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# Influence of heat treatment on microstructure and properties of bainitic cast steel used for frogs in railway crossovers

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## Abstract

This work deals with influence of heat treatment on microstructure and properties of sample cast assigned as a material used for frogs in railway crossover. Materials used in railway industry for frogs (manganese cast steel and forged pearlitic steel) do not fulfil strict conditions of exploitation of railway. One of the solutions is using cast steel with bainitic or bainite-martensite microstructure, what allows to gain high resistance properties ($R_m$ = 1400 MPa, $R_{p0,2}$ = 900 MPa, hardness to 400 HBW). The cooling rates of rail type UIC60 shows that it is possible to reach the bainitic microstructure in cast of frog. The microstructure of lower banite should have an advantageous influence on cracking resistance. In order to set the parameters of heat treatment, the critical temperatures were determined by dilatometric methods determined. This heat treatment consisted of normalizing that prepared it to the farther process of resistance welding. Moreover, the CCT diagram of proposed bainitic cast steel was prepared. The exams were done that can be used to evaluate the influence of heat treatment on microstructure and properties of the sample cast.

**Keywords:** heat treatment, metallography, bainitic cast steel, railway frogs, railway crossover, CCT diagrams.

## 1. Introduction

On many European lines the speed of trains was raised, the pressures on railway rolling stock, axis and the intensity of transport have grown, new types of cars and locomotives were introduced. The railway crossover is one of the most complex elements of railway, not only because of its construction, but also because of its intensive wearing. The frogs, wing rail and actual frog point that are the parts of railway crossover are also elements of rail that are being worn the most quickly.

Higher and higher demands are put to rails and railway crossovers. These demands concern metallurgic parameters as well as mechanical properties. According to the Decision UIC number 1692/96 it is necessary that the joints are made in non butt joint method and are able to operate the lines of trans-European system of conventional rail, with the maximum speed of 200 km/h with pressure on axis not lower than 230 kN. Butt joint (fish-plate joint) that are currently used do not fulfil these requirements. Only non butt joints can fulfil these demands: resistance butt welding thermit welding. Nowadays, the forged steel with pearlitic microstructure (R260) or Hadfield steel (L120G13) are used as materials on rail frogs [8]. However, joining of different materials having different mechanical and electric properties and different thermal conduction, leads to many problems, and among the others these connected to the lack of microstructure stability [9-11]. In order to prevent the problems listed above, the joint is made with buffer layer from austenite steel, Fe-Ni alloys or pure nickel [12].

The ways of increasing mechanical properties of presently used materials in rail industry by heat treatment were described in work [1]. High strength properties and hardness of rails received as a result of heat treatment do not guarantee good properties as far as exploitation wearing is concerned, that is still a problem known in world rail industry [2]. The next step to the further development were the materials characterized with bainitic microstructure for which it is possible to reach $R_m$ to 1400 MPa, $R_{p0,2}$ = 900 MPa in raw condition and hardness to 400 HBW [3]. The works [3-8] show further increased interest of using bainitic steel as a material on highly loaded elements of railway.

In order to design optimal microstructure of alloys on matrix of iron, it is important to make diagrams CTT [13-15]. Following problems concern technology of casting of frogs [16] and cracking of casts of Hadfield steel [17]. The fundamental problem is connected with the process of joining the casted materials [18].

The aim of these researches was to define the influence of heat treatment (normalizing) on microstructure and properties of bainitic cast steel used on frogs in railway crossovers, this heat treatment should prepare material to the process of resistance welding.

## 2. Material

Material to these researches is a sample cast of bainitic cast steel, with chemical composition designed on the basis of standard ISO 4991 and was modified on the basis of work was examined [19]. The cast was made in Foundry Research Institute in Cracow. The cast was made with in measures 100x100x5000 mm and the weight of about 50 kg. The melt analysis of examined cast steel is given in table 1.

Table 1.
Chemical composition of the examined cast steel (mass %)

| C | Mn | Si | P | S | Cr | Ni | Mo | Ti |
|---|---|---|---|---|---|---|---|---|
| 0.17 | 0.57 | 0.28 | 0.014 | 0.013 | 1.70 | 2.60 | 0.46 | 0.03 |

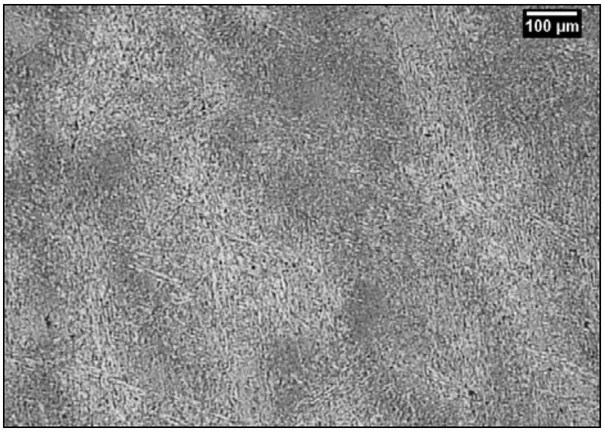
## 3. Experimental methods

In order to examine the influence of heat treatment on microstructure and properties of cast steel, the metallographic observations of the microstructure of cast were performed in a raw condition (after casting) and after heat treatment (normalizing). The exams of hardness were made by the Vickers method with loading 294,2 N (30 kG). Additionally, the Charpy impact and static tensile test were run.

