PROPERTIES OF STEEL FOR THE REINFORCEMENT OF CONCRETE IN BANGLADESH

M. A. A. Siddique*

Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
**Corresponding Author: alamin@ce.buet.ac.bd*

ABSTRACT

This paper presents the statistical analysis of test results for different properties of steel for the reinforcement of concrete in Bangladesh. A number of tests have been conducted on reinforcing bars having different steel grades such as 276 MPa (40 ksi), 414 MPa (60 ksi) and 500 MPa (72 ksi). These bars have been used or will be intended to use for a wide range of structural applications such as buildings, bridges, flyover, culverts, road drainage networks etc. These include constructions by government and semi-government organizations, private as well as developer companies. From the experimental results, it is observed that tested diameters of rebars are usually lesser than that of the specified nominal diameter. This trend is found more dominant for 500 MPa bars than that of 276 MPa and 414 MPa bars. Average yield strength of rebars satisfies the minimum standard requirements set forth by ASTM and BDS ISO. The ratio between tensile strength to the yield strength and percent elongation are observed higher both for 276 MPa and 414 MPa bars than those of 500 MPa bars. Higher coefficient of variation is shown for bars with yield strength of 414 MPa.

Keywords: Reinforcing bar; grade; yield strength; tensile strength; percent elongation

INTRODUCTION

Three types of steel reinforcement bars (rebars) such as hot-rolled (HR), cold twisted deformed (CTD), and thermo-mechanically treated (TMT) have been used in concrete structures. HR rebars are produced through hot rolling followed by a slow cooling to an ambient temperature. The high yield strength of the bar is obtained by raising carbon as well as manganese contents, and to a great extent, by cold twisting. CTD bars are produced by cold working process, which is basically a mechanical process that involves stretching and twisting of mild steel, beyond the yield plateau, and subsequently releasing the load. There has been an increasing demand for high strength deformed bars. TMT bars were introduced in Bangladesh in the last decade. Thermo mechanical treatment is an advanced heat treatment process in which hot bars coming out of last rolling mill stand are rapidly quenched through a series of water jets. Rapid quenching provides intensive cooling of surface resulting in the bars having hardened surface with hot core. The rebars are then allowed to cool in ambient conditions. During the course of such slow cooling, the heat released from core tempers the hardened surface of martensite while core is turned into ferrite-pearlite aggregate composition (Islam, 2010). The design of reinforced concrete (RC) structures in Bangladesh was dominated by the use of steel reinforcement with a yield strength, f_y, equal to 276 MPa (40 ksi) and 414 MPa (60 ksi). Currently, 500 MPa (72 ksi) rebars are widely used in concrete industry. ACI 318 (ACI 2011) and AASHTO (2012) edition of the AASHTO LRFD Bridge Design Specifications permit the use of rebars beyond 552 MPa. Earlier versions of these codes, the yield strength of rebars was limited to 552 MPa as the behaviour of structural members using rebars with yield strength above 552 MPa was not well documented. Use of high strength bars for design could provide various benefits to the concrete construction industry by reducing member cross-sections and reinforcing quantities, which would lead to savings in materials, shipping, and placement costs. However, the use of high strength reinforcements such as 500 MPa bars is not fully utilized in design practice in Bangladesh. This may due to the fact that the behaviour of structural RC members having reinforcing steel with yield strength of 500 MPa is not well documented. However, upcoming BNBC-2015 might permit the use of reinforcing bar up to 600 MPa considering different ductility classes following BDS ISO standards. This ductility class depends on tensile strength-to-yield strength (TS/YS) ratio and specified characteristic value of elongation at maximum force, A_{gt}. According to H. Bachmann (2000), RC structures may be classified as moderate ductile when TS/YS ≥ 1.15 and A_{gt} ≥ 6% are met and high ductility having TS/YS ≥ 1.25. In addition, no maximum limit is specified for upper yield strength of the rebars. Although, 500 MPa bars are now currently in use for the construction industry in Bangladesh, there is a concern in structural behaviour of concrete members having high strength rebars. If a higher strength reinforcing steel is used in concrete but not fully accounted for in design phase, there may be an inherent overstrength in the members that has not been properly taken into account in the design phase. Overstrength in one member may result in unanticipated higher loads being transmitted to adjacent members or joints affecting assumed structural behaviour. This concern is most critical for members in seismic areas or when progressive collapse state is considered.

