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Investigation of rail metal of Kaunas fortress fortification narrow – gauge railway

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1. Introduction

In 2005, on building the underground telecommunications near the Student street, a construction of narrow – gauge railway rails was found in soil, approximately in 1 meter and 75 centimeters depth. The railway finding place was at the same place where earlier were fortifications of Kaunas fortress, therefore it was no doubt that the mentioned find had depended to this fortress.

Kaunas fortress was begun to build in 1879 trying to make stronger the west frontier of Russia. According to the plan of that time, the star defending fortifications and zone of forts had to surround Kaunas town. This fortress had to become the fortress of the first class, while at that time, the first class category had only the fortresses of Warsaw, Bret and Novogeorgijavsk. Therefore, building this fortress, the most new engineering inventions of Russia were introduced. The building of fortress lasted about 20 years therefore, when it was completed, the requirement to restore it appeared since technical progress had advanced. So it was begun to build the new fortifications and forts in the fortress. One of such fortification connected the rivers Nemunas and Neris. There was found this railway.

Metal construction of narrow – gauge railway, i.e. rails, sleepers, elements of attaching and connection, are produced from iron alloy. This is carrying over and assembled from separate sections railway which destination is unknown. Probably it was used for operative transportation of heavy goods in such places where it was no suitable way for other transportation. The existence of such railway was found in archives of Kaunas district [1].

On talking about the level of engineering and metallurgy of that period (the end of 19 century – the beginning of 20century), the largest amount of steel was produced in Siemens – Marten furnaces and Bessemer converters [2]. For steel production pig iron smelted in blast furnaces was used.

Small amounts of iron were produced by ancient means, i.e. in ore furnaces or by twice stage process of iron production – pig iron was smelted in blast furnaces and then it was remelted in puddling furnaces. Such iron was of good weldability and plasticity but rather low strength because the base of its structure was ferrite [3, 4]. This iron was remelted to steel in crucible furnaces but the steel in such way produced was expensive because its production was non – efficient [5].

Engineering evolution of 19 century and development on industry demanded higher amounts of iron alloys than it was possible to produce by the latter methods. Especially great amount of iron alloys was necessary for rapidly developing railway transport at this time.

In 1855 Henry Bessemer had patented very efficient method of steel production by converters. The steel obtained in such a way was not expensive but its mechanical properties were very poor (ultimate strength was about 150 MPa) and it could not compare with the steel melted in crucible furnace [6]. The reason of that was not properly mastered the process of production and therefore to ensure the stable steel mechanical properties were impossible. So the converter method of steel production didn't get great recognition.

In 1865, in Siemens Company, using melting furnaces presented there and the method of metal – makers Emilio Martin and Pjero Martin, the most efficient method of steel production was created. The steel made like this had good and stable mechanical properties (ultimate strength was about 500 MPa – 550 MPa [7]) therefore this method spread quickly in the whole world.

Steel made by Marten furnaces was cast into pigs, which further were rolled into the various blanks. Stability of the process and steel properties depended greatly on the size and productivity of the furnace. The larger it was the better metal was obtained. For that reason, around the melting plant, some metallurgical factories had to be established in which the steel castings were cast and rolled in to various assortment blanks. Near such plants there were the plants producing the railway rails.

The convert steel melting process gradually was progressing. Therefore mechanical properties of the steel produced by this method became similar to those of steel obtained in the Marten furnaces.

The converters of various type depending on their construction and capacity were found. Some of such were the smallest Bessemer converters. These converters especially were suitable on organizing production of railway rails in such places where there were no the metallurgical works. Like raw material it was possible to use pig iron of blast furnace brought from the distant districts. This cast iron was melted in the shaft furnaces and remelted into steel in converters. Rightly selecting the productivity of such shaft furnace and evaluating the capacity of rolling mills, it was possible to organize production so that it would be not surplus of melted steel. Besides such works it was possible to build not attaching to the geographical localities where it was the basic raw materials necessary for production (ore, coal). From technical positions, the great strength requirements were not the aim therefore from the end of 19 century mostly for railway rails production it was used Bessemer steel [8].

