A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 57 2012 Issue 1
DOI: 10.2478/v10172-012-0020-9

S. PARZYCH*, J. KRAWCZYK*

THE INFLUENCE OF HEAT TREATMENT ON MICROSTRUCTURE AND TRIBOLOGICAL PROPERTIES OF RESISTANCE BUTT WELDS MADE OF A CAST BAINITIC STEEL

WPŁYW OBRÓBKI CIEPLNEJ NA MIKROSTRUKTURĘ I WŁASNOŚCI TRIBOLOGICZNE ZŁĄCZA ZGRZEWANEGO WYKONANEGO ZE STALIWA BAINITYCZNEGO

This work deals with the influence of heat treatment on microstructure and tribological properties of specimen cast assigned as a material used for frogs in railway crossovers. Materials used nowadays in the railway industry for frogs: Hadfield cast steel (GX120Mn13) and forged pearlitic steel (R260) do not fulfil strict conditions of exploitation and speed that should be reached on railway as indicated in the UIC Decision No. 1692/96. One of the possible solutions is using cast steel with bainitic or bainitic-martensitic microstructure, which allows to gain high strength properties (R_m = 1400 MPa, $R_{p0,2}$ = 900 MPa and up to 400 BHN). The test material is an alternative to railway frogs made of Hadfield cast steel. It remains problematic to determine the properties at the weld of the frog with the rail, which can also have bainitic microstructure.

To ensure similar wear in both the resistance joint and the base material the resistance butt joint should have almost the same mechanical and tribological properties as the base metal. The main objective of the present work is to study the influence of heat treatment on microstructure and tribological properties of resistance welds made of bainitic cast steel used for frogs in railway crossovers.

Keywords: heat treatment, bainitic cast steel, railway frogs, resistance butt welding

Niniejsza praca dotyczy wpływu obróbki cieplnej na mikrostrukturę i własności tribologiczne odlewu próbnego przeznaczonego jako materiałna krzyżownice kolejowe. Dotychczasowe materiały stosowane w kolejnictwie na krzyżownice: staliwo Hadfielda (GX120Mn13) oraz kuta stal perlityczna (R260) nie spełniają rygorystycznych warunków eksploatacji i prędkości osiąganych na nawierzchniach kolejowych zawartych w Decyzji UIC nr 1692/96. Jednym z rozwiązań jest zastosowanie materiałów o mikrostrukturze bainitycznej lub bainityczno-martenzytycznej, co umożliwia uzyskanie wysokich własności wytrzymałościowych (R_m =1400 MPa, $R_{p0,2}$ =900 MPa, twardości do 400 HBW). Badany materiałjest alternatywą dla krzyżownic kolejowych ze staliwa Hadfielda. Problematyczne pozostaje określenie również własności w miejscu połączenia krzyżownicy z szyną, która również może mieć mikrostrukturę bainityczną.

Wykonane złącze zgrzewane powinno wykazywać jak najbliższe własności (mechaniczne, tribologiczne itp.) do materiału rodzimego gdyż wówczas zapewniają one równomierne zużywanie się zarówno w obszarze złącza jak i samego materiału rodzimego. W pracy określono wpływ obróbki cieplnej na mikrostrukturę i własności tribologiczne zgrzein wykonanych ze staliwa bainitycznego stosowanego na krzyżownice do rozjazdów kolejowych.

1. Introduction

The railway crossovers are the most complex elements of the railway track, not only because of their construction, but also because of intensive wear. According to the Decision UIC No. 1692/96 it is necessary that the joints between the frog and the rail are made in non butt joint method in order to increase the rail speed to 200 km/h with pressure on axis not lower than 230 kN. Forged steel with pearlitic microstructure (R260) and Hadfield cast steel (GX120Mn13) are currently used for frogs [1].

The possible means of increasing mechanical properties of materials presently used in the rail transport by heat treatment were described in ref [2]. It has been proved that the combination of high mechanical strength and hardness of heat treated rails do not guarantee good wear properties [3]. Therefore there is a growing interest in using bainitic steels as a more suitable material for heavily loaded elements of the railway track [4-13]. The bainitic steels currently used for frogs are mostly

* FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, 30 MICKIEWICZA AV., POLAND

low-alloy steels, normalized between 850 and 950°C, hardened, and tempered at 300÷400°C [14,15]. As described in ref [16] the resistance to wear of bainitic cast steels depends on the temperature of isothermal transformation and tempering conditions, whereas the prior normalizing is indispensable for preparing the material to welding [17]. It is essential that the available CCT diagrams allow to obtain bainitic microstructure across the cast frog with negligible amount of retained austenite [17].