In structural design, uncertainties in loadings, design and constructions are considered by load factors and strength reduction factors. The purpose of these factors is to limit the probability of structural failure to an acceptable low level. For the case of material property variations, the variability of the physical and mechanical properties of reinforcing steel affects the performance of RC structures. In Bangladesh, these properties have minimum requirements, as detailed by ASTM A615 and BDS ISO 6935-2. These standards do not set maximum limits for yield strengths except ASTM A706. Designers normally use the minimum values in design without considering the true strength of rebars. This may be of concern because member behaviour can differ from the assumed response if material properties are significantly higher than those used in the design. If the reinforcement is too strong in RC flexural member, it will be over-reinforced and this can result in brittle failure with the concrete crushing before the steel yields. Therefore, the objective of this paper is to evaluate the variability of mechanical properties of reinforcing steel produced in Bangladesh and to analyze the degree to which manufacturers satisfy the minimum requirements established by ASTM and BDS standards. The study is conducted statistically by analyzing the tested rebar data. Trends in the data are evaluated based on different grades and bar sizes. Cross-sectional properties such as diameter as well as weight per meter length are considered. For the mechanical properties, yield strength (YS), tensile strength (TS), strength ratio (TS/YS), and percent elongation (%) are considered. General data descriptors are used, including mean, standard deviation, coefficient of variation, minimum and maximum values for each grade and bar size. These results would provide the quality assessment of reinforcing bars for concrete used in construction sectors in Bangladesh.

METHODOLOGY

A statistical analysis has been carried out on the tested data to evaluate the variability in the properties of steel reinforcements. Cross-sectional property such as nominal weight as well as actual diameter and mechanical properties such as yield and tensile strengths, strength ratio (TS/YS) and percent elongation are assessed in terms of the requirements as set forth by ASTM and BDS. Three grades of rebars such are 276 MPa, 414 MPa and 500 MPa are considered in the study. Available diameters range from 10 mm to 20 mm for 276 MPa bars whereas 8 mm to 25 mm are considered for 414 MPa and 500 MPa rebars. In addition, 28 mm, 32 mm and 40 mm are considered for 500 MPa bars and 32 mm for 414 MPa bars. All the reinforcing bars were tested in universal testing machine to obtain the mechanical properties of rebars following ASTM A370.

RESULTS AND DISCUSSIONS

In this paper, a statistical analysis is conducted to evaluate the physical and mechanical properties of rebars and to compare these properties with requirements set forth by ASTM and BDS standards. Table 1 presents the number of specimens tested in the laboratory for different grades and bar sizes. These rebars are tested in the year of 2015-16 and are used or intended to use for a wide range of structural applications. From the analysis, it is observed that average diameter of 20 mm rebar having grades of 500 MPa and 414 MPa are obtained 19.9 mm with a lower standard deviation and co-efficient of variation (CoV) for 500 MPa than those of 414 MPa bar. However, average diameter is obtained 20.1 mm for 276 MPa bar with a higher standard deviation and a higher CoV. These statistical values can be determined for other bar diameters as well as for different grades of rebars. Fig. 1 shows the variation of 20 mm bar dia for three grades as well as average dia vs. nominal values.

Table 1: Number of rebar specimens used for analysis

Grade	Bar size (mm)									
ksi (MPa)	8	10	12	16	20	22	25	28	32	40
40(276)	---	162	193	175	147	---	---	---	---	---
60(414)	12	216	164	187	179	12	118		17	---
72(500)	45	324	278	364	375	21	168	15	18	12

