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Influence of non-metallic inclusions on the strength properties of screws made of 35B2+Cr steel after softening

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ABSTRACT

Purpose: This paper presents the results of the research on the influence of non-metallic inclusions on strength properties of 35B2+Cr steel screws.

Design/methodology/approach: The investigations were carried out on screws after softening. The investigated steels with different fraction of non-metallic inclusions were delivered by three different suppliers.

Findings: It was proved, that in spite of the level of fraction of non-metallic inclusions compatible with the corresponding standards, they directly or indirectly influence the strength properties of 35B2+Cr steel screws. This influence depends on the character of the inclusions.

Research limitations/implications: The investigations were carried out only on screws made of only one steel grade.

Practical implications: Influence of non-metallic inclusions on properties of 35B2+Cr steel, within analysed range of their content, is not significant enough to be a critical factor in relation to operating failures of the screws made of this steel.

Originality/value: Influence of non-metallic inclusions on properties of 35B2+Cr steel was analysed.

Keywords: Structural steel; Strength; Inclusion engineering; Non-metallic inclusions; Softening

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1. Introduction

Despite of numerous studies in the field of inclusions engineering [1] (a term introduced in recent years and defining a controlled by the type, size and density of non-metallic inclusions influence on specific properties of steel), in many cases of specific grades of steel and their applications need to be further investigated in order to increase the knowledge about the effects of non-metallic inclusions during the process of cracking of steel [2,3]. The effect of the inclusions on the ductility and fracture type consists of the nucleation of micro-voids around inclusions so further crack propagation would require coalescence of those voids. The creation and coalescence of micro-voids depend mainly of the matrix ductility. Modification of matrix ductility can be obtained on the way of heat treatment such as softening.

The investigations concerning the methods of restricting the content of non-metallic inclusions in structural steels as well as modification of the morphology of these inclusions for the improvement of the properties of such steels are still carried out by many researchers [4-10]. Such research is being performed in spite of the fact, that today's metallurgical technologies assure the content of non-metallic inclusions on the level required by corresponding technical standards (for example DIN 50 602, and ASTM E45-97 standards) [11]. Despite the fact, that many research works [12-14] describe the role of non-metallic inclusions in initiation of cracking or in fatigue wear [14-16], there is still a need to investigate the relation between non-metallic inclusions content and parameters describing the strength properties of steels. Such research is also important for the sake of verification of the proposed theories of the influence of non-metallic inclusions on the properties of steels [1,17] and numerical models based on these theories [18].

The objective of this study is to determine the influence of non-metallic inclusions content in steel of 35B2+Cr type in softened state on mechanical properties of the screws made of that material.

2. Material for testing

The research was conducted on screws made of steel of 35B2+Cr type received from three different suppliers. The chemical compositions of ingots are presented in Table 1. The screws made of investigated steels were subjected to soft annealing (Fig. 1) to ensure high plasticity of the material and large zone of plastic strain in front of developing crack [12]. The microstructures of the investigated screws are shown in Figure 2. The microstructure of investigated steels consists of fine ferrite and spheroidite, which is present in the regions of prior pearlite grains. It can be noticed, that the microstructures of steels obtained from different suppliers are very similar. Only a small difference in distribution homogeneity of carbides is noticeable between steel no. 3 and steels from other suppliers. It can indicate lower banding propensity of this steel due to slightly lower content of phosphorous. The magnitude of these differences in microstructure should not have significant influence on investigated properties of the steel. The hardness of these steels is also similar (about 167 HV30).