Welding of materials with bainitic microstructure promotes local hardening within the heat affected zone (HAZ) which yields increased hardness of the joint. The joint should have similar mechanical and tribological properties to the base material in order to ensure similar wear rate of the resistance joint and the base material. Therefore in this work it was attempted to determine the influence of heat treatment on microstructure and tribological properties of welds made of a bainitic cast steel designed for the frogs in railway crossovers.

2. Experimental procedure

A 50 kg bainitic steel ingot, 100×100×5000 mm, was provided by the Foundry Research Institute in Krakow in as-cast condition. Its chemical composition is presented in Table 1.

TABLE 1
Chemical composition of the experimental cast steel (wt.%)

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*

The ingot was cut into smaller pieces perpendicular to its longer edge and then the specimens were cut out parallel to the side surface of the ingot. To design the heat treatment process the Ac_{1s}, Ac_{1f} and Ac_3 critical temperatures were first estimated by means of dilatometry. As shown in Fig. 1, prior to welding the cast steel specimens were normalized for 30 minutes at 930°C. After welding the butt joints were re-heated to 930°C, held for 30 minutes at temperature and cooled in air. In the next stage the welds were tempered for 60 minutes between 350 and 650°C at 50°C intervals.

The heat treated specimens were subsequently tested for hardness using the Vickers pyramid and a load of 294.2 N (30 kG). The tribological tests were performed on a block-on-ring type tribometer, where the ring was made of the 100Cr6 grade bearing steel heat treated to 57 HRC. The test consisted in determining the loss of mass of the test specimen that covered a wear path of 5000 m under a constant load of 45 N.

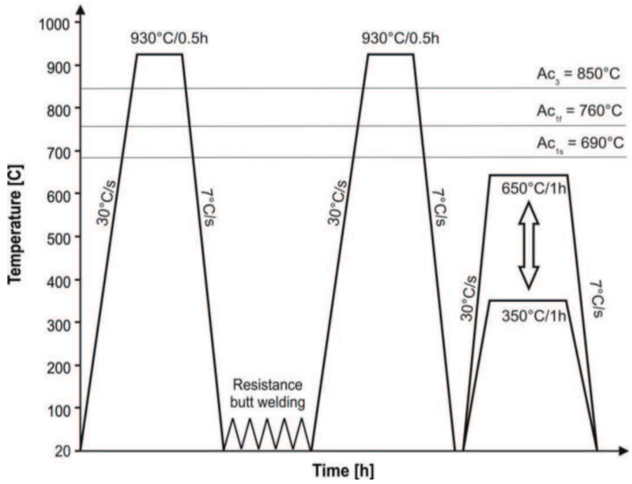

Fig. 1. Schematic representation of the heat treatment operations

3. Results and discussion

As shown in Fig. 2, the as-normalized hardness is 340÷360 HV30 across the tested area and do not decrease after tempering at between 350 and 600°C (320÷350 HV30). Significant decrease in hardness occurs after tempering at 650°C. This indicates that the optimal tempering temperature lies between 350 and 600°C.

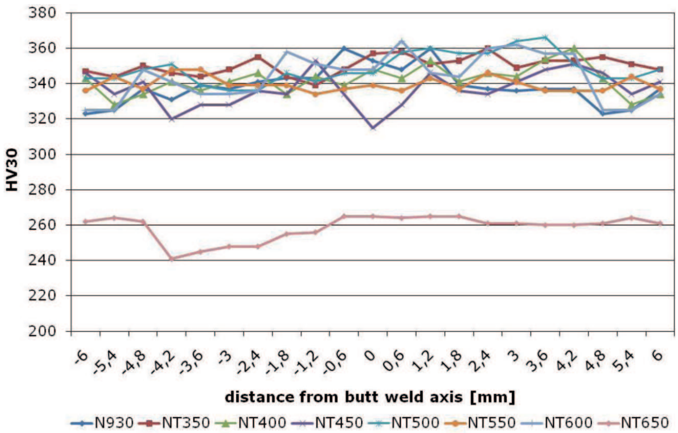

Fig. 2. Hardness profiles across the butt welds

Figure 3 shows the wear patterns observed within the butt weld (BW) and heat affected zone (HAZ) areas for each variant of heat treatment. The wear surface topographies imply that the tested specimens were mainly worn by adhesive wear and by abrasion, e.g. the HAZ in the normalized specimen N-HAZ (Fig. 3a) shows evidence of adhesive wear, whereas the abrasive mode of wear prevails in the butt weld area (Fig. 3b). Tempering at 350°C apparently increases the contribution of adhesive wear (Figs 3c and 3d). Further increase in the tempering temperature does not influence significantly the wear mechanism (Fig. 3e-k). The biggest contribution of adhesive wear at the weld area can be observed after tempering at 500°C. The increase in abrasive wear can be observed only after tempering at 550°C, whereas further growth of tempering temperature restores domination of adhesive mode.

