Yield Strength and Ductility Analysis on Steel Reinforcing Bars Used in Ethiopian Construction Industry

Tefera Eniyew[1](✉), Assefa Asmare[1], and Wim Dewulf[2]

[1] Department of Mechanical Engineering, Bahir Dar University, Bahir Dar Institute of Technology, Bahir Dar, Ethiopia
[2] Department of Mechanical Engineering, KU Leuven – University of Leuven, Leuven, Belgium

Abstract. One of the most utilized materials in the construction sectors having enormous compressive strength but weak in tension is concrete. This weakness overcomes with addition of the steel reinforcing bars whose properties must comply standards. Thermomechanical treated steel is an ideal material available at affordable cost to reinforce concrete as it has good ductility with high modulus of elasticity and same thermal expansion with concrete. The Ethiopian construction industry uses locally manufactured and imported rebar available from an open market. Locally produced reinforcing steel bars are milled from imported billets or local billets manufactured from scraps collected as obsolete products. Reinforcing bars produced from Ethiopian metal industries are selected next to the imported one without justifiable reasons. This paper dealt with evaluation of yield strength and ductility of rebar based on the compulsory Ethiopian standard to comply the quality of these locally manufactured rebar in order to build customers confidence. The Strength of four samples 14 mm diameter rebar three from locally produced and one the imported taken from the construction site were tested using universal testing machine. Additionally tension test data of different rebar collected from Amhara Design Supervision and Consultancy Work Enterprise were analyzed. Based on the results obtained, some of reinforcing bars from imported and locally produced have faced rejection.

Keywords: Tensile testing · Mechanical properties · Yield strength · Ductility

1 Introduction

Steel is virtually useful in all sectors of economy and the steel manufacturing industries are the most important sectors to determine the level of economic development of any nation [1]. It is an ideal material available at low cost to reinforce concrete as it is having good ductility with high modulus of elasticity [2]. Currently Ethiopian construction industries are boomed with the requirement of different construction materials, due to the rapid population and economic growth. The needs of materials of the construction sector is satisfied by importing various materials from abroad and/or locally produced

M. A. Delele et al. (Eds.): ICAST 2020, LNICST 385, pp. 302–314, 2021.
https://doi.org/10.1007/978-3-030-80618-7_20

products. One of the most utilized construction materials with high annual consumption is the reinforced steel bar. There are newly established steel rolling mills engaged to manufacture rebar from imported billets and/or by recycling end of life (EOL) steel products. Ribbed reinforcing bar is used for concrete structures in range of residential, commercial and infrastructure applications. Steel reinforcing bar is a crucial construction material to improve the tensional and flexural strength of concrete [3]. Due to the possibility to determine the properties of reinforcing bar before application, it plays a key role in the construction industry. Steel reinforcing bars used in the construction industry of different countries are obtained from both internal and external sources [3]. In the Ethiopian context, the internal sources are mini mills located in limited areas of the country. Imported steel bars coming into the country Ethiopia are mainly from Turkey, India, China, Russia and Ukraine [4]. The most common type of rebar is carbon steel, typically consisting of hot-rolled round bars with deformed patterns called thermo-mechanical treated (TMT). The properties of rebar can be modified by alloying with suitable elements, depending on their application area. For example, corrosion resistance is an essential property of material used in marine, and regions with high humidity content and in seismic zones, the specific ultimate tensile to yield stress (UTS/YS) ratio should be maintained close to 1.25 [5].