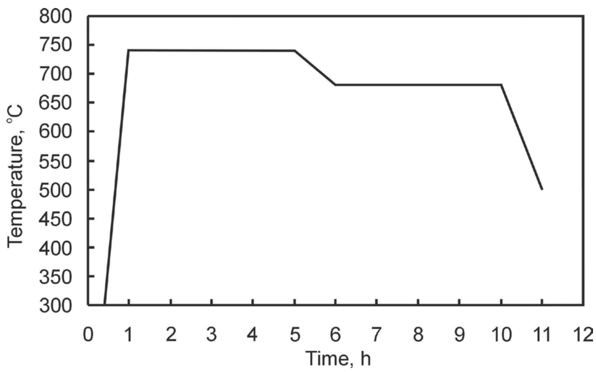

Fig. 1. The scheme of softening process of investigated steels

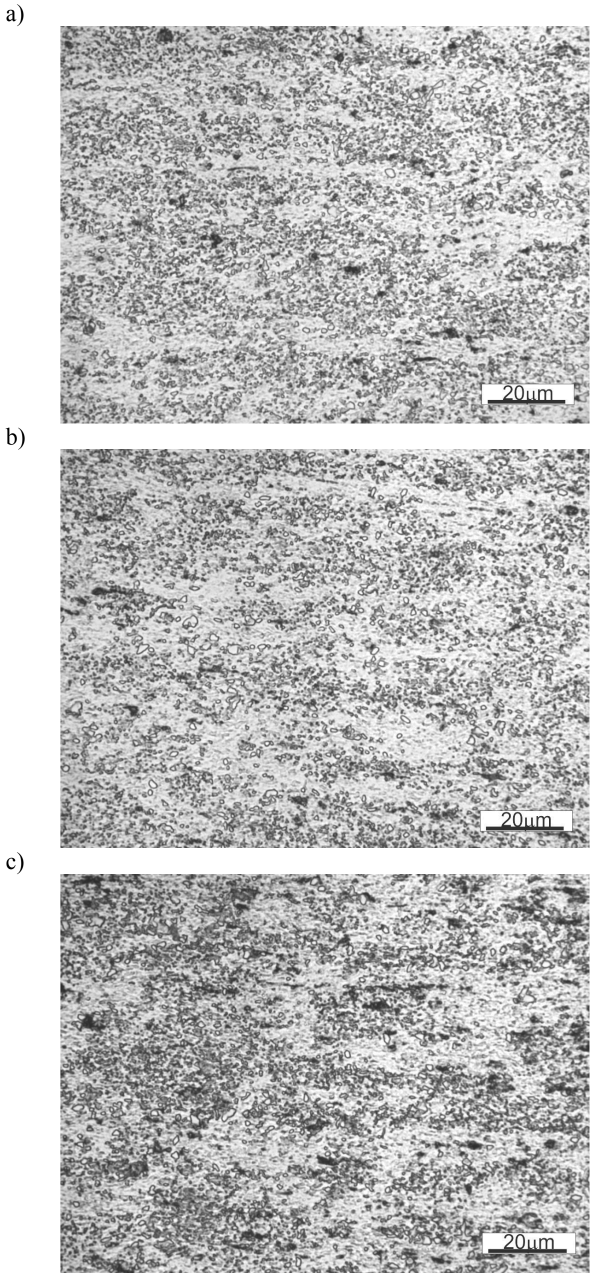

Fig. 2. Microstructure of investigated steels after softening: a) steel no. 1, b) steel no. 2, c) steel no. 3. Etched with 2% nital

3. Experimental procedure

Tensile test of the screws was performed using ZD 40 kN machine (Fig. 3), according to ISO 6892 standard. It was conducted on full size screws. The test was performed at room temperature. During the test, tensile load was applied to minimal free length of thread equal to single diameter (d_1). Tensile strength R_m and yield point $R_{p0.2}$ were determined.

Table 1.
Chemical composition (wt. %) of investigated steels

Steel	C	Si	Mn	P	S	Cr	Mo	Ti	Al	B	N
no 1	0.37	0.07	0.75	0.009	0.010	0.27	0.008	0.030	0.036	0.0040	0.0070
no 2	0.38	0.08	0.73	0.010	0.005	0.28	0.006	0.035	0.042	0.0033	0.0077
no 3	0.37	0.08	0.68	0.008	0.012	0.24	-	-	0.042	0.0027	0.0048

a)

b)

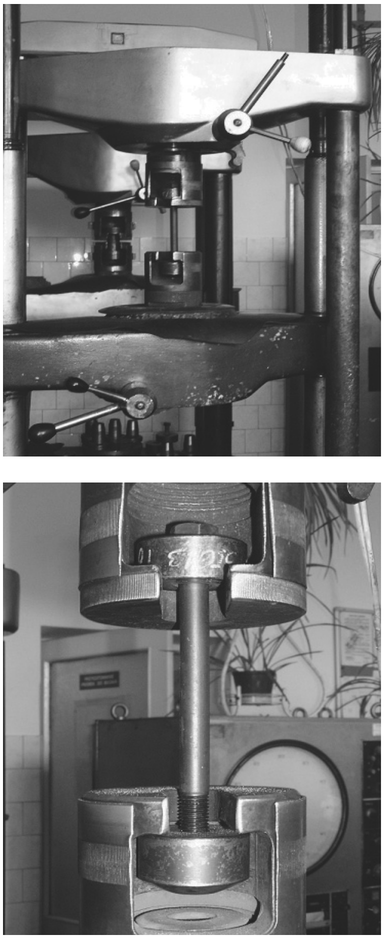

Fig. 3. Tensile test: a) ZD 40kN testing machine, b) screw fixing method

In order to ensure correct matching of the samples with actual supplier in technological conditions the tests were performed on ready screws with the same diameter (M16) but with different individual length for each supplier. M16x140 screws were made of steel no. 1 (Fig. 4). M16x160 screws were made of steel no. 2 (Fig. 5), while M16x200 screws were made of steel no. 3 (Fig. 6).