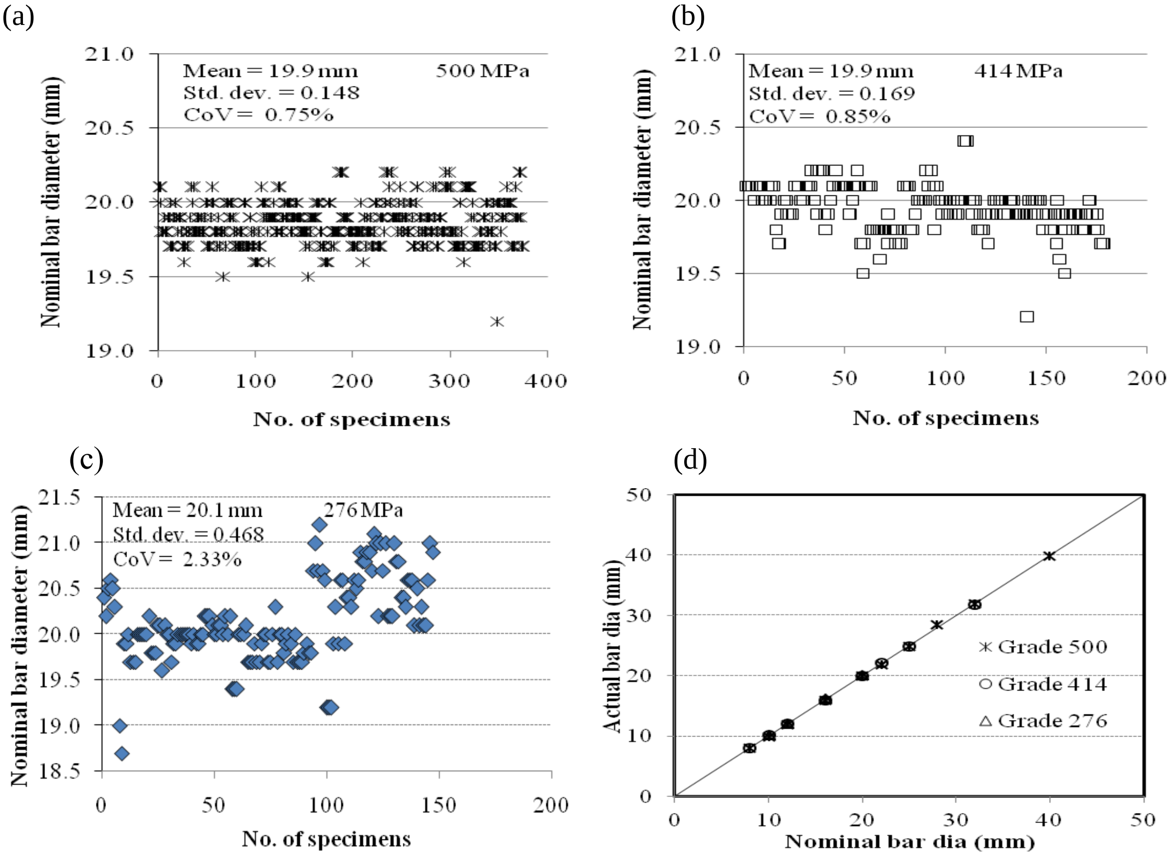

Fig.1: Variation of 20 mm bar diameters for different grades of rebars (a) 500MPa (b) 414 MPa (c) 276 MPa and (d) average bar dia for three grades

Fig. 2 shows the variation of yield strength, tensile strength, TS/YS ratio and percent elongation for 500 MPa rebars with maximum and minimum values for each parameters. From Fig. 2(a), it is observed that a wide range of yield strength is obtained with a minimum 325 MPa for 12 mm bar and a maximum 750 MPa for 8 mm bar. A number of specimen fall below the minimum yield strength values. Similar trend is observed for tensile strength, TS/YS ratio and percent elongation as shown in Figs. 2(b), 2(c) and 2(d), respectively. Figures 3 and 4 present the variations of the same parameters as mentioned in Fig. 2 for the rebar grades 414 MPa and 276 MPa, resepctively. From these figures it is observed that average yield strength is well above the standard minimum criteria. However, a higher strength variation is observed for 12 mm of 500 MPa and 16 mm of 414 MPa bars. Percent elongation as well as strength ratio values are hgher for 414 MPa and 276 MPa bars than those of 500 MPa bars. Fig. 5 shows CoV of different parameters for three grades of rebars. From this figure, it is shown that a higher CoV is observed for yield strength and strength ratio of 414 MPa bars than those of 500 MPa bars. However, CoV for percent elongation is comparable for the tested three grades of rebars as shown in Fig. 5(d)

