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HOT ROLLED STRETCH FLANGE STEEL (SFHS-600): EXPERIENCE AT TATA STEEL

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Abstract

Fuel economy together with safety considerations is the driving forces for the steadily increasing usages of higher strength steels in automotive industry. Dual phase steel based on ferrite and martensite structure possesses a potential to reduce the weight of the automobile components as they have good combination of strength and elongations, and a low yield ratio. However, their use is not fully established for wheel rim application due to softening in HAZ leading to localized necking during stretching of the welded hoop.

This paper presents the development work on high strength steel for wheel rim and disc applications. The steel chemistry selected has low carbon, high manganese and approximately 0.04%Nb. Thermodynamic calculations were made to predict various phases formed during run out table (ROT) cooling. The steel was commercially processed through the basic oxygen process (BOF)-ladle furnace (LF)-slab caster route. Transformation behavior of the steel and ROT simulation was carried out using a thermo mechanical simulator. The microstructure of the steel consisted of ferrite and 15-20% bainite. The material showed yield strength of the order of 520 MPa while ultimate tensile strength and percentage elongation were found to be 610 MPa and 29 percent respectively. The hot rolled strip was commercially processed into wheel rim and disc successfully. The weld joint of the rim was examined in the as welded condition to assess its soundness.

Introduction

In the recent years, weight reduction of auto bodies has become a main objective for automakers for reducing CO_2 gas emissions as well as for improving fuel efficiency. These two factors along with safety considerations of an automobile are responsible for the increasing usage of high strength steels in the automotive industry. Compared to other materials, such as the light metals aluminum and magnesium or plastics and composites, the higher strength steels have a number of additional advantages such as an easier processing route, lower fabrication cost and better recyclability, leading to a reduction in the overall fabrication cost and weight savings [1].

A variety of high strength steels are in use for automobile application to meet different strength and formability requirements. High strength steels based on the interstitial free grades exhibit outstanding cold formability properties [2] and are used for various deep drawn components. For less stringent forming applications, low carbon phosphorous alloyed or bake hardening steels are applied. Efforts are being made to increase the strength of the material and ductility based on the suitable microstructure, processing conditions and grain refinement. Some of these steels are DP (ferrite-martensite), TRIP, ferrite–bainitic and fully bainitic steels [3, 4].

The use of high strength steels for wheel rim and disc applications is one of the most effective ways to realize weight reduction of a vehicle. However, the properties required in steels for wheel applications include tensile properties, weldability, formability after flash butt welding for the wheel rim, stretch flangeability and fatigue strength [5]. Dual phase steels with ferrite and martensite structure possess a good combination of strength and elongations and show a low yield to tensile ratio [6, 7]. However, their use is not fully established for wheel rim fabrication because of the unique problem of softening of the heat affected zone (HAZ) leading to localized necking and fracture that occur when the welded hoop is expanded. Steels based on ferritic-bainitic microstructure have been reported to be more suitable for rim application [8].

This paper presents and discusses the work carried out to produce SFHS-600, a ferritic-bainitic grade steel in hot rolled condition. The work includes production of SFHS-600 ferritic-bainitic steel characteristics of weld joint material including forming after welding.

Experiment

Thermodynamic calculations were carried out to predict the transformation temperature and precipitate formation using the Thermo-Calc software. A pseudo binary diagram was constructed and the effect of manganese and silicon on the phase equilibrium lines was assessed using Thermo-Calc. Transformation temperatures during heating were determined for the steel composition under investigation. The solubility of carbon and niobium at different temperatures was determined to assess niobium carbide precipitation.

Based on the thermodynamic calculations, a composition was chosen with low carbon, high manganese and with niobium as a microalloying element. Silicon was added to enhance ferrite formation on the run out table. Niobium was used to resist the softening behavior of the heat affected zone (HAZ) due to the precipitation of fine niobium carbides (NbC).

