International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 5 Issue 6, June - 2021, Pages: 28-32

Effect of Thermomechanical Treatment on T/Y Ratio in Recycled Plain Carbon Steel Reinforcement Bars

Christopher SENFUKA[1], Paul Kizito MUBIRU[2],

[1]Dept of Mechanical Engineering, Kabale University, P. O. Box 317 Kabale, Uganda
[2]Dept of Mechanical and Prod. Eng. Kyambogo University, P. O. Box 1 Kyambogo, Kampala, Uganda
senfukac@gmail.com[1], kizito.mubiru@yahoo.com[2]

Abstract: *- Ensuring that the bars for reinforcement purposes behave as intended means maintaining a limit on the yield stress so that that the TS/YS ratio is kept at 1.25. While this is easy to control in core hardened steel bars, the composite nature of thermo mechanically treated (TMT) bars with a pearlite/ferrite core surrounded by a tempered bainite/martensite outer ring through phase transformation strengthening renders them less predictable. In this research the influence of the chemical composition of the TMT against its heat treatment is compared to that in annealed and core hardened bars of the same samples. Parts of TMT bars were fully annealed while others were fully quenched and had their composition determined in each case while they ultimate stresses and yield stress were recorded. A plot of the ratio T/Y against their calculated carbon equivalent was made. It was shown that the T/Y ratio reduces with growing carbon equivalent and that the plot for the T/Y ratio for the TMT bars fits between those for fully annealed and for the fully quenched group. Hence the reliability of the TMT bars in earthquake conditions will be less than that of fully annealed bars but higher than those that are fully martesized.*

Keywords: Tensile to yield ratio, thermo-mechanically treated bars, steel carbon equivalent, bar ductility, inelastic deformation

1. Introduction

Steel is demonstrably a linearly elastic material within the elastic zone until yielding occurs. Beyond this point and prior to ultimate failure, stress ceases to be proportional to strain. Considerable strength development is achieved, however, after the yield plateau but prior to failure.

In this nonelastic portion, also known as the strain hardening region, further strength gain results as larger strain is imposed. Beyond the strain hardening region, further straining results in strain softening until failure occurs. The peak stress, considered the ultimate stress, is followed by the necking range (Fig.1).

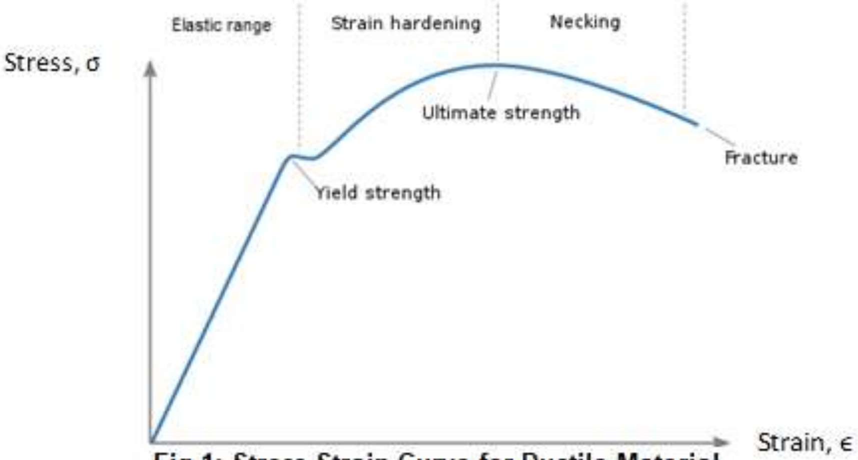

Fig.1: Stress-Strain Curve for Ductile Material

IN ORDER to optimize the useful weight in modern steel structures, the strength of their construction materials is often increased, thereby improving on the economical efficiency of the designs and leading to the much besought reduction in dead weight for building structures. The steel industry has taken this desire for lightweight design into account by developing high strength structural steel bars with elevated yield strengths. This is achieved by either:

- microalloying in order to increase levels of phase solutes and consequent solid solution strengthening where the size difference of the foreign elements makes them create resistance to dislocation slip resulting in higher material strength. This is achieved with the addition of niobium, vanadium or a combination of these [7] and produces a bar with hardness not requiring heat treatment.

