IOP Conf. Series: Materials Science and Engineering **225** (2017) 012297 doi:10.1088/1757-899X/225/1/012297

Optimum Temperature of Hot Rolled Reinforced Bars at the Cooling Bed

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Abstract- Maintaining high accuracy temperature measurements at the cooling section is essential in order to attain the overall quality of the finished product, and to realise the correct properties. A series of "heat" numbers or batches of molten steel from an Electric Arc Furnace (EAF) for the production of Y12 mm reinforced bars (rebars) were observed at a steel plant to establish the optimum temperature of the rebar at the cooling bed. The casting was done in billet casters and the billets with 100mm×100mm cross-section were then hot rolledto the required size. The finish rolling temperature was between 850-900℃ at 11m/s rolling speed. Therebars were water quenched in the water box, and lastlysent for cooling on the cooling bed. Tensile tests and bend tests were carried out on rebars every after 15 minutes during the production to ensure that correct mechanical properties were achieved. It was observed that 850℃ was the bestfinishing temperature and 250 ℃ was the optimum temperature at the cooling bed after equalization.Theresults for the tensile tests and microstructures wereconsistent with prescribed standards. The rebar samples were all of low carbon steel.

1.Introduction

Rebars are one of the important construction materials and control of the temperature during the production of such a material in a hot rolling process can ensure good quality product. During the hot working process of steel, the flow stress, strain-rate and recrystallization are controlled by the temperature [1].The changes in the microstructure of rolled product are influenced by a series of dynamic events usually accompanied by heat transfer between the work piece, the work roll and the surrounding. All these events have a role in determining the mechanical properties of the final product.It has also been observed that controlling the temperatureat the finishing stand guarantees a good final product than controlling temperature during the roughing stage [1].In a hot rolling process the ultimate is to obtain a fine ferrite grain size. However, whilst temperature control is important at the finishing stand, control of temperature at the cooling bed is even more crucial because this is where the final mechanical properties are established.So in order to achieve the required mechanical properties of rebar, monitoring with precision measuring tools becomes imperative.

The microstructureof the billet before rolling is initially composed of coarse grains of austenite. The austenite grain structure begins to change when the billet passes through the rollers and is compressed. During this stage the austenite grains are elongated into pancaked structure and each grain experiences a change in dimension and usually with deformation bands induced within the grains [2, 3]. During these dynamic events, recrystallization becomes an important and powerful tool for achieving significant grain size refinement. The dynamics of this recrystallization process involves dynamic

recovery, dynamic recrystallization (DRX) and static recrystallization (SRX) [4].When this process occurs during deformation, it is referred to as 'dynamic recrystallization' (DRX), whereas the term 'static' is applied when it happens after deformation [4]. During hot rolling, each pass is characterised by the applied strain, the strain rate, the temperature and the interpass time. These process parameters, together with the material characteristics usually involving chemical composition and initial grain size, have an influence on the recrystallization kinetics and the resulting grain size.The evolution of the recrystallized fraction with time is represented in equation (1) as articulated by Avrami [4],

$$X = 1 - \exp\left(-\ln 2 \cdot \left(\frac{t}{t_{0.5x}}\right)^n\right) \quad (1)$$

In equation (1),*X* is the recrystallized fraction after a time *t*. The kinetics of recrystallisation is expressed through $t_{0.5}$ which is the time for 50% recrystallization and this time depends on deformation before, the temperature of deformation, and the initial microstructure. The value '*n*' is a material constant. A typical recrystallization process during hot rolling is shown in figure 1.

