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Nanocrystalline structures obtained by isothermal treatment in bearing steels

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INTRODUCTION

Over the past decade, nanomaterials have been the subject of enormous interest. Metals and alloys with nanocrystalline structure are notable for their high mechanical properties, which, in general, are better than metallic materials with larger grain size. Until now, the most popular methods used for obtaining a nanocrystalline structure in metals consisted of severe plastic deformation (SPD). In steels, the nanocrystalline structure can be also obtained by phase transformations occurring during appropriate heat treatments.
In this work, two types of bearing steels (67SiMnCr6-6-4, 100CrMnSi6-4) were subjected to isothermal heat treatment in order to obtain a nanocrystalline structure. The prime objective of this study was to investigate the influence of grain refinement down to nanometric scale on the structure and mechanical properties of two bearing steels.

EXPERIMENTAL

The heat treatment consisted of austenitisation, cooling down to the temperature of 260°C or 320°C and then isothermal annealing. Heat-treatment parameters were determined from dilatometric studies of phase transformations in the steels investigated.
The structure of steels after isothermal processes was investigated with transmission electron microscopy. The mechanical properties were determined by static tensile tests, impact tests and hardness measurements.
The mechanical properties of both bearing steels, but with different content of alloying elements were compared and discussed.

Table 1. Chemical composition of 100CrMnSi6-4 steel according to PN-74/H-84041 [5] and 67SiMnCr6-6-4 steel as pre the manufacturer's certificate (% wt.)

	C [%]	Si [%]	Mn [%]	Cr [%]	Mo [%]	Ni [%]	Cu [%]	P [%]	S [%]
100CrMnSi6-4	0,95-1,10	0,40-0,65	0,95-1,25	1,30-1,65	-	Max. 0,30	Max. 0,25	Max. 0,027	Max. 0,02
67SiMnCr6-6-4	0,65-0,70	1,45-1,60	1,35-1,55	1,00-1,20	0,23-0,27	Max. 0,25	-	Max. 0,025	0,015-0,02