2. Experimental

Rail construction consists of rails, metal sleepers, yokes for rails attaching to sleepers and rail section coupling mechanism. For the investigation rail *2*, sleeper *1*, and attaching yoke *3* (Fig. 1) metal were chosen.

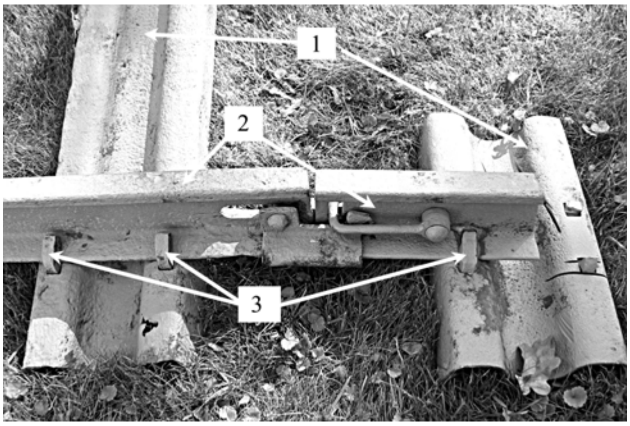


Fig. 1 Construction of found rail: *1* – sleepers; *2* – rails; *3* – yokes of rails attaching to sleepers

Aim of the investigation was to determine the steel chemical composition, to research its microstructure and to evaluate quality. It was also intended to determine the production engineering and to compare with steel used for production of modern rails.

The specimens from the elements of investigated metal constructions were cut out. The investigations of chemical composition, microstructure and mechanical properties were carried out.

Chemical composition was determined by "Spektrolab" device. Carbon content was investigated by chemical method separately. Specimens for microstructure investigation were prepared by the specific vortical method [9] using the emulsion of chromium oxide powders. For microstructure etching it was used 3% HNO_3 solution in ethyl alcohol. Evaluation of the quantity of structure components was carried out by the digital metallographic method using the metallographic microscope LMA, the image fixing camera YCH15, personal computer and original software [10]. Microhardness of the microstructure components was investigated by the microhardness tester PMT-3U42.

Sulphur is a harmful impurity in steel. It exists in steel in the form of combinations which worsen the mechanical and operation properties. The inclusions of sulphur combinations distribute in steel unevenly composing the sulphur segregations. Investigations of sulphur segregation were carried out by Bauman method.

Since it was not sufficient amount of metal for manufacture of standard specimens therefore steel mechanical properties were investigated by hardness tests. Steel hardness correlates with its strength and plasticity so, when hardness is known, it is possible to determine the other most important mechanical properties. The hardness tests were carried out by hardness tester.

3. Results and discussion

The investigation of the different rail construction elements (rail, sleeper, rail attacking yoke) had shown that all these elements are manufactured from different sorts of steel (Fig. 2).