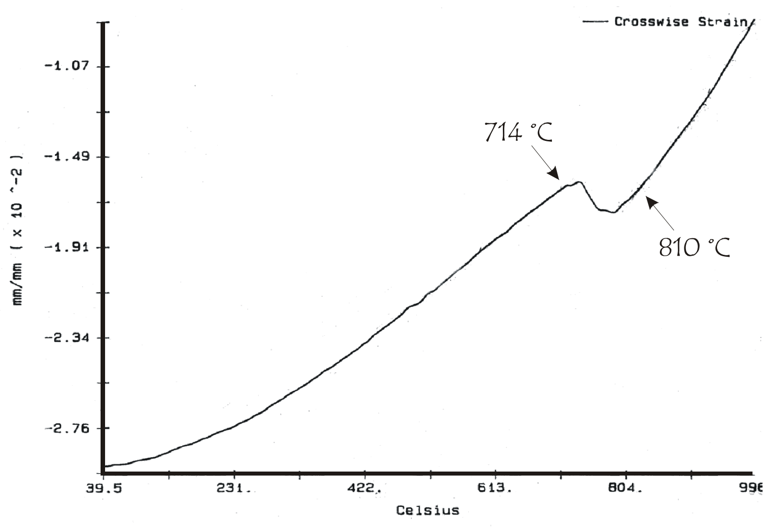

Figure 1. Dilatation curve of the steel at 10 °C/s.

The steel was processed through the BOF-LF-Slab caster route. Samples from slabs were collected to evaluate continuous cooling transformation behaviors for optimum processing of the steel in the hot strip mill. Austenite transformation temperatures were determined from the dilatation plot using the thermomechanical Simulator Gleeble-1500. A typical dilatation plot for a cooling rate of 1 $^{\circ}$C/second is shown in Figure 1.

Slabs were rolled in the hot strip mill (HSM) at a finish rolling temperature in the austenitic region. The strips were cooled from ~740^{0}C to coiling temperature. Samples from commercially processed coils were collected for property evaluation. Tensile tests were conducted on the strip samples as per the IS: 1608. The average anisotropy ratio ($\bar{r}$ value) was evaluated by the tensile test method. The BH value was also evaluated. The polished samples were etched with Le Pera reagent to reveal the ferrite, bainite and martensite phase in the optical microscope [9]. This special etching technique colors ferrite as tan, bainite as black and martensite as white grains. The ferrite grain size was measured using the grid method in an image analyzer. Specimens from the hot rolled strip were examined under the transmission electron microscope (TEM).

Results and Discussion

The effect of Mn on the Ac_3 is shown in Figure 2. As the Mn content increases, the Ac_3 line shifts to lower temperatures since Mn is an austenite stabilizer. In the present study, Mn was kept between 1.3 and 1.5%. Silicon has very little effect on the transformation temperature since it was restricted to low amounts (~0.5%). The solubility behavior of niobium and carbon was assessed using Thermo-Calc as shown in Figure 3.

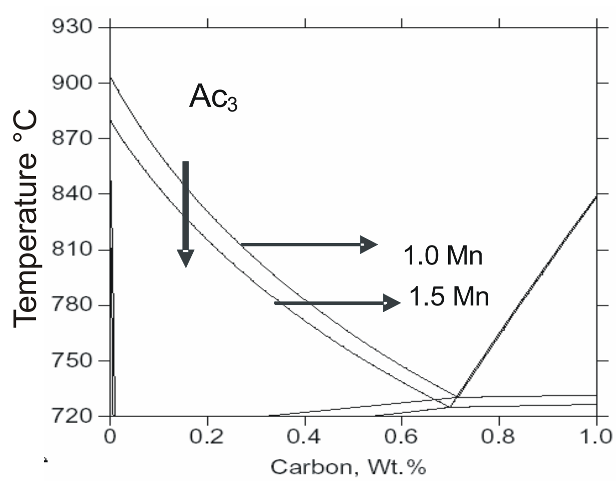

Figure 2. Effect of Mn on Ac_3 transformation temperature.

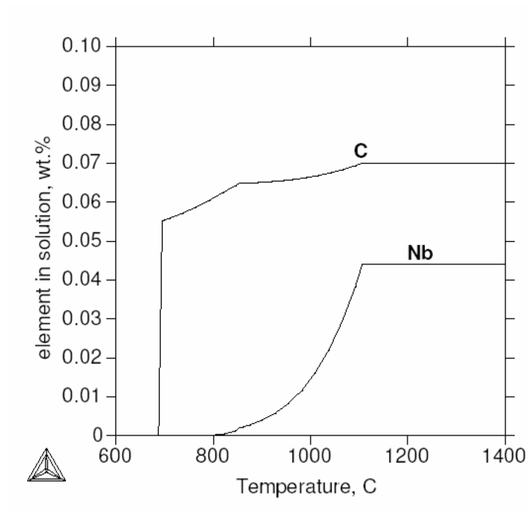

Figure 3. Solubility of carbon and niobium at different temperature.