TRANSMISSION ELECTRON MICROSCOPY OBSERVATION OF MICROSTRUCTURE

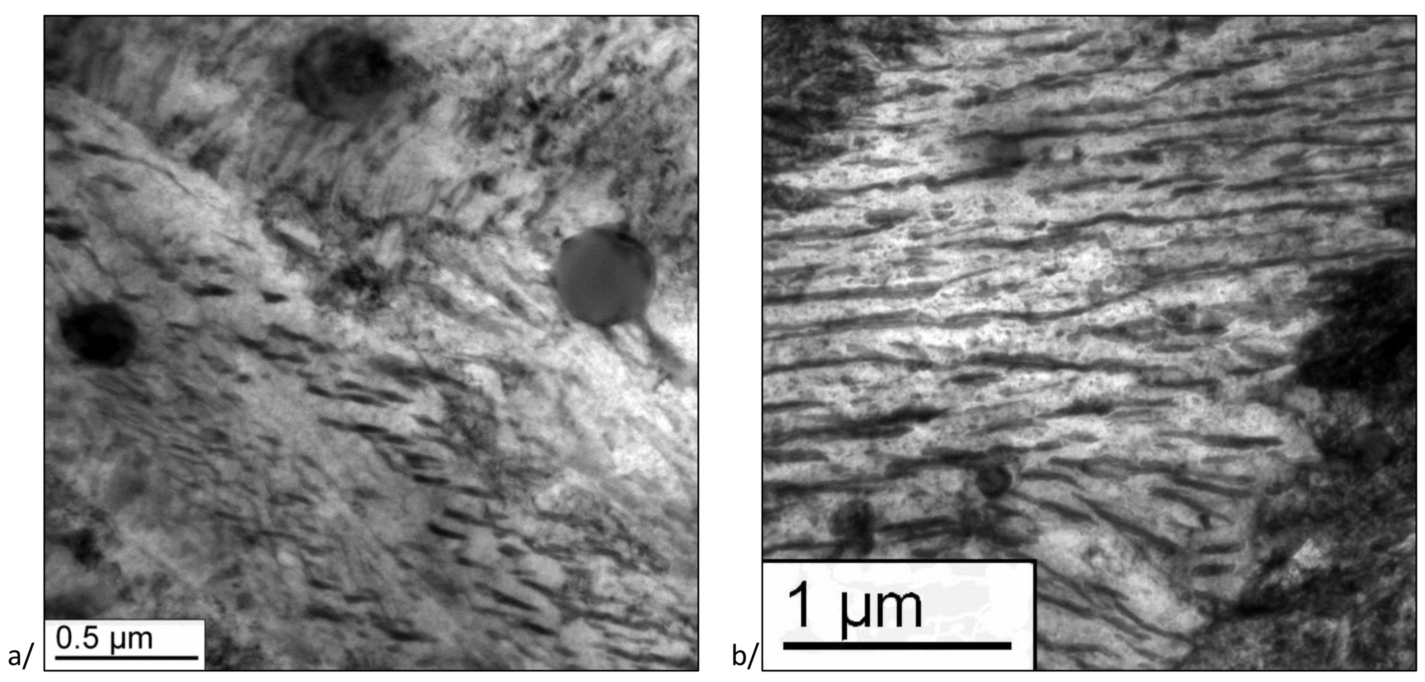

Fig. 1. Bright-field TEM figures of microstructures obtained by heat treatment of:
a/ 100CrMnSi6-4 steel after the H.I.900-15_260 procedure;
b/ 100CrMnSi6-4 steel after the H.I.900-15_320 procedure.

The Fig. 1a and 1b show structures obtained for 100CrMnSi6-4 steel. After isothermal holding at 260°C (Fig. 1a), steel reveals mainly a structure that is specific for lower bainite, i.e. bainitic ferrite laths with cementite precipitations arranged at a defined angle to the axes of the laths. Additionally, small areas of nanobainite of various morphology and spherical primary carbides can be seen. The presence of cementite can be explained by relatively low content of silicon and the absence of austenite that could absorb excess of carbon on precipitation of bainitic ferrite. After exposure to isothermal holding at 320°C, steel 100CrMnSi6-4 has a nanobainitic structure consisting of ferrite and austenite laths of nanometric thickness. Moreover, at this temperature there are no cementite precipitations in the structure. The absence of cementite may results from higher annealing temperature which permits faster diffusion of carbon into retained austenite .

