Comparative Experimental and Finite Element Analysis of Mild Steel and EN31 Steel Under Uniaxial Tensile

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Abstract — This paper presents an experimental and finite-element study of the tensile behaviour of mild steel and EN31 steel. Round specimens were tested on a universal testing machine (UTM) to obtain yield load, yield strength, ultimate tensile strength, breaking load, percentage elongation and reduction in area. Tensile simulations were then carried out in ANSYS Static Structural, with the axial load set equal to the yield load measured for each material. The UTM yield loads were 57.04 kN for mild steel and 31.96 kN for EN31 steel, and the ultimate tensile strengths were 583.567 MPa and 861.220 MPa, respectively. Mild steel showed the higher elongation (25.00% against 5.00%), whereas EN31 steel showed the higher ultimate strength. The ANSYS maximum total deformations were 1.1727 mm for mild steel and 0.81392 mm for EN31 steel, and both agree with the elastic-extension relation $\delta = PL/(AE)$ to within 0.01%. For mild steel, the ANSYS maximum equivalent stress was 548.52 MPa and the maximum equivalent elastic strain was 0.0027464. The results give a consistent experimental and numerical basis for comparing the two steels under tensile loading.

Keywords: Mild Steel, EN31 Steel, Tensile Test, Universal Testing Machine, ANSYS, Finite-Element Analysis, Yield Strength

I. Introduction

Tensile testing determines how a material responds to an approximately uniaxial tensile load. The commonly reported properties are yield strength, ultimate tensile strength, percentage elongation and reduction in area. They are used to compare metals and to support preliminary design. ASTM E8/E8M describes tension-test methods for strength and ductility of metallic materials [1], and ISO 6892-1:2019 specifies tensile testing at room temperature [2].

Mild steel is a low-carbon steel used widely in structural and general machine parts because it is ductile, easy to machine and easy to weld. EN31 is a high-carbon chromium alloy steel used where hardness and wear resistance are needed, for example in shafts, bearings and tooling.

Finite-element analysis (FEA) estimates displacement, stress and strain for a defined geometry, load and constraint set. ANSYS Static Structural solves such problems for steady loading [3]. A useful comparison between a UTM test and an FEA model needs the same geometry, load definition and material assumptions.

This work is limited to tensile loading of mild steel and EN31 steel. Its objectives are (i) to record the UTM tensile properties of both steels, (ii) to simulate each specimen in ANSYS at its measured yield load, and (iii) to check the simulated deformation against the analytical elastic-extension relation.

II. Literature Review

Ali et al. [4] compared FEA with UTM and strain-gauge data for a welded mild-steel T-joint and found agreement in the elastic range. Cabezas and Celentano [5] combined tensile tests with finite-element simulation for sheet specimens. Singh et al. [6] studied how the tensile and compressive behaviour of mild steel depends on strain rate. Susanto et al. [7] proposed FEM tensile simulation of ST-37 steel as an alternative to physical testing. These studies deal with a single steel, a special geometry or simulation alone. None of those reviewed compared a mild steel and an alloy steel such as EN31 under the same test-and-FEA procedure, and this is the gap addressed here.

III. Materials and Specimens

Solid round specimens of mild steel (12 mm diameter) and EN31 steel (10 mm diameter) were used. The total specimen lengths were 465 mm and 400 mm. The UTM gauge lengths were different: 60 mm (5 diameters) for mild steel and 200 mm (20 diameters) for EN31 steel. Table I lists the specimen data and the FEA elastic constants.

Parameter	Mild steel	EN31 steel
Specimen form	Solid round	Solid round
Diameter	12 mm	10 mm
Total length	465 mm	400 mm
UTM gauge length	60 mm	200 mm
Area (UTM report)	113.098 mm²	78.54 mm²
Young's modulus*	200 GPa*	200 GPa*
Poisson's ratio*	0.30*	0.30*

Table I: Specimen Data and Fea Material Inputs
Elastic constants are representative values for steel; they were not measured by the UTM.

IV. Experimental Procedure and UTM Results

Tensile tests were performed on the UTM until fracture. For each specimen the machine recorded the load against displacement (mild steel) or against crosshead travel (EN31), and the reported loads, final diameter and final gauge length were recorded. Table II lists the values, and Figs. 1 and 2 show the load plots.