- decreasing grain size to utilize boundary strengthening since smaller grains increase the likelihood of dislocations running into grain boundaries after shorter distances and boundaries are very strong dislocation barriers so that in general, smaller grains make the material harder.
- with increased volume fractions of second phase
- or online thermomechanical treatment and self-tempering leading to the manipulation of the martensite volume fraction by heat treatment.

The comparative low cost and the relative ease with which thermomechanical treatment can be achieved, have endeared the process in many developing countries.

The basic principle of thermomechanical treatment is that, upon completion of the rolling process at approximately 850℃, the bar in its austenitic state travelling at approximately 11.5 m/s, enters into the quenching system in which the surface is cooled by water spray at a pressure and flow rate large enough to decrease the temperature of the surface layer below the martensite start temperature [3].

The cooling system consists of several boxes of cooling tubes in which a water flow of 600 to 800 m^3/minute is introduced, depending on the diameter of the bar being processed, at pressures of the order of 1.2 MPa [7]. This whole arrangement is intended to result in the creation of a martensite rim.

When the bar leaves the cooling area, the heat accumulated in the core is driven outward, causing the self-tempering of the martensite layer. Finally, in the cooling bed, the still austenitic core becomes transformed to ferrite and pearlite due to the now subcritical cooling rate [6].

With this combination of structures, lower carbon and manganese contents are necessary to fulfill mechanical properties requirements for higher strength to weight ratios. Importantly too, a strong tough composite re-enforcement bar is obtained at a lower alloying cost [6].

In the end, however, all these modern compositions and processing routes have had less effect on the yield stress than on the ultimate tensile strength [2] both of which depend on impeding the movement of dislocations; invariably leading to higher tensile stress to yield stress ratios, (T/Y).

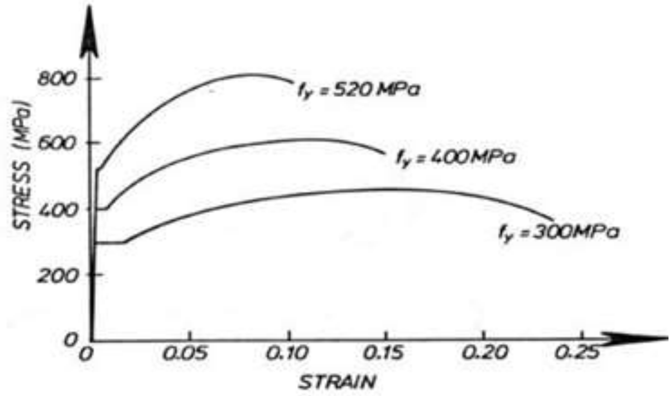

Fig.2: Typical stress–strain curves for reinforcing steel.

Two outstanding features characterize the desired growth in strength.

- Typical stress strain curves indicate that the strain at which the ultimate strength occurs keeps reducing (Fig.2) with growing ultimate strength even as the length of the yield plateau decreases as the yield strength increases [2]. All these suggest reduced deformation prior to yield and ultimate strength
- The mathematical parameter to characterize the relation between the ultimate tensile and yield stresses is the Tensile to Yield (T/Y) ratio which can be seen to reduce with growing ultimate stress.

Thus, higher tensile strengths invariably mean increased brittleness. This is indicated by a reduced yield plateau and a very limited strain hardening region (Fig.2). This means that the yield region and its capacity to absorb energy through inelastic deformation is severely limited and must be optimized by intentionally controlling the T/Y ratio [8].

