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Tensile Strength/Yield Strength (TS/YS) Ratios of High-Strength Steel (HSS) Reinforcing Bars

Tavio[1,a)], Retno Anggraini[2,b)], I Gede Putu Raka[1,c)], and Agustiar[3,d)]

[1]*Department of Civil Engineering, InstitutTeknologiSepuluhNopember (ITS), Surabaya, Indonesia*
[2]*Doctoral Candidate, Department of Civil Engineering, InstitutTeknologiSepuluhNopember (ITS), Surabaya,Indonesia and Department of Civil Engineering, Brawijaya University, Malang, Indonesia*
[3]*Doctoral Candidate, Department of Civil Engineering, InstitutTeknologiSepuluhNopember (ITS), Surabaya, Indonesia and Department of Civil Engineering, Muhammadiyah University of Aceh, Banda Aceh, Indonesia*

[a)]tavio_w@yahoo.com
[b)]coresponding author : retnoang@ub.ac.id
[c)]igp_raka@yahoo.com
[d)] ampenan70@yahoo.com

Abstract. The building codes such as American Concrete Institute (ACI) 318M-14 and Standard National Indonesia (SNI) 2847:2013 require that the ratio of tensile strength (TS) and yield strength (YS) should not less than 1.25. The requirement is based on the assumption that a capability of a structural member to develop inelastic rotation capacity is a function of the length of the yield region. This paper reports an investigation on various steel grades, namely Grades 420, 550, 650, and 700 MPa, to examine the impact of different TS/YS ratios if it is less or greater than the required value. Grades 550, 650, and 700 MPa were purposely selected with the intention to examine if these higher grades are still promising to be implemented in special structural systems since they are prohibited by the building codes for longitudinal reinforcement, whereas Grade 420 MPa bars are the maximum limit of yield strength of reinforcing bars that is allowable for longitudinal reinforcement of special structural systems. Tensile tests of these steel samples were conducted under displacement controlled mode to capture the complete stress-strain curves and particularly the post-yield response of the steel bars. From the study, it can be concluded that Grade 420 performed higher TS/YS ratios and they were able to reach up to more than 1.25. However, the High Strength Still (HSS) bars (Grades 550, 600, and 700 MPa) resulted in lower TS/YS ratios (less than 1.25) compared with those of Grade 420 MPa.

INTRODUCTION

High strength steels (YS>450 MPa) have a significant potential contribution which still remains largely unrealized. This is predominantly due to design code limitations, the upper allowable limit of yield stress/ultimate stress ratio being particularly severe. This report presents a review of current literature on the origins,causes and structural significance of high TS/YS ratios in steels.Treatment of TS/YS in design codes, the origin of the limits and current thinking on acceptable limits are first reviewed.

For reinforcement concrete design, ACI-318-14 (2014)have 3 limitations: value of yield strength, tensile and yield strength ratio, and elongation of steel reinforcing bars which used in reinforcement concrete. One of three limitation based on ACI-318-14 (2014), tensile and yield strength ratio, limited should not less than 1.25. The requirement is based on the assumption that a capability of a structural member to develop inelastic rotation capacity is a function of the length of the yield region.[1]

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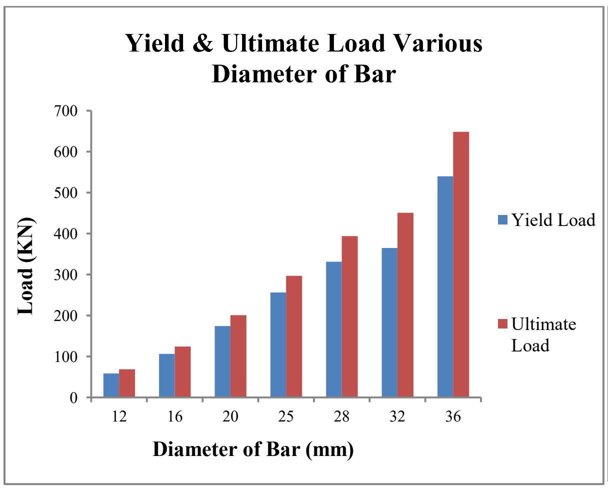
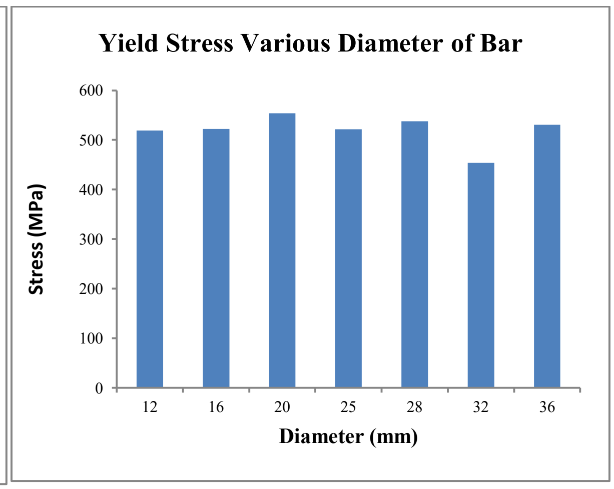
Research Background