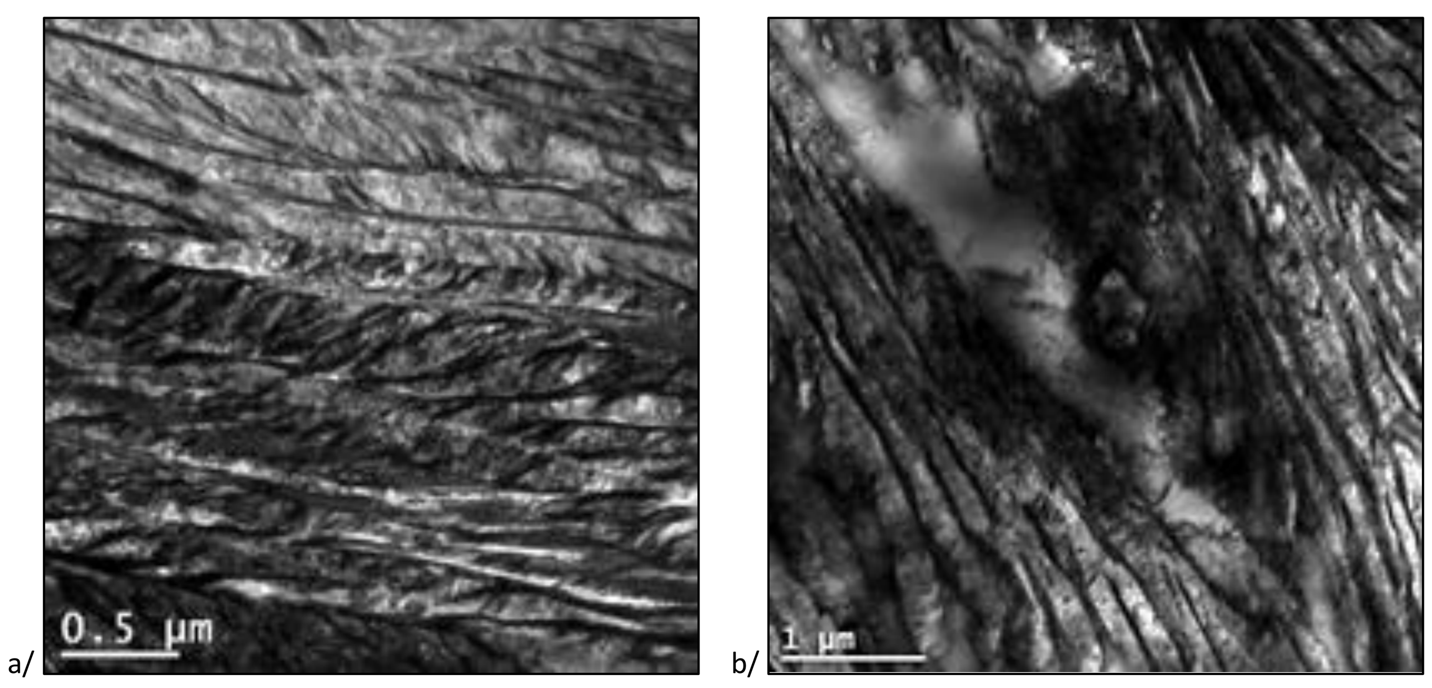

Fig. 2. Bright-field TEM figures of microstructures obtained by heat treatment of:
a/ 67SiMnCr6-6-4 steel after the H.I.925-10_260 procedure;
b/ 67SiMnCr6-6-4 steel after the H.I.925-10_320 procedure.

Revealed by TEM typical microstructures for 67SiMnCr6-6-4 steel are shown in Fig. 2a and 2b. After annealing with isothermal hold at 260°C, this grade of steel has a structure of nanocrystalline laths of bainitic ferrite separated by nanometric layers of austenite. After hardening with isothermal hold at 320°C, one can also find dislocation-containing block-like austenite within the structure. The large content of silicon prevents the precipitation of cementite in the structure of tested steel.

SUMMARY

By applying isothermal annealing temperature of approx. 320°C it was possible to obtain nanocrystalline bainitic structure in both tested grades of steel, resulting in improved mechanical properties thereof. The obtained nanostructure closely resembles that of specially engineered nanobainitic steel, protected by patents.
On correlating the obtained results with chemical composition of the tested steel, one could observe that:
- the higher content of carbon in 100CrMnSi6-4 steel has allowed obtaining higher hardness and higher tensile strength after annealing at 320°C;
- the higher content of silicon and the higher level of retained austenite in 67SiMnCr6-6-4 steel have resulted in higher plasticity of the material as confirmed by high impact strength and significant elongation after isothermal hardening, for each of the tested annealing temperatures.