The graph shows that at ~1150 $^{\circ}$C no NbC precipitation is expected, as up to this temperature the C and Nb are fully in solution. Thereafter, as soon as NbC is about to form, the elements in solution start decreasing. At about 800 $^{\circ}$C, the NbC precipitation is complete and there is no Nb left in solution.

Based on the above thermodynamic calculations, the composition for the commercial heat was selected and a phase diagram for this composition is shown in Figure 4. The Ac_3 temperature for the steel was found out to be ~850 °C. The FRT was kept ~20 $^{\circ}$C above the Ac_3. The amount of carbon in the austenite after 80% ferrite formation was calculated. Using the carbon content of remaining austenite, bainite start (B_s) and martensite start (M_s) temperatures for the composition were calculated. These were found to be ~480 and 370 °C, respectively. The coiling temperature was selected based on these temperatures.

The microstructure of hot rolled dual phase (ferritic-bainitic) is shown in Figure 5. It clearly shows bainite as the second phase after etching with Le Pera reagent. The average grain size was found to be ~7 µm. Quantitative measurement of the amount of bainitic phase was carried out by image analysis and was found to be 10 to 20%. The presence of bainite as second phase was confirmed from the TEM photographs as shown in Figure 6. The NbC precipitates observed under transmission electron microscopy (TEM) are shown in the Figure 7. Mechanical properties of the steel in HR condition are shown in Table I. It shows a yield strength of 523 MPa and an UTS of 610 MPa. The YS/UTS ratio was found to be ~0.84. Ferrite-bainite steels have a higher YS/UTS ratio than the conventional ferrite-martensitic dual phase steels, in which the YS/UTS is very low [5].

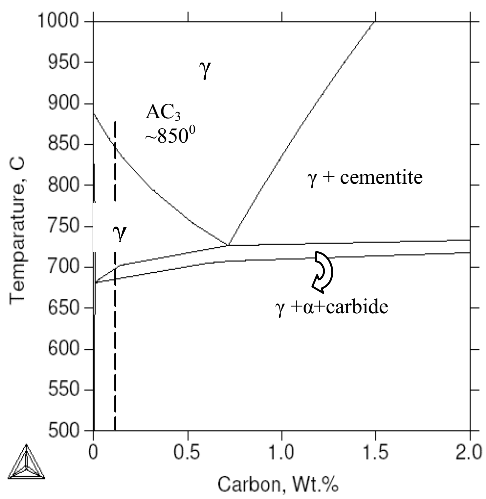

Figure 4. Phase diagram of the present steel.

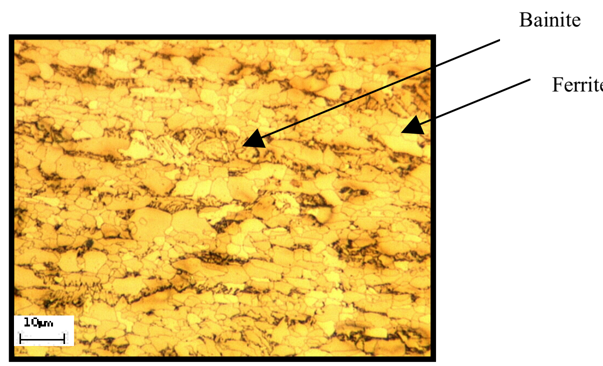

Figure 5. Optical microstructure of hot rolled SFHS-600.

