Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

REINFORCED CONCRETE BEAMS USING LOCALLY MANUFACTURED STEEL BARS: INVESTIGATION OF FLEXURAL BEHAVIOR

SHEHAB MOURAD, ABDELHAMID CHARIF, and IQBAL KHAN

Dept of Civil Engineering, King Saud University, Riyadh,
Kingdom of Saudi Arabia

While much attention has been and continue deservedly to be given to the effect of the variability of concrete strength and properties on the response of reinforced concrete structures, there is little, if any, information on the effects of variability of steel strength. Steel mechanical properties, including its yield strength, can significantly exceed the minimum nominal strength values for a specific grade of steel depending on the steel manufacturing processes. Such an increase in yield strength can have negative effects on the flexural behavior of beams designed as tension controlled, and reduce their ductility, an essential property in seismic resisting structures. An experimental and analytical study of the flexural behavior of RC beams was conducted through the investigation of the Moment-Curvature relationships and the ultimate steel strains. The main variable was the level of the actual steel yield stress as compared to the nominal value. It was found that unexpectedly high values of steel yield stress reduce the beam ductility and violate the tension-control condition, which was enforced in the design stage. Appropriate design corrections are proposed to account for high yield stress values in order to achieve the desired ductility of beams while maintaining the moment capacities.

Keywords: Flexural Behavior, Reinforced Concrete, Yield Strength, Ductility, Steel Ratio, Curvature.

1 INTRODUCTION

The quality and mechanical properties of steel are governed by the method of production, the chemical compositions, the mechanical working of rebars and the heat treatment (Davis *et al.* 1995). Seismic standards have been developed in many countries following the design philosophy to allow the steel to deform but not fail during an earthquake. In this regard, most international specifications outline and control the mechanical property requirements for rebars to be used in seismic resistant systems (Milbourn 2010). This approach allows the structure to effectively absorb the energy of the earthquake without collapsing. In order to satisfy such behavior, rebars should possess high strength with sufficient ductility and low variation in yield strength to experience high number of inelastic cycles of deformation with high plastic strains. However, most rebars manufactured locally in the Gulf Area, as well as other areas, show high variability in steel yield strength that exceeds its nominal values. The increase in both yield and ultimate strength of rebars will certainly improve the member strength but it may also affect adversely the behavior and reduce its ductility. In most design codes (ACI-318R, 2008), this is required to ensure a ductile flexural behavior, it is stated that steel should not only reach yielding stage but also needs to reach a minimum strain of 0.005. In addition, ACI-318R-2008 states that the maximum allowed steel ratio in the beam should not exceed (ρ_{max}), given by:

$$\rho_{\max} = \frac{3}{8} \quad \frac{0.85\beta_1 f_c'}{f_y} \tag{1}$$

where, $f'_c$is the specified concrete compressive strength, $f_y$is the nominal steel yield strength and $\beta_1$is a factor relating depth of equivalent rectangular compressive stress block to neutral axis depth, and it equal to 0.85 for $f'_c \leq 27.6$ MPa.

2 EXPERIMENTAL INVESTIGATION

As part of the experimental investigation, random samples were taken from two different local steel producers. As the tensile strength of the rebars depends on the process of its manufacturing, an investigation was made to compare the tensile strength of rebars prepared by two different processes of tempering and quenching processes as obtained from two different producers. The grade of steel in both processes was Grade 60 with nominal yield stress of 420MPa and nominal ultimate strength of 620 MPa. Tensile tests were done on different rebar diameters for each type of steel. The ratios of the mean to nominal yield strength "γ_y" and the ratio of mean to nominal ultimate strength"γ_u" were computed as given in Table 1 for different rebars diameters. As can be noticed, the values of γ_y for rebars prepared by tempering process are almost approaching 1.00, while the values of γ_y for rebars prepared by quenching process are much higher and can reach up to 1.43. The values of γ_u for both types of steel rebars are within reasonable range of 1.00 to 1.15. The results indicate that rebars prepared by quenching process exhibit higher values of yield strength as compared to its nominal values. Typical stress-strain curves for 16mm and 20mm rebars manufactured by both tempering and quenching processes are shown in Figure 1. It was anticipated that such relatively high values of yield strength will have a significant effect on the flexural behavior of beams.

Table 1. Comparison of mean-to-nominal strength values for tempered and quenched steel rebars.

