) were characterized by the lowest number of impurities. In the $w \geq 2 \mu\text{m}$ interval, converter melting with vacuum degassing (KP) produced steel of the highest purity class, while the highest number of impurities were noted in the electrical method with argon refining (EA). The smallest number of large inclusions ($w \geq 10 \mu\text{m}$) were observed in vacuum degassed heats melted in a converter (KP). An analysis of all investigated size intervals revealed that argon refining did not have a conclusive effect on the improvement of steel purity. A lower number of non-metallic inclusions in $w \geq 2 \mu\text{m}$ and $w \geq 10 \mu\text{m}$ intervals was observed in converter melting with vacuum degassing than in the electrical melting process (both E and EA).

4. Conclusions

The results of this study suggest that material purity and the dimensional structure of inclusions are determined by the steel melting process. The number of inclusions produced by various melting methods differs at each size interval. Converter melting with vacuum degassing is the most effective method of eliminating inclusions larger than $2 \mu\text{m}$. The above process is more effective in capturing oxide impurities than the remaining melting methods examined in this study.

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