Although for use in reinforced concrete, many standards specify that the TS/YS ratio shall not be less than 1.25, its significance to design is often obscured by the focus given on the tensile strength and yield strength individually [1]. The tensile-to- yield ratio (T/Y) is a measure of strain hardening ability and thus the ductility of steel. The higher the T/Y ratio, the higher the strain hardening ability and the greater the material ductility and therefore its capacity to absorb energy inelastically in the strain hardening zone.

In his study on the performance reinforcement bars in the earthquake in Wenchuan, China in 2008, Youlin Xu [9] actually emphasizes the need to use materials that have a high ratio of tensile strength and yield strength.

The term ductility refers to the ability of a member to undergo large deformations without rupture. Ductile members could therefore bend and deform but remain intact. This essential capability of properly designed reinforced concrete members insures against total structure collapse and provides protection to building occupants at the critical instant when failure is occurring. Brittle members on the other hand, fail suddenly and completely with very little or no warning. This sudden failure may damage adjacent elements or overload other portions leading to progressive total collapse.

Ductility thus includes the ability to survive large deformations and the capacity to absorb energy in the process. In general, the seismic forces developed in a structure during a seismic event decrease with increasing ductility. For this reason, it is the single most important property sought especially in buildings especially when located in regions of high seismicity. It is therefore necessary to ensure ductility of members to allow visible development of large deformations before total collapse occurs, thus providing ample warning to occupants.

Y/T ratio therefore becomes an important consideration in steel structural systems with ductile moment resisting frames or ductile plate walls, in steel structural components such as connections and link beams, and in elements of steel structural members including flanges, webs, flange holes and tension members with holes that are expected to withstand strain-hardening range stresses and strain or even necking range strains [3].

Both yield stress and the ultimate stress of the reinforcement steel bars are dependent on the heat treatment given prior to their deployment. While fully annealed steel would provide the highest levels of ductility, the corresponding values of yield and ultimate stresses would return low. A core hardened steel bar would have practically not ductility at all.

In the recent past, the use of thermomechanically treated bars has been record high.
This research seeks to compare the value of T/Y obtained by the TMT process with that of fully annealed bars and those that are core hardened in order to quantify and compare the variation of the T/Y ratios for different steel bar levels of strength. Analysis is made of the effect of this treatment on the relation and manifestation of the ultimate and yield strengths and the subsequent difference between them.

2. Equipment and methods

Ten 16mm diameter thermomechanically treated reinforcement steel bars were randomly selected from the open market from 10 building steel bar manufacturers in 3-meter lengths. Nine 300mm lengths were prepared from each manufacturer and three pieces from each factory were annealed by heating them in an ELSKLO RSV heat treatment furnace to 400˚C and allowing them to cool in still air while similar 3 pieces were heated to their martensisation temperature at 850℃ and quenched in water.

The prepared pieces were then subjected to tensile testing using a MFL SYSTEM hydraulic universal tensile testing machine in accordance to the EAS 412-1:2005 and their respective yield strengths and tensile strengths determined. The results of the tests were compiled separately for the core hardened, annealed and the TMT bars. The same pieces were cut into 5mm lengths. The composition of each sample was then determined using a SPECTRO LAB apparatus spectromenter to be able to enable the calculation of their carbon equivalents (Table 1) using the Dearden and O'Neill's formula:

$$CE_{IIW} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \dots\dots\dots\dots\dots i)$$

From the tensile and yield strengths values for each group, the quotient T/Y was computed for each bar in the thermomechanically treated, annealed and the core hardened samples and the corresponding plot of T/Y vs carbon equivalent were plotted on an excel format (Fig.3).

3. Results

Table 1: Carbon Equivalent Values (%).

No.	1	2	3	4	5	6	7	8	9	10
C_{eq}	0.36	0.40	0.38	0.39	0.40	0.41	0.42	0.37	0.36	0.40

For all the test pieces in the experiment, the values of the carbon equivalent were as shown in table 1. To these, there corresponded values of tensile and yield strength for the TMT pieces which were tested as delivered, annealed pieces which were heated to the steel annealing temperature and the core hardened.