Steel reinforcing bars can be made from the virgin material or by secondary manufacturing process (recycling). Recycling of steel reduces the amount of energy consumed and environmental pollution in addition to the reduction of natural resources depletion. Most of the Ethiopian steel industries are engaged to manufacture reinforcing bars from steel scraps of different end of life steel products or imported billets. The collected ends off life steel products may have different chemical compositions and may need characterization in each foundry works. To minimize the complexity of material characterization, it is better to sort collected steel products using different sorting mechanism to predetermine the chemical composition of charged materials. The scrap materials are collected from different application areas stored on different places might be attacked by contaminants and their chemical composition may be affected. The chemical composition with the adverse manufacturing process will have higher influence on the mechanical properties obtained from products made by recycling process. The current state of the art can show that design of reinforced concrete in the developing countries may not be fully reliable. In the developing countries specially African where imported steel is very expensive, milling companies have taken up the challenge to re-cycle obsolete vehicle and machine metal parts for the production of structural and reinforcing steel [2]. The property of steel is greatly affected by its chemical composition, heat treatment and the method of manufacturing. The existing desired mechanical properties of rebar can be achieved through conventional rolling process by appropriate modification of chemical composition [6]. Most commonly yield strength, ultimate strength, Young's modulus of elasticity, Poisson's ratio and percentage elongation determine the mechanical properties of reinforcement bar. Thermo-Mechanical Treated bars are manufactured by rolling and in-line controlled cooling process is another alternative to get strength with ductility [7]. Based on the Ethiopian Building Code Standard, the yield strength of reinforcing bars limits to 400 to 600 MPa [8]. The world average specification for high yield steel bar is 460-500MPa which is difficult to achieve by conventional manufacturing process [6].

Thermo- mechanical Treated (TMT) rebar is an appropriate material for reinforcing concrete structures due to its similarity in thermal expansion with concrete, ability to bond well with concrete and ability to shoulder most of the tensile stress acting on the structure [9]. Today TMT bars are manufactured by rolling and in-line controlled cooling process. The industry level technology is patented under the names of Tempcore (western Europe) and Thermex (United states) [10] both with similar controlled cooling processes. Steel rebar with high strength combined with ductility, weldability and toughness can be obtained by applying Tempcore process for its fabrication [11]. In Tempcore hot rolled deformed bars are quenched at the end of rolling mill by applying high pressure jets of cold water on the red hot steel surface and this process hardens a crust near the steel surface while the bar core remains with high ductility [10]. The composition of martensite and ferrite/pearlite micro-structure of thermos- mechanically treated bar is shown in Fig. 1.

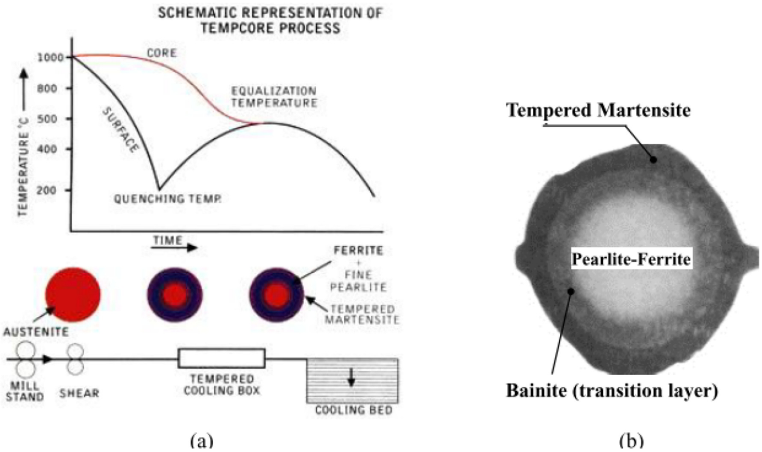

Fig. 1. Schematic representation of Tempcore process (a) TMT temperature profile with respect to time and (b) Typical TMT cross section observed in laboratory [10]

Thermo-mechanical-treatment is common in the manufacturing of most steel types, thermo- mechanical treated steel rebar has a ductile core and hard outer layer, the composite action gives sufficient ductility and yield strength [10]. TMT, the modified manufacturing process (i.e., in the cooling stage to control the microstructure formation) of steel led to a better performance than mild steel rebar at reduced cost of production. The TMT manufacturing process of rebar results in tempered martensitic at the periphery, ferrite-pearlite core, and a bainite transition layer. The pearlite core gives ductility to the bar and the martensitic layer gives the tensile strength and increases the corrosion resistance. Such type combination of microstructure can be considered dual phase (DP) steel belongs to the family of high strength low alloy steels [12, 13]. If the composition of structure constitute 20 to 30 percent of martensitic and the presence of a concentric and uniformly thick martensitic peripheral ring can assure the quality of the bar [7].