## 4. Results and discussion

The critical temperatures were set on based on dilatometric methods ($Ac_{1s}$ = 690°C, $Ac_{1f}$ = 760°C and $Ac_3$ = 850°C), and normalizing process was designed. On figure 1 the as-cast condition microstructures of the examined cast steel in a raw condition (after casting) are shown. Cooling of cast during its solidification to the room temperature allowed to reach the microstructure of bainite (fig. 1). Cooling after normalizing from the area of homogeneous austenite (930°C) to the room temperature brought about its hardening to bainite once again (fig. 2). As a result of diversified intensity of etching in microstructure (fig. 2a) the segregation places formed during crystallization are visible. In comparison with the as-cast condition (fig. 1) the microstructure was refined and easily etching net is appears mostly along the prior boundaries of grains of former austenite. The appearance of easily etching places is caused by increased cooling rate after normalizing in comparison to slowly cooled massive cast. Fast cooling of the areas along the original boundaries of austenite, enriched in carbon and elements of alloy, do not allow to precipitation of carbides. In these areas the temperature $M_S$ is decreased, what leads to higher amount of retained austenite in them after cooling (fig. 2). The slow cooling results in precipitation of carbides from super saturated bainitic ferrite, taking off carbon from the areas of segregation after the original boundaries of austenite (fig. 1).

a)




b)

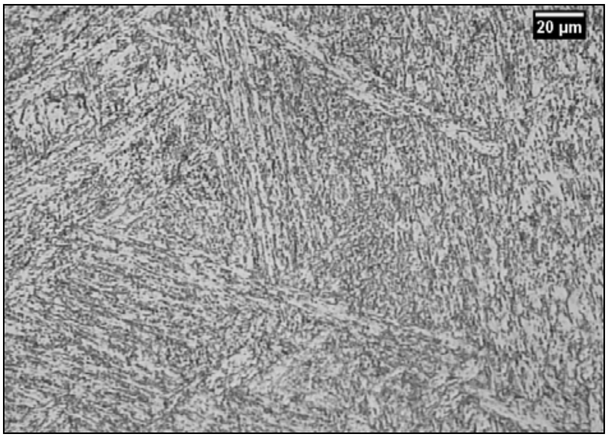



Fig. 1. Microstructure of the bainitic cast steel in as-cast condition. Etching 4% nital

Low number of non-metallic inclusions in places not exposed on such a strong etching was noticed (fig. 2a). Beside bainitic microstructure, some amount at martensite was observed in areas of segregation. Which is result of higher cooling rates of laboratory samples compared to bulk cast.

In table 2 more important mechanical properties of an examined cast steel are presented in a raw condition (after casting) and after the heat treatment. Cast steel with hardness of 336 HV30 is characterized by quite high proof stress, $R_{p0,2}$ = 556 MPa and by high submitted to strength $R_m$ = 1068 MPa with elongation $A_5$ on level 12%. It is known that the cast before resistance welding will be additional heat treatment, which will consist of normalizing. Cooling of this material in air will be equivalent of transformation to bainite. As it can be seen hardness after normalizing (tab. 3) increased to 366 HV30. The increase of hardness is caused by appearing of a slight quantity of martensite along the prior grains of austenite. The process of normalization affected the proof stress significantly and as well resistance to ultimate strength, increasing them relevantly $R_{p0,2}$ to 667 MPa and $R_m$ to 1125 MPa. Similarly as in the state after casting the material after normalization is characterized by the elongation $A_5$ on level 12÷14%.

Moreover, the CTT diagram was prepared for the sample cast from the normalized condition in order to verify of project study (fig. 3).

Table 2.
The results of mechanical testing of the cast steel in a raw condition and after heat treatment

| Properties | Without heat treatment | With heat treatment |
|---|---|---|
| HV30 | 336±9 | 366±5 |
| KCV [J/cm$^2$] | 23,9±4,3 | 24,9±0,7 |
| $R_m$ [MPa] | 1068±6 | 1125±4 |
| $R_{p0,2}$ [MPa] | 556±7 | 667±25 |
| $A_5$ [%] | 12±1 | 14±1 |

a) b)