Fig. 3 shows the resultant three graphs depicting the expected fall in the T/Y ratio with carbon equivalent growth on the same axes to form a graphical comparison.

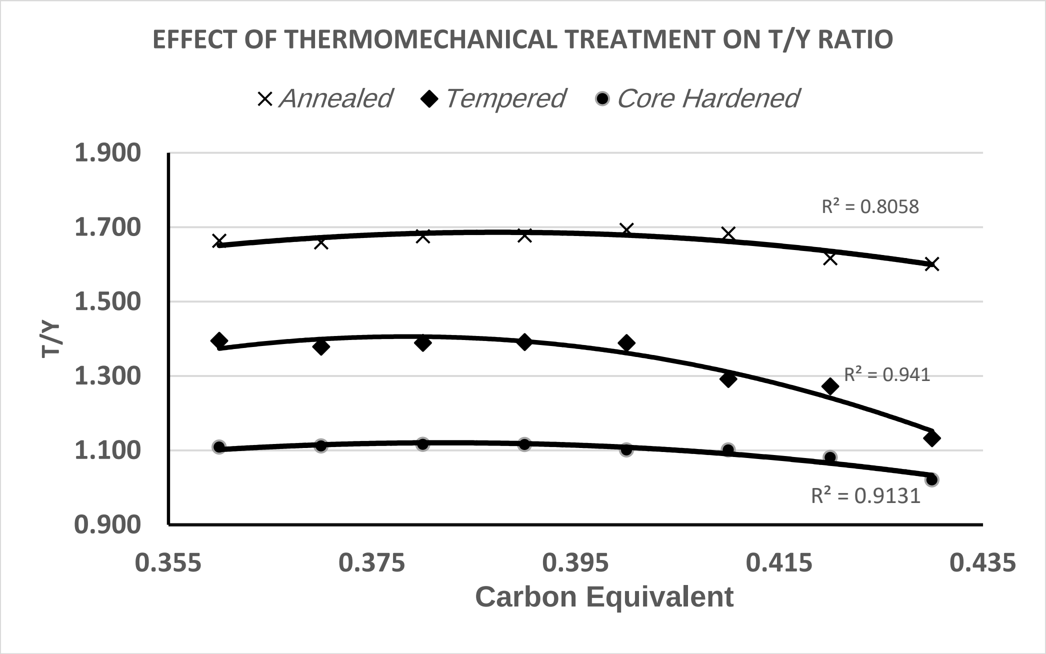

Fig. 1: T/Y vs Carbon Equivalent

4. Observations and conclusions

Fig.3 shows in all the three cases, annealed, tempered (TMT) and core hardened, it is evident that, the T/Y ratio decreases with increasing carbon equivalent which increases with the yield stress of steel grade. T/Y ratio also decreases with increasing tensile strengths of steel.

The curves as obtained for the different heat treatments: annealing, core hardening to obtain an entirely martensitic section and thermomechanical treatment to create a martensitic outer layer and a pearlitic-bainitic interior core. The values calculated for T/Y for each case show a general trend in that annealed steel bars show the largest T/Y values meaning that they have larger strain hardening ability along the Y-axis and thus higher ductility although talking of smaller absolute values of both yield and ultimate stresses. Smaller absolute values also mean larger deformation along the X-axis, still pointing to superior energy absorption prior to final failure [4].

The core hardened samples on the converse, returned consistently lower T/Y values and similarly while this means smaller difference between the yield and the ultimate stresses, it more importantly means smaller displacement before failure occurs as seen in figure 2.

The TMT (tempered) bars whose core has been left pearlite/bainite composition and the exterior quenched and converted to tempered martensite effectively producing a composite section returned values of T/Y between the first two curves with extension similarly occupying a position in between. This means their capacity to absorb energy through inelastic deformation falls between core hardened samples and the annealed ones.