Gong Deping, Zhang Kaijian, Yang Jiaqi (2003) study about development of high Strength Steel Bar with grade 500 MPa. They introduce the research process, technical plan of developing the 500MPa High Strength Steel Bar and application effect of alloy addition of vanadium nitride. This research says that the trial 500 MPa rebar has a property of resisting stain aging effect. The test has shown qualified mechanical and technological properties with the yield strength being over 520 MPa, tensile strength over 695MPa, elongation rate over 20% and elongationrate under max tension over 10%. The cold bending and negative bending has been tested qualified [2].

M.Hadi (2008) study about the use of high strength steel bar on a beam reinforcement concrete. All the steel reinforcing bars were 500 MPa grade steel with nominal diameters of 12, 16, 20, 25, 28, 32, 36 mm. For each bar size two concrete sizes (240 and 300 mm diameter) were conducted. All reinforcing bars were tested for their tensile strength. Bars with the diameters 12, 16, 20, 25, and 28 mm were tested at the University of Wollongong and those with 32 and 36 mm diameter were tested at the University of New South Wales. One strain gauge was placed on each size of the bar surface to measure the strain value during the tensile test. The change in length in millimeters was recorded at test completion. The experimental results are shown in Fig1. As the results of tensile test show that the bars were able to produce high value of strength in every specimen, except in the case of 32 mm bars where the bar failed suddenly during the test [3].



(a)



(b)

FIGURE 1. (a) Yield and Ultimate Loads of Various Bar Diameters; (b) Yield Stress of Various Bar Diameters

Prabir et al, study about characteristics of steel reinforcement for RC structures. They say that Good strength, bond with concrete, thermal expansion characteristics (similar to concrete) and bendability are prime attributes which make steel rebars most effective reinforcing material for engineering of RC structures. Besides strength, the durability of the structure depends upon rebar quality.

Durability is the ability of the structure to maintain safety and serviceability criteria during its design life. Durability is dependent on the condition of concrete and reinforcement. Corrosion of reinforcement is one of the main factors that could impair durability. Corrosion can be either due to chloride intrusion or due to the effect of carbonation. Chemical composition of reinforcement plays an important role in this respect.

The mechanical properties of rebars, whose minimum values are generally given in most of the specifications, are yield strength, ultimate strength (or maximum tensile strength) and elongation as parameters for characterization. Following observations could be made from the comparative study. Table 1 showsthe comparisonof mechanical properties of steel reinforcing bars from several countries [4].

TABLE1. Mechanical Properties ofTwo Different Grades of Rebars (Grades 420and500 MPa)

Code	Tensile Strength		Yield Strength		Elongation	
	Grade		Grade		Grade	
	420 MPa	500 MPa	420 MPa	500 MPa	420 MPa	500 MPa
IS 1786	10%more than fy and not less than 485MPa	8%more than fy and not less than 545 MPa	415	500	14.5	12
ASTM 615M	620	690	420	520	7-9 depend on diameter of bar	6-7 depend of diameter of bar
Russian	585	600	395	500	14	14

Used of High Strength Steel reinforcing bar also do by another researcher. Tavio, et al (2011) has applied high strength steel bar for transversal reinforcement. High-strength steel as transverse reinforcement is seldom used for confining steel in high-strength concrete columns. To obtain an accurate ductility of high-strength concrete confined columns, it requires an analytical stress-strain model of confined concrete which is capable of describing an actual strength and ductility behavior. In their paper, an analytical stress-strain relationship for confined high-strength concrete is proposed. The model is found to provide a reasonably good prediction of the available experimental data of circular and square high-strength concrete column specimens confined by high-strength transverse steel with various configurations. The effects of concrete strength and lateral steel strength on ductility of confined concrete were so closely [5].