UTM parameter	Mild steel	EN31 steel
Yield load	57,040 N	31.96 kN
Yield stress	504.332 MPa	406.928 MPa
Peak (ultimate) load	66,000 N	67.640 kN
Ultimate tensile strength	583.567 MPa	861.220 MPa
Breaking load	47,440 N	3.140 kN
Breaking stress	419.461 MPa	—
Elongation	25.00 %	5.00 %
Reduction in area	65.972 %	43.75 %
Diameter, initial / final	12 / 7 mm	10 / 7.5 mm

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Gauge length, initial / final	60 / 75 mm	200 / 210 mm

Table II: UTM Tensile Test Results

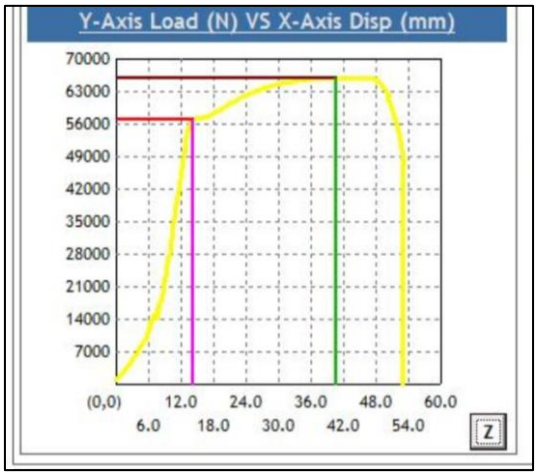

Fig. 1: Mild-steel UTM load–displacement plot.

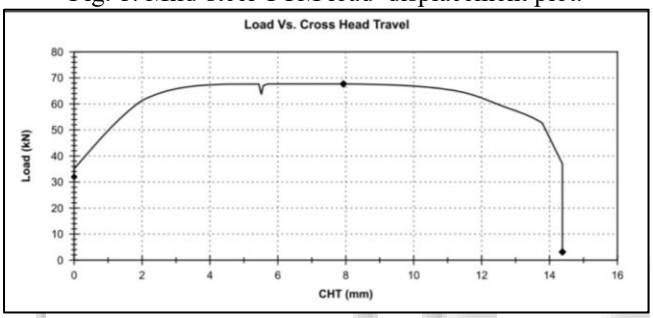

Fig. 2: EN31-steel UTM load–crosshead-travel plot.

V. ANSYS FINITE-ELEMENT ANALYSIS

Each specimen was modelled as a solid round bar in ANSYS Static Structural with a structured mesh. One end was fixed, and the axial load was applied at the other end. The load equalled the UTM yield load of the material: 57,040 N for mild steel and 31,960 N for EN31 steel. The material was taken as linear elastic with the constants in Table I.

The nominal engineering stress is

$$\sigma = P / A \qquad (5.1)$$

where P is the axial load and $A = \pi d^2/4$ is the original area. Engineering strain is $\varepsilon = \Delta L / L_0$, and percentage elongation is 100ε. For a uniform bar in the linear-elastic range, the axial extension is

$$\delta = PL / (AE) \qquad (5.2)$$

where L is the loaded length and E is Young's modulus. Using the UTM yield loads and areas, (5.1) gives 504.34 MPa for mild steel and 406.93 MPa for EN31 steel, which match the yield stresses printed in the UTM reports (504.332 MPa and 406.928 MPa) within rounding.

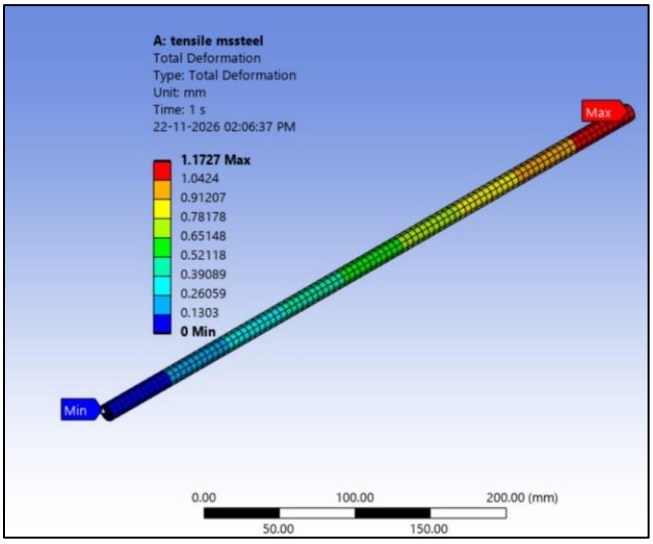

Fig. 3: Mild-steel ANSYS total deformation; maximum 1.1727 mm.