Even though the slight change of chemical composition of reinforcing bar affects the properties of steel, the tests in most construction sites have been restricted to tensile and bend tests [11, 14]. Since strength and ductility related capacities in reinforced concrete (RC) flexural members are largely controlled by steel reinforcing bars. Besides metallurgical/chemical compositions of the steel used, required properties especially those controlling the inelastic portion of the stress-strain curve which largely depends on the method of rebar manufacturing [15].

Different codes can be applied to specify the limits on the properties and testing procedures of the steel rebar based on the countries requirement. Worldwide, the most commonly utilized codes are ASTM A615, BS4449, ISO 6935-2 and EN 10080. Most of the developing countries adapt one of the above standard codes and contextualized to their requirement. In the case of Ethiopia, the standard agency adopts ISO 6935-2 standard for reinforcing bar and nominated as Compulsory Ethiopian Standard coded as CES- 101-2013. ASTM standards include a 550 MPa and in Germany the existing grades have 520 MPa minimum, and there are no grades with less strength [16].

Introduction of 600 MPa as minimum grade was considering as in ISO standard in some Asian countries. Contractors and consultants argued on that using high strength rebar will reduce rebar overcrowding in anti-seismic design, particularly in column-beam crossings, and reducing total steel mass needed for the overall construction [16]. Countries may use common terms yield strength, ultimate tensile strength, elongation and ratio of UTS with YS with different values are used to measure the conformity of rebar to their specific application (Fig. 2).

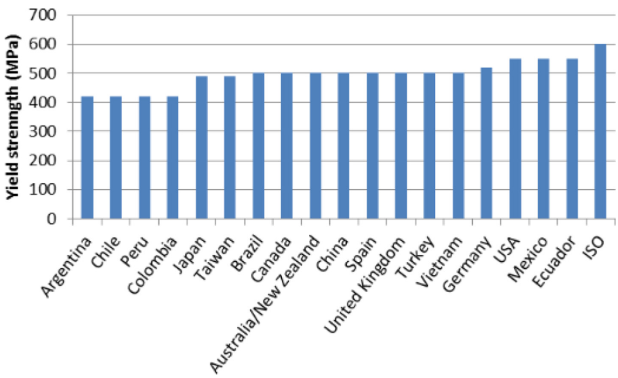

Fig. 2. Minimum yield strength for reinforcing bars (in MPa), on different standards [16]

According to Charles and Kankam typical stress–strain curves for standard steel bars used in reinforced concrete construction when loaded monotonically in tension exhibit an initial elastic portion which is a yield plateau and its length is a function of the strength of steel. Extending in the yield plateau region there is strain hardening range in which stress again increases with strain and finally, a range in which the stress drops off before fracture occurs. High strength, high-carbon types of steel generally have a much shorter yield plateau than lower strength low carbon steel [2].

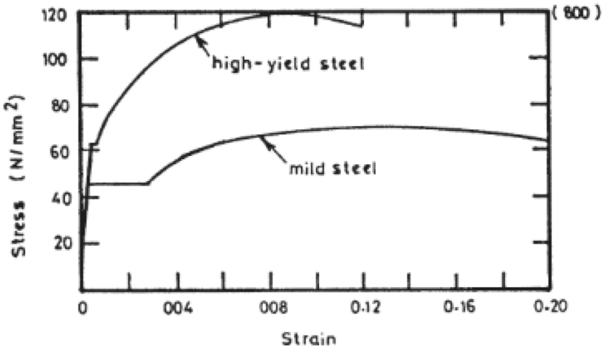

Fig. 3. Typical stress–strain curves for steel reinforcement [2]

There is no adequate information provided on the manufacturing process of reinforcing bar in Ethiopia. Additionally the strength analysis of the reinforcing bars used in Ethiopian construction industry is not recorded properly and the domestic trade of the reinforcing bar practiced an open market system. The open market system of the reinforcing bar did not provide enough information to the customer about the characteristic strength and chemical composition of reinforcing bars available on the market (Fig. 3).