Code Requirement

ACI 318-14 (2014) name that for deformed nonprestressed longitudinal reinforcement resisting earthquake-induced moment, axial force, or both, in special moment frames, special structural walls, and all components of special structural walls including coupling beams and wall piers shall be in accordance with ASTM A706(2006) and ASTM A615(2004) are satisfied :

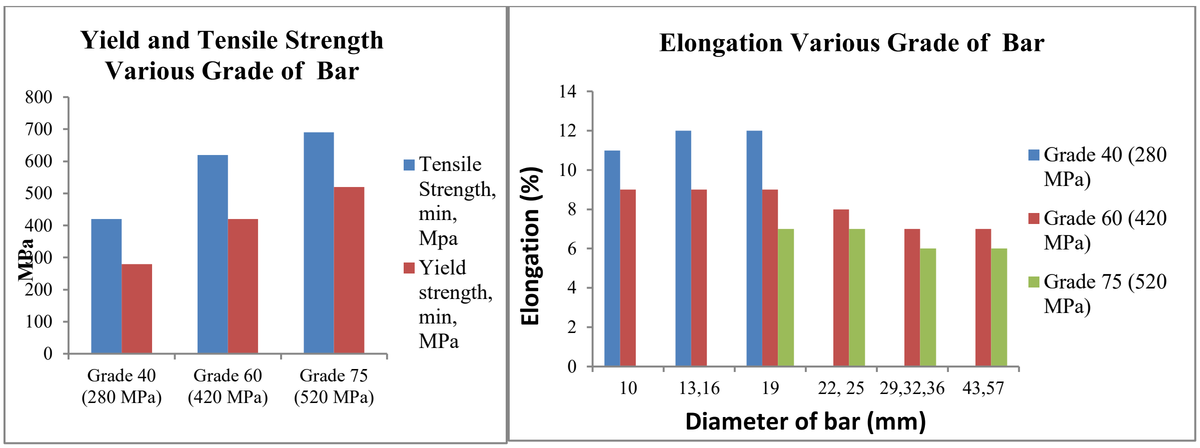
(i) Actual yield strength based on mill tests does not exceed ***fy***by more than 18,000 psi
(ii) Ratio of the actual tensile strength to the actual yield strength is at least 1.25
(iii) Minimum elongation in 8 in. shall be at least 14Percent for bar sizes No. 3 through No. 6, at least 12 percent for bar sizes No. 7 through No. 11, and at least 10 percent for bar sizes No. 14 and No. 18.

The requirement for the tensile strength to be greater than the yield strength of the reinforcement by a factor of 1.25 is based on the assumption that the capability of a structural member to develop inelastic rotation capacity is a function of the length of the yield region along the axis of the member. In interpreting experimental results, the length of the yield region has been related to the relative magnitudes of probable and yield moments (ACI 352R, 2010). According to this interpretation, the greater the ratio of probable-to-yield moment, the longer the yield region will be. Members with reinforcement not satisfying this condition can also develop inelastic rotation, but their behavior is sufficiently different to exclude them from direct consideration on the basis of rules derived from experience with members reinforced with strain-hardening steel [6].

Based on ASTM 615M-2017, the material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Fig.2.It shows that for each grade of steel bars must satisfied value of yield and tensile strength. Based on this table, tensile strength of each grade must higher about 1.5 times for grade 40 and 60, and 1.33 times for grade 75 from yield strength value [7].

To ensure that yield strength value of steel bars is satisfied that requirement so the yield point or yield strength shall be determined by one of the following methods:

a. The yield point shall be determined by drop of the beam or halt in the gage of the testing machine.
b. Where the steel tested does not have a well-defined yield point, the yield strength shall be determined by reading the stress corresponding to the prescribed strain using an autographic diagram method or an extensometer as described in Test Methods and Definitions A 370. The strain shall be 0.5 % of gage length for Grade 40 (280 MPa) and Grade 60 (420 MPa) and shall be 0.35 % of gage length for Grade 75 (520 MPa). When material is furnished in coils, the test sample shall be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid formation of local sharp bends and to minimize cold work. Insufficient straightening prior to attaching the extensometer can result in lower-than-actual yield strength readings.