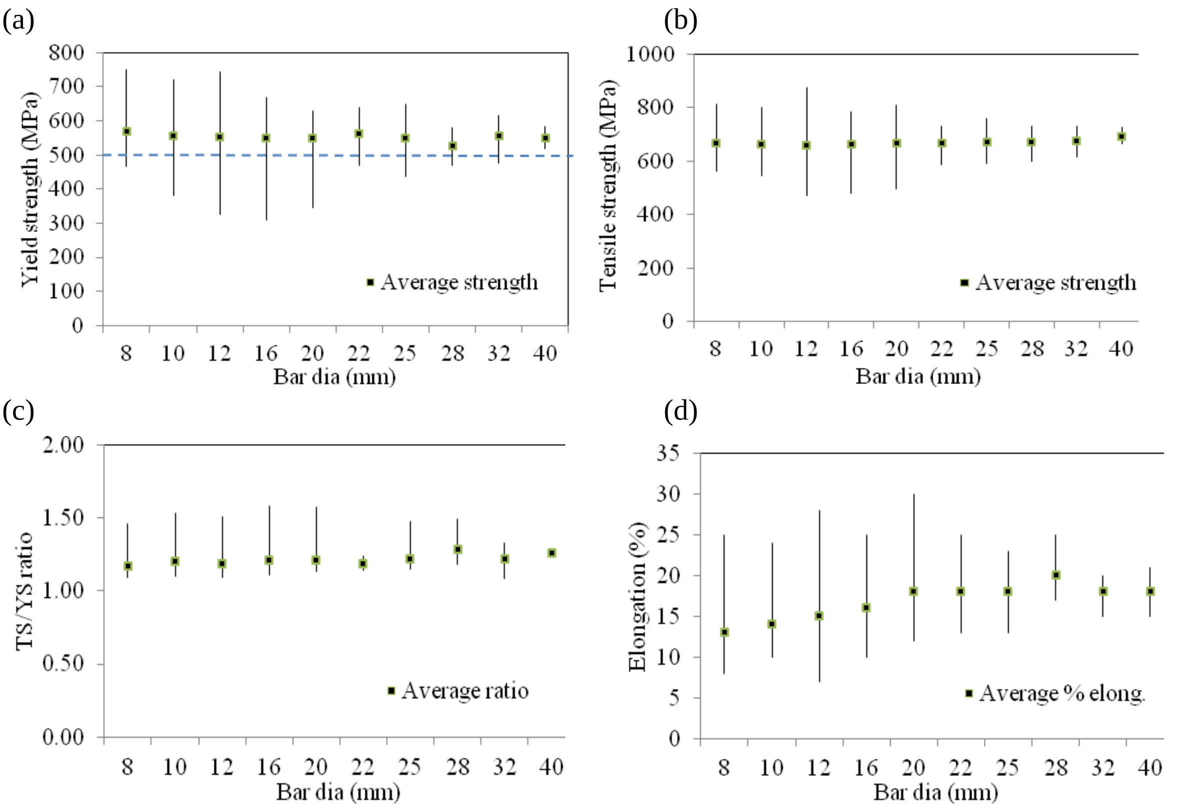

Fig.2: Variation of different properties of 500 MPa rebars (a) Yield strength (b) Tensile strength (c) Strength ratio (TS/YS) (d) Percent elongation