This research provides information on the conformity of mechanical properties of steel reinforcing bars used in Ethiopian construction industry considering their yield strength and ductility based on the compulsory Ethiopian standard (CES-1 2013). The main purpose of the work is to have justified reason to conduct further research to improve the quality of locally manufactured reinforcing bars to achieve the required mechanical properties. The tension test was conducted on four samples of 14 mm diameter rebar using universal testing machine. Additionally tensional test data on 12, 14, 16, 20, 24 and 32 mm diameters were collected from Amhara Design and Supervision Works Enterprise which is an authorized institution found in Amhara regional state Bahir Dar- Ethiopia.

2 Methodology

The most common required mechanical properties of reinforcing bars can be evaluated by conducting tensile test on the selected samples using Universal Testing Machine (UTM). The tensile test helped in the determination of Yield Strength (YS), Ultimate Tensile Strength (UTS), Percentage Elongation (PE) and Percentage Reduction in Area (PRA) [1]. In this paper the experimental data collection methods for the tension test are categorized in to two tasks. On both cases the yield strength analysis is used to determine the load carrying capacity of different structures and ratio of UTS to YS & elongation values were analyzed to determine the level of ductility in respect to the compulsory Ethiopian Standard (CES -101-2013) and Ethiopian Building Code Standard (EBCS) to justify the failure or conformity of bars to use as reinforcement for concrete in the Ethiopian construction industry.

Task 1: Conducting Tension Test on 14 mm Diameter Reinforcing Bar. The Ethiopian construction industry uses imported and locally manufactured steel reinforced bars. The local manufactured reinforced bars are from two sources, one is recycled from the steel scraps and the other is from imported billets. The reinforcing bars used in Ethiopian construction are graded as B300, B400, B500 and B600 with its ductility grade A to D. Three samples of 14 mm diameter with 200 mm gauge length of local manufactured rebar from three different industries and one sample from imported one (turkey) are taken for tension test to determine their strength. The sources/manufacturers of the selected reinforcing bar are nominated as AIS, HSM, ES and Tur to assure the security. These sources/factories are selected based on the products availability on the market at the time of supervision. From 14 mm diameters of reinforcing bars, three required specimens for each sample are selected from the market in random way. A total of twelve specimens, three from each sample are selected. The samples are denoted as AIS 1, 2 & 3, ES 1, 2 & 3, HSM 1, 2&3 and Tur 1, 2 & 3. The number 1, 2, or 3 will not show quality difference, it is simply for the purpose of identification of specimens as shown in Table 1. Each sample was tested with universal testing machine for tensional strength that gives information about tensile strength, yield strength and ductility. The test result of UTM machine manipulated with MaxTest.exe program. The program delivers the amount of load applied, yield strength, ultimate tensile strength, elongation and stress- strain diagram of the test. The sequence of test is arranged in the form of lottery as shown in Table 1. All results of force, stress, strain and elongation are recorded on Table 2.

Task 2: Analysis of Yield Strength and Ductility of Reinforcing Bar Tension Test Data Collected from Amhara Design and Supervision Works Enterprise (ADSWE). To have enough data to draw conclusion on the conformity of rebar in Ethiopian construction industry, the tension test data on 12, 14, 16, 20, 24 and 32 mm diameter reinforced bars were collected from AMHARA DESIGN AND SUPERVISION WORKS ENTERPRISE (ADSWE). The test was conducted from February to June 2019 using universal tensile testing machine on 200 mm gauge length reinforcing bars. Amhara Design and Supervision Works Enterprise (ADSWE) was established as public enterprise in the regional sate of Amhara- Ethiopia to realize the objective of the wellbeing of people through providing excel consultancy service. ADSWE is an authorized organization by Amhara regional state to conduct tension test on reinforcing bars.

In ADSWE three specimens was tested on each sample, the average result is used for analysis. The average value of the three specimens for each thirty nine samples were collected from seven local steel reinforcing bars manufacturing industries and 22 samples imported from turkey except one sample from Ukraine. The yield strength, ultimate tensile strength, ratio of UTS to YS and elongation results are used to check the conformity of reinforcing bars in terms of result and ductility.