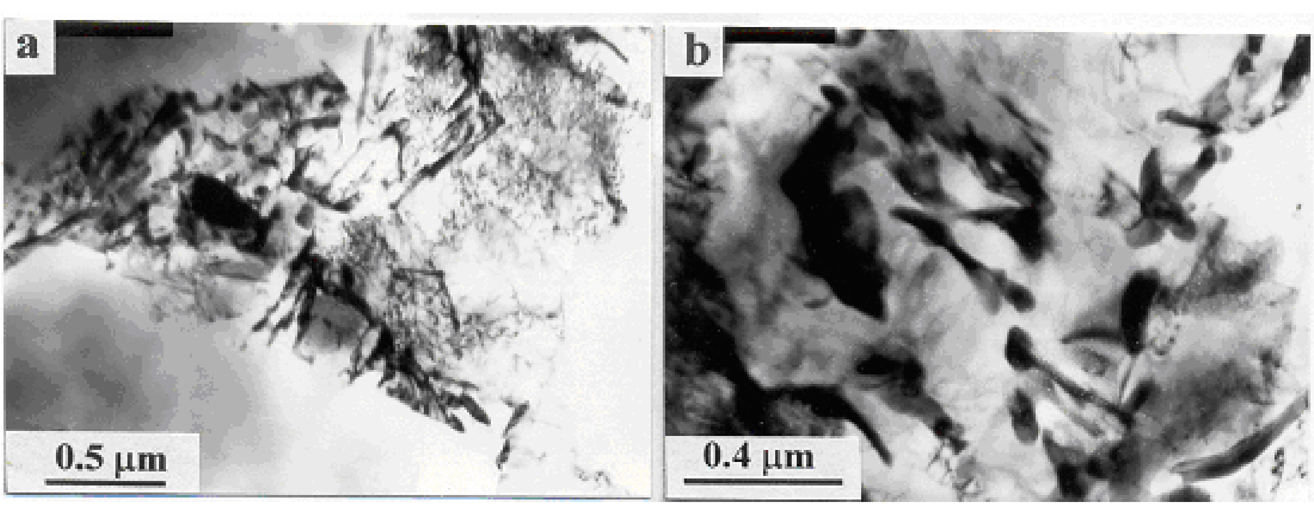

Figure 6. TEMs showing bainite as second phase.

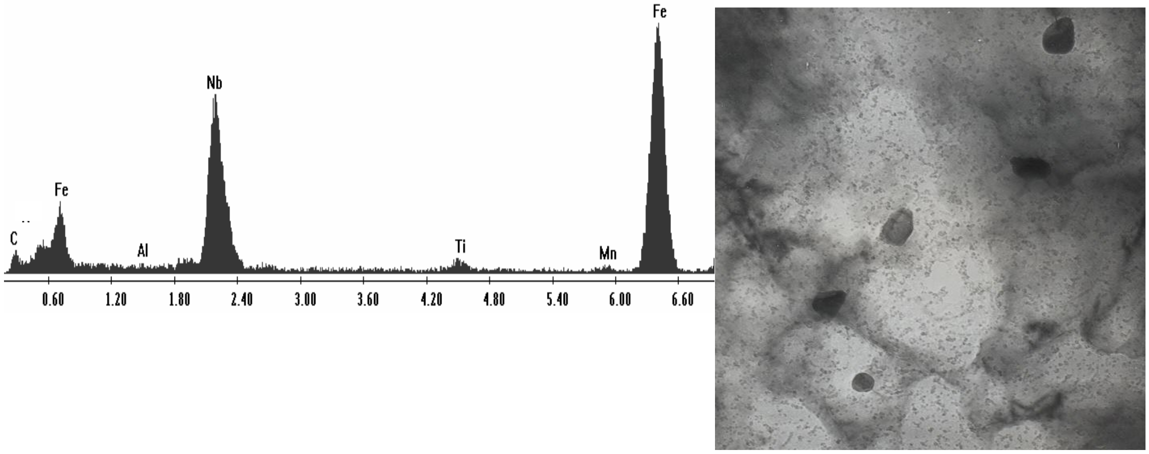

Figure 7. TEMs showing NbC precipitates.

Table I. Mechanical Properties of Hot rolled SFHS steel.

Gauge, mm	YS, MPa	UTS, MPa	El,%	n-value	$\bar{r}$ -value	GS, µm (Avg.)	Amount of 2[nd] Phase, %	BH value
3.2	523	616	26	0.15	0.91	7	10-20	20

The stress-strain curve of this steel is shown in Figure 8. A yield point phenomenon was observed. The strength of the dual phase steel should be expected to increase when either the volume fraction of second phase or strength of the second phase increases. In addition, the strength of the mixture increases as the strength of the ferrite or matrix phase increases [10]. The lower UTS of this steel is due to lower strength of bainite as compared to martensite, although the matrix has higher strength due to fine grains and solid solution hardening by alloying elements.

Excellent total elongation or TS-El combination was obtained when the second phase was not martensite but bainite as reported [5]. This is due to the difference in the solute carbon content. As reported, solute carbon was found to remain in solution in the dual phase steel due to rapid cooling to room temperature whereas less solute carbon was found in the bainitic steel. It was also reported [5] that a remarkable improvement in the stretch flangeability can also be observed when the second phase is bainite instead of pearlite or martensite. This difference comes from the ductility of the second phase. The strain-hardening exponent (n) was found to be 0.15 whereas the average anisotropy ratio was found to be 0.9. An average anisotropy value of ~1 indicates the microstructure to be random. The BH value was found to be ~20 MPa, which is particularly good.

Commercial Processing of Wheel Rim and Disc

Rim and disc were commercially manufactured for a 14 inch wheel size of a passenger car. The schematic processing line for wheel rim and disc are shown in the Figure 9 and 10, respectively.

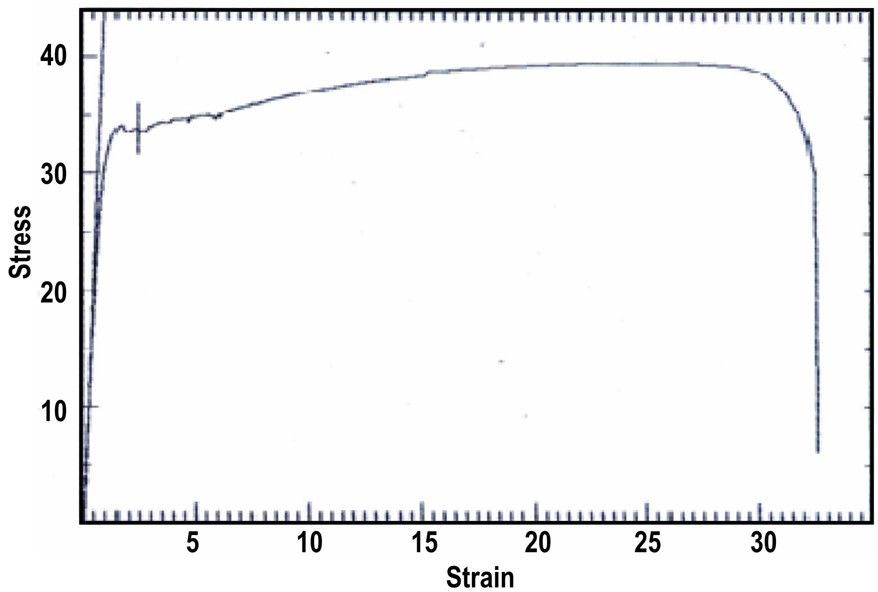

Figure 8. Tensile stress – strain curve showing yield point and very good uniform elongation.

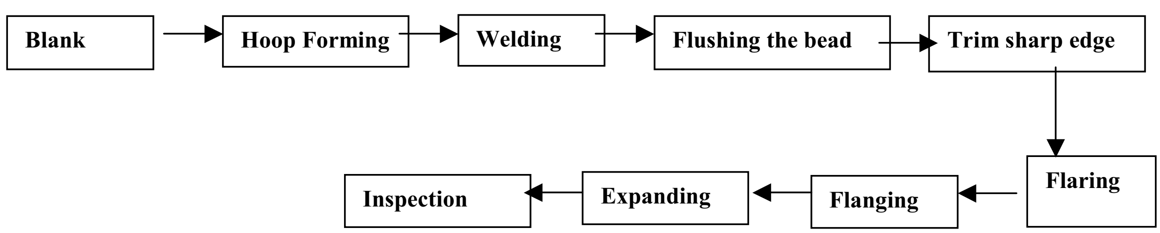

Figure 9. Typical schematic diagram of wheel rim manufacturing.

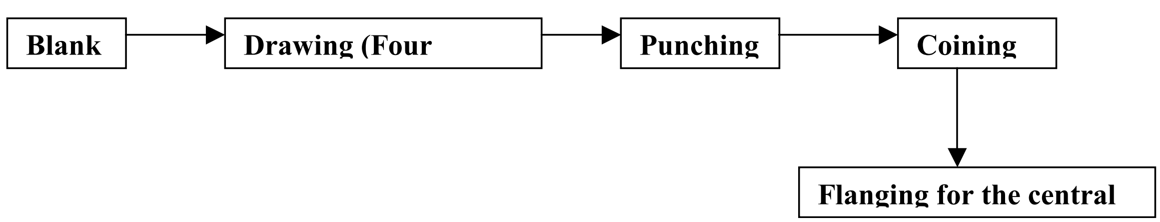

Figure 10. Typical schematic diagram of wheel disc manufacturing.

It is evident from the line diagram that welding is followed by a few critical forming steps (e.g flaring, flanging and expanding). Therefore, soundness of the weld zone during forming is of utmost importance. Hence, the soundness of as welded material (rim blank) was assessed. Microstructures of HAZ and the fusion zone are shown in Figure 11 and 12, respectively. The microstructure revealed no grain coarsening in HAZ due to precipitation of NbC (as evident from TEM examination). The microstructure of the weld revealed the presence of low temperature transformation products. However, a hardness profile across the thickness shown in Figure 13 revealed a marginal increase in the hardness from the parent metal to weld zone.

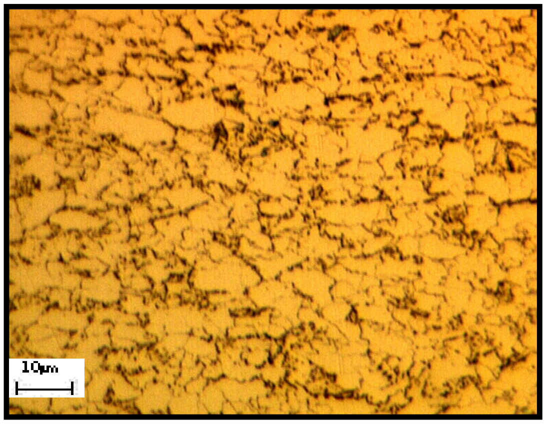

Figure 11. Microstructure of the HAZ

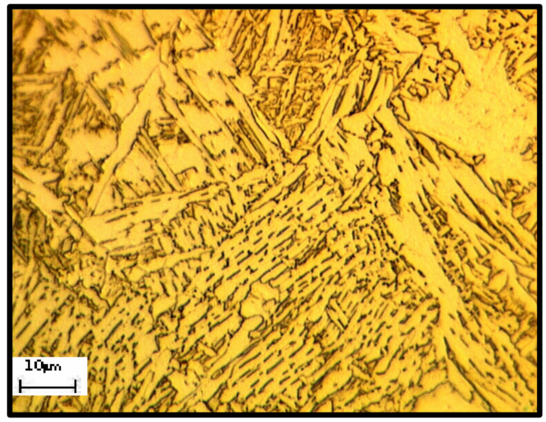

Figure 12. Microstructure of the fusion zone

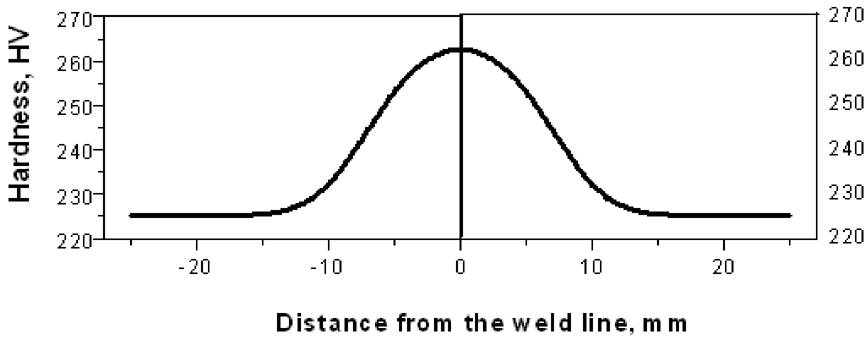

Figure 13. Hardness profile across the weldment.

Conclusions

1. It was found that niobium carbide fully precipitates out at around 800 °C and above 1150 °C no niobium carbide is present, i.e., niobium and carbon are in solution.
2. The amount of second phase (bainite) was found to be ~10-20%
3. Niobium carbide precipitation (NbC) was observed being responsible for restricting the softening of the HAZ.
4. The steel was found to be suitable for production of the wheel rim and disc.

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