MODIFICATION OF SELECTED HIGH STRENGTH CAST STEELS BY A LOW AMOUNT OF TITANIUM

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Abstract:

The article deals with two middle alloyed high strength cast steels and the possibility of their mechanical properties improvement with modification by titanium. The presented study has two main topics. The former is the evaluation of basic mechanical properties of modified and unmodified samples in normalizing and quenched-and-tempered states. The latter is the effect of modification exhibited on the nitridation process and parameters evaluated after nitridation as the course of micro hardness across nitridation layer, the depth of the layer and hardness of nitride surface.

1 Introduction

Cast steels are characterized by a relative higher carbon content and more coarse-grained microstructure in comparison with constructional steels. The higher carbon content is needed to provide good casting properties like fluidity and viscosity, which allows an effective application of the casting process. Due to more coarse-grained structure, casting steel has lower values of mechanical properties in comparison with equal constructional steels. This unwanted result of the casting process could be minimized by alloying steel with elements causing grain refinement like titanium.
The object of presented study is the casting of complex shape made by middle alloyed high strength steel applied as an element of additional armour protection for mobile vehicles. Rolling or forging processes cannot be used to improve mechanical properties in a way which is commonly used in production of commercial semi products of constructional steels with very high strength like sheets, bars, rods, etc. [1]. The purpose of the presented study is to verify the effect of chemical composition modification by a low amount of titanium in order to improve mechanical properties of the casting described above after application of several selected heat and heat chemical treatments.

2 Titanium as an alloying element in steel

Titanium has properties similar to carbon and nitrogen and forms alloys significantly affecting final characteristics of steel. Carbides and nitrides segregated at grain boundaries prevent dislocations in movement and cause precipitation hardening of steel. These phases are also affecting grain refinement. They are stabile at high temperatures and prevent grain growth by segregation at boundaries. This effect could be used at primary crystallization as well as at heat treatment. Besides grain refinement, titanium content also affects fractions with an amount of (pearlite, bainite, etc.) after γ phase transformation [2].
Moreover, titanium binds nitrogen atoms, which eliminates negative nitrogen influences on steel properties (decreasing of toughness), otherwise nitrogen forms unstable solid solutions with iron,

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hich results in ageing of steel [3, 4]. Titanium oxides and nitrides along with aluminium-rich inclusions and manganese-sulfide are very effective in stimulating nucleation of intragranular ferrite because they work as the heterogeneous nucleation sites of ferrite [5]. Intragranular ferrite is known to provide an optimal combination of both high strength and toughness [6].

However, titanium is very reactive with nitrogen, oxygen as well as the sulphur content. Excessive formation of TiN and TiO, formed in liquid steel can cause defects in final products [7, 8]. Sulfides based on Ti have lower melting point and therefore they can be segregated on austenite grains border and cause a decrease in their cohesion strength and then liquation breaking during cooling of the material.

Titanium has positive effect on steel properties mainly at very low concentrations when it is dissolved in solid solutions. In case of higher concentrations, titanium is segregated in the form of intermetallic phases (like $FeTi_2$), which has a considerably negative effect on steel. Therefore, titanium is used as an alloy element for steels in very low amounts not exceeding the level of its solubility in γ iron (0.7%) [9, 10].

The affinity of the titanium for nitrogen may also have the effect on the application of chemical-baheat processes as is the nitriding where titanium nitrides are created in the diffusion surface layer causing thus an increase in the surface hardness.

Titanium addition in steel is also used in welding to increase mechanical properties level of the weld metal [11, 12, 13, 14].

3 Materials and sample preparation

Two high strength middle alloyed cast steels G40NiCrMo4 (Steel A) and G27MnCrV4 with (Steel B) were chosen for the production of investigated cast and are used for experiment (see Table 1). Unfortunately, both materials are typical casting alloys with deteriorative addition content like sulphur. The content of nitrogen and oxygen has not been investigated due to technical limitations of available spectral analyser but it is considered to be almost constant in each of experimental variants due to sample preparation process conditions.

The experimental specimens are made by casting steels using investment casting process to the ceramic shell mould. The process starts with melt preparation of required chemical content of original material (Table 1. - A, B) in the induction furnace and the moulds with samples considered as unmodified were cast. Then, the same remaining melt was modified by addition of 330 g FeTi to the cast pan to cast the mould with Ti modified samples. This amount of FeTi is calculated in order to increase the Ti content approximately about 0.03÷0.05%. Real Ti content evaluated by spectral analysis on modified samples is stated in Table 1. (A+Ti, B+Ti). Modified and unmodified samples were cast from the same melts of used steels, therefore, the content of chemical elements is almost equal except for increased Ti content.

Each of the three moulds consists of 5 samples designated for tensile strength test and 5 samples designated for Charpy impact test. Several moulds were cast by this procedure in order to acquire sufficient experimental samples.

In next step, all modified and unmodified experimental specimens were normalized in order to refine the grain and minimize the raw casting dendritic structure. Also, the effect of grain refinement by titanium modification would become more evident on new austenitic grains growing during normalizing process.

Then, in the next step, the third part of the samples was put out of the treatment and rest of them were quenched and tempered.