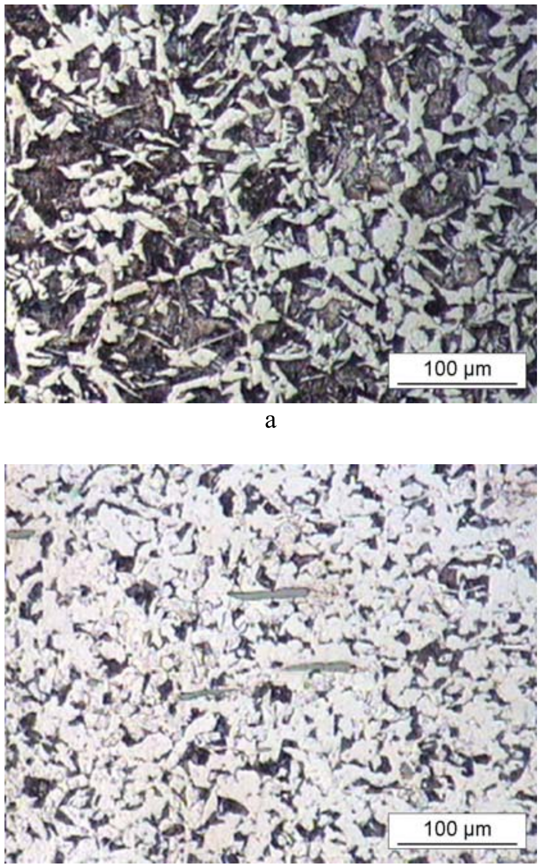


Fig. 2 Microstructure of railway elements: a - rail; b - sleeper

On observing the non-etched microsections, prepared on the rotating polishing disk, the great amount of nonmetalic inclusions in the whole specimens was noticed. The distribution of these inclusions had achieved the grade number 4. To evaluate exactly the amount of nonmetalic inclusions and their geometric parameters the vortical microsection preparing method was used since on preparing microsections by the traditional methods, the rotating polishing disk drags out the nonmetalic inclusions from their presenting places forming the hollows. For that reason, the evaluation of nonetched microstructure is not precise. The vortical method doesn't change the shape and place of nonmetal inclusions therefore it is possible to evaluate that precisely. This method particularly well enables to determine the place and shape of silicates because they are plastic.

After preparing the microsections by vortical method, it was possible to observe in the structure a greater amount of other nonmetalic inclusions achieving the grade number 5. Besides that, in the structure presenting silicates were observed extremely well (Figs. 2 and 3). Great amount of oxides in metal structure indicates that it was produced in a converter. During Bessemer production, on blowing metal by air, the active processes of metal oxidation proceed and the composed oxides to remove completely from metal during the process of deoxidation it is impossible. Marten steel possesses the better mechanical properties than Bessemer steel because the liquid metal contacts with the furnace gaseous atmosphere only by the surface of metal bath so the amount of metal oxides in it is lower.

Since the silicate inclusions present in a metal are soft and easily deformed so, according to their character of distribution, it is possible to decide on the nature of steel plastic deformation. The case, when silicates of stretched shape are oriented in the same direction, demonstrates that rolling of the article was carried out. The silicates of such type were found in the whole construction elements of the investigated rail.

Investigation of the microstructure has shown that these construction elements are made from steel with different carbon content (Fig. 2). Mostly pearlite in the structure had the rail metal and quite low content of it was in the metal of rail attaching yoke. Percent ratio of pearlite/feritte in the rails metal was 50/50, in the sleepers metal – 15/85, in the attaching yokes metal 2-10/90-98.

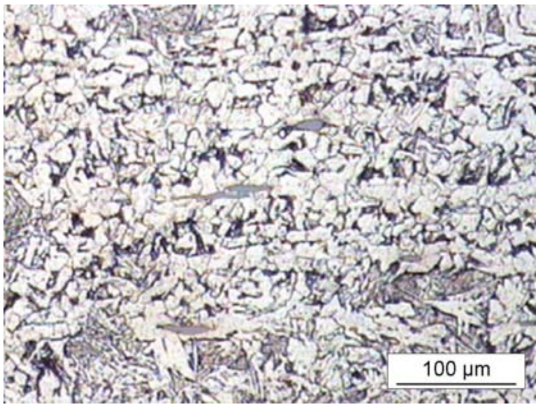
Such different steels were chosen not by chance but trying to give for railway construction the different plasticity of separated parts. The largest load on usage of such railway undergoes the rails so the steel of higher carbon content was used for them securing the greater strength and wear resistance.

The sleeper metal undergoes the smaller loads so the steel of lower carbon content was chosen securing the great plasticity and good plastic workability. The sleeper profile is formed from sheet and sheet steel is more convenient to work by cold plastic deformation. The low carbon content steel undergoes the plastic deformations well and it doesn't destroy.

