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Decrease in Energy Consumption and Increase in Productivity & Quality of Wheels at Wheel And Axle Plant Of Durgapur Steel Plant, Durgapur

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Abstract- Wheel and Axle plant of Durgapur Steel Plant is producing Coach and Locomotive wheels as per Indian Railway Specification. Wheels are produced through forging, rolling and rim hardening process. Heat treatment process is very critical for increasing the productivity of Wheel and Axle Plant.Hot charging of wheels during heat treatment has some obvious benefits of conserving energy and reduction in furnace residence time. Lower residence time in heat treatment leads to increase in productivity of heat treatment section and improve the quality of wheel. Prior to introduction of hot charging in heat treatment a process study was carried out keeping in view the existing shop practice of rolling and heat treatment. Issues addressed are of time-temperature relationship, process delay and heat treatment process requirement. It is essential to lower the temperature of wheels below their Ar_3 temperature. Since forging and rolling temperatures are high, bigger and mixed grains are characteristics of as rolled wheels. Wheels need to undergo transformation from austenitic range. Once this is achieved a finer and more uniform grain structure can be obtained in subsequent heat treatment.

In order to increase productivity of heat-treatment and reduce energy consumption, hot charging has been introduced in wheel and axle plant. Dialatometry was carried out to determine Ar3 temperature for wheel steel. Time temperature relationship of wheels after stamping and cooling in air were predicted using ANSYS software. Results were validated by pyrometer. Based on data analysis shop logistics were worked out to synchronise rolling, air cooling and furnace duration. Modified thermal regime in heat treatment furnace was incorporated.

In order to minimize reheat treatment, simulation of heat treatment was carried out using Themo-Mechanical simulator 'Gleeble' ANSYS package of FEM. Heat treatment cycle was simulated in 'Gleeble' and cooling rates were determined to get desired hardness at tread in wheel. Temperature profiles were generated selecting flow rates and differential flow at tread surface. Based on the results spray ring was modified to have intense as well as differential cooling. Water flow meter, IR pyrometer have been installed in all the three rim spray machines in Wheel & Axle Plant.

To maintain consistency in wheel quality and reduction in reheat treatment a new spray ring has been procured along with dovetail nozzles. These nozzles are capable of delivering 25 lpm at 2 kg/cm^2 pressure. Modified rim spray ring has been installed in wheel & axle plant. This ring is made of stainless steel. Special care has been taken to maintain uniform flow from all direction so that consistency in rim spray is obtained.

Furnace cycle time has been reduced from 4 to 2hrs 30mins for coach wheel and from 5 to 4hrs for loco wheel. This has resulted in increase in productivity of heat-treatment shop by more than 30%. Optimisation of heat-treatment parameters reduced occurrences of reheat-treatment from more than 10% to less than 3%. Energy saving of around 20% has been achieved after introduction of hot charging. Quality of wheels has improved due to finer inter lamellar spacing. UTS is now in higher band of specification with average UTS increase from 860 to 875 MPa and decrease in standard deviation from 45 MPa to 25 MPa. Values of hardness of front rim face in, as rim sprayed condition, improved by ~15-20 BHN.

Key words: Railway wheel, heat treatment, hardening, hot charging.

1. INTRODUCTION

Wheel and Axle plant of Durgapur Steel Plant, Durgapur is producing broad gauge coach and locomotive wheels as per the Indian Railway specification R-19-93 and R-34-99 respectively. Wheels are produced through forging, rolling and rim hardening process. Required properties are imparted to these wheels through rim spray and tempering process. A fine pearlitic structure at tread is generated to get desired hardness range upto 30 mm from the tread surface by modifying the initial microstructure. Desired compressive stresses are also generated at rim, whereas stresses in web remain tensile in nature. Presently wheels are cold charged in heat treatment. Wheels are allowed to cool after forging, rolling and dishing operation Heat treatment section remains one of the major constraints in improving the overall production of wheel & axle plant. Major reasons of low productivity of heat treatment section are ineffective heat extraction during rim spray and longer furnace heating duration due to cold charging. Since, forging and rolling capacity of the Wheel & Axle plant is substantially high, increase in the productivity of heat treatment section will enhance the overall wheel production. Optimisation of heat treatment process is required to decrease the cases of reheat treatment

2. LITERATURE SEARCH/TECHNOLOGICAL STATUS

2.1 Wheel Making Process

Railway wheels are produced in Durgapur Steel Plant through forging–rolling-dishing-heat treatment-machining process. Wheels after rolling and dishing are stacked heatwise and allowed to cool down to room temperature. In this process latent heat of wheels after dishing is lost.

2.2 Heat Treatment Process for Railway Wheels

Modern rolling stock material – especially for high speed wheels – needs modern heat treatment technologies to assure highest quality and product safety combined with cost efficient mass production. Railway wheels belong to the most stressed components of railway vehicles. They carry axle loads of up to 25 tonnes and more. They guide the train on the track, through curves and switches and are subjected to wear processes. They transfer acceleration and deceleration forces to the rails and are exposed to thermal stressing due to sliding and block breaking processes. Moreover, considerable centrifugal forces are acting especially on high speed wheels. Different functional parts of the wheel such as flange, rim, centre or hub fulfil different tasks and have therefore different material properties. These properties are mainly determined by the chemical composition of the wheel material, hot forming and – most of all – by the heat treatment process [1]. The railway wheel is a mass product and a high-safety part. Therefore, during the production process of the wheel, special attention has to be given to the reliability, availability and safety of the product as well as to the quality, reproducibility and cost efficiency of the production process.

The wheels are heated in a rotary hearth type gas fired furnace at Durgapur Steel Plant. These wheels are rim sprayed in a rim quenching machine for preset duration and pressure. Wheels are placed with the help of mobile chargers on a guide cone in the centre of a disc rotating at 16 rpm. Hardening is done by means of a stationary spray ring with flat jet nozzles. Arrangement of 16 nos of nozzles and rotation of the wheel provides a uniform spray of water upon the tread. Wheels are subsequently tempered in a tempering furnace and then air cooled to ambient temperature. Schematic of heat treatment process and Rim spray machine is shown in Fig.-1 and Fig.-2 respectively.

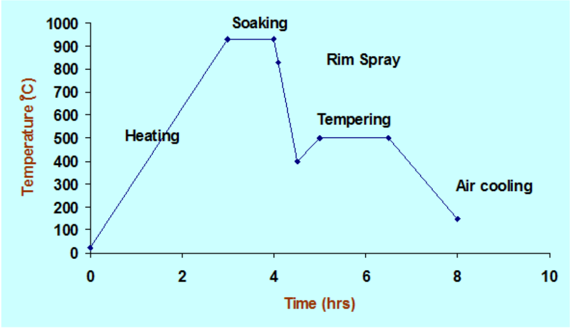


Fig.1 Schematic of heat treatment process

Fig.2 Rim spray Machine

2.3 Requirement of the wheel material

Railway wheels are usually made of unalloyed or low alloyed steels with a high degree of purity. Tight tolerances for the single alloying elements are desired in order to assure a low variation of the material properties from heat to heat. National and international standards define the wheel steel grades and partly also their manufacturing. Depending on the steel grade, requirements for wheels produced according to this standard are e.g.: • Tensile strength of the rim (between 780 and 1050 MPa), • Impact toughness of the rim (≥ 9 J, U-notch, measured at ambient temperatures), • Residual stress (compression stresses are required in the as-manufactured wheel rim), • Tensile strength of the centre (between 100 and 130 MPa lower than the rim strength), • Fatigue strength of the centre (≥ 450 MPa, machined centre, 10^7 load cycles). The microstructure is the “carrier” of the above-mentioned material properties [2,3]. Fine-grain steels with a fine-lamellar ferrite-pearlite microstructure provide an optimal compromise between mechanical properties, wear resistance and thermal stability. Therefore, ferritic-pearlitic steels are predominantly used for railway wheels. However, in recent years bainitic steels have also been intensively investigated for rolling stock applications [4].

2.4 Requirement of the heat treatment process

The heat treatment of the wheels is of central importance in providing the wheel with the necessary product properties. Railway wheels are heat treated by means of a so-called rim hardening process [5]. After austenitisation at temperatures close to 900°C, only the wheel rim is rapidly cooled to temperatures of about 300°C – usually by using water. After finishing the rim quenching, centre and hub are still at temperatures near the transition temperature. Further cooling takes place in air, giving the wheel rim high strength and compressive residual stresses and producing a more flexible wheel centre. The final tempering step at about 500°C can be considered to be a stress relief treatment with no significant changes to the microstructure or the mechanical properties of the wheel material.Fig.-3 shows a time temperature transition diagram for an unalloyed steel with approximately 0.5 wt.% carbon. This steel matches very well with wheel steels defined by R-19 and R-34 of Indian Railway standard. Three cooling paths 1-3 and the corresponding micrographs are shown. The desired cooling path for rim quenching would be somewhat to the left of path 2, crossing the pearlite region, producing a minimum volume fraction of ferrite and leaving the bainite and martensite region untouched. The different and controlled cooling rates in the different functional parts of the wheel lead to different material properties. This allows a "material engineering" with respect to the future service conditions of the wheel [6]. A main goal of the heat treatment process is high homogeneity of the microstructure of the rim in a radial and circumferential direction. This is optimal for a uniform wear characteristic of the wheel tread and assures highest travelling comfort due to the prevention of wheel unroundnesses. Additionally, wheel damages such as rolling contact fatigue failures will be minimised [7]. Fig.-4 dipicts the Pearlitic-ferritic microstructure of a wheel steel

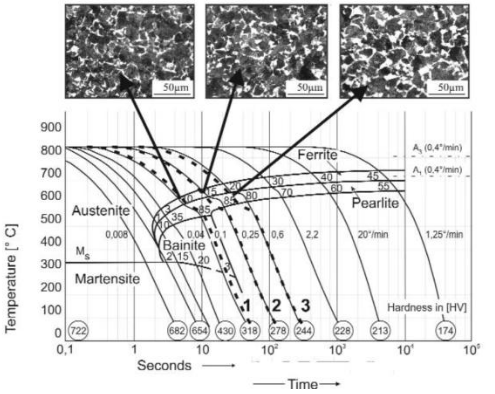


Fig.-3 Time Temperature Transition diagram for an unalloyed steel with approximately 0.5 wt.% carbon with different cooling paths (1-3) and the corresponding micrographs.

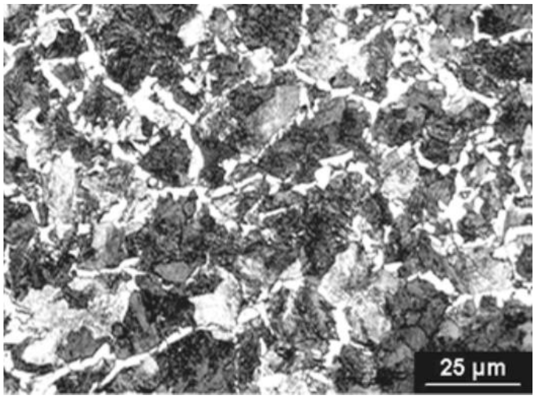


Fig.-4 Pearlitic-ferritic microstructure of a wheel steel

2.5 Requirement of the rim spray technology

As explained above, the controlled cooling of the wheels is the most important heat treatment step. It mainly defines microstructure and mechanical properties and therefore the quality of the product. The cooling process is controlled by varying the cooling flow rates and the water spray duration with the wheel surface. The introduced cooling technology has proven to be able to produce wheels which meet the demands on the mechanical properties (such as strength and toughness) and fulfil the microstructural requirements [8]. Objective is to achieve desired hardness of 241-277 BHN for coach and 300-341 BHN for locomotive wheel upto a depth of 30mm from tread surface. Hardness obtained at 4th point in coach and 9th point in locomotive wheels is usually lowest. It is basically due to rim profile. Thickness difference across the tread results in varying cooling rate with uniform spray at tread surface. Therefore in order to increase as quench hardness, water flow rate is to be increased and to achieve uniform hardness across the thickness of rim, differential cooling needs to be introduced [9].

2.6 Requirement on the furnace technology

The hardening and tempering in DSP are done in rotary hearth type furnaces. The design allows for very easy and fast maintenance of the furnaces. Typically set of two wheels are positioned on the hearth on a cast support. The side and bottom row of burner arrangement and control of the burners guarantee a very homogeneous temperature profile inside the furnace. The furnace technology meets the customer demand for temperature uniformity for the hardening as well as the tempering furnace. Furnace parameters such as the temperatures of the different heating zones, the consumptions of gas and combustion air, the temperatures of combustion air and waste gas, the furnace pressure are being recorded, archived and documented. Due to the precise time and temperature control of the heating processes, the furnaces essentially contribute to the reproducible mass production of wheels with high quality and a minimum scatter of material properties.

2.7 Hot charging in heat treatment

Hot charging of wheels during heat treatment has some obvious benefits of conserving energy and reduction in furnace residence time. Lower residence time in heat treatment leads to increase in productivity of heat treatment section and improve the quality of wheel. Prior to introduction of hot charging in heat treatment a process study is required to be carried out keeping in view the existing shop practice of rolling and heat treatment. Issues to be addressed are of time, temperature, process delay and heat treatment process requirement. It is essential to lower the temperature of wheels below their Ar_3 temperature. Since forging and rolling temperatures are high, bigger and mixed grains are characteristics of as rolled wheels. Wheels need to undergo transformation from austenitic range. Once this is achieved a finer and more uniform grain structure can be obtained in subsequent heat treatment.

2.8 Spray Ring

Existing rim spray ring is made up of mild steel pipe. It is bend locally into round shape by filling sand in it and rotating it into round while continuously heating with oxy-acetylene torch. Limitations of process result in uneven bending. This leads to non-uniform height of spray nozzles. Further existing nozzles are flat jet nozzles. Maintaining fixed spray angle and cleaning of nozzles is difficult. These problems can be largely avoided by use of stainless steel ring made circular in banding machine and using dovetail type nozzles.

3. APPROACH

Following approach has been adopted to achieve the objectives of the project:

I. Introduction of hot charging.
II. Modification of quenching ring of rim spray machine
III. Optimisation of heat treatment process.
IV. Evaluation of wheel quality

4. EXPERIMENTAL

4.1 Introduction of hot charging

In order to increase productivity of heat-treatment process and achieve energy saving, hot charging has been introduced. Dialatometry was carried out to determine Ar_3 temperature for wheel steel as shown in Fig.-5. Time temperature relationship of wheels after stamping and cooling in air were predicted using ANSYS software and shown in Fig.-6 . Results were validated by pyrometer (Fig.-7 and Fig.-8). Based on data analysis shop logistics were worked out to synchronise rolling, air cooling and furnace duration. Wheels are allowed to cool for one hour after dishing to get a temperature of around 500 °C. These hot wheels are charged in heat treatment furnaces, instead of earlier practice of charging at room temperature. Modified thermal regime in heat treatment furnace has been incorporated. Furnace cycle time has been reduced from 4 to 2hrs 30mins for coach wheel and from 5 to 4hrs for loco wheels.

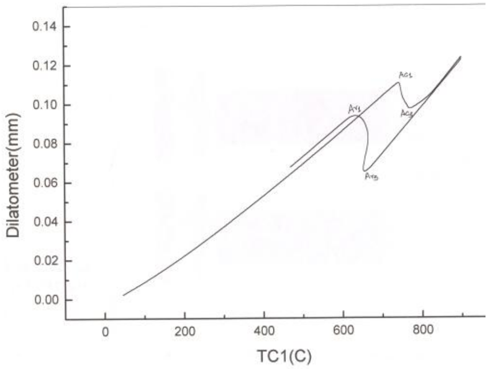


Fig.-5 Dilatometer test to determine Ar3 temperature of wheel steel

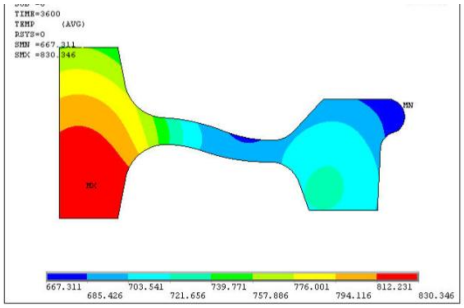
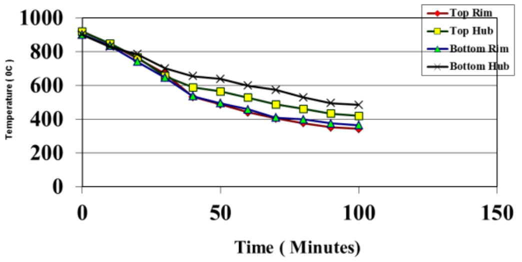


Fig.-6 Temperature of BG Coach Wheel after stamping after one hour air cooling (determined by ANSAYS sofware)



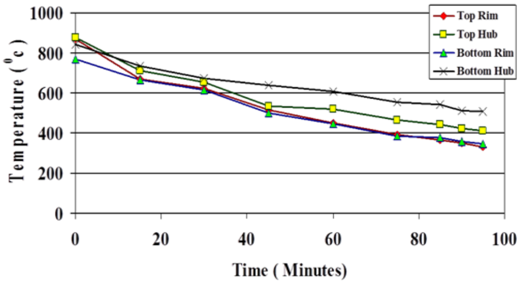


Fig.-7 Time Temperature relationship of BG Coach Wheel after stamping (measurement by pyrometer)

Fig.-8 Time Temperature relationship of BG Loco Wheel after stamping (measurement by pyrometer)

4.2 Modification in rim spray ring

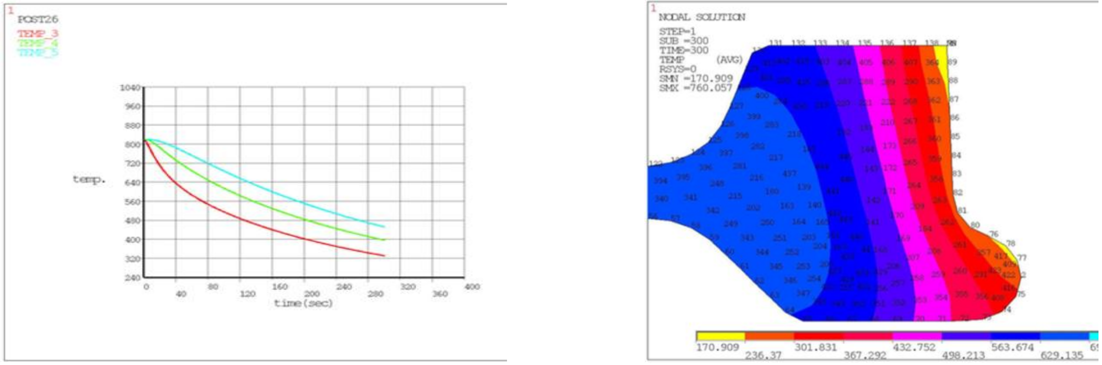


Fig.-9 Cooling curves and temperature profile of hardness points in rim at 30 mm depth from tread in earlier system of rim spray

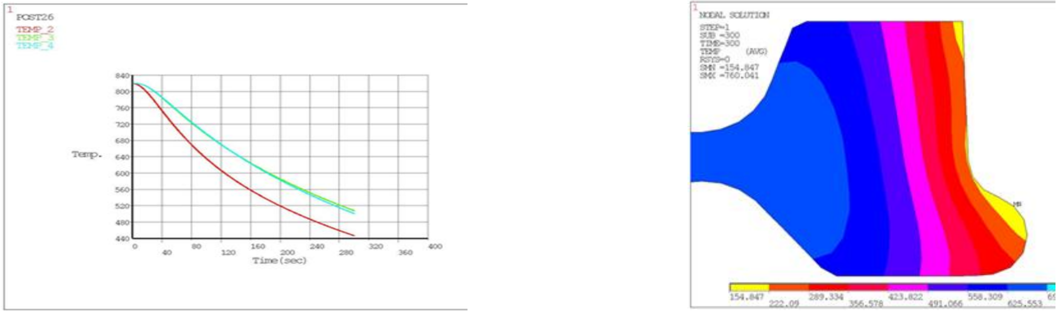
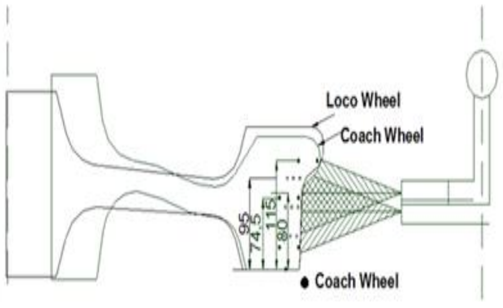


Fig.-10 Temperature profile and cooling curves of hardness points in rim at 30 mm depth from tread in overlapped system of rim spray



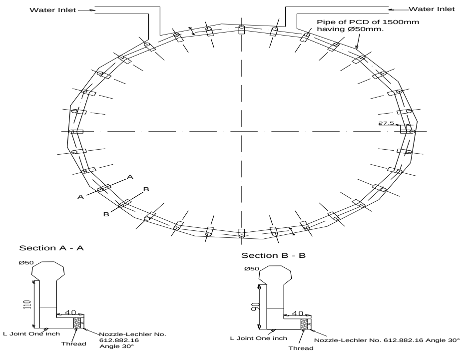


Fig.-11 Hardness Measurement Points for Loco & Coach Wheels and overlapped rim spray

Fig.-12 Modified Rim Spray Ring

Simulation of heat treatment process was carried out using Thermo-Mechanical simulator 'Gleeble' and ANSYS package of FEM. Heat treatment cycle was simulated in 'Gleeble' and cooling rates were determined to get desired as quenched hardness in wheel material. Austinitizing temperature was kept 850 and 875 ^{o}C. Temperature profiles were generated in ANSYS selecting flow rates and differential flow at tread surface. Based on the results spray ring was modified to have intense as well as differential cooling .Number of nozzles increased from 16 to 24 and alternate nozzles were staggered by 20 mm to achieve differential cooling. Orientation of spray nozzles was changed to 30^{o} to cover whole tread of the wheel. Worn out nozzles were replaced with new nozzles before start of heat treatment process. Modified spray ring have been installed in all the three rim spray machines in Wheel & Axle Plant. Process modification were also carried out

Effect of differential cooling on temperature profile at 30 mm in rim is demonstrated in Fig. 9 & 10. When water is distributed in 60/40 ratio, two cooling rates become similar. This indicates that hardness at critical 4th point can be increased by differential cooling.

Modified rim spray ring and overlap flow pattern is shown in Fig. 11 & 12 respectively. Modified design of spray ring resulted in increased water flow rate of 15±0.5 m3/hr from earlier 10±0.5 m3/hr during rim spray. Accelerated cooling reduces inter lamellar spacing of pearlite at tread surface resulting in higher hardness and strength. IR pyrometers and flow meters also has been installed to get the consistency in results

4.3 Optimization of heat treatment process

Extensive plant trials were carried out with modified process parameters. Temperature of heating and soaking zone of heat treatment furnaces were lowered by 30 ^{o}C. Heat treatment parameters were modified and furnace duration lowered. Temperature of each wheel was measured and maintained between 800-820 ^{o}C at rim spray machine followed by accelerated cooling. Wheels having lower temperature than the specified range were drawn out for recharging. Standard tempering cycle was followed after rim spray

4.4 Quality evaluation of wheels

Hardness survey in wheels was carried out for rim by measuring hardness at six positions in case of coach wheel and at nine locations in case of locomotive wheels. Mechanical and microstructural property evaluation was carried out. Tensile strength obtained is plotted in Fig.-13. Inter lamellar spacing in wheel samples were measured and shown in Fig.- 14 and Fig.-15.

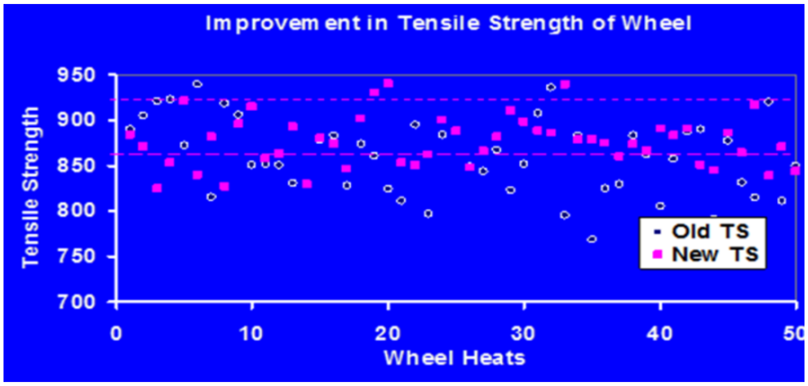


Fig.-13 Improvement in Tensile strength of wheel

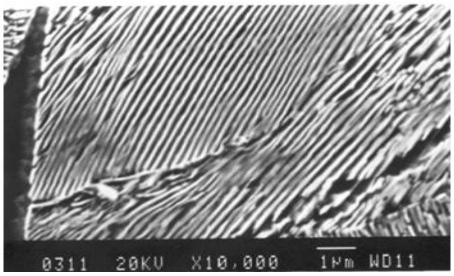


Fig.-14 Inter-lamellar Spacing at 10mm depth-0.28micron before modification in rim spray

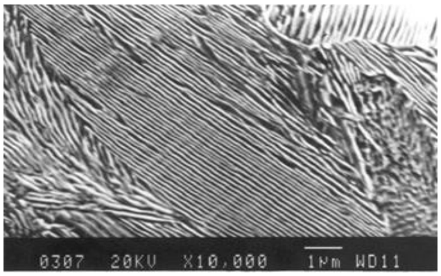


Fig.-15 Inter-lamellar Spacing at 10mm depth-0.21micron after modification in rim spray

5. RESULTS AND DISCUSSION

Furnace cycle time has been reduced from 4 to 2hrs 30mins for coach wheel and from 5 to 4hrs for Loco wheel after introduction of hot charging. This has resulted in increase in productivity of heat-treatment shop by more than 30% and energy saving of around 20%. Besides utilizing heat of hot wheels, lesser duration in furnace results in better microstructure and mechanical properties.

Optimization of heat-treatment parameters, installation of modified ring, intensified and differential cooling during rim spray has improved the hardness at critical points in coach and loco wheels.

Higher cooling rate during rim spray gives better quality wheel w. r. t. to tensile strength, hardness and microstructure. Quality of wheels has improved due to finer inter lamellar spacing. UTS is now in higher band of specification with average UTS increase from 860 to 875 MPa and decrease in standard deviation from 45 MPa to 25 MPa. Values of hardness of front rim face in as rim sprayed condition, improved by ~15-20 BHN. Optimization of heat-treatment parameters reduced occurrences of reheat-treatment from more than 10% to less than 3%.

6. CONCLUSIONS

Hot charging in heat treatment of wheels has been successfully introduced to improve productivity and energy saving. Modified spray ring and optimization of heat treatment parameters decreased the reheat treatment occurrences substantially. Quality of wheels also increased.

7. ACKNOWELDGEMENT

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