Table 1. Chemical composition of both experimental steels (wt. %)

A	C	Mn	Si	Cr	Mo	Ni	V	**Ti**	P	S
	0.4308	0.897	0.583	0.891	0.448	1.84	0.0175	**0.0017**	0.024	0.019
A+Ti	C	Mn	Si	Cr	Mo	Ni	V	**Ti**	P	S
	0.4377	0.922	0.65	0.91	0.442	1.841	0.0213	**0.028**	0.025	0.019
B	C	Mn	Si	Cr	Mo	Ni	V	**Ti**	P	S
	0.3782	1.47	0.54	0.807	0.577	0.0969	0.3435	**0.0027**	0.026	0.020
B+Ti	C	Mn	Si	Cr	Mo	Ni	V	**Ti**	P	S
	0.3802	1.41	0.597	0.81	0.612	0.0988	0.342	**0.036**	0.028	0.022

Finally, half of quenched and tempered samples were treated by nitriding. Conditions of all these processes are described in more detail in [1].

As a result, three groups of experimental samples were prepared: group of samples in normalizing state (N) without any other treatment, group of samples in quenched and tempered (QT) state and finally group of nitriding samples.

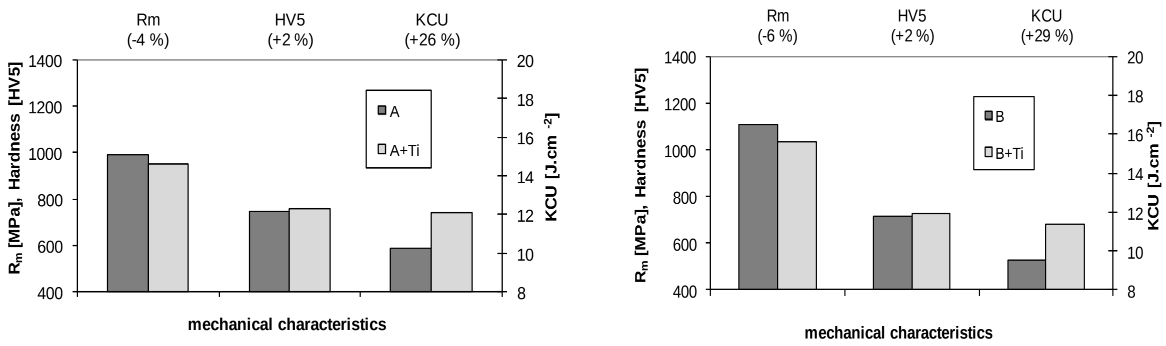
4 Effect of the modification to basic mechanical properties

Tensile strength test according to STN EN ISO 6892 standard was performed on experimental samples to determine tensile strength R_m, conventional yield strength $R_{p0,2}$ and elongation A. Vicker hardness HV5 is evaluated on the samples according the STN EN ISO 6507 standard and toughness KCU according to Charpy impact test following STN EN ISO 148 standard. The results from all tests are given in Table 2 where all presented values are the average of five or more measurements.

The experimental results show that the Ti modification caused the change in values of toughness KCU, hardness HV5 as well as strength R_m. The changes of these characteristics for both investigated materials and their treatment states are summarized in Figures 1 and 2. The graphs columns show a comparison of mechanical characteristic obtained from modified and unmodified specimens in normalizing (Fig. 1) and QT state (Fig. 2).

Table 2. Experimental results of mechanical properties with and without Ti modification

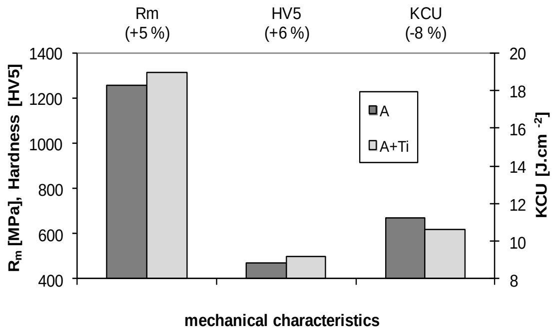
Material / Heat treatment		**R_m [MPa]**	**$R_{p0,2}$ [MPa]**	**A [%]**	**HV5**	**KCU [J.cm^{-2}]**
Normalizing	A	970.06	950.68	7.70	747	13.4
	A+Ti	952.30	931.20	8.00	759	17.8
	B	1126.04	1101.09	6.90	717	11.6
	B+Ti	1034.31	1011.39	6.00	722	16
Quenching + tempering	A	1254.81	1182.88	6.30	472	19.8
	A+Ti	1276.25	1214.98	6.60	502	14.2
	B	1318.70	1173.49	4.30	543	11.4
	B+Ti	1379.03	1232.91	4.90	551	10



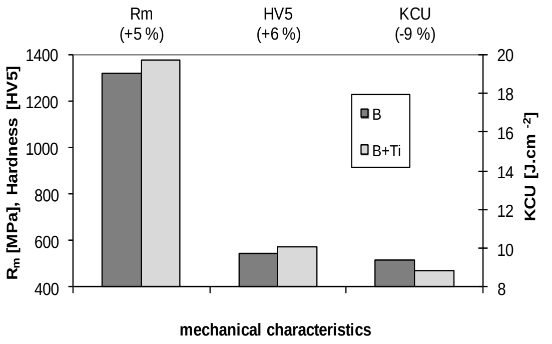
Steel A

Steel B

Figure 1. Effect of Ti modification on selected mechanical characteristics in normalizing state.