MECHANICAL PROPERTIES

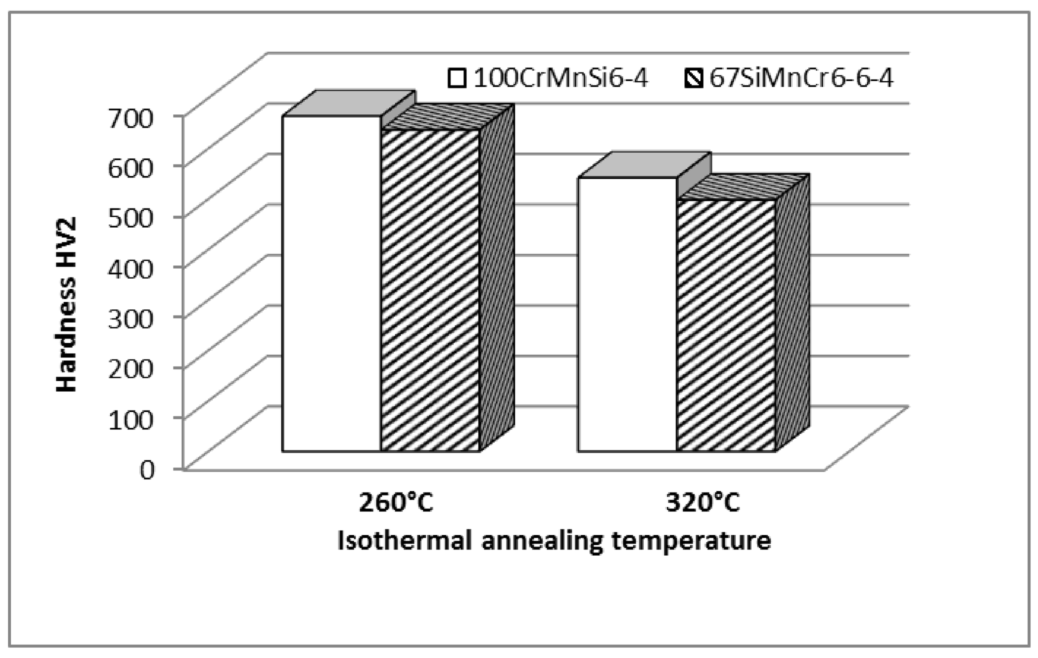

Fig. 3. Hardness data for samples of 100CrMnSi6-4 and 67SiMnCr6-6-4 steel after isothermal treatment

Hardness of the tested steel grades after isothermal treatment decreases with increased temperature of isothermal annealing (Fig. 3). Due to higher carbon content the hardness of 100CrMnSi6-4 steel is by approx. 50HV2 units higher than that of 67SiMnCr6-6-4 steel at any of the applied isothermal holding temperatures.

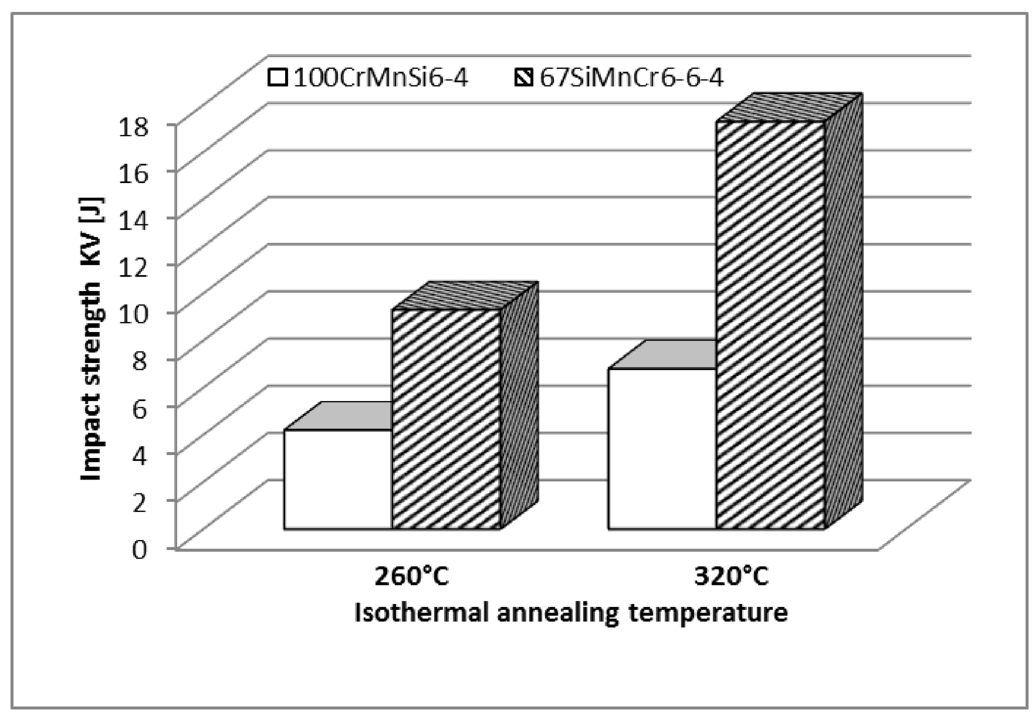

Fig. 4. Impact strength data for samples of 100CrMnSi6-4 and 67SiMnCr6-6-4 steel after isothermal treatment

Impact strength (KV) of the tested steel after isothermal treatment increased with increasing isothermal annealing temperature (Fig. 4). Impact strength of 67SiMnCr6-6-4 steel is more than twice that KV value of 100CrMnSi6-4 steel which can result from a higher content of austenite in 67SiMnCr6-6-4 steel after isothermal annealing at both temperatures.