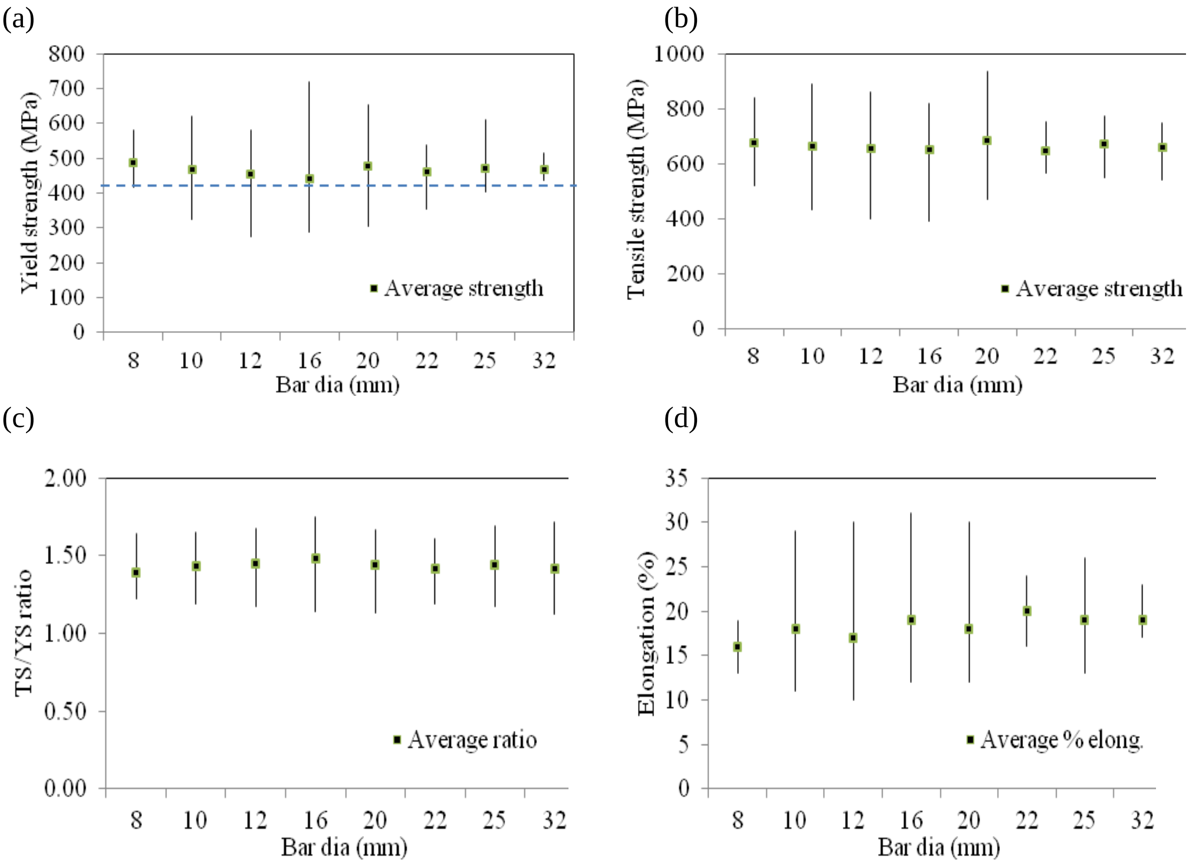

Fig.3: Variation of different properties of 414 MPa rebars (a) Yield strength (b) Tensile strength (c) Strength ratio (TS/YS) (d) Percent elongation