3 Result and Discution

3.1 Results

Tension test results conducted by universal testing machine on 14 mm diameter rebar, three samples from local manufactured and one sample imported from turkey, are tabulated as shown in Table 2 below. The recorded data is taken directly from the summary of

Table 1. Sequence of test for candidate materials

No	Nomination symbol	Gauge length mm	Nominal diameter	Total length mm	Remark
1	ES1	200	14	360	Local
2	HSM3	200	14	360	Local
3	TUR2	200	14	360	Imported
4	HSM2	200	14	360	Local
5	TUR3	200	14	360	Imported
6	AIS1	200	14	360	Local
7	AIS2	200	14	360	Local
8	TUR1	200	14	360	Imported
9	ES3	200	14	360	Local
10	AIS3	200	14	360	Local
11	HSM1	200	14	360	Local
12	ES2	200	14	360	Local

tension test result tabulated by the program **MaxTest.exe** integrated with UTM machine. Most of the stress strain diagrams of the conducted tension test samples show similar pattern. It includes the elastic limit, plastic limit and fracture point of all tension test with different values. Figure 4 shows how samples were breaking during the tension test at the fracture point.

Data collected from Amhara design and supervision works enterprise (ADWSE) is tabulated as shown from Table 3, Table 4, Table 5, Table 6, Table 7 and Table 8 based on their nominal diameter.

3.2 Discussion

The results obtained from tension test were evaluated based on Ethiopian standards such as CES 101–2013 and ECBS-2- 2013 Standards. In the case of strength the maximum yield strength did not restricted in most of the steel grades. The minimum yield strength is specified as 400 MPa in Ethiopian building code standard [8]. From the tested samples, products from two companies nominated as AIS1 and ES1 did not satisfy the requirements of the Ethiopian Standards.

In the case of ductility requirement, ratio of UTS/YS and Elongation are taken together in to consideration to check conformity of reinforcing bars. By considering elongation with the ratio UTS/YS together, most of locally manufactured bars are failed to satisfy the requirement, for example AIS2 and AIS3 bar have yield strength 576 and 594 respectively and have UTS/YS 1.16 requires minimum elongation at fracture 14% where as 11% elongation is recorded here. So the reinforcing bars are failed to satisfy CES- 101 in addition to the previously rejected one (AIS1 and ES1). Reinforcing bars nominated as HSM1, HSM2 and HSM3 have 596, 553 and 564 MPa yield

Table 2. Recorded data from tension test result of 14 mm diameter reinforcing bar from four different sources.

Sr. No	Sample	Yield strength ReH (MPa)	Ultimate Tensile Strength Rm (MPa)	Elongation after fracture (%)	Remark
1	AIS 1	375	530	23	Local
2	AIS 2	579	672	11	Local
3	AIS 3	594	692	11	Local
	Average	**516**	**631.33**	**15**	
4	ES 1	349	493	32.5	Local
5	ES 2	565	630	12	Local
6	ES 3	463	592	24	Local
	Average	459	571.66	22.83	
7	HSM 1	596	676	13	Local
8	HSM 2	553	654	13	Local
9	HSM 3	564	659	13	Local
	Average	**571**	**663**	**13**	
10	TUR 1	608	703	14	Imported
11	TUR 2	602	696	13	Imported
12	TUR 3	631	719	12.5	Imported
	Average	**613.66**	**706**	**13.16**	