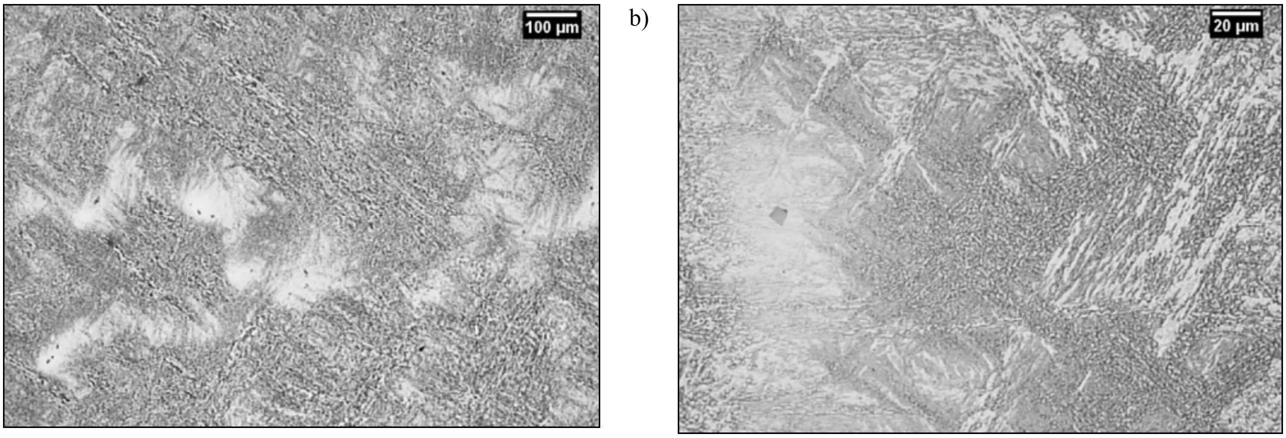



Fig. 2. Microstructure of the bainitic cast steel after normalizing. Etching 4% natal

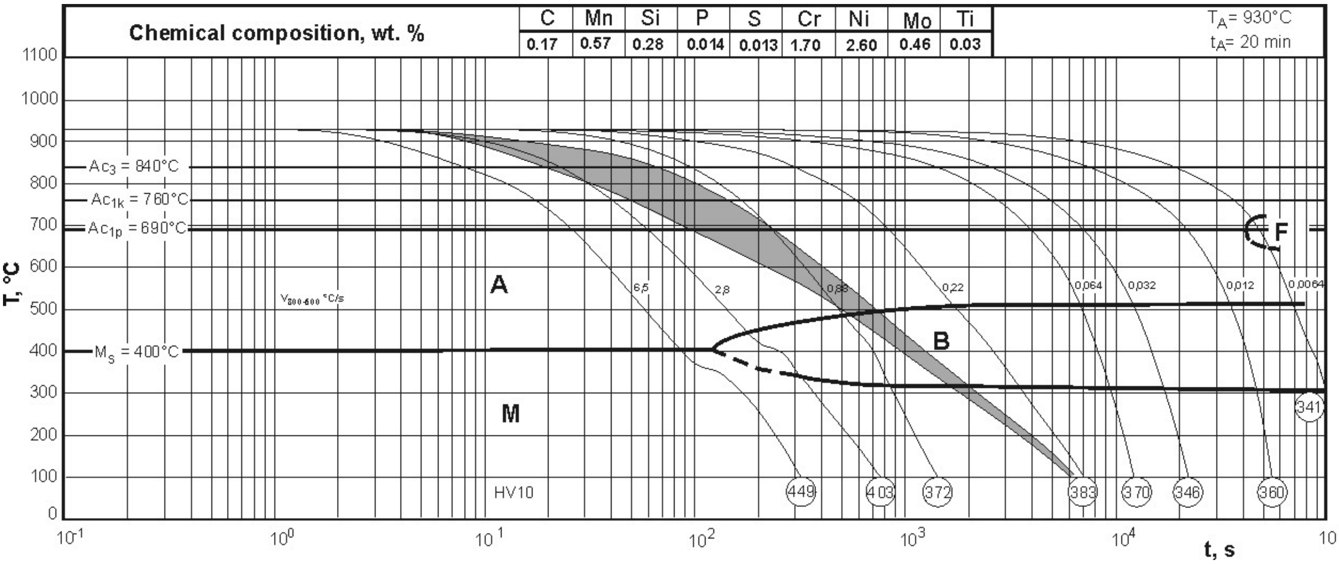



Fig. 3. CCT diagram of bainitic cast steel. Shaded area includes the ranges of air cooling curves, realised on a cross section of UIC60 type

On the diagram the ranges of cooling (shaded areas) of rail type UIC60 are shown, prepared in works [20,21]. The cooling rate in air from the temperature of austenitizing, allows to reach the microstructures of bainite on the whole section of cast of frog and probably slight amount of retained austenite (fig. 3). Assigned critical temperatures and high bainitic hardenability of examined material should not be a reason for technological problems, because the temperature of normalizing at 900°C ± 10°C ($Ac_3$ + 50°C). High $M_S$ temperature – 400°C additionally decreases the risk of appearance of hardening cracks.

# 4. Conclusions

The results described in this work allow to form the following conclusions:

- cast steel proposed as a material for frogs in railway crossovers fulfils of microstructure and hardness requirements;
- critical temperatures ($Ac_{1s}$, $Ac_{1f}$, $Ac_3$) were estimated by dilatometric methods, which allowed to set the parameters of heat treatment correctly;
- confirmed heat treatment of raw cast caused complete crystallization of an original grain of austenite which confirmed homogeneous microstructure necessary for furtherr process of resistance welding;
- The CCT diagram shows strong bainitic character of examined cast steel and enables to anticipate the microstructure and mechanical properties after heat treatment.

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