Bar Diameter (mm)	**Tempered Steel rebars**		**Quenched Steel rebars**	
	γ_y	γ_u	γ_y	γ_u
10	1.00	1.06	1.40	0.97
16	1.01	1.10	1.43	1.15
18	1.00	1.07	1.31	1.11
20	0.99	1.09	1.30	1.11

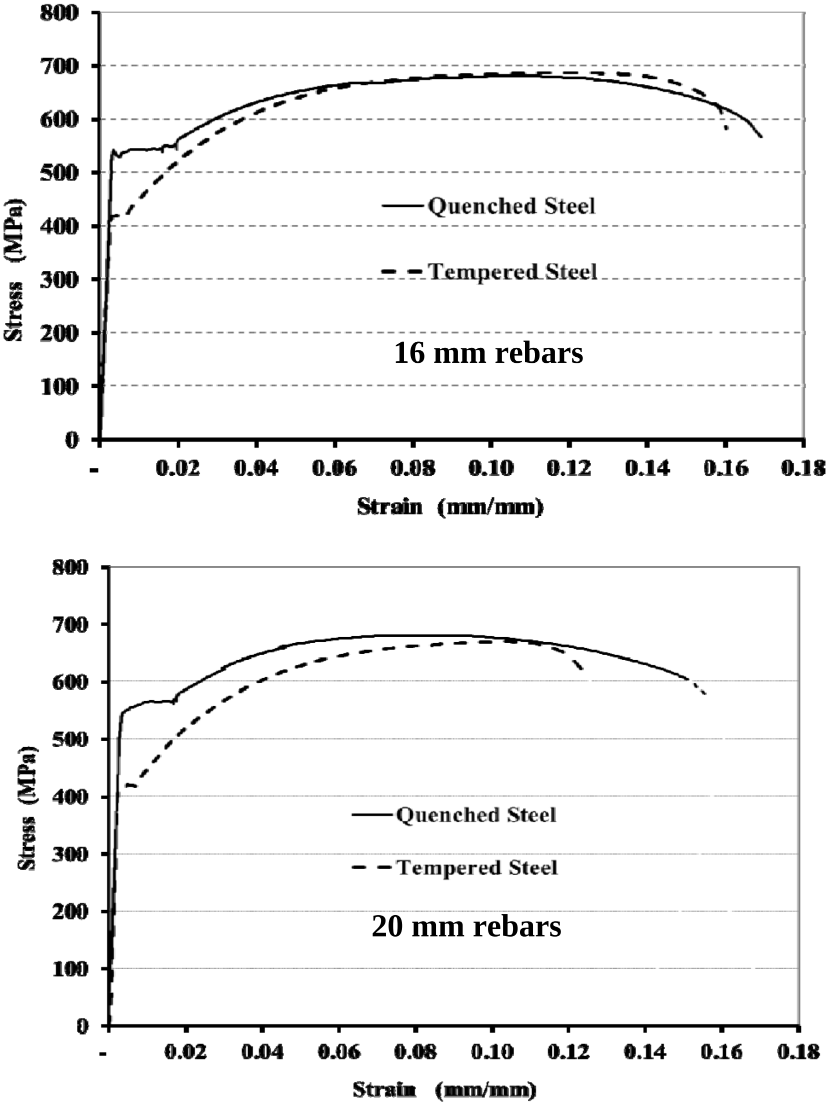

Figure 1. Typical stress-strain curves for 16 mm and 20 mm rebars.