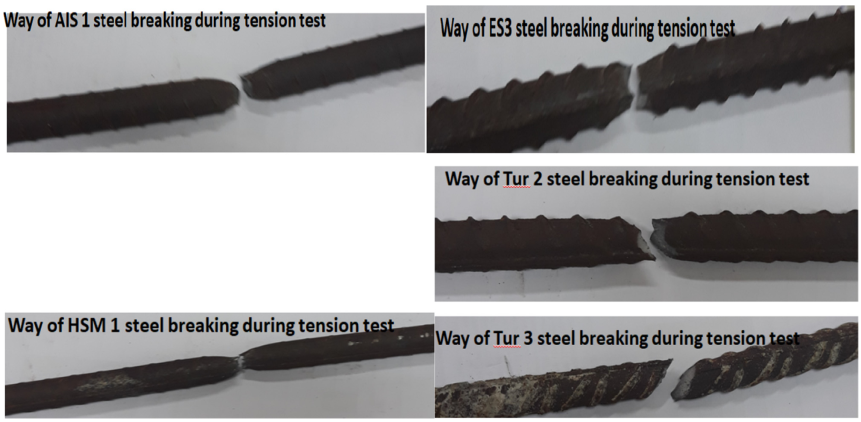

Fig. 4. The how steel samples were break during tension test

strength respectively. Referring their UTS/YS ratio the required elongation is 14% but they obtained 13% elongation, so they are failed to achieve the requirement of CES-101-2013.

Table 3. Data collected from ADSWE tension test data for 12 mm diameter bar from February to June

Sr. No	Origin of bar	Dia.	Cr.A (mm^2)	YS (Mpa)	UTS (Mpa)	UTS/YS	Elongation (%)
1	Turkey	12	113.10	532.5	638.2	1.198	11.961
2	ES	12	113.10	567.566	729.333	1.285	15.182
3	Apollo	12	113.10	538.653	631.316	1.172	14.286
4	Apollo	12	113.10	529.044	619.828	1.172	15.500
5	BIGS	12	113.10	478.969	673.622	1.406	10.926
6	BIGS	12	113.10	478.969	673.622	1.406	10.926
7	EK	12	113.10	420.229	609.159	1.450	20.931
8	HSMA	12	113.10	571.692	690.033	1.207	11.640
9	ZG	12	113.10	508.236	678.362	1.335	14.607
10	Turkey	12	113.10	516.165	612.350	1.186	15.049
11	Turkey	12	113.10	495.710	656.191	1.324	14.013
12	Turkey	12	113.10	557.457	657.026	1.179	13.815
13	Turkey	12	113.10	577.587	674.627	1.168	14.111
14	Turkey	12	113.10	528.278	653.109	1.236	16.084
15	Turkey	12	113.10	431.724	651.285	1.508	15.051
16	Turkey	12	113.10	563.115	666.510	1.183	13.935

Table 4. Data collected from ADSWE tension test result for 14 mm bar from February to June

Sr. No	Origin of bar	Di.	Cr.A (mm^2)	YS (Mpa)	UTS (Mpa)	UTS/YS	Elongation (%)
1	ES	14	153.94	547.7	741.7	1.3	16.738
2	BiGS	14	153.94	538.3	717.0	1.332	12.850
3	ZG	14	153.94	559.7	689.6	1.232	18.604
4	Apollo	14	153.94	520.7	625.8	1.202	18.412
5	Apollo	14	153.94	523.1	601.1	1.15	19.392
6	ZG	14	153.94	538.2	685.8	1.27	20.675
7	ZG	14	153.94	524.92	655.34	1.25	19.537
8	Apollo	14	153.94	569.79	662.91	1.16	16.423
9	Turkey	14	153.94	543.00	729.29	1.34	14.794

Imported reinforcing bars nominated as TUR2 obtained 602 MPa yield strength and 1.15 UTS to YS ratio. The required elongation 14% but the recorded one 13%, it fails

Table 5. Data collected from ADSWE tension test result for 16 mm bar from February to June

Sr. No	Origin of bar	Di.	Cr.A (mm^2)	YS (MPa)	UTS (MPa)	UTS/YS	Elongation (%)
1	AIS	16	201.062	339.56	490.30	1.44	30.80
2	AIS	16	201.062	564.58	685.09	1.21	16.30
3	Apollo	16	201.062	499.94	606.42	1.21	20.34
4	BIGS	16	201.062	576.36	650.98	1.12	14.62
5	BIGS	16	201.062	495.11	608.20	1.22	20.52
6	BIGS	16	201.062	577.50	657.45	1.13	16.02
7	BIGs	16	201.062	585.44	678.89	1.15	15.88
8	EK	16	201.062	380.56	582.57	1.53	25.66
9	EST	16	201.062	504.45	643.40	1.27	21.06
10	ZG	16	201.062	527.03	702.37	1.33	17.66
11	ZG	16	201.062	534.39	673.04	1.25	21.67
12	Turkey	16	201.062	513.69	613.96	1.19	21.78
13	Turkey	16	201.062	522.99	635.62	1.21	18.54
14	Turkey	16	201.062	546.22	607.60	1.11	14.35
15	Turkey	16	201.062	536.20	645.55	1.20	15.05
16	Turkey	16	201.062	549.18	654.01	1.19	18.04