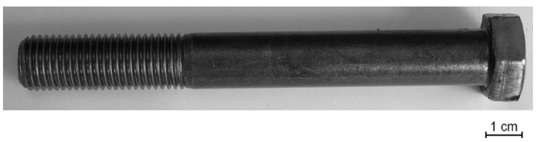

Fig. 4. Macroscopic picture of the screw made of steel no. 1

Fig. 5. Macroscopic picture of the screw made of steel no. 2

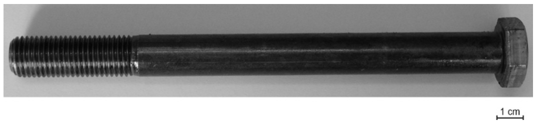

Fig. 6. Macroscopic picture of the screw made of steel no. 3

The fraction of non-metallic inclusions (V_v) was evaluated on polished cross-sections using "point method". The measurements of non-metallic inclusion content were performed on two randomly chosen samples taken from each sort of supplied steels, using 55 projections for each sample. The number of points in the projected nets was 441. The samples were analyzed under the magnification of 630x.

Basing on the morphology of non-metallic inclusions (according to PN-64/H-04510 standard), they were divided (identified) into oxides, sulfides, nitrides and other inclusions described in this study as exogenous inclusions.

4. Results and discussion

Sample pictures of polished cross-sections of specimens with visible non-metallic inclusions are shown in Figure 7. Chosen non-metallic inclusions were marked as follows: O - oxides, S - sulfides, N - nitrides, E - exogenous inclusions. It can be observed, that brighter colour was characteristic for inclusions of nitrides and so called "correct" (angular) shape (Fig. 7b). Nitrides were present in small number in the investigated steels and their distribution may be considered as uniform. Sulfides were more often present in a form of precipitations elongated along the direction of deformation. They were darker as compared to the nitrides and brighter as compared to the oxides (Fig. 7a-c). The most difficult part was to distinguish oxide inclusions from exogenous inclusions. It was assumed, that oxides should be considered as fine dispersion inclusions (Fig. 7b,c). The classic oxide strings were not observed. Non-metallic inclusions of large dimension, characterized by "fuzzy" shape, were considered as exogenous inclusions (Fig. 7c). The inclusions, described above as exogenous inclusions, may partly be endogenous inclusions of silicates, but identifying them basing on the observations of polished cross-section, with a use of the light microscope, is difficult. For simplicity, these inclusions are considered as exogenous in this work.

Summarized fraction of non-metallic inclusions as well as after dividing them into particular type of inclusions in steels coming from the particular supplier is shown in Table 2.

Table 2.
Non-metallic inclusions fraction (volume %) in investigated steels

steel	non-metallic inclusions	oxides	sulfides	nitrides	exogenous inclusions
no 1	0.299±0.032	0.157±0.012	0.091±0.041	0.024±0.011	0.027±0.009
no 2	0.270±0.015	0.136±0.006	0.095±0.023	0.027±0.003	0.012±0.006
no 3	0.210±0.012	0.115±0.017	0.062±0.023	0.016±0.001	0.016±0.006

a)

b)

c)