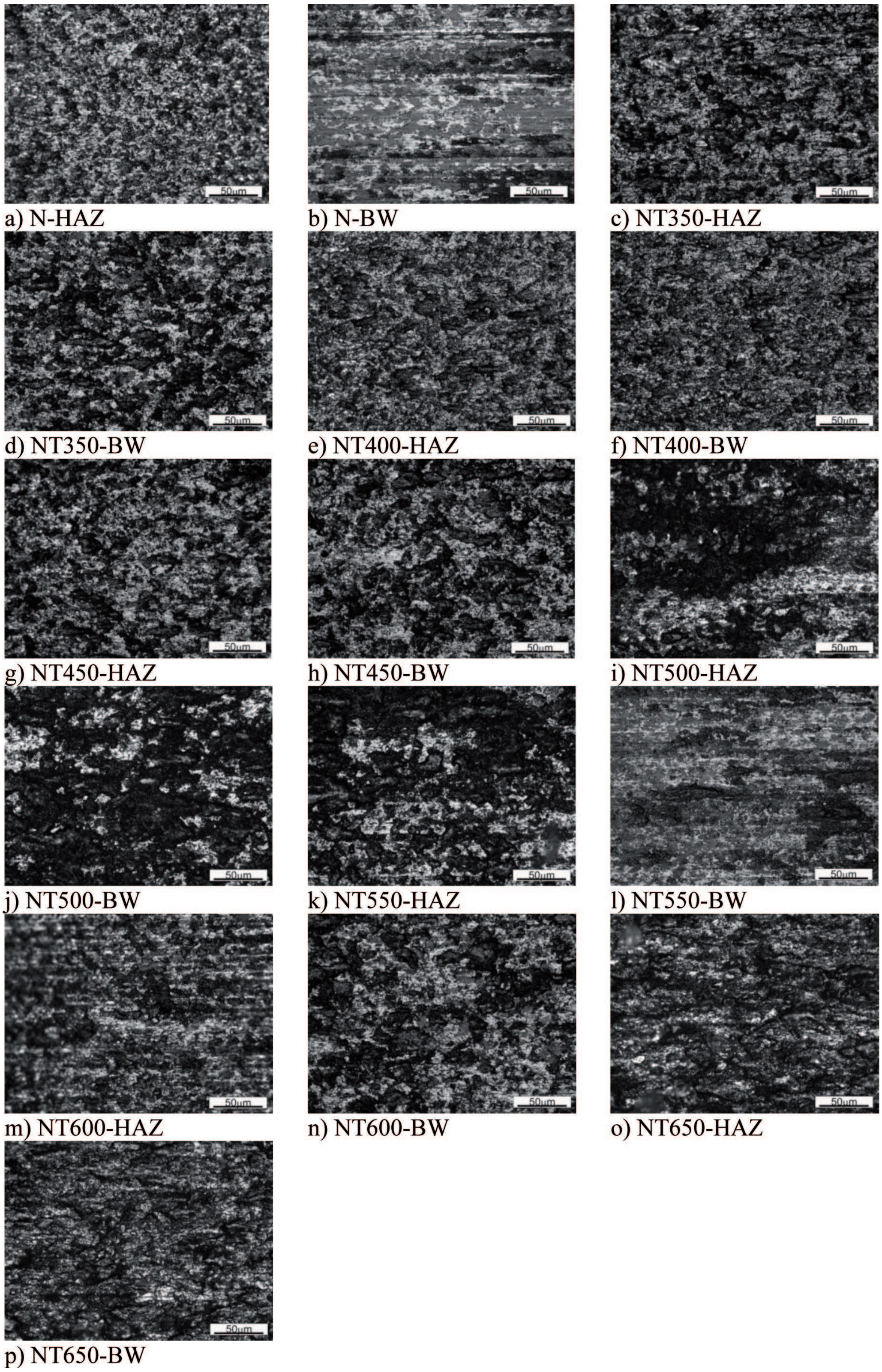

Fig. 3. Wear surfaces within the butt weld area (BW) and heat affected zone (HAZ) observed on as-normalized (N) and as-tempered (NT) test specimens

The dependence of total wear on tempering temperature is presented in Fig. 4. The maximum loss of mass (0.0316 g) was recorded for specimens tempered at 650°C, whereas the minimum wear showed specimens tempered at 500°C. Tempering at 350°C did not have any effect on the wear rate which was nearly the same as upon normalizing.