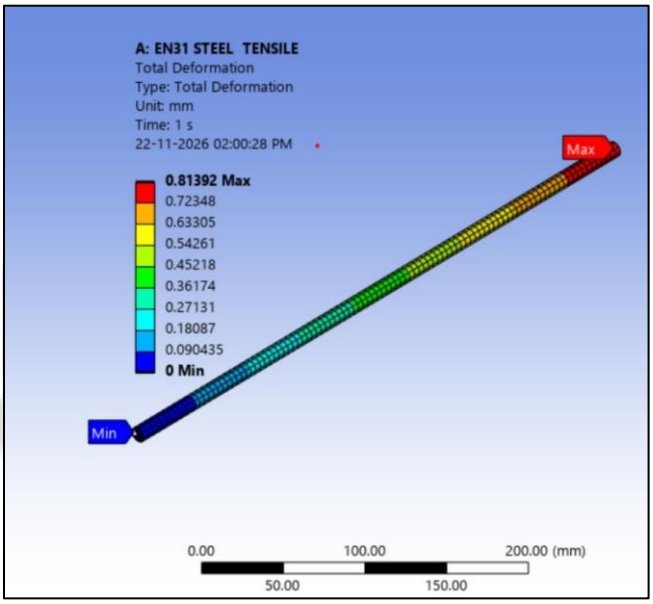

Fig. 4: EN31-steel ANSYS total deformation; maximum 0.81392 mm.

VI. RESULTS AND DISCUSSION

A. Tensile properties from the UTM

EN31 steel reached a higher ultimate tensile strength (861.220 MPa) than mild steel (583.567 MPa), about 48% higher. Mild steel showed the greater ductility, with 25.00% elongation and 65.972% reduction in area, against 5.00% and 43.75% for EN31 steel. The yield-to-ultimate ratio was 0.86 for mild steel and 0.47 for EN31 steel. Percentage elongation depends on the gauge length used (5 times the diameter for mild steel and 20 times for EN31), so the elongation values compare the two tests only indicatively. These are specimen-level results and should not be generalised to all grades or heat-treatment conditions without repeat tests.

B. ANSYS Results and Analytical Check

Result	Mild steel	EN31 steel
Applied load (= UTM yield load)	57,040 N	31,960 N

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ANSYS max. total deformation	1.1727 mm	0.81392 mm
Analytical δ = PL/(AE)	1.1726 mm	0.8139 mm
Difference	0.009 %	0.008 %
Nominal stress P/A	504.34 MPa	406.93 MPa
ANSYS max. equivalent stress	548.52 MPa	—†
ANSYS max. equivalent elastic strain	0.0027464	—†

Table III: Ansys Results and Analytical Check

Equivalent stress and strain contours for EN31 steel were not extracted from the ANSYS solution and are therefore not reported.

Applying (5.2) with the total specimen length, the UTM area and E = 200 GPa gives 1.1726 mm for mild steel and 0.8139 mm for EN31 steel. The ANSYS deformations (1.1727 mm and 0.81392 mm) differ from these by less than 0.01%, so the models reproduce the expected elastic extension of the full-length bars. This confirms the model length, load and modulus. It checks the ANSYS solution against theory and is not an independent validation against the UTM tests.

For mild steel, the maximum equivalent stress of 548.52 MPa is 8.76% higher than the nominal stress of 504.34 MPa. This is expected for a maximum local value: the fixed end restrains lateral contraction and raises the local stress, whereas the nominal stress is an average over the original area. The maximum equivalent strain of 0.0027464 corresponds to a modulus of about 200 GPa (548.52 MPa / 0.0027464), consistent with the elastic constants used. A like-for-like comparison with the UTM yield stress should use the stress in the gauge section away from the supports.

The UTM gives elongation over the gauge length at the end of the test, whereas ANSYS gives total displacement of the whole bar at yield load. The two deformation values are therefore not directly comparable and no experimental-versus-numerical deformation error is claimed.

VII. Limitations and Future Scope

The simulations are linear-elastic and were run at the yield load, so they do not represent yielding, necking or fracture. The elastic constants were taken as representative values, and a mesh-convergence study was not performed. Only one specimen of each steel was tested, and the strain-measurement method and test speed should be stated for formal reporting. The EN31 yield stress (406.928 MPa) is low relative to its ultimate strength and should be confirmed against the material certificate and heat-treatment condition. Future work can add EN31 stress and strain results, a mesh study, plasticity models, repeat tests and gauge-section comparisons.

VIII. Conclusion

Tensile tests and ANSYS simulations were carried out on mild steel and EN31 steel. The UTM yield loads were 57.04 kN and 31.96 kN, and the ultimate tensile strengths were 583.567 MPa and 861.220 MPa, respectively. Mild steel was the more ductile (25.00% elongation) and EN31 the stronger (higher ultimate strength) in the tested specimens. The ANSYS total deformations of 1.1727 mm and 0.81392 mm under the yield loads agree with the analytical elastic extension within 0.01%. The mild-steel maximum equivalent stress was 548.52 MPa and the maximum equivalent elastic strain was 0.0027464. A full numerical validation of the stress fields will need the EN31 stress and strain results and gauge-section comparisons.

Acknowledgment

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