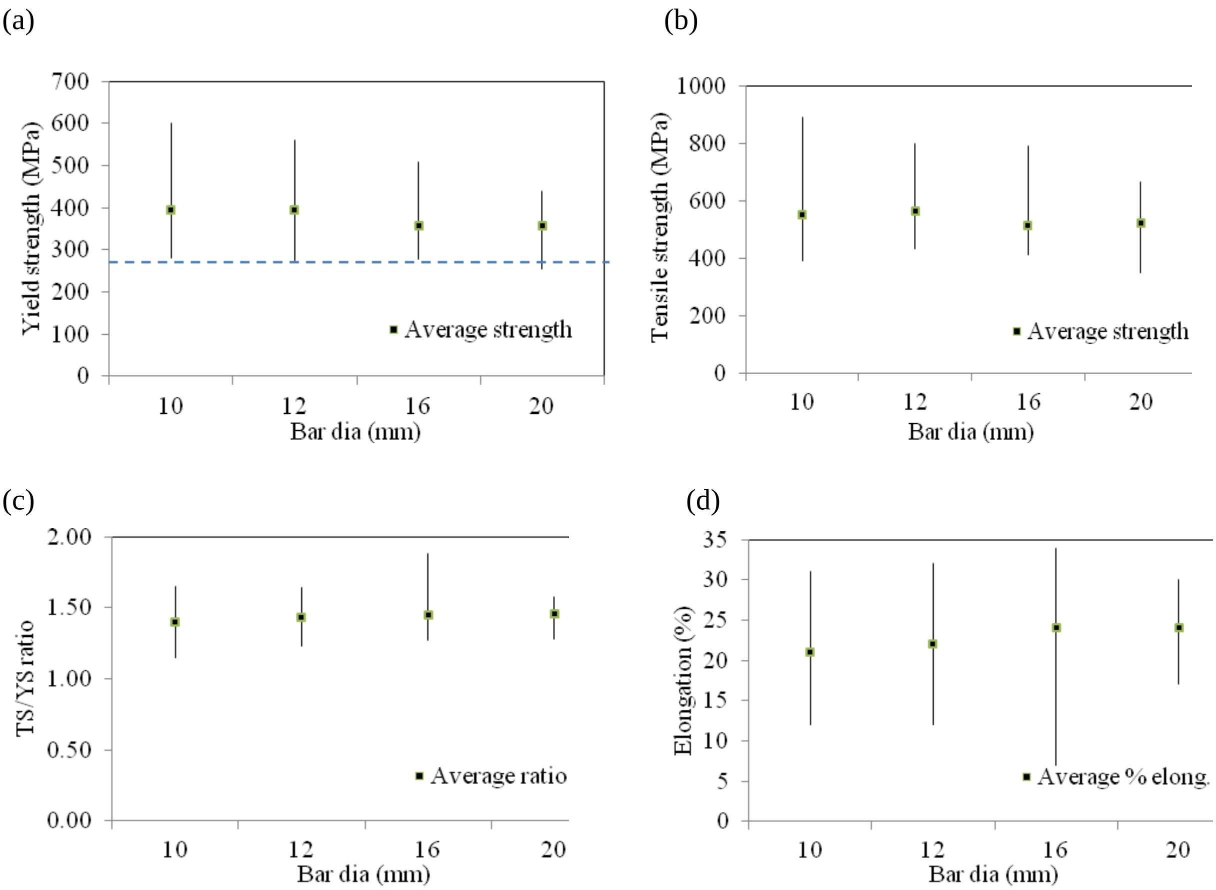

Fig. 4: Variation of different properties of 276 MPa rebars (a) Yield strength (b) Tensile strength (c) Strength ratio (TS/YS) (d) Percent elongation