3 FLEXURAL BEHAVIOR OF BEAM SPECIMENS

The experimental investigation on beam specimens was part of undergraduate-senior student project at King Saud University, (Allorani, *et al.* 2012). A total of four specimens were divided in two groups (two beams in each group). The first group of specimens was reinforced with Tempered steel rebars and designated at “T”, whereas the second group of specimens was prepared using Quenched steelrebars and designated as “Q”. The grade of steel in both groups was Grade 60 with nominal yield stress of 420MPa and nominal ultimate strength of 620 MPa. The beams were designed for a compressive strength of 25 MPa. Two specimens of each group were designed for two different failure strains (0.004 and 0.0065) in tension steel. The beam specimens of first group were designated as T-0.004 and T-0.0065, whereas specimens of second group were identified as, Q-0.004, and Q-0.0065 respectively. Details of beam specimens are shown in Figure 2. All beams were 3.1 m long with a width and depth of 200 mm and 500 mm respectively. The concrete cover at sides was 20 mm. Top and bottom covers were adjusted in order to achieve the desired effective depth that corresponds to the design failure strains in bottom steel. The flexural reinforcement was provided in two layers. One 8 mm bar was used in compression side to support the stirrups. Shear reinforcement of all the beams was designed according to ACI-318R-2008. It was intended that flexural failure of beams will be prominent. The effective depth corresponding to each failure steel strain was computed based on the assumption that the ultimate compressive strain in concrete will reach 0.003, and the nominal yield stress of both groups was 420 MPa. The computed effective depths corresponding to groups "T" and "Q" were 425.9 mm and 444.0 mm respectively.

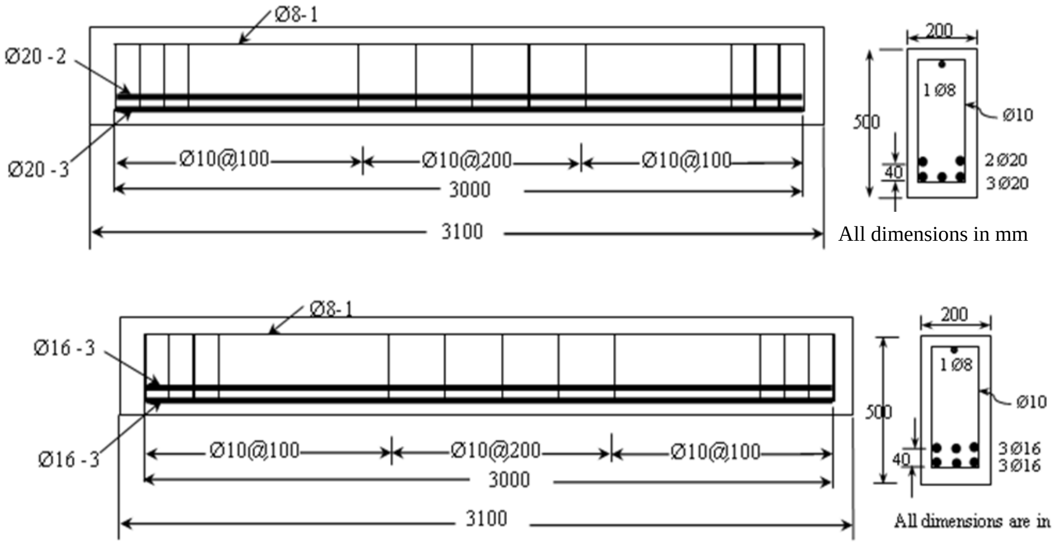

Figure 2. Details of beam specimens.

The specimens were instrumented to provide strain readings. Two strain gauges were installed on tension steel and compression steel of beam specimens at mid span. The strain gauges in the tension steel were placed in the bottom layer of the flexural reinforcement. One linear voltage differential transducer (LVDT) with 50 mm travel was used to measure mid span deflections. The load was monitored using load cells at third points. The beams were simply supported and two equal concentrated loads were applied at the third point of the span. Load was applied continuously at a displacement rate of 2 mm per minute up to failure. Load, deflections and strains were recorded using a data acquisition system.

4 TEST RESULTS

The resulted moment-curvature relationships of the four specimens are shown in Figure 3. The experimental values of ultimate moments, curvatures and curvature ductility are given in Table 2.

