Rail steel production consists of proper combination of alloying elements and heat treatment, where a wide range of grades can be produced, differing in terms of hardness and the corresponding resistance to wear. A railway’s choice of rail grade is made in terms of traffic and track conditions and excellent service life can be achieved, particularly if modern rail head lubrication and grinding practices are used. This investigations deal with changing the standard heat treatment, based on classic perlitic steel to save energy during the production. For this reason the investigated R350HT steel was subjected to isothermal heat treatment, consisting of hardening to obtain bainitic microstructure. The steel was then annealed, after this step a further cooling took place with furnace then final cooling have been made in air. The microstructure of the steel was examined in the light metallographic microscope Zeiss and scanning electron microscope. In addition, on samples cross-section Vicker's microhardness examination was performed as well as friction wear test was carried out with the use of a tribometer. Also Charpy impact toughness test was performed at room temperature for evaluation of the obtained mechanical properties. On the basis of the carried out analysis of the light microscope structure investigations, it was found, that the microstructure of the R350B steel was formed of relative large irregular grains. The obtained results of the mechanical properties investigations reveals only a low increase of the hardness, wear resistance of the 350B steel compared to the classical 350HT steel. The obtained results have not confirmed the occurrence of the bainitic structure in the 350B steel, however the present ferritic structure reveals some advantage related mainly to lower energy consumption during heat treatment with a hardness and wear resistance values nearly on the same level as in case of the 350HT steel.

**Key words:** isothermal heat treatment, rail steel, perlitic, bainite, microstructure.

### 1. INTRODUCTION

The first steel rails used anywhere in the world were laid in Derby station on the Midland Railway in 1857. The metallurgical structure of those rails was essentially the same as that of the rail steel still used today — a perlitic structure based on a carbon/manganese composition (Tab. 1).

Rails not only wear, they also break mainly due to rolling contact fatigue (RCF) and brittle fracture. Their inherent toughness is poor as a result of the presence of the brittle carbide phase. Fracture can occur from relatively minor stress-concentrating features inside the rail, or on the surface, as a result of manufacture or subsequent handling damage. At least one European railway network suffers almost 4000 rail fractures every year. These are rarely dangerous, as modern track signalling systems and routine inspections will find most. However, they do have a high replacement cost and can be very disruptive to the network.

Up until the 1970s, rails for passenger and freight trains were regarded as relatively simple undemanding products and the specifications had changed very little for decades (Fig. 1). However, investments in railway systems, the advent of high-speed passenger trains and the requirement for longer life track imposed a demand for rails of high quality, greater strength and tighter geometric tolerances.

Therefore there have been major innovations in the past 20 years in terms of the method of manufacture, degree of inspection and range of products.

As was mentioned above, the rails are subject to heavy contact cyclic loading that accompanies increased car size and loading, to 100 and 125 ton capacity, increased train size, and increased train speeds used to transport bulk products over the last several decades. These increasing demands manufacturing and metallurgical approaches that offset wear and other types of failure that limit rail life. Depending upon the properties required, the rails are either cooled normally in air or subjected to enhanced cooling for the development of high strength. On cooling to room temperature, the rails are passed through a roller-straightener machine which subjects the section to a number of severe bending reversals and emerge with a very high degree of straightness. Finally, the rails pass through a series of ultrasonic, eddy current and laser inspection stations which monitor non-metallic inclusions, internal and external defects and the flatness of the running surface.

Bainitic rail steels are considered as promising candidates for the next generation of rail steels because they have lower carbon content (better weldability) and superior mechanical properties than perlitic steels, however lower wear resistance. Bainitic rail steel have superior resistance to rolling contact fatigue than perlitic steels.
2. INVESTIGATIONS METHOD

For investigations the rail steel R350HT was used, with the chemical composition presented in Table 2. The measurement of the chemical composition was made on the optical spectrometer LECO GD-S850A, three measurements were made and then calculated their average. Table 3 gives the chemical composition of the steel tested according to PN-EN13674-1: 2006. A part of the sample of steel R350HT was subjected to isothermal heat treatment — hardening to obtain bainitic microstructure (the sample was signed R350B). Sample R350B has been subjected to an isothermal heat treatment consisting of austenitizing at 850°C for 30 minutes and then accelerated cooling with compressed air to temperature 350°C in 14 seconds. Steel was then annealed at this temperature for 25 minutes, after this time a further cooling took place with furnace to 200°C then final cooling have been made in air (Fig. 2). Heat treatment parameters being selected in accordance with the graph CTP (Fig. 3) for obtaining bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. Austenitizing have place in furnace Czylok FCF 2,5P, isotermic hardening in Czylok FCF 4/160M/PG containing bainitic microstructure. 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For the wear resistance investigations the wear profile was obtained (Figs. 12 and 14). For the steel sample R350B the maximal wear depth was measured as 7.5 µm, whereas for the steel sample R350B it was determined as 5 µm. The lower wear resistance for the R350B steel is of practical interest because of the steadily wear occurred during usage, what lowers the costs of maintaining the rails, without the necessity to machine it during service.

Differences between the steels R350B and R350HT are also visible for the friction coefficient values. For the R350 steel the friction coefficient is in the range between 0.5÷0.6 and cannot be unequivocally determined on the basis of the obtained results (Fig. 13). While the friction coefficient for the steel R350 HT is equal 0.6 and constant (Fig. 15).