Table 6. Data collected from ADSWE tension test results for 20 mm bar from February to June

Sr. NO	Dia. (mm)	Origin of the Bar	YS (Mpa)	UTS (Mpa)	Ratio UTS/ YS	Elongation (%)
1	20	Turkey	523.60	639.41	1.221	20.137
2	20	BIGS	568.43	662.94	1.166	17.132
3	20	HSMA	560.52	691.07	1.232	13.564
4	20	Apollo	415.81	569.62	1.369	23.124
5	20	Apollo	540.60	654.73	1.211	18.518
6	20	HSM	472.67	646.99	1.368	16.537
7	20	Turkey	524.28	651.19	1.242	18.769
8	20	Turkey	500.29	614.82	1.228	21.170
9	20	HSMA	520.97	643.90	1.235	17.446
10	20	HSMB	415.63	623.72	1.500	15.901

to satisfy the requirement of CES- 101-2013. The imported TUR1 has yield strength 608 MPa and UTs to YS ratio 1.15 required elongations is 14% and also the recorded

Table 7. Data collected from ADSWE tension test result for 24 mm bar from February to June

Sr. NO	Dia. (mm)	Origin of Bar	YS (Mpa)	UTS (Mpa)	Ratio UTS/YS	Elongation (%)
1	24	Turkey	547.63	645.46	1.18	20.486
2	24	ZG	528.26	675.29	1.28	24.866
3	24	BIGS	452.48	561.12	1.24	27.895
4	24	Apollo	520.20	631.86	1.21	22.222
5	24	KSMG	502.32	638.57	1.27	29.312
6	24	Turkey	596.38	694.37	1.16	17.940

Table 8. Data Collected from ADSWE tension test result for 32 mm bar from February to June

Sr. NO	Dia. (mm^2)	Origin of Bar	YS (MPa)	UTS (MPa)	Ratio UTS/YS	Elongation (%)
1	32	Turkey	378.13	756.54	2.00	12.20
2	32	BIGS	566.68	731.64	1.29	13.35
3	32	UHRAINE	518.76	633.85	1.22	11.19
4	32	Turkey	459.18	594.30	1.29	16.93

one is 14%, it satisfies the requirement. The imported TUR3 has yield strength 631 MPa and UTS/YS ratio 1.14 required elongation is 10% and the recorded one 12.5% it also satisfies the need of CES- 101-2013.

Data collected from Amhara design and supervision works enterprise as referred from Table 3, Table 4, Table 5, Table 6, Table 7 and Table 8 shows all the required information in terms of ultimate tensile strength, yield strength and ductility. On the 12 mm diameter reinforcing bar all the samples satisfied the minimum yield strength (400MPa), because all the samples record more than 400 MPa. But in terms of ductility the amount of elongation and ratio of UTS to YS 50% of samples are failed to satisfy the requirement. From the same statistics 8 samples of the turkey products was examined and 4 of them are failed to satisfy the requirement. From 14 mm diameter samples only one sample from the local manufactured reinforcing bar was failed to satisfy the requirement in terms of elongation or ductility. Again from the collected data all 16 mm diameter reinforcing bar samples were passed all the requirements. According to the data collected from ADSWE samples with their nominal diameter less than 16 mm record failure to satisfy the requirements specified on CES-101-2013 and EBCS-2 2013 Ethiopian standards, most of the failed reinforcing bars were luck to achieve ductility. This may happen one due to the absence sufficient amount of temperature at the core of the bar required for self-tempering process of the reinforcing bar on the quenched surface. Two it may be due the presence of high amount of carbon or alloyed elements that form carbides harder than iron carbide. Re-bar with smaller diameter may cool in the fast rate without retain enough amount of temperature for self-tempering process due their surface area to volume ratio. Whereas rebar with larger diameter may able to retain enough amount of temperature at the core region and make self-tempering process. Because of the capability to store sufficient amount of self-tempering temperature at the core area during the quenching process, rebar with larger diameter are able to achieve the required ductility and they were satisfied CES- 101-2013.