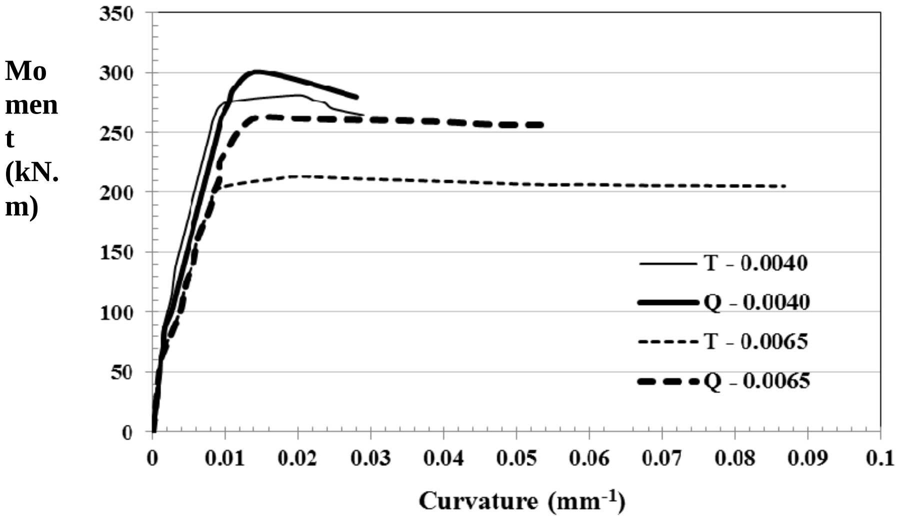

Figure 3. Moment-curvature relationship of the tested beam specimens.

Table 2. Experimental results of beams reinforced with Tempered and Quenched steel.

Specimen	**Ultimate moment M_u (kN.m)**	**Curvature at first yield of steel ϕ_y (mm^{-1})**	**Ultimate curvature ϕ_u (mm^{-1})**	**Curvature ductility $\mu_\phi = \phi_u / \phi_y$**
T-0.040	281.4	0.009795	0.02895	2.96
T-0.065	213.15	0.009600	0.08670	9.03
Q-0.004	301.1	0.009979	0.02834	2.84
Q-0.065	262.5	0.008761	0.05330	6.08

It is noticed that specimens T-0.0065 and Q-0.0065 exhibit higher curvature and ductility as compared to specimens T-0.004 and Q-0.004, due to the fact that its rebars have greater chance to yield before reaching the ultimate concrete strain. However, specimens made of quenched rebars; Q-0.004 and Q-0.0065, exhibit higher ultimate moments with less curvature and ductility as compared to those specimens made of tempered steel, T-0.004 and T-0.0065. Such behavior is attributed to the fact that the rebars manufactured by quenching process have higher yield strength and it will not be able to experience the whole yielding plateau before concrete failure. The increase in steel yield strength has negative effect of reducing the beam's ductility capacity and positive effect of increasing the beam's moment capacity. However in seismic design, it is required to increase both the ductility and ultimate moment capacities. To achieve such goal with the increase in steel yield strength and utilizing the maximum steel ratio the following procedure is proposed. The maximum steel ratio allowed in design "ρ_{max}" as given by ACI-318R-08, should account for the expected increase in the steel yield strength which can be indicated by the value of mean yield strength to nominal yield strength "γ_y". Therefore, the modified maximum steel ratio can be computed as $(\rho_{max})_{modified}$ and given by:

$$(\rho_{\max})_{\mathrm{modified}} = \frac{\rho_{\max}}{\gamma_y} \qquad (2)$$

Equation (2) will reduce the ρ_{max} by the factor (1/ γ_y), and allows the beam to exhibit tension control failure and increase its ductility. However, it will reduce its moment capacity by the same factor. In order to increase the moment capacity in such case, additional compression steel can be utilized.

5 CONCLUSIONS

From the experimental tensile tests on rebars manufactured by both tempering and quenching processes, it was shown that mean to nominal value for yield strength " γ_y" are higher for rebars manufactured by quenching process, and can reach values up to 1.40. The effect for such high yield strength was investigated experimentally on full-scale beams. Results showed its negative effect of reducing ductility especially when the beams were designed for high steel strain failure of 0.0065. Such negative effect on ductility can be resolved by reducing the maximum allowed steel ratio by a suggested factor "1/ γ_y".

References

ACI-318R, *Building code requirements for structural concrete (ACI Committee 318)*, American Concrete Institute, Farmington Hill, Michigan, 2008.

Allorani, M., *et al.*, Tensile Strain limits for ductile design of RC beams reinforced with Saudi rebars, *Senior Undergraduate Project No.CE 499-32/33-I-02/2,-Department of Civil Engineering- King Saud University*, 2012.

Davis, H. E., *et al.*, *The Testing of Engineering Materials*, McGraw-Hill, 4th ed., 1982.

Milbourn, D., Metallurgical Benefits of Vanadium Microalloying in Producing High Strength Seismic Grade Rebar, *Proceedings of International Seminar on Production and Application of High Strength Seismic Grade Rebar Containing Vanadium*, 32-43, Beijing China, 2010.