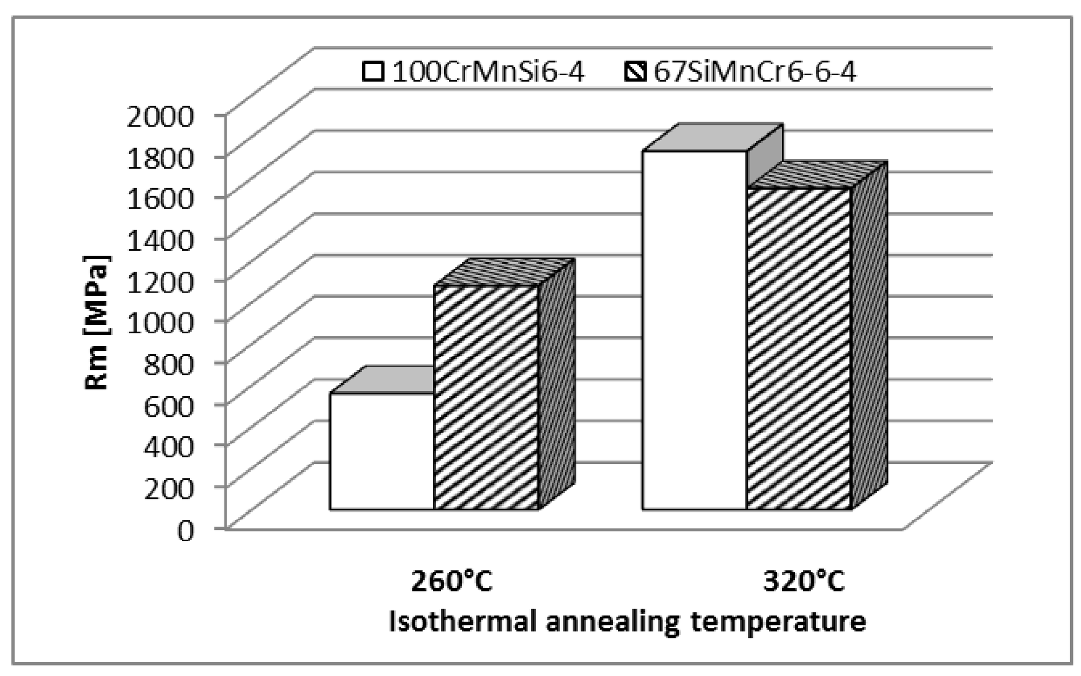

Fig. 5. Strength values data for samples of 100CrMnSi6-4 and 67SiMnCr6-6-4 steels after isothermal treatment

After isothermal annealing at 260°C, samples of both steels ruptured before reaching the yield point. It proves their high brittleness and explains the low value of their tensile strength R_m as compared to the samples treated at 320°C (Fig. 5). This could indicate that after annealing at 260°C structure of each grade of steel is characterized by a higher threshold of stresses necessary for plastic stress relaxation as compared to that of rupture in the tensile test. On the other hand, after isothermal annealing at 320°C the samples underwent plastic deformation. The yield points ($R_{0,2}$) are approx. 1300 MPa and 1100 MPa, for 100CrMnSi6-4 and 67SiMnCr6-6-4 steel grades, respectively. In case of isothermal holding temperature of 320°C, tensile strength of 100CrMnSi6-4 steel is 1730 MPa, i.e. it exceeds that of 67SiMnCr6-6-4 steel by 180 MPa. After such treatment, 67SiMnCr6-6-4 steel is distinguished by high plasticity, as confirmed by total elongation of approx. 22%, i.e. a three-fold total elongation of the other steel grade.

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