(a) (b)

FIGURE. 2. (a) Tensile and Yield Strength Requirements; (b). Elongation Requirements Based on ASTM 615-2017

From those background, the purpose of this review is to establish the current state of knowledge on the effects that the TS/YS ratio has on the mechanical/fracture behavior of steels, from the published literature. This paper reports an investigation on various steel grades, namely Grades 420, 550, 650, and 700 MP, to examine the impact of different TS/YS ratios if it is less or greater than the required value.

MATERIALS AND METHODS

The one of issue in predicting the behavior of reinforcing bar is the tensile and yield strength ratio of those materials. That is used to know how it can hold out from loading, Materials were startup to maximumyield condition. The flexural behavior of reinforced concrete can be estimated. In recent years, the possible use of high-strength steel reinforcing bars for buildings constructed using reinforced concrete has been considered. But there are few experimental data or design guidelines for the use of high-strength steel. Thispaper will provide much-needed information on the behavior of high-strength steel especially on tensile and yield ratio. Research findings for high-strength steel reinforcing bars however, are relatively scarce in the literature. For reinforcing bars with yield strength of 550, 650 and 700 MPa compare with low-strength steel bar with yield strength 420 MPa.

The experimental included 12 tests using twelve specimens of steel reinforcing bars tested under tension up to failure. Twelve specimens divided into 4 grade of reinforcing bars i.e. 420MPa. 550 MPa, 650 MPa and 700 MPa. All specimens were 50cm long and were in 10 mm of diameters.

Tensile tests of these steel samples were conducted under displacement controlled mode to capture the complete stress-strain curves and particularly the post-yield response of the steel bars The instrument testing is Universal Testing Machine with loading capacity is 200ton, and strain rate for this testing is 12.5 mm/minute, based on ASTM A370 (2016). The equipment for tension testing shown in Fig. 3 [9].

FIGURE 3. Equipment for Tensile Testing

RESULT AND DISCUSSION

Tensile & Yield Strength of Various Strength Reinforcing Bars

Based on tension testing, ratioTS/YS of specimen for various grade reinforcing bars are shown in Table 2.It shown value of yield strength, tensile strength, and ratio of various grades of steel reinforcing bars. There are four grade of steel reinforcing bars, i.e. Grade 420, 550, 650, and Grade 700Mpa. And for each grade of steel reinforcing bars, there are three sample bars.

TABLE .2. Tensile and Yield Strength Ratios

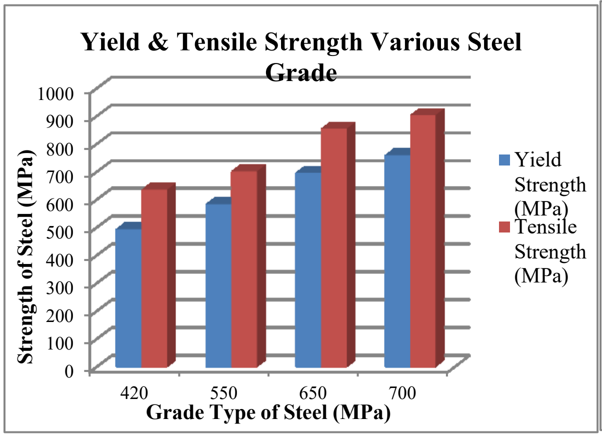
Grade (MPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Ratio TS/YS	Average Ratio
420	489.223	634.827	1.298	1.287
	498.340	638.341	1.281	
	496.240	636.555	1.283	
550	579.423	697.988	1.206	1.210
	584.203	706.264	1.212	
	589.847	704.100	1.210	
650	724.527	855.575	1.181	1.229
	678.952	858.459	1.264	
	688.285	854.652	1.242	
700	762.906	887.129	1.163	1.189
	760.774	911.417	1.198	
	757.777	914.706	1.207	

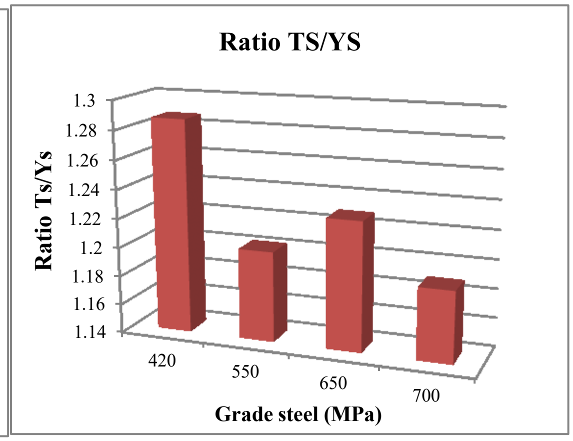
The value of Ratio Tensile/Yield Strength can obtained from :

$$Ratio\,\frac{TS}{YS} = \frac{Tensile\ Strength}{Yield\ Strength} \quad (1)$$

Discussion on Ratios of Tensile and Yield Strengths (TS/YS)