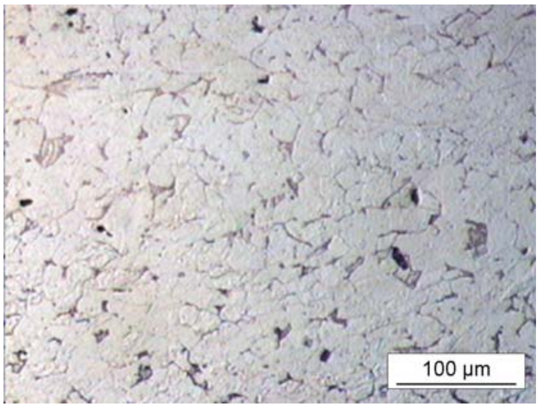
The rail attaching yokes undergo the smallest loads during railway exploitation but they also have to endure the stability of the whole construction. On producing these yokes and assembling the construction, good metal plasticity is required. The yoke was manufactured from the square shape bar. On chopping the bars into the blanks, forming these blanks into the articles of "U" shape and assembling the construction, the metal is deforming plastically. In order to it withstand these operations and not destroy, the steel must be plastic.

The microstructure investigation of rail attaching yoke had shown that there was great decarburization of the metal surface layers. At the specimen edges only ferrite grains were observed but on coming to the centre part of the specimen the quantity of pearlite grains appeared and increased (Fig. 3). Probably it is technological spoilage. Decarburization occurs in the metal surface when the technological regimes are not observed and the metal too long is held in the uncovered heating furnace. But the plasticity of decarburized surface layers is larger and that ensures to perform the successful deformation during the process of manufacturing. Perhaps decarburization of detail surface layers was performed purposively.

A vidmanstetic steel structure was observed. It is possible to affirm that, on manufacturing the parts, the hot deformation temperature regimes were not kept and the articles were overheated. Vidmanstetic structure forming is stimulated also by the higher content of manganese in steel composition since manganese stimulates the growth of austenite grains. Such structure worsens markedly the steel mechanical properties. Overheating of steel formed because heating equipments of that period didn't have the temperature regulating devices besides it was low engineer organization level of production.

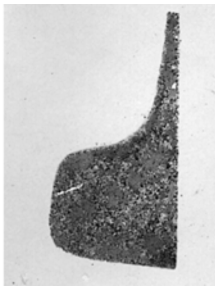


a



b

Fig. 3 Microstructure of rail attaching element: a – central part of specimen; b – decarbonized surface part of specimen



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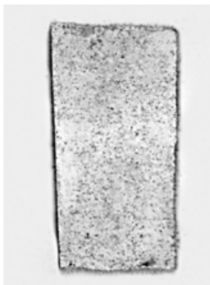

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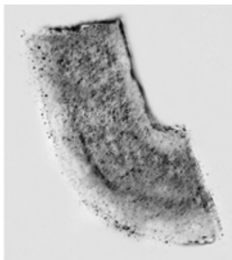

c

Fig. 4 Investigation of sulphur segregation in the separated railway elements: a – rail; b – sleeper; c – yoke of rail attaching

Though the microstructure investigation had shown that there were a lot of sulphides which for their great plasticity had arranged, in the inclusions according to the rolling direction but, wishing to be quite sure, the sulphur segregation test was performed. Bauman test had shown that there was great sulphide segregation in the whole railway elements (Fig. 4). It was possible to decide that on performing the primary melting coke was used. Coke was hold at that period like the new progressive material. To the middle of 19 century, on performing the primary melting in the blast furnace, charcoal was used which was expensive. But demerit of coke was that there was inevitably allways 0.5% - 2.0% sulphur in it which on melting passed into the metal and worsened its properties.

Investigation of chemical composition had shown that sleeper was made from low carbon steel and rail – medium carbon steel.

The results of the investigation of chemical composition are given in the table.