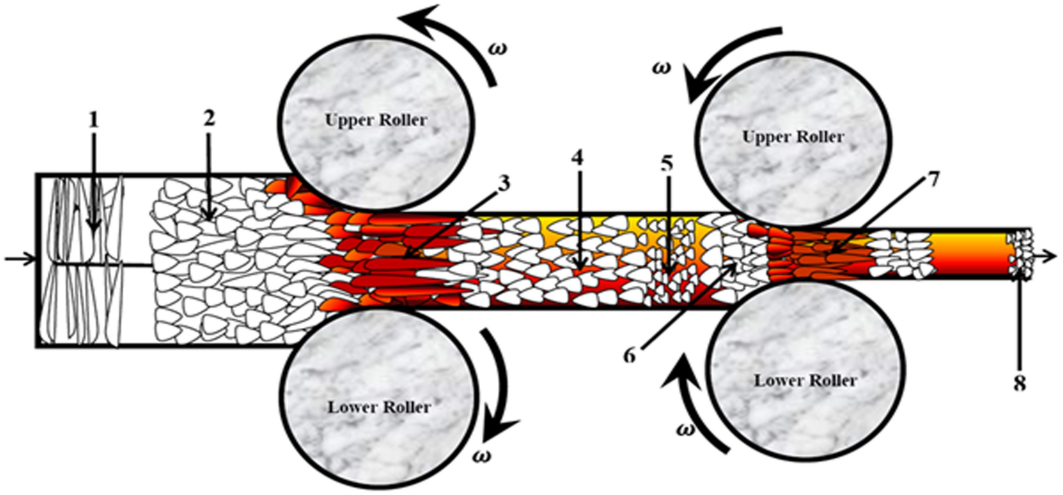

Figure 1.Recrystallization during hot rolling process: (1) Ingot with non-uniform grains, (2) Coarse equiaxed grains, (3) pancaking (grains elongated), (4) Static recrystallization, (5) Complete recrystallization, (6) Grain growth, (7) Dynamic recrystallization, (8) Complete recrystallization with finer grains.

As soon asrecrystallizationis completed, the growth of austenite grains will be facilitated by the high temperature developed during the deformation process as long as the interpass time is sufficient. The evolution of the austenite grain size after recrystallization, under isothermal conditions, is usually described in equation (2) asfollows [4]:

$$D^n = D_{rex}^n + B.t_q \cdot exp\left(-\frac{Q_{gg}}{RT}\right) \quad (2)$$

In equation (2),D_{rex} is recrystallized grain size, whereas$t_q$represents the time once recrystallization has completed and this is usually considered as a 95% recrystallized fraction ($t_q = t_{ip} - t_{0.95srx}$, t_{ip}being the interpass time). In this equation, Q_{gg} denotes the activation energy for grain growth and also depending on the chemical composition of the material *n* and *B* in the equationare

taken as constant values. The time and the temperature are not the only parameters that affect grain growth. It should be further noted that, the recrystallized grain size is also asignificant variable, considering thatthe tendency for larger grains to grow is lower compared to the smaller grains. It can therefore be deduced that, the kinetics of grain growthconsequently depends on the recrystallized grain size to a large extent [4].

Upon completion of the rolling process, the rebar in the austenitic state enters a water boxwhere the surface is superficially cooled by water at a pressure and flow rate enough to decrease the temperature of a surface layer below the martensite start temperature. The dwell time for this quenching process is less than one second. When the rebar leaves the water box, the heat accumulated in the core is driven outward and this results into self-tempering of the martensite periphery. Eventually the austenitic core is transformed into ferrite and pearlite at the cooling bed[5].The temperature difference between the core and the outer surface results in the equalization process at the cooling bed. It should also be noted that a substantial increase in the ultimate tensile strength and yield strength is also achieved due to self-tempering of the martensite without compromising the ductility.The core can transform to pearlite and ferrite or indeed a mixed microstructure including bainite can be formed. These variations in microstructure are, however, influenced by the composition of the material,the finishing temperature and cooling rate.

2. Experimental procedures

2.1 Chemical composition

The chemical composition for the material wasestablished using an Optical Emission Spectrometer (OES). The samples were then weighed using the Adams scale and subjected to tensile and bending tests. The chemical composition of the alloying elements of rebar was (wt. %): 0.24C, 0.32Mn, 0.08Si, 0.020S, 0.044P, 0.23Cr, 0.12Ni, 0.02Mo, 0.34Cu and 0.079V. The percentage carbon equivalent (%CE) was calculated using equation (3) to establish the combined effect of the alloying elements[6],

$$\%\,CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (3)$$

2.2 Methodology

Seven Y12 mm rebar samples were selected from every “heat”and twenty eight (28) samples were subjected to tensile tests and bending tests using a computerised 60 metric tons TUE-C-600 Universal Testing Machine. ASTM E-290 standard was used to conduct the bending test. This standard requires that the testing is done primarily to assess the extent of ductility in the material.Other conditions for this standard are that, after testing the curved surface of the bend specimen should have no cracks or any open defects after a visual inspection [7]. Optimum tensile strength and yield strengths were then recordedfor analysis. The standard guide used to prepare the samples for observation in the microscopy was ASTM E3-11.The samples were mirror polished and etched using 2% Nital. The etching time was in the range of 15 to 20 seconds and samples where then viewed in the optical microscopy to identify the grain structure.Monitoring of temperature at the cooling bed was done using a hold peak infra-red (hp-1300) thermometer with the temperature range of (-50℃ to 1300℃) and distance to diameter ratio of 4:1.