In conclusion, the use of use of TMT bars leads to reduced ductility in comparison to simply annealed bars of similar composition, size and marking. That is made more evident when the hardening is done to the core leading to full martensisation.

The predictability and mechanical performance of the steel bars with TMT format is however more difficult for while this is easily controlled in core hardened steel bars, the composite nature of thermo mechanically treated (TMT) bars with a pearlite/ferrite core surrounded by a tempered bainite/martensite outer ring through phase transformation strengthening renders them less easily predetermined as its ultimate composition and annulus size are dependent on a multiplicity of factors including water flow rate, surface condition of the bar and it travel speed and others. This leads to less consistent readings in the graphing in figure 3.

Since ensuring that the bars for reinforcement purposes behave as intended means maintaining a limit on the yield stress so that that the TS/YS ratio is kept at 1.25, the control of the annulus parameters needs be much more serious. This also goes to the condition of the surface of the bars being irrigated [10].

In general, the T/Y ratio increases with increasing yield stress of the steel grade and also increases with increasing tensile strengths of steel. This ratio is, however, largely irrelevant in the design and behaviour structures that remain elastic even at extreme loadings and so do not lend themselves for ductile design. The T/Y ratio may become relevant in steel structural systems that are expected to withstand strain-hardening range stresses. This ratio may determine whether a tension member or the tension flange containing fastener holes fail in yielding (ductile) or due to net section fracture (brittle).

5. References

1) J. Madias, M. Wright, P. Wolkowicz (2017) Reinforcing Bar: Hardening Mechanisms and Performance in Use. Published in the Conference Proceedings, The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., USA.

2) I. Chakrabarti, T. Bhattacharyya, et al (2006) High strength rebars for the Indian construction industry. Tata Search 2: 395-403.

3) P. Bała, (2009). Tempcore process analysis based on the kinetics of phase transformations. Archives of Metallurgy and Materials, Vol. 54, pp. 1223-1230.

4) K.S. Sivakumaran (2010). Role of Yield-to-Tensile Strength Ratio in the Design of Steel Structures. The Minerals, Metals and Material Society, Canada.

5) I.R. Kabir, and M.A. Islam, (2014), Hardened Case Properties and Tensile Behaviours of TMT Steel Bars; American Journal of Mechanical Engineering, vol. 2, no. 1 (2014): 8-14. doi: 10.12691/ajme-2-1-2

6) S.E. Lundberg (2010), Quenched and Self-Tempered Rebar - Process Overview, Layouts, Operational Parameters and Cost Savings, AISTech Conference Proceedings - Volume II, (pp. 717-726,).

7) J. Madias, M. Wright, P. Wolkowicz (2017), Reinforcing Bar: Hardening Mechanisms and Performance in Use, Iron and Steel Technology Conference and Exposition, Pittsburgh, Pa., USA, Published in the Conference Proceedings.

8) P. Moore, G. Booth (2015), The Welding Engineers Guide to Fracture and Fatigue, ISBN, 978-1-78242-370-6, Woodhead Publishing. Copyright © 2015 Elsevier Ltd.

9) Y. Xu, (2010) Optimization and Selection of Reinforced Steel Bar in the Applicable Code for Concrete Structures of P.R. China, “Performance of the Reinforced Steel Bar in the Wenchuan Earthquake Disaster,” Proceedings of the International Seminar on Production and Application of High-Strength Seismic Grade Rebar Containing Vanadium, pp. 17–31.

10) V. Musonda, E. Akinlabi and T. Jen, 2017. Effect of Water Flow Rate on the Yield Strength of a Reinforced bar, Advances in Engineering Research (AER), volume 102 353, 2nd Int. Conf. on Mechanics, Materials and Structural Engineering (ICMMSE), January, DOI:10.2991/icmmse-17,58, Atlantis Press