The new heat treatment shows low increase in hardness (Fig. 16) and toughness (Fig. 17) of the 350B rail steel compared to the 350HT rail steel.
Fig. 10. Microstructure of the R350HT steel sample; SEM
Rys. 10. Mikrostruktura próbki ze stali R350HT; SEM

Fig. 11. Microstructure of the R350B steel sample; SEM
Rys. 11. Mikrostruktura próbki ze stali R350B; SEM

Fig. 12. Wear profile of the steel sample R350B
Rys. 12. Profil wytarcia próbki ze stali R350B

Fig. 13. Wear coefficient measurement of the steel sample R350B
Rys. 13. Współczynnik tarcia próbki ze stali R350B

Fig. 14. Wear profile of the steel sample R350HT
Rys. 14. Profil wytarcia próbki ze stali R350HT

Fig. 15. Wear coefficient measurement of the steel sample R350HT
Rys. 15. Współczynnik tarcia próbki ze stali R350HT

Fig. 16. Hardness measurement results
Rys. 16. Wyniki pomiarów twardości

Fig. 17. Diagram of the Charpy V notch impact toughness for the R350HT and R350B steels
Rys. 17. Porównanie udarności Charpy’ego stali R350HT i R350 B dla próbek z karbem V
3. CONCLUSIONS

According to the obtained results the bainitic structure was not achieved, however the present ferritic structure reveals some advantage related mainly to the energy consumption during heat treatment with a relatively high hardness and wear resistance values.

Particularly the light microscopy analysis results confirmed that the steel R350HT has a more uniform structure than the steel R350B both concerning the cross-section (Figs. 4 and 5) as well as the longitudinal direction (Figs. 6 and 7). Investigation performed on the scanning microscope showed that the distance between the perlite plates in the steel HT R350 is higher and equal to 0.36 µm (Fig. 10), while in the steel R350B is approximately 0.26 µm (Fig. 11). The abrasive wear testing has shown that a higher abrasive resistance was obtained for the steel R350B, however, the steel R350HT has a more constant friction coefficient.

Whereas, investigations of the mechanical properties showed that a slightly higher hardness (Fig. 16) and toughness (Fig. 17) has the steel R350B compared to the 350HT steel.

REFERENCES

Zastosowanie izotermicznej obróbki cieplnej dla perlitycznej stali szynowej

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1. CEL PRACY

Stawiane obecnie wymagania dotyczące szyzn kolejowych są coraz bardziej restrykcyjne i obejmują coraz więcej wad oraz nieuwzględnianych parametrów. Wraz ze zwiększającymi się wymaganiami idzie potrzeba usprawniania procesu technologicznego obejmującego szereg etapów, takich jak: ciągłe odlewanie stali, walcowanie, obróbka cieplna i prostowanie. Konieczne jest opracowywanie nowych gatunków stali o lepszych właściwościach, w szczególności odporności na wadę cienistą. Największe możliwości sterowania właściwościami stali stosowanych na syzny daje modyfikacja mikrostruktury z perlitycznej na bainitę.

Celem podjętej pracy było uzyskanie w stali szynowej o składzie chemicznym odpowiadającym gatunkowi R350HT struktury bainitu, a następnie porównanie twardości i odporności na ścieranie oraz struktury stali zahartowanej ze stali w stanie przed obróbką izotermiczną (struktura perlityczna).

W skład badanego materiału wykorzystanego do produkcji stali szynowej wchodziły odpowiednio dobrane dodatki stopowe oraz została zastosowana określona obróbka cieplna. Istnieje wiele gałązí szynowej wchodziły odpowiednio dobrane dodatki stopowe oraz izotermiczna (struktura perlityczna) oraz struktury stali zahartowanej ze stali w stanie przed obróbką bainityczną, a następnie porównanie twardości i odporności na zużycie ścierne zastosowano metodę kula–tarcza.

3. WYNIKI I ICH DYSKUSJA

W wyniku obserwacji mikrostruktury za pomocą mikroskopu świetlnego, w próbce R350B zaobserwowano większe ziarna w porównaniu z ziarnami w stanie przed obróbką cieplną. Może mieć na to wpływ zbyt długi czas austenityzowania stali. Można mówić o znaczącym zwiększeniu się utrudnień w porównaniu ze stalią R350HT.

Różnice pomiędzy stalą R350B a R350HT są widoczne również dla współczynnika tarcia. Dla stali R350 współczynnik tarcia za wiera się w przedziale 0,5÷0,6 i nie można go jednoznacznie określić na podstawie uzyskanych wyników. Natomiast współczynnik tarcia dla stali R350 HT wynosi 0,6 i ma charakter stały. Nie stwierdzono znaczącego zwiększenia się utrudnień po obróbce cieplnej.

4. PODSUMOWANIE

Wyniki obserwacji za pomocą mikroskopu świetlnego potwierdziły, że stal R350HT charakteryzuje się bardziej równomiernej mikrostrukturą niż stal R350B zarówno na przekroju poprzecznym, jak i na wzdłużnym. Badania za pomocą skaningowego mikroskopu elektronowego wykazały, że wadność między płytkami perlitu w stali R350HT jest większa i wynosi około 0,36 μm, natomiast w stali R350B jest mniejsza i wynosi około 0,26 μm. Badania zużycia cierne wykazały, że lepszą odpornością na zużycie cierne charakteryzuje się stal R350HT, która cechuje się również bardziej stabilnym współczynnikiem tarcia. Badania właściwości mechanicznych wykazały, że z obu badanych stali większą twardością i odpornością charakteryzuje się stal R350B.