3. Data collected and results

3.1 Tensile test reports and cooling bed temperature.

Tensile test reports for heat numbers A and B, and the cooling bed temperature were compiled and are represented in table 1 and table 2. The relationship between mechanical properties and the cooling bed temperature were derived from these tables and this relationship is illustratedgraphically in figure 2(a) and (b) respectively. The interpretation of these graphs is discussed under section 4 of this paper.

Table1. Tensile test report (To rod mill) for Y 12 mm rebars, Heat number A.

Sample number	Finish rolling temp. (℃)	Wt.of test specimen (Kg)	Length of test specimen (mm)	Wt./Mtr (kg)	Yield stress (MPa)	Tensile strength (MPa)	%El.	Cooling bed temp. (℃)
01	850	0.395	446	0.886	482.89	589.25	23.33	178
02	860	0.419	471	0.889	523.10	611.52	21.67	195
03	870	0.417	481	0.866	525.90	618.26	20.00	198
04	880	0.478	557	0.858	475.85	581.22	21.67	168
05	890	0.366	423	0.865	511.15	605.86	20.00	180
06	900	0.384	448	0.857	512.13	605.55	18.33	188
07	950	0.441	511	0.863	512.47	605.80	21.67	190

Table2. Tensile test report (To rod mill) forY12 mm rebar, Heat number B.

Sample number	Finish rolling temp. (℃)	Wt. of test specimen (Kg)	Length oftest specimen (mm)	Wt./Mtr (Kg)	Yield stress (MPa)	Tensile strength (MPa)	% El.	Coolingbed temp. (℃)
01	850	0.364	419	0.868	524.82	619.16	18.33	222
02	860	0.386	438	0.881	586.83	662.18	20.00	260
03	870	0.403	469	0.859	537.17	619.39	23.33	236
04	880	0.415	480	0.864	555.67	641.74	21.67	238
05	890	0.378	438	0.863	532.12	617.26	20.00	228
06	900	0.390	451	0.864	532.69	610.03	21.67	232
07	950	0.464	536	0.866	500.56	585.44	23.33	180

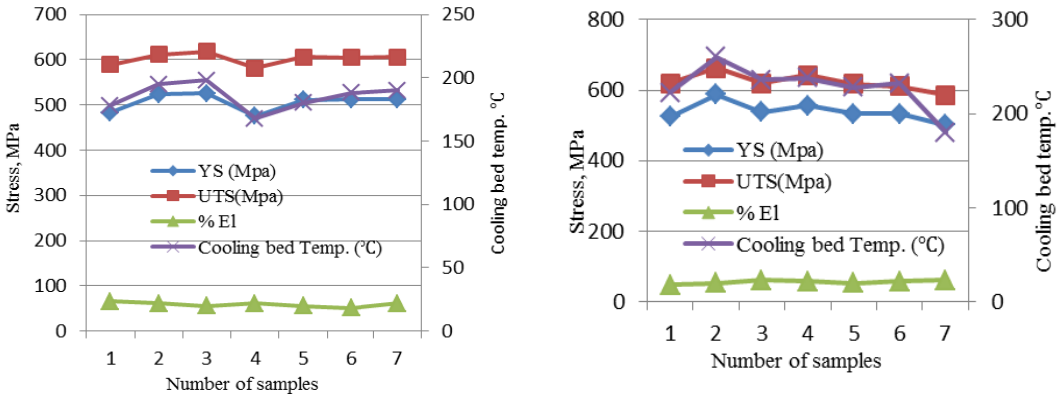

Figure.2. (a) Relationship between mechanical properties and cooling bed temperature for heat number A, (b) Relationship between mechanical properties and cooling bed temperature for heat number B.

3.2. Bend test visual observation.

A visual observation of the curved surfaces of the specimens was conducted on the specimens to identify cracks or other defects. The results shown in figure 3(a) to (c) reveal that, there were no visible cracks or open defects in the samples tested. This is an indication of how ductile the produced rebars were.

