Review Paper on Experimental and Structural Analysis of Mild Steel and EN31 Steel under Tensile Loading Using UTM and ANSYS

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Abstract — This review paper examines the experimental and numerical characterisation of mild steel and EN31 steel under uniaxial tensile loading using the universal testing machine (UTM) and ANSYS Workbench. The literature indicates that UTM tests supply the load–displacement response and the yield and ultimate strengths on which finite element (FE) material models depend; that linear-elastic ANSYS analysis describes stress and deformation up to yield but cannot represent plastic flow, necking or fracture; and that nonlinear plasticity models calibrated from true stress–strain data, with mesh convergence checked, can reproduce measured ultimate stress to within about 5 % in the best-documented case reviewed. Studies that test and simulate mild steel and EN31 together are scarce. Verified published values are compared, student project measurements are presented separately for context only, and research gaps and future directions are outlined.

Keywords: Mild Steel, EN31 Steel, Tensile Loading, Universal Testing Machine, ANSYS Workbench, Finite Element Analysis

I. Introduction

Machine elements are designed around a few measurable material responses—strength, stiffness, ductility and toughness—and the uniaxial tensile test remains the standard route to them [1], [2]. Mild steel, a low-carbon steel, is widely used because it is ductile, weldable, easily machined and inexpensive [1]. EN31 is a high-carbon, chromium-alloyed steel hardened and tempered for wear-resistant components and bearings [3], [4]. The two sit at opposite ends of the strength–ductility trade-off.

The UTM applies a controlled axial load to a standardised specimen and records load against crosshead travel or extensometer elongation, from which yield strength, ultimate tensile strength (UTS) and ductility are derived per ASTM E8/E8M [5] and ISO 6892-1 [6]. ANSYS Workbench is a finite element package in which the same specimen can be modelled and post-processed for deformation and equivalent (von Mises) stress, but its predictions are only as good as the geometry, mesh, boundary conditions and material model supplied [7]–[9]. Agreement between test and simulation, known as experimental validation, is what makes a model trustworthy. Few studies place mild steel and EN31 under the same test-and-simulate framework, which motivates this review.

Method and scope. Records were searched online using the terms mild steel, EN31, tensile test, UTM, ANSYS and finite element validation. Only sources whose authors, venue, year and DOI or publisher record could be confirmed were retained, so the corpus is smaller than the 20–30 papers initially targeted. This is a review: no new experiment or simulation is claimed as a finding. Student project measurements appear only in Section VI-B.

II. Material Properties

A. Mild Steel

Mild steel is a plain carbon steel with below about 0.25 wt% carbon; its microstructure is mainly ferrite with some pearlite, giving low hardness, high ductility and often a pronounced yield point [1]. The elastic modulus of steels is close to 200–210 GPa and Poisson's ratio about 0.3, largely independent of composition and heat treatment [1], [2]. As one specified grade, EN 10025-2 S235JR has a minimum yield strength of 235 MPa (thickness up to 16 mm) and a tensile strength of 360–510 MPa [10].

B. EN31 Steel

EN31 has a nominal composition of about 1.00 C, 0.50 Mn, 1.40 Cr and 0.20 Si (wt %) [4] and is hardened by austenitising and quenching, then tempered. Bulk hardness fell as tempering temperature rose from 423 K to 848 K, where martensite decomposed into ferrite and cementite [4]. In an EN31/EN8 comparison, hardness rose from furnace cooling to water quenching to a maximum of 254.60 BHN for EN31, while UTM tensile strength fell in the same direction; 675 N/mm^2 was reported as the maximum tensile strength of water-quenched EN31 [3]. Because hardness and tensile strength commonly rise together [2], this opposite trend may reflect differences in processing or testing. Austempering and martempering routes have also been examined [11]. Since EN31 depends so strongly on heat treatment, no single yield or tensile strength can be quoted without stating the condition (Table I).