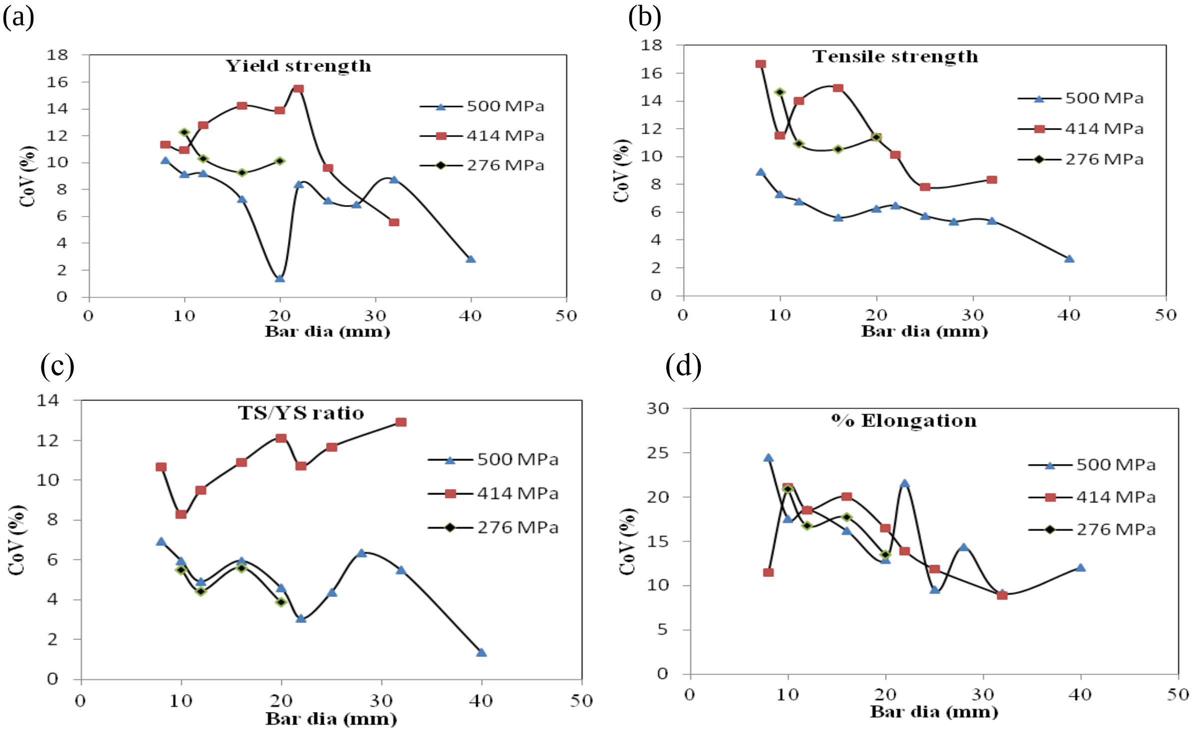

Fig. 5: Variation of CoV for three grades of rebars (a) Yield strength (b) Tensile strength (c) TS/YS ratio (d) Percent elongation

CONCLUSIONS

A statistical analysis is conducted in this paper to evaluate the physical and mechanical properties of reinforcing bars and to assess the quality of the rebars used in concrete construction in Bangladesh. Three grades such as 500 MPa, 414 MPa and 276 MPa are considered. A wide range of rebar diameters from 8 mm to 40 mm are considered for wide areas of construction applications by government and private sectors. Following conclusions can be drawn from the present study:

- Average yield strength values for all the tested speciemns satisfy the minimum yield strength requirements set forth by ASTM and BDS standards.
- Tensile strength-to-yield strength ratio and percent elongation are observed higher values for 414 MPa and 276 MPa bars than those of 500 MPa bars.
- Higher CoV are obtained for yield strength values of 414 MPa bars than those of 500 MPa and 276 MPa bars. However, almost the same CoV is shown for percent elongation for three grades of rebars.

ACKNOWLEDGMENTS

The author would like to express his gratitude to BRTC, BUET for providing the experimental data. The author is also thankful to all lab technician/assistants of SM lab, Department of Civil Engineering, BUET for their assistance in conducting the tests.

REFERENCES

AASHTO .2012., AASHTO LRFD Bridge Design specifications, 6th Ed. Washington, DC.

American Concrete Institute (ACI). 2011. Building Code requirements for reinforced concrete and commentary, ACI 318-11/ACI 318R-11, Farmington Hills, MI, USA.

ASTM. 2014. Standard test methods and definitions for mechanical testing of steel products, A 370-14, West Conshohocken, PA, USA.

ASTM. 2014. Standard specification for deformed and plain carbon steel bars for concrete reinforcement, A615/A615M-14, West Conshohocken, PA, USA.

ASTM. 2014. Standard specification for deformed and plain low-alloy steel bars for concrete reinforcement, A706/A706M-14, West Conshohocken, PA, USA.

Bachmann, H. 2000. Problems relevant to poor ductility properties of european reinforcing steel. *12th World conference on Earthquake Engineering*, Auckland, New Zealand.

Bangladesh Standards and Testing Institution (BSTI). 2015. Steel for the reinforcement of concrete-Part 2: Ribbed bars, BDS ISO6935-2, Tejgaon, Dhaka, Bangladesh.

Housing and Building Research Institute (HBRI). 2006. Bangladesh National Building Code (BNBC), Mirpur, Dhaka, Bangladesh

Islam, MA. 2010. Thermomechanically treated advanced steels for structural applications. *Proceedings of MARTECC 2010, The International Conference on Marine Technology*, BUET, Dhaka, Bangladesh, pp. 149-153.