From tensile testing of reinforcing bars, the tensile and yield strengths of each reinforcing bar shown in **Fig 4 (a).** Values of Ratios of Tensile and Yield Strengths for various grades of bars can be calculatedby dividing the Tensile Strength with the Yield Strength (shown in **Fig 4.b**) as follows:





(a) (b)

FIGURE.4. (a) Yield and Tensile Strengths of Various Steel Grades; (b) TS/YS Ratio

Figure 5 shows the differences ratio tensile and yield strength of various grade of reinforcing bars. It looked that for grade 420 Mpa, the ratio TS/YS is satisfied ACI requirements, but for the others grade (550, 650, and 700 MPa) are not satisfied. Grade 420 MPa can reach ratio TS/YS up to 1.28, more than ACI requirement 1.25. But for another grade the ratio tensile/yield is less than 1.25. Overall, grade 550 MPa have the lowest ratio. The differences of ratio TS/YS based on grade 420 MPa shown in fig.5. There are shown that grade 700 MPa have the biggest differences with grade 420 MPa, it is about more than 7%.

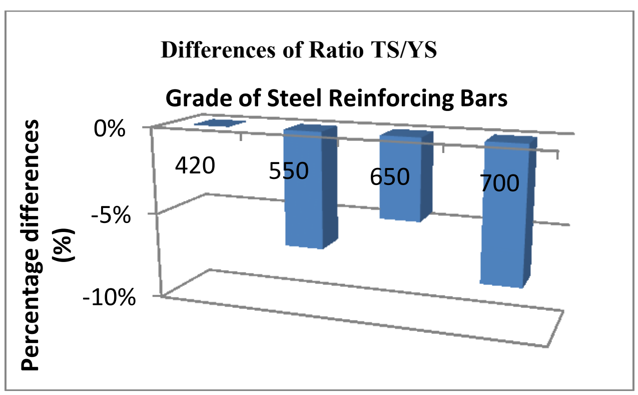


FIGURE 5. Differencesin Ratio of Steel Reinforcing Bars for Various grades andGrade 420 MPa

In conventional structural design, the working stress is usually taken as a proportion of the yield stress; typical valuesare 60% YS in normal loading and up to 80% in severe loading (4). The TS/YS ratio is largely irrelevant for such elasticcases. More recently, structures have been designed using plastic design concepts whereby the ability of thestructure to yield and redistribute load without catastrophic failure is required. In such cases the post-yield behaviorof the steel assumes an increasing importance.

In engineering terms were selected to idealize the ability to withstand plastic loading is the TS/YS ratio. This parameter provides a basic measure of the capacity for strain hardening of the material, it is not the TS/YS ratio per sewhich is the governing factor but it is readily measurable from information contained in a steel test certificate and can be related to the strain hardening exponent (n), the exact relationship between Y/T, n and other tensile parameters is discussed later, suffice to say at this stage that n decreases as TS/YS increases. To this end various restrictions were introduced to ensure adequate plastic deformation capacity. These include upper limits to Y/T, design stress expressed as a limit of UTS, a given percentage of uniform elongation and a given length of yield plateau.The reasons for higher TS/YS ratios in steels and the relationships between TS/YS and other parameters, principally the strain hardening exponent, are then assessed. The structural significance of TS/YS is then reviewed with reference to the influence of cracks and the behavior of high TS/YS steels in buildings, bridges, pressure vessels, tubular structures and pipelines.

CONCLUSIONS

From the study, it can be concluded that Grade 420 MPa performed higher TS/YS ratios and they were able to reach up to more than 1.25. However, the HSS bars (Grades 550, 600, and 700 MPa) resulted in lower TS/YS ratios (less than 1.25) compared with those of Grade 420 MPa. It can beinferred that HSS cannot reach ductility requirement.

The level of structural ductility required depends upon the application and the structural behavior assumed in the design method used.

So, for further application of high strength steel bar as a reinforcing bar for reinforcement concrete, it needs material improvement especiallyin the chemical composition to gain higher TS/YS ratio, sincewith the higher TS/YS ratio of steel bars, the structures might have better ductility.

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