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BAINITIC STEELS FOR TRACK STRUCTURE APPLICATION IN THE CZECH REPUBLIC AND WORLDWIDE

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Actual trends of worldwide railway transport development are characterized by increasing speed and growth of railway's axels load. Increasing load together with transverse, longitudinal wheel displacement and braking on the rails results into heavy surface tension. One of many applications for bainitic steel is in railway transport for highly strength and wear resistant rails. Rail steel must be designed to be able to resist plastic deformation, wear, rolling contact fatigue, bending stress and thermal stress during rail welding process and rails resurfacing.

1. Actual and developing worldwide trends of bainitic rail steels

Bainitic structure steels that could achieve strength up to 1400 MPa and also higher plastic characteristics (ductility between 15 and 18 percent), without decrease of fracture toughness as the main request for developing of new qualitative high strength steels with sufficient wear resistance became the background for future development of rails, both molten and rolled steels.

The objective for these new bainitic steels development is to meet several requests like weldability, wears minimization, good fatigue and fracture characteristics, good castability and machinability, low material and production costs.

Bainitic structure has generally higher wear than pearlitic structures because pearlitic structure consists of carbide particles finely spread over the matrix of fine ferritic structure. Carbide causes particles shelling away from ferritic matrix during run over bainitic rails. This accelerated wear removes fatigue damaged surface layer out of the top of the rail. Rolled low-alloyed rail steel with bainitic structure that was developed by Nippon Steel Corporation in Japan, has lower strength limit because of fixed ferritic matrix and roughly dispersive particles of carbides [1].

However bainitic steels with appropriate chemical composition (***Table 1***), and appropriate thermo-mechanical treatment are considered as materials applicable for heavy load rails.

In Nippon Steel Corporation case is visible successful application of bainitic steels in railway crossings, points and level crossing [2, 3].

Problems with wear of bainitic steels can be solved with production of bainitic structure rails prepared with addition higher percentage of chrome or other alloying elements that can provide demanded high strength. Alloying elements are not only expensive, but also forms hard and brittleness martensitic structure in rails welds and resurfaces.

Table 1 Chemical composition and hardness of tested bainitic steels in Japan [1]

Spec.	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**V**	**Mo**	**Nb**	**B**	**Hardness**
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[HV]
A	***0,28***	***0,3***	***1,21***	***0,013***	***0,009***	***1,65***	***0,1***				***422***
B	0,31	0,31	1,32	0,013	0,008	1,32		0,26			374
C	0,29	0,55	1,10	0,01	0,006	2,21			0,04		396
D	0,34	0,32	0,70	0,011	0,007	2,51				0,0015	410

The objective was to produce highly strength rail from low-alloyed steels with bainitic structure with excellent rolling contact fatigue resistance and fatigue cracks resistance. This steel has hardness between 300 HV and 400 HV. This hardness is achieved after cooling of steel A on the air.

Steel A (***Fig. 1***) includes big part of extremely fine bainite formed along grains boundaries. Lighter region is rich on alloying element with smaller content of carbon.

Wear of steel A surface (***Fig. 2***) is smoother than other steels and wear of plates was lower and less numerous. Cross cut of steel's A worn surface (422 HV) presents deformed area with thick around 10 µm compared with at least 30 µm for steel B (374 HV). Austenite content in high-carbon steels was around 17 percent but in low- carbon steels only 6 percent [2].

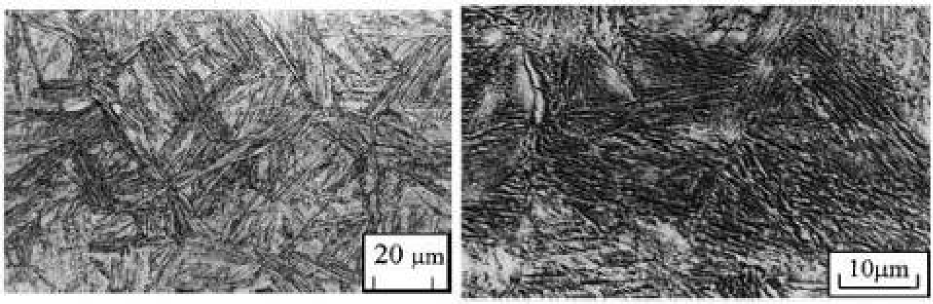

Fig. 1 Bainitic experimental microstructure – steel A.

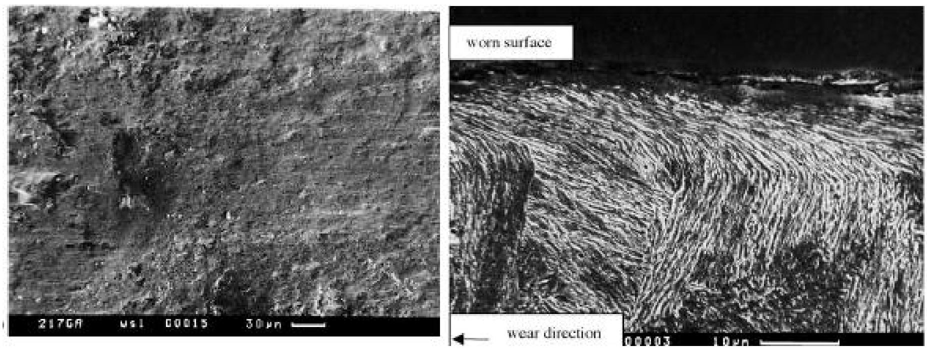

Fig. 2 Worn bainitic experimental microstructure - steel A.

Excellent characteristics of steel A are predicated to carbide absence and possibility of microstructures to tolerate great degree of plastic deformation where residual austenite is transformed to martensite. Bainitic rail from steel A has suitable mechanical properties also for use in practice for high-speed Shinkansen lines.

Bainitic steel is also used for frogs on British railways as well as in London tube. British scientists had a task to developed high strength and wear resistant bainitic steel in cooperation with the American railway institute [3].

British bainitic rails were installed on slightly curved tracks used for personal transportation like a development program for molten frogs. It was proved by measuring of wear that the bainitic steels had slightly lower lifetime period than pearlitic steels with hardness app. 280 HB. The next objective was to produce steel with good castability, machinability and good weldability with common rail steel.

The main part of the task was to produce six alloys marked J1 to J6 (***Table 2***) and investigate effects of bainitic microstructure on wear resistance. The alloy J6 achieved the best results.

Rail steel has average grain size about 50 µm in comparison with classical bainitic steel with grains size about 90 µm from microstructure point of view with values of failure strength limit at 1500 MPa, yield strength at 1100 MPa and ductility about 13 percent.

Table 2 Chemical composition and hardness of tested bainitic steels in the USA [3]

Spec.	**C**	**Mn**	**Si**	**Cr**	**Mo**	**Ni**	**B**	**Hardness**
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[HB]
J1	0,181	2,01	1,13	1.94	0,48	0,01	0,003	415
J2	0,115	3,97	0,27	0.02	0,47	0,01	0,003	375
J3	0,077	2,03	0,27	1.97	-	1,93	-	363
J4	0,023	2,02	0,27	1.96	0,48	1,93	0,003	271
J5	0,026	4,04	0,27	0.02	-	0,02	-	288
J6	0,258	2,00	1,81	1.93	0,49	0,00	0,003	490

2. Bainitic rail steels in the Czech Republic.

After four-years running of low-carbon bainitic steel was this variant taken back out of running based on development and testing experiences of two bainitic rails variants on German railways (in ghaut saint Gotthard on Switzerland-Italian borders) due to contact fatigue defects characteristics and wrinkles. Extremely high plasticity in relation with steel strength serves probably as the source. Medium-carbon variant of bainitic steel remained in running under extreme conditions without contact fatigue defects for eight years.

The extensive research of possible and effective usage of mentioned medium-carbon variants of this bainitic steel for Czech railways was done at Trinec Steel (Železárny Třinec a.s.) based on the above mentioned references. There were prepared and tested bainitic steel marked as bainite 1400 with additional chrome where the mentioned alloys support bainitic structure without additional heat treatment. Based on the done wear tests mainly the character of the load seems to be the key limit for future running. Bainitic steel (initial hardness 429 HB) with ability of given deformation hardness has higher dynamic pressure load capacity versus standard pearlitic steel. In case of wear resistance characteristics are both materials comparable [4].

Czech frogs producer DT Vyhybkarna a mostarna, Inc. Prostejov in cooperation with Trinec Steel (Železárny Třinec a.s.) designed own new material marked Lo8CrNiMo within their own development program „ Bainitic steels for steel casting frogs" and continues in its testing during running on Czech railways.

Chemical compositions (***Table 3***) is selected in order to achieve bainitic microstructure after slow cooling on air immediately after rolling. Hardness of molten bainitic steel is between 380 and 400 HV and impact toughness at 20°C is around 47.5

KCV. The material is determined mainly for monoblocks of frog’s production and presents financial saving as a replacement of manganese (Hadfield) austenitic steels.

Table 3 Chemical composition, ultimate strength and ductility of tested bainitic steels in the Czech Republic [4]

Spec.	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**Nb**	**P**	**S**	R_m	A_5
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[MPa]	[%]
Low-carbon bainite	0,055	0,22	3,95	0,11	0,01	-	0,08	0,008	0,011	883	18,4
Medium-carbon bainite	0,30	0,43	0,66	3,15	0,01	-	-	0,013	0,009	1334	15
	0,28	1,26	0,69	2,65	0,25	-	-	0,012	0,012	1336	16
Bainite 1400	0,3	1,0	0,7	3,0	0,20	-	-	-	-	>1400	>15
Lo8CrNiMo	**0,122**	**0,49**	**0,89**	**1,94**	**0,53**	**2,83**	**V(0,1)**	**0,012**	**0,008**	**1185**	**12**

3. Conclusion

It is sensible from the bainitic steels given above that with preservation of bainitic matrix it is possible to achieve wide range of mechanical features. Their values are the main advantage from rails running load point of view. Wear of the top of the rail parts from bainitic materials is lower than parts made from classical pearlitic steels. The same reason leads to their extended running life. The rails welding where it is necessary to achieve values at least comparable with features of basic material is also connected with mechanical features [5].

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Bibliography

1. KAGEYAMA, HIDEAKI, UEDA, MASAHARU, Process for manufacturing high-strength bainitic steel rails with excellent rolling-contact fatigue resistance, vyd. Nippon Steel Corporation, Tokio, 1994, s. 1-24.
2. CHANG L. C. The rolling/sliding wear performance of high silicon carbide-free bainitic steels, Wear 258, 2005, s. 730–743.
3. BHADESHIA H. K. D. H. Bainite in steels 2nd edition, vyd. The University Press, Cambridge 2001, ISBN 1-86125-112-2, s. 382-387.
4. KUFA T., MATUSEK P. Materialova uroven kolejnic TZ v porovnani s kolejnicemi nekterych prednich evropskych vyrobcu, Hutnicke listy 7-8, Ocelot Praha, 1994, ISSN 0018-8069, s. 34-42.

5. SCHMIDOVA, E. Vyvoj technologie navarovani bez predehrevu pro kolejove aplikace. In: Sborník prednasek odborneho seminare “Svarovani v zeleznicni doprave 2007“: 7.-8.2.2007, Ceska Trebova, Ceska Trebova: Dopravni fakulta Jana Pernera, Univerzita Pardubice, 2005, s. 56-61. ISBN 80-7194-740-7.

Resume

BAINITICKÉ OCELI PRO APLIKACE KOLEJOVÉHO SVRŠKU V ČESKÉ REPUBLICE A VE SVĚTĚ

Ivo HLAVATÝ, Marián SIGMUND, Kateřina HALUZÍKOVÁ, Jiří HLAVATÝ

Současná etapa rozvoje železniční dopravy je v celém světě charakterizována zvyšováním rychlosti a růstem zatížení železničních náprav. Jedno z mnoha využití bainitických ocelí je v železniční dopravě na vysoce pevné a otěruvzdorné kolejnice. Kolejnicová ocel musí být navržena tak, aby odolávala plastickým deformacím, opotřebení a kontaktní únavě, namáhání v ohybu a tepelnému namáhání (změnou teplot) při procesu svařování a navařování kolejnic.

Summary

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Actual trends of worldwide railway transport development are characterized by increasing speed and growth of railway’s axels load. One of many applications for bainitic steel is in railway transport for highly strength and wear resistant rails. Rail steel must be designed to be able to resist plastic deformation, wear, rolling contact fatigue, bending stress and thermal stress during rail welding process and rails resurfacing.

It is sensible from the bainitic steels (in the paper) given above that with preservation of bainitic matrix it is possible to achieve wide range of mechanical features. Their values are the main advantage from rails running load point of view. Wear of the top of the rail parts from bainitic materials is lower than parts made from classical pearlitic steels. The same reason leads to their extended running life. The rails welding where it is necessary to achieve values at least comparable with features of basic material is also connected with mechanical features.

Zusammenfassung

DIE BAINITISCHESTAHLEN FÜR DIE ANWENDUNG DES SCHIENEOBERBAU IN DER TSCHECHISCHEN REPUBLIK UND IN DER WELT

Ivo HLAVATÝ, Marián SIGMUND, Kateřina HALUZÍKOVÁ, Jiří HLAVATÝ

Derzeitige Etappe der Bahntransportsentwicklung ist in der ganzen Welt mit der Steigerung der Geschwindigkeit und dem Anstieg der Achsenbelastung kennzeichnet. Eine von vielen Nutzung des Bianitic-Stahles in dem Bahntransport ist im Bereich der hochfesten und abreibbeständigen Schienen. Der Schienenstahl muss so vorgeschlagen sein, damit der Schienenstahl den plastischen Deformationen, der Abnutzung, der Kontaktermüdung, der Biegeanspruchung und der Wärmebeanspruchung (die Temperaturänderung) beim Prozess der Schweißung und der Aufschweißung der Schienen widerstehen könnte.