Table

Chemical composition of steels of construction elements

Articles	Content of chemical elements by mass, %													
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Ti	V	Sn	Fe
Rail	0,360	0,098	1,440	0,090	0,027	0,007	0,005	0,004	0,005	0,005	0,001	0,038	0,002	98,02
Sleeper	0,240	0,056	0,850	0,085	0,071	0,008	0,014	0,014	0,001	0,009	0,001	0,030	0,001	98,68

It is possible by device “Spektrolab” to perform precisely the quantity analysis of steel up to 25 chemical elements, but quantity of carbon may be determined incorrectly. In order to determine the precise carbon content, the chemical quantity analysis of carbon by chemical method was performed additionally. It was determined that the carbon content in the rail is 0.36 % and in the sleeper – 0.24 %. It appeared that in the rail metal it was unusually large content of manganese. Manganese on steel melting was used like deoxidizer, so its quantity approximately to 0.6 % was inevitable. This metal dissolves in the ferrite increasing its hardness. So this element is used like the inexpensive alloying one.

That manganese in the alloy was not by chance the investigation of microhardness of microstructure components had shown. Hardness of pearlite varied from 1479 to 2445 MPa and ferrite from 1122 to 2935 MPa. Usually microhardness of ferrite is lower than that of pearlite but at this case very great influence has manganese.

The investigation results of metal hardness were also unlike. The highest hardness had the rail – 280 HV, the sleeper had the medium hardness – 235 HV and yoke metal – 225 HV. It is possible to decide by the hardness tests what strength possesses the metal [11]. In this case the ultimate strength of rail metal is 880 – 950 MPa, the sleeper metal – 700 – 730 MPa and the yoke metal – 620 – 630 MPa.

The steels of resembling composition are used for production the modern rails in the various countries [12]. The content of manganese attains 0.6 up to 1.4% in the rail steels. But the content of carbon in the modern steels is higher and ranges from 0.4 to 0.8%. The higher content of carbon increases the strength and wear resistance. The modern rails also are hardened by heat treatment, so the higher content of carbon is necessary. Such rails deform quite a little and their durability is greater. The content of other components in steel of the investigated rail differs insignificantly from that of modern steels.

The ultimate strength of modern rail steel ranges from 700 to 930 MPa. Our investigation results get into these results, so it is possible to affirm that the found rail mechanical properties are very close to the mechanical properties of the modern rails.

4. Conclusions

1. The investigations had shown that for railway rails, sleepers and attacking yokes production engineering that are used in the modern industry was used. But the microstructure investigations showed that, on production these railway elements, engineering regimes were not observed or at that time engineering knowing level was low.

2. High content of oxides and sulphides showed that the whole railway elements were produced from Bessemer steel. Bessemer steel production method at the end of 19 century was one of the new and very productive methods of steel production.

3. The investigation of sulphide segregation had shown that, on steel production, during metallurgical process, coke was used. It pushed out charcoal which was used widely in metallurgy at that time.

4. The chemical composition of the investigated railway rail differed a little of that of various countries. The carbon content was a little lower and manganese content a little higher. It is possible to affirm that manganese was used as not expensive alloying element for increasing steel strength.

References

1. Kaunas district archives, stock I-465, file 268, paper case 1. (in Lithuanian).
2. **Gedike, G., Gok, U., Dolgof, E. and others**. Industry and Engineering. Encyclopaedia of Industry Knowledge. Volume 6. -S. Petersburg, 1902-1909.-624p. (in Russian).
3. **Clark, D.S., Varney, W.R.** Physical Metallurgy for Engineers.-New York, 1966.-705p.
4. Marks‘ Standard Handbook for Mechanical Engineers. -New York: McGraw-hill book company, 1975.-947p.
5. **Abrosimov, E.V., Anseles, I.I, Kudrin, V.A and others.** Steel Metallurgy.-Moscow, 1961.-680p. (in Russian).
6. **Chertkov, G.V.** Technology of Metals.-Leningrad, 1939.-452p. (in Russian).
7. **Knabe, V.S.** Foundry Practice. Volume 6.-S. Petersburg, 1901.-265p. (in Russian).
8. **Editor Martens, L.K.** Technical Encyclopaedia. Volume 21.-Moscow, 1933.-951p. (in Russian).