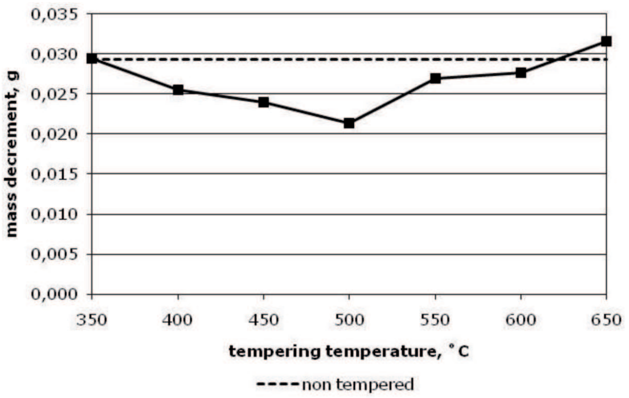

Fig. 4. Loss of mass as a function of tempering temperature

4. Conclusions

- Tempering at 350÷600°C has negligible effect on hardness within the weld area (320÷350 HV30), whereas the hardness markedly decreases (240÷260 HV30) after tempering at 650°C.
- The level of wear does not depend on hardness.
- The specimen's wear was minimized after tempering at 500°C, where mainly adhesion induced material transfer was observed within the HAZ and BW.

Acknowledgements

The research program was financed by the Ministry of Science and Higher Education and performed within the Supervisor's Grant No. N507 473337.

REFERENCES

[1] M. Hotzman, I. Dlouhy, J. Zboril, Mechanical properties and fracture behaviour of cast steel with bainitic microstructure and its use for cast crossings, Hutnicke Listy **58**, 8-20 (2003).

[2] D. Korab, The Modern construction and technological solutions in the field of railway crossover, Railway Review **131**, 89-92 (2000) (in Polish).

[3] J. Pacyna, J. Krawczyk, The wear mechanism of toughened rails, Metallurgy and Foundry Engineering **27**, 2, 229-235 (2001).

Received: 10 January 2011.

[4] H.A. Aglan, Z.Y. Liu, M.F. Hassan, M. Fateh, Mechanical and fracture behaviour of bainitic rail steel, Journal of Materials Processing Technology **151**, 268-274 (2004).

[5] J. Pacyna, The first Polish bainitic rails, Polish Metallurgy in years 2002-2006, Committee of Metallurgy of The Polish Academy of Science, 651-656 Krakow (2006) (in Polish).

[6] F.C. Robles Hernández, N.G. Demas, D.D. Davis, A.A. Polycarpou, L. Maal, Mechanical properties and wear performance of premium rail steels, Wear **263**, 766-772 (2007).

[7] K.M. Lee, A.A. Polycarpou, Wear of conventional pearlitic and improved bainitic rail steels, Wear **259**, 391-399 (2005).

[8] P. Clayton, Tribological aspects of wheel-rail contact: a review of recent experimental research, Wear **191**, 170-183 (1996).

[9] J. Pacyna, P. Bała, Microstructure and properties of new bainitic cast for railway frogs, V Nationwide Scientific – Technical Conference „Welding railways – the quality, reliability, safety". Bochnia, 12 - 14 May (2010) (in Polish).

[10] J. Pacyna, T. Skrzypek, Phase transformations of super-cooled austenite of new bainitic materials for railway frogs, Archives of Foundry Engineering, 8, 111-115 (2008).

[11] R.K. Steele, Steel alloys with lower bainite microstructures for use in railroad cars and track, Report of the Federal Railroad Administration, Washington, D.C. (2002).

[12] H. Bąkowski, A. Posmyk, J. Krawczyk, Tribological properties of rail steel in straight moderately loaded sections of railway tracks, Archives of Metallurgy and Materials **56**, 3, 813-822 (2011).

[13] J. Krawczyk, M. Witaszek, K. Witaszek, Tribological properties of tyre steel in rolling-sliding contact against bainitic rail steel, Archives of Metallurgy and Materials **56**, 3, 710-715 (2011).

[14] F.C. Zhang, C.L. Zheng, B. Lv, T.S. Wang, M. Li, M. Zhang, Effects of hydrogen on the properties of bainitic steel crossing Engineering Failure Analysis **16**, 5, 1461-1467 (2009).

[15] D.R. Pendelton, K. Compton, E.G. Jones, Welded and cast – Centre crossings accepted after trawl, Railway Gazette International, 3, (1986).

[16] M.R. Green, W.M. Rainforth, M.F. Frolish, J.H. Beynon, The effect of microstructure and composition on the rolling contact fatigue behaviour of cast bainitic steels, Wear **263**, 1-6, 756-765 (2007).

[17] S. Parzych, E. Tasak, Influence of heat treatment on microstructure and properties of bainitic cast steel used for frogs in railway crossovers, Archives of Foundry Engineering **10**, 1, 113-116 (2010).