Steel A



Steel B

Figure 2. Effect of Ti modification on selected mechanical characteristics in QT state.

The most significant changes occurred in KCU5 values, specifically their increase in normalized state. An increase of steel toughness in normalizing state after Ti modification were also detected in works of other authors where the main reasons are the change of grain size and fraction ratio of phases after γ transformation [2].

In the case of R_m strength, its small decrease occurred after modification in normalizing state. The reason is probably in segregating Ti compounds with other elements (S, N, and O) on grain boundaries during normalising process.

But on the contrary, a soft increase in the R_m is noticed in QT state. Hardness HV5 of all investigated materials increased softly after Ti modification in normalized state, but increasing is relatively higher in QT state. Hardness is increased in presence of hard Ti compounds (carbides, oxides) in material because of Ti modification.

5 Effect of the modification to nitridation layer properties

Experimental samples used for this experiment are nitrided at temperature T = 505°C and in time t = 12 h. Then, the course of micro hardness HV0,5 across nitridation layer was measured on these samples where Vickers hardness test is performed with low load (4,9 N) in accordance with EN ISO 6507 standard. The values from micro hardness course are also used to calculate the nitridation layer depth (Nht) according to DIN 50190. Finally, surface hardness of nitride samples was measured by Vickers test with the load of 49 N.

All these tests were performed on both unmodified and Ti modified samples where the results are compared to consider the influence of the Ti modification on nitridation process.

The courses of micro hardness for both examined steels are shown in Figures 3 and 4.

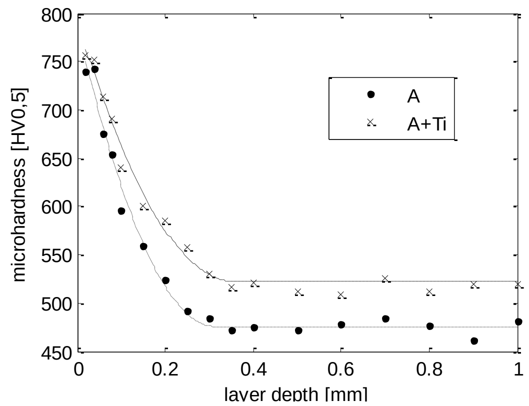


Figure 3. Course of microhardness HV0, 5 across nitridation layer from surface to core material – Steel A.

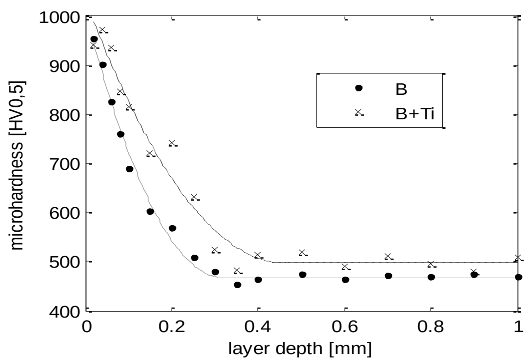


Figure 4. Course of microhardness HV0, 5 across nitridation layer from surface to core material – Steel B.

The final fit curves were calculated from measured values by polynomial regression in Matlab. The Quadratic polynomial ($y = b_1 \cdot x_2 + b_2 \cdot x + b_3$) was used as a regression model for non-linear parts of the curves. Linear parts were calculated by standard linear regression.
There is a significant difference between hardness courses of modified and unmodified samples. The curves of modified samples lies higher for both examined steels because of higher measured hardness values in all position of the nitrided layer.
The titanium modification also causes the increasing of nitrided layer depth approximately about 20%. Values of calculated nitrided layer depth and their comparison are shown in Table 3.

Table 3. Nitriding layer depth

Nitriding layer depth Nht [µm]					
A	**A+Ti**	**Δ**	**B**	**B+Ti**	**Δ**
201	235	+17%	241	290	+21%

Vickers Hardness test HV5 shown the increase of surface hardness for modified samples of both examined steel as is displayed in the Table 4. The increasing of surface hardness is relatively low, just about 5 ÷ 7%.

Table 4. Surface hardness

Surface Hardness [HV5]					
A	**A+Ti**	**Δ**	**B**	**B+Ti**	**Δ**
703	751	+7%	834	872	+5%

6 Conclusion

The effect of modification by Ti caused a soft increase in HV5 hardness and R_m tensile strength in QT state, which is important when considering the application of examined steels. These mechanical properties were either negatively affected in normalizing state or are slowly increased (HV5).
KCU increase about almost 30% in normalizing is interesting but useless when strength and hardness have very low values in the same condition.
The influence of the Ti modification on the nitrided samples was also significant since the course of microhardness across nitriding layer has higher hardness values for Ti modified samples. Nitriding layer depth as well as surface hardness is also increased by modification.

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