4 Conclusion

From the tension test results conducted by universal testing machine and tension test data collected from ADSWE the following conclusions are drawn:

1. The quality of the reinforcing bar will not be assured by the origin of the country. According to the data collected from the tension test and ADSWE tension test data both the imported and local manufactured had faced rejection based on the requirements set by the Ethiopian Standard Agency (CES -101- 2013).
2. Most of the samples satisfy the required yield and ultimate tensile strength but they were failed to achieve ductility. This shows achieving higher strength without scarifying ductility is difficult in conventional manufacturing process especially at the smallest diameter reinforcing bar.
3. Reinforcing bars with higher diameter satisfied minimum yield strength and ductility better than reinforcing bars with smaller diameter. This might happen due to the composition of ferrite–pearlite and martensitic structure formed during the cooling process. The ferrite- pearlite and martensitic structure will depend on self-tempering process due to the temperature difference at the surface and core of the reinforcing bar. The core temperature during cooling is higher in larger diameter bars due to the difference in surface area to volume ratio. Materials with smaller diameter bars have larger surface area to volume ratio than larger diameters and smaller diameters release temperature in the fast rate than larger diameter bars.

References

1. Kareem, B.: Tensile and chemical analyses of selected steel bars produced in Nigeria. Res. Gate (2009)
2. Charles, M.A.-A., Kankam, K.: Strength and ductility characteristics of reinforcing steel bars milled from scrap metals. Mater. Des. Mater. Des. **23**(2002), 537–545 (2002)
3. Ejeh, S.P., Jibrin, M.U.: Tensile Tests on Reinforcing Steel Bars in the Nigerian Construction Industry (2012)
4. Jica, R.: Basic Metal and Engineering Industries: Policy Framework and the Firm-level Study (2010)
5. Panigrahi, S.S.B.K., Sahoo, G.: Effect of alloying elements on tensile properties, microstructure, and corrosion resistance of reinforcing bar steel. J. Mater. Eng. Perform. **18**(8), 1102 (2009)
6. Balogun, S., Esezobor, D., Adeosun, S., Sekunowo, O.: Challenges of Producing Quality Construction Steel Bars in West Africa: Case Study of Nigeria Steel Industry (2009)

7. Gokul, P.N., Sarvani, A.O.N., Radhakrishna, S.P.: Variations in microstructure and mechanical properties of Thermo-Mechanically-Treated (TMT) Steel Reinforcement Bars (2015)
8. EBCS: Ethiopian Building Code Standards, Design of Concrete Structures (2013)
9. Souvik Das, J.M., Bhattacharyya, T., Bhattacharyya, S.: Failure analysis of re-bars during bending operations (2014)
10. Sooraj, G.P.R., Nair, A.O., Sethuraj, R., Nandipati, S., Radhakrishna, G.P.: Variations in microstructure and mechanical properties of Thermo-Mechanically-Treated (TMT) steel reinforcement bars (2018)
11. Salman, F.D.A.: Variability of Chemical Analysis of Reinforcing Bar Produced in Saudi Arabia
12. Yu Cao, J.A., Karlsson, B.: The influence of temperatures and strain rates on the mechanical behavior of dual phase steel in different conditions (2014)
13. Vladimir Torganchuk, A.B., Kaibyshev, R.: Effect of rolling temperature on microstructure and mechanical properties of 18%Mn TWIP/TRIP steels
14. Andrey Belyakov, R.K., Torganchuk, V.: Microstructure and Mechanical Properties of 18%Mn TWIP/TRIP Steels Processed by Warm or Hot Rolling (2017)
15. Rai, S.K.J.D.C., Chakrabarti, I.: Evaluation of Properties of Steel Reinforcing Bars for Seismic Design (2012)
16. Jorge Madias, M.W., Behr, G., Valladares, V.: Analysis of International Standards on Concrete Reinforcing Steel Bar (2017)