Property	Mild steel	EN31
Carbon (wt%)	Below about 0.25 [1]	About 1.00 [4]
Microstructure	Ferrite + pearlite [1]	Martensite-based when hardened [4]
Elastic modulus	≈200–210 GPa [1]	≈200–210 GPa [1]
Yield strength	≥235 MPa, S235JR [10]	Condition-dependent; no single value
Tensile strength	360–510 MPa, S235JR [10]	675 N/mm^2 max., water-quenched [3]
Hardness	Low	Up to 254.60 BHN [3]
Ductility	High	Lower (qualitative)

Table I: Published Or Specified Properties of Mild Steel and EN31

Values are as reported by the cited sources under their stated conditions, not measurements by the authors.

III. Experimental Analysis Using UTM

A UTM has a rigid load frame with fixed and movable crossheads, a hydraulic or electromechanical drive, grips, a load cell and a displacement measuring system. Crosshead

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travel includes deformation of grips and frame, so elongation taken from it overstates specimen strain and gives an apparent modulus well below the true value; an extensometer on the gauge length is preferred when modulus is required [5], [6].

Specimens have enlarged shoulders for the grips and a reduced parallel gauge section. ASTM E8/E8M gives, for example, a round specimen of 12.5 mm diameter with 50 mm gauge length [5], while ISO 6892-1 uses proportional specimens with $L_0 = 5.65\sqrt{S_0}$ [6]. Smooth transition radii limit stress concentration, and alignment with the load axis avoids bending. The original dimensions are measured, a monotonic load is applied at a controlled rate until fracture, and after fracture the halves are fitted together to measure final length and minimum diameter [5]. The load–displacement record is converted using:

$$\sigma = P / A_0 \quad (3.1)$$

$$\varepsilon = \Delta L / L_0 \quad (3.2)$$

$$E = \sigma / \varepsilon \quad (3.3)$$

$$\% \text{ Elongation} = [(L_f - L_0) / L_0] \times 100 \quad (3.4)$$

$$\% \text{ RA} = [(A_0 - A_f) / A_0] \times 100 \quad (3.5)$$

where σ is engineering stress (MPa), P the axial load (N), A_0 and A_f the original and final minimum cross-sectional areas (mm^2), ε the engineering strain, L_0 and L_f the original and final gauge lengths (mm), and E Young's modulus. Yield strength is read at the upper or lower yield point for steels with a distinct yield, typical of mild steel, and as the 0.2 % offset proof stress otherwise [5], [6]. The UTS is $\sigma_u = P_{max}/A_0$. Beyond P_{max} the specimen necks; engineering stress falls although true stress in the neck keeps rising [2]. Up to necking, true stress and strain are

$$\sigma_t = \sigma(1 + \varepsilon) \quad (3.6)$$

$$\varepsilon_t = \ln(1 + \varepsilon) \quad (3.7)$$

and many metals follow the Hollomon relation [12], $\sigma_t = K\varepsilon_t^n$, where K is the strength coefficient and n the strain-hardening exponent. As a theoretical check of (3.1), a 12 mm bar (A_0 = 113.1 mm^2) just meeting 235 MPa yields at about 26.6 kN, and a 10 mm bar (A_0 = 78.54 mm^2) carrying 675 MPa supports about 53.0 kN. Ductile mild steel typically fractures after pronounced necking with a cup-and-cone surface, whereas high-strength steels of limited ductility fracture after little necking [2].

IV. Structural Analysis using ANSYS

In ANSYS Workbench the Static Structural system is the usual starting point: geometry, engineering data, mesh, boundary conditions, solution, post-processing and comparison with UTM load–displacement data [13]. Specimens are drawn in the geometry editor or imported from CAD [7]; symmetry reduces cost, whereas a full model keeps the shoulder and grip transitions. A linear-elastic model needs only E and Poisson's ratio (about 200 GPa and 0.3 for ANSYS's default structural steel). Plasticity needs bilinear or multilinear isotropic hardening defined from true stress–plastic strain points [13]; the necking portion can be derived iteratively in ANSYS [9], and rate-dependent flow represented by Cowper–Symonds or Johnson–Cook models [7], [14].

Element type and size strongly affect results. Kumar and Singh used eight-node hexahedra [7]; Kassaye et al. used 0.5 mm linear tetrahedra [13]; Petrík and Ároch varied element size and type [9]. A convergence study refines the mesh in the gauge section and at fillets until the quantity of interest changes by less than a chosen tolerance. Stresses at geometric singularities do not converge and must not be read as material stresses.

A fixed support is applied at one end and a force or prescribed displacement at the other. Displacement control is preferable when the load peaks and then falls, since load control cannot follow softening. The von Mises stress is

$$\sigma_{vm} = \sqrt{\{\tfrac{1}{2}[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2]\}} \quad (4.1)$$

where σ_1, σ_2, σ_3 are the principal stresses. In a uniform gauge section σ_{vm} approaches P/A_0, while shoulders and grips show higher local values. A linear-elastic analysis assumes stress proportional to strain at every load, so results above yield are unreliable; it cannot reproduce necking, which needs plasticity with large-deformation analysis, and has no mechanism for damage or fracture. At the neck the stress state is triaxial and the axial stress must be corrected [16], so post-necking curves are often recovered iteratively [9]. Within its range, linear-elastic analysis remains a quick check of stress distribution and stiffness [8].

V. Literature Review

A. Mild and Structural Steels

Kumar and Singh simulated tension and compression of mild steel at strain rates of 1–1500 s^{-1} in ANSYS using Cowper–Symonds and Johnson–Cook models; the simulated curves agreed well with model predictions and with the experimental work of Singh et al. [7], [17]. The limitation is that the regime is dynamic rather than quasi-static and the constants depend on prior tests. Carvalho and Baltar tested eight ASTM A572 Gr 50 specimens, found results above the standard minimum, and simulated the elastic range in ANSYS Workbench; simulated values were generally lower than analytical ones and mesh refinement was suggested [15]. Dzioba et al. derived true stress–strain relations for S355 steel and verified an FE tension model against measured data [18]; Garcia Garino et al. addressed FE simulation of the simple tension test [19]. These steels are close to, but not identical with, mild steel.

B. EN31 Steel

The EN31 literature is dominated by heat treatment, hardness and wear. Baburaj et al. related hardening and tempering to microstructure, hardness and abrasive wear, concluding that higher hardness gave higher wear resistance [4]; Das et al. compared furnace cooling, oil quenching and water quenching of EN31 and EN8 [3] (for EN8: maximum 241.18 BHN and 631 N/mm^2); Yadav and Tripathi studied austempering and martempering [11]. Tensile data are sparse and, in the records examined, lack yield strength, elongation and stress–strain curves. No study combining UTM testing of EN31 with an ANSYS tensile model was located.

C. FE Tensile Simulation and Validation

Cabezas and Celentano combined tensile testing and numerical analysis on sheet specimens [8]. Petrík and Ároch built the true stress–strain curve including necking iteratively in ANSYS and showed dependence on element size and type [9]. Kassaye et al. tested round and flat specimens of hot-

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rolled Q&P 5Mn steel and simulated them with multilinear isotropic hardening; FE von Mises stresses of 1496 MPa (flat) and 1514 MPa (round) were consistent with experimental true stresses [13]. Eom et al. compared FE simulation with tensile experiments for 22MnB5 steel [20].

D. Synthesis

Three themes emerge. Validation quality depends on constitutive data: feeding true stress–strain curves, including the necking branch, into nonlinear FE models gives the closest agreement [9], [13], [18]. Mesh type and size are tuneable variables rather than fixed settings [7], [9], [13]. And the two steels are covered unevenly—mild steel through strain-rate and structural-steel validation, EN31 through heat-treatment studies—with no shared test-and-simulate study.

VI. Comparative Analysis

A. Properties and Published Experiment–FE Comparison

The steels share the same elastic stiffness, so at equal stress their elastic strains are equal ($\sigma = 400$ MPa, $E = 200$ GPa give $\varepsilon = 0.0020$ for either; (3.3)). The difference lies beyond the elastic range: mild steel yields at lower stress but extends far more before fracture, while hardened EN31 reaches higher strength and hardness at the cost of ductility, with values that move with heat treatment [3], [4]. Table II gives the only quantitative experiment–FE comparison that could be confirmed.

Specimen	Exp. true UTS (MPa)	FE (MPa)	Difference
Round	1514	1514	0 %
Flat	1423	1496	5.1 %

Table II: Experiment–FE Comparison Found in the Literature [13]

Steel is Q&P 5Mn; percentages are not transferable to mild steel or EN31. Other studies report agreement qualitatively [7], [15].

Published evidence shows differences of a few percent where nonlinear models use experimental true stress–strain data [13], and under-prediction by elastic models relative to analytical values [15]. Like-for-like differences between the two steels cannot be drawn, because no single study subjects both to the same test and model.

B. Student-Supplied Project Data (Context Only)

The authors' own project measurements are listed in Table III separately from the literature; they are not findings of the review. Nominal stress is calculated from (3.1).

Quantity	Mild steel	EN31
Round specimen diameter	12 mm	10 mm
Gauge length	60 mm	200 mm
Area A_0	113.098 mm^2	78.54 mm^2
Load at yield (UTM)	57.04 kN	31.96 kN*
Yield stress (UTM)	504.332 MPa	406.928 MPa*
Maximum load	66.00 kN	67.64 kN
Tensile strength	583.567 MPa	861.220 MPa
Elongation	25.0 %	5.00 %
Reduction of area	65.972 %	43.75 %
ANSYS load applied	57,040 N	31,960 N
Nominal P/A_0 (calc.)	504.3 MPa	406.9 MPa
ANSYS max. equivalent stress	548.52 MPa	442.67 MPa
ANSYS max. equiv. elastic strain	0.0027464	0.0022164
ANSYS max. total deformation	1.1727 mm	0.81392 mm
ANSYS max. stress / nominal	1.088	1.088

Table III: Student Project Data: UTM Reports and Ansys Maxima

Machine-reported, derived from the load–crosshead-travel record (no extensometer); the EN31 plot begins at about 32 kN at zero travel, so this value should be re-verified. The mild-steel report states that a stress–%strain graph was not available. ANSYS results are linear-static maxima at the load shown.

The maximum von Mises stress is about 8.8 % above nominal in both models, consistent with local stress raising near shoulders or the loaded end rather than plasticity, and the ratio of the ANSYS stress to strain maxima is about 199.7 GPa, matching the 200 GPa assigned to steel. The measured tensile strengths (583.6 and 861.2 MPa) lie in the plastic regime and cannot be compared with linear-elastic ANSYS stresses; a like-for-like comparison needs a multilinear hardening model and a load–displacement comparison. The mild-steel yield stress exceeds the S235JR minimum, which is permitted since specifications give minima, but the grade and supply condition should be recorded.

VII. Research Gaps and Future Scope

A. Gaps

(i) No study located tests and simulates mild steel and EN31 together under one protocol. (ii) EN31 hardness and strength vary with quenching and tempering, with apparently inconsistent trends between studies [3], [4], so each dataset needs its condition stated. (iii) Elastic models under-predict analytical values [15], and crosshead-based strain adds machine compliance. (iv) Stress and strain depend on element type and size [9], so convergence evidence should accompany every result. (v) Elastic models cannot describe yield, necking or rate effects, while nonlinear models need reliable true stress–strain data [13], [18]. (vi) Damage and failure criteria are rarely validated against UTM fracture for these steels. (vii) Grip slip, misalignment, machining quality, rate control and the choice of yield definition all enter reported values [5], [6]. Future studies should report material grade, condition and heat-treatment route