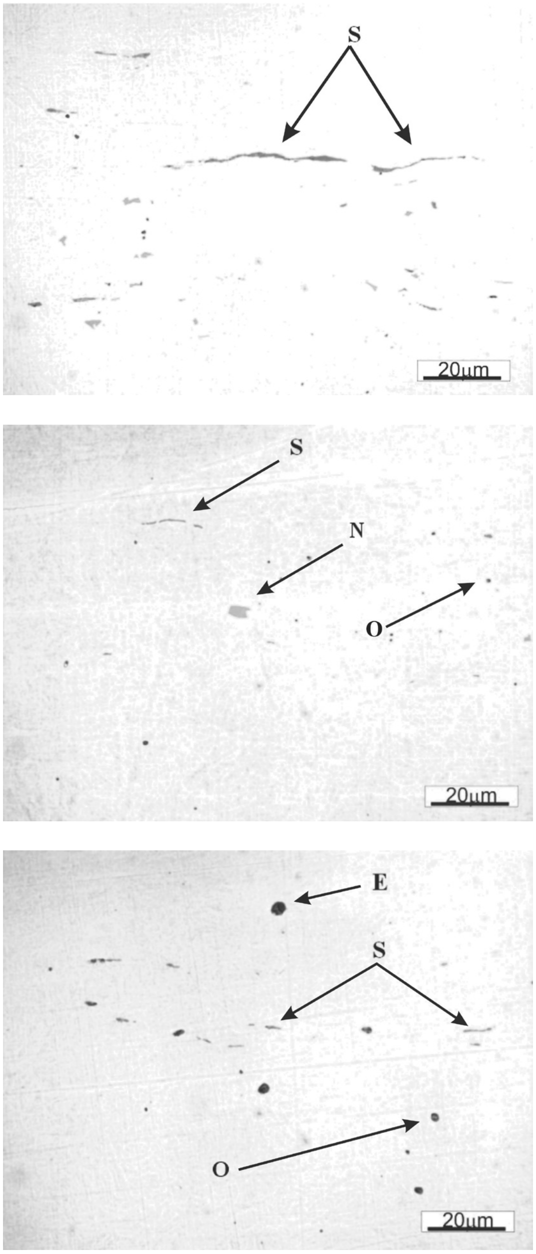

Fig. 7. The areas of high non-metallic inclusions concentration in screws: a) steel no. 1; b) steel no. 2; c) steel no. 3. The longer side of pictures is parallel to the screw axis

An example of experimental stress-strain curve for screw made of steel no. 2 in softened state is presented in Figure 8.

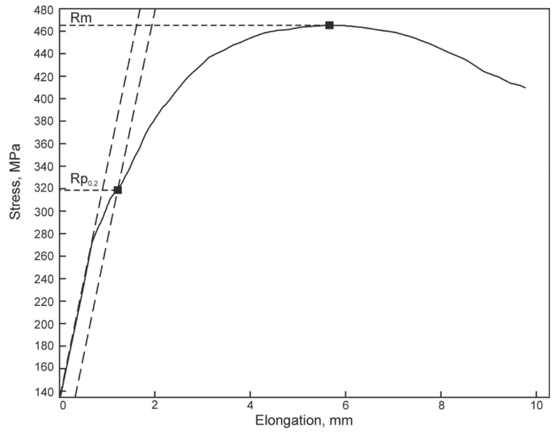

Fig. 8. Experimental stress-strain curve for screw made of steel no. 2 in softened state

Results of testing the strength (R_m) are listed in Figure 9. One may observe that the highest R_m characterizes the screws in softened state made of steel no. 3, while the lowest strength characterizes the screws made of steel no. 2. In case of steel no. 2 there was the greatest scatter of test results. The smallest scatter of R_m measurements in softened state characterizes the screw made of steel no. 1.

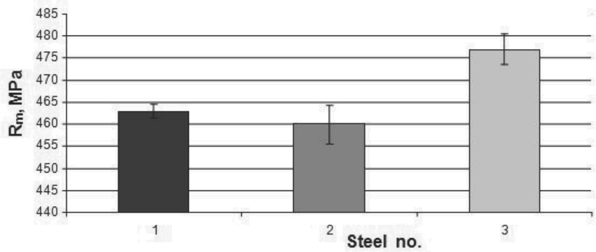

Fig. 9. Strength obtained in tensile test of screws in softened state from individual supplier

Besides non-metallic inclusions the above presented results may be affected not only by non-metallic inclusions but the scatter in microstructure as well. It should be recalled here that steel no. 3 was characterized by the highest homogeneity of carbides distribution in softened state.

Results analysis of yield point $R_{p0.2}$ measurements of investigated screws points to the differences in relation to results of strength measurements. In case of softened state the highest yield point had screws made of steel no. 3, while the lowest made of steel no. 1 (Fig. 10). The smallest $R_{p0.2}$ measurement scatter had the screws made of steel no. 2. Results of $R_{p0.2}$ measurements seem to correlate with the content of non-metallic inclusions, especially oxides as it is presented in Figs. 11 and 12.

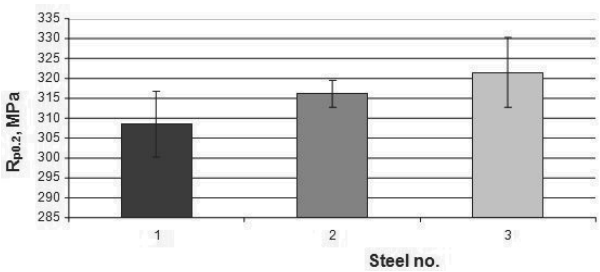

Fig. 10. Yield point in static tensile test of screws in softened state from individual supplier

In case of softened state it seems that non-metallic inclusions poorly lower the strength and yield points of investigated screws (Figs. 11-15). It seems that the smallest influence have the exogenous inclusions (Fig. 15).

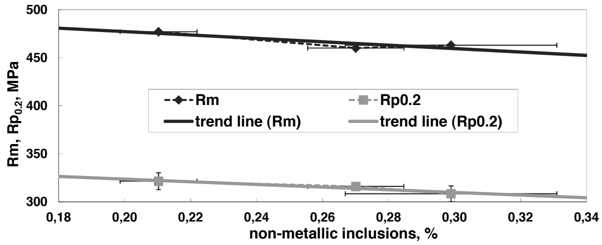

Fig. 11. Influence of non-metallic inclusions on strength and yield point in softened state

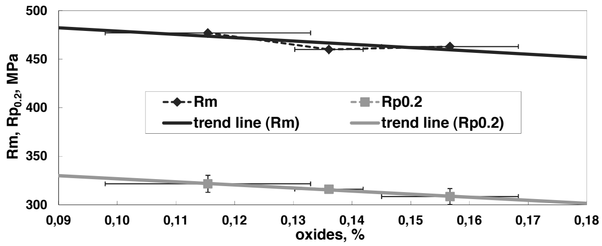

Fig. 12. Influence of oxides on strength and yield point in softened state

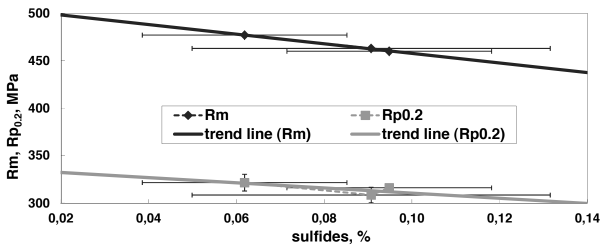

Fig. 13. Influence of sulfides on strength and yield point in softened state

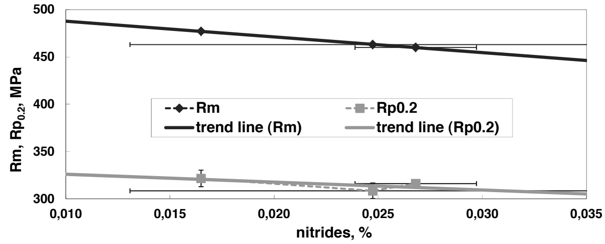

Fig. 14. Influence of nitrides on strength and yield point in softened state

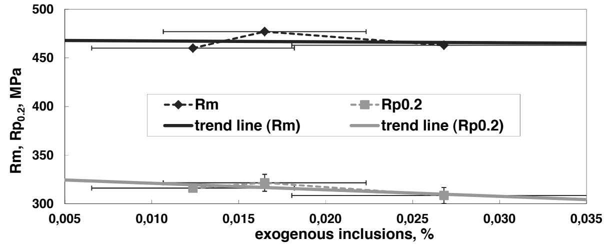

Fig. 15. Influence of exogenous inclusions on strength and yield point in softened state

5. Conclusions

Similar microstructure and hardness of the three steels from different suppliers are characterized by different content of non-metallic inclusions and this in connection with results of mechanical testing allow to formulate the following conclusions:

1. Differences in non-metallic inclusions content within the range required in order to comply with the standard have the influence on strength and yield point of the screws made of 35B2+Cr steel in softened state.
2. Non-metallic inclusions result in decrease of mechanical properties and yield point of the screws made of 35B2+Cr steel in softened state.
3. Large non-metallic inclusions (called in this work as exogenous) have the smallest influence on mechanical properties of the screws made of 35B2+Cr steel in softened state.
4. Influence of non-metallic inclusions on properties of 35B2+Cr steel, within analysed range of their content, is not significant enough to be a critical factor in relation to operating failures of the screws made of this steel.

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