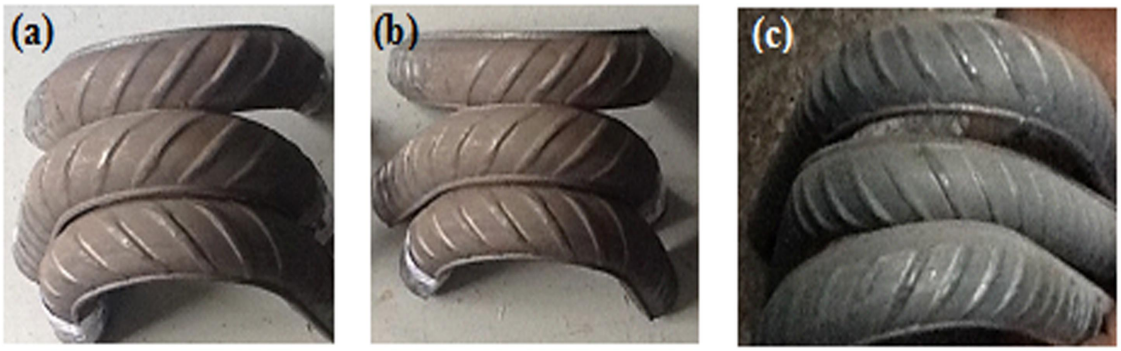

Figure.3 (a) to (c) shows crack free surfaces and without open defects after the bend test.

3.3 Microstructural observation.

The microstructures in transverse and longitudinal sections were examined at different positions in the samples to see the uniformity of the microstructure. Figure 4(a) to (c) shows the microstructureat different positions: (a)Longitudinal section of pearlite(dark) and ferrite(white), (b) Transverse core section of pearlite(dark) and ferrite(white), (c) Mixed microstructure of: (1) case of martensite, (2) TransitionZone (TZ), bainiteand (3) core areaof pearlite and ferrite.

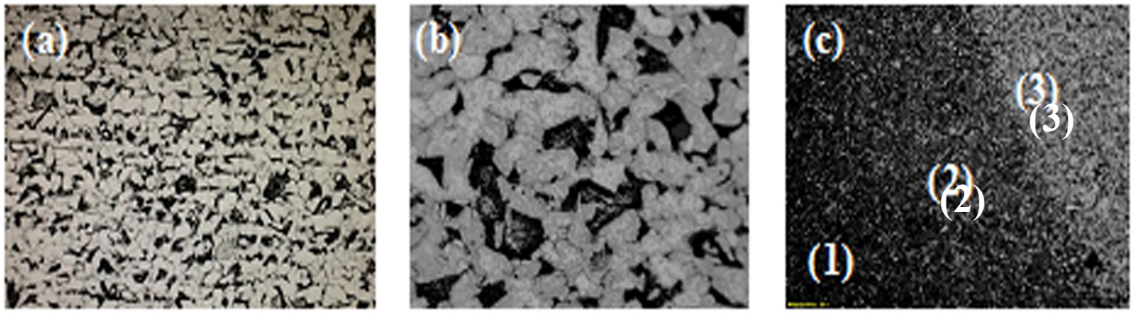

Figure 4. Microstructure of (a) core area in longitudinal section, (b)core area, in transverse(c) Mixed microstructure: (1) case of martensite, (2) TransitionZone (TZ), bainite, (3) core of pearlite and ferrite.

Discussion of test results.

The tensile test reports compiled in table 1 and table 2 together with the graphs shown in figure 2(a) and (b) clearly show that the cooling bed temperature was fluctuating between 180 ℃ and 260℃. It can also be observed that there is a direct relationship between the cooling bed temperature and the mechanical properties. In all cases (figure 2 (a) and (b)), the yield stress and tensile strength is within the guaranteed minimum of 450 MPa and maximum of 550 MPa for yield stress and 650 MPa maximum for tensile strength.The percentage elongation was 21% on average indicating that the steel is able to satisfy the main qualities looked for in a steel rebar such as 'yield point',weldability, fatigue resistance, and sufficient ductility for the intended use. From the yield stress and tensile strengths values obtained the optimum cooling bed temperature range is 200- 250℃. These results are consistent and in agreement with [8].The surface temperature of rebar should be cooled to below 200 ℃ at the cooling bed within ten seconds. Since the core temperature remains at 800℃ after leaving the water box, it implies that there will be equalization of the temperatureto about 650℃ on the cooling bed before settling to room temperature.

Conclusions

This study has established that, the surface optimum cooling bed temperature for the production of Y12 mm rebar is in the range 190℃-250℃.Within this temperature range, optimum mechanical properties can be achieved and hence a good quality product can be produced. It should also be noted that the water flow rate and quenching dwell time was set at 645m³/h and 0.8 seconds respectively. These two variables are easy to control but very important for proper heat treatment of steel.

Acknowledgements

This research was made possible by Kafue Steel Plant at Universal Mining and Chemical Industries Limited (UMCIL) in Zambia. We sincerely thank the entire management and workshop staff members for the unconditional support during this study.

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