9. **Chodocinskas, S.J., Kuliavas, L.** Vortical microsection preparing method.-Mechanical Technology: Scientific Works. -Kaunas Technological University. -Kaunas: Technologija, 2005, v.33, p.65-70 (in Lithuanian).
10. **Bendikiene, R., Chodocinskas, S.J.** Computer plangraphic investigation.-Mechanical Technology: Scientific Works. -Kaunas Technological University. -Kaunas: Technologija, 2000, v.28, p.77-81 (in Lithuanian).
11. **Pavaras, A.** Structural Steels.-Vilnius, 1978.-240p. (in Lithuanian).
12. **Pavaras, A., Žvinys, J.** Steels. -Kaunas: Technologija, 1995.-416p. (in Lithuanian).

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KAUNO TVIRTOVĖS ĮTVIRTINIMŲ SIAUROJO GELEŽINKELIO BĖGIO METALO TYRIMAS

R e z i u m ė

Tiesiant požemines telefono komunikacijas Kauno mieste 1.75 m gylyje buvo aptiktas geležinkelis. Buvo nustatyta, kad tai geležinkelis funkcionavęs Kauno tvirtovėje, kuri buvo pradėta statyti 1879 metais ir buvo statoma apie 20 metų. Kadangi šios geležinkelio detalės buvo pagamintos daugiau kaip prie šimtą metų, kilo klausimų apie to laikmečio metalurgijos lygį, plieno kokybę bei plastinio apdirbimo technologijas. Tai buvo laikmetis, kai geležies lydinių metalurgijoje vyko dideli pokyčiai, atsirado efektingesni ir masiškesni plieno gamybos būdai, tačiau pagamintų plienų kokybė dar nebuvo aukšta. Tyrimo tikslas buvo nustatyti plieno, iš kurio buvo pagamintas geležinkelis, cheminę sudėtį, ištirti jo mikrostruktūrą, įvertinti kokybę, atlikti mechaninių savybių tyrimą ir nustatyti gamybos technologiją. Įvertinus tiriamus plienus, jie buvo lyginami su šiuolaikinių geležinkelių gamybai naudojamais plienais.

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INVESTIGATION OF RAIL METAL OF KAUNAS FORTRESS FORTIFICATION NARROW – GAUGE RAILWAY

S u m m a r y

On building the underground telephone lines in Kaunas town in 1 metre and 75 centimeters depth a railway was discovered. It was determined that this railway, functionated in Kaunas fortress, which was started to build in 1879 and has been build for 20 years. Since this railway was build more than a hundred year ago so it arised the questions about the metallurgy level of that period, quality of steel and technology of plastic working. It was the period when the great changes in the iron alloys metallurgy proceeded, the more effective and mass steel production methods appeared but the quality of made steels was not high. The aim of the investigation was to determine the steel, from which the railway was made, the chemical composition, to investigate its microstructure, to estimate the quality, to carry out the investigation of mechanical properties and to determine the production technology. After estimation the investigated steel, they were compared with the steels used for modern railways production.

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ИССЛЕДОВАНИЕ УЗКОКОЛЕЙНОЙ ЖЕЛЕЗНОЙ ДОРОГИ КАУНАССКОГО КРЕПОСТНОГО СООРУЖЕНИЯ

Р е з ю м е

Прокладывая подземные телекоммуникации в Каунасе, на глубине 1.75 м была обнаружена железная дорога. Установлено, что железная дорога функционировала в Каунасской крепости, строительство которой была начата в 1879 году, и длилась около 20 лет. Так как сама железная дорога была изготовлена больше чем сто лет назад, то возникли вопросы об уровне металлургии того времени, о качестве стали и о технологии производства стали. Это было время, когда в металлургии стали происходили большие перемены, появились боле эффективные и боле массовые способы производства стали, но изготовленная сталь еще была низкого качества. Цель исследования было, установить химический состав стали, из которой была изготовлена железная дорога, определить микроструктуру, оценить качество металла, провести исследование механических свойств и установить, технологический процесс производства стали. Оценив исследуемые стали, они сравнивались со сталью, которая используется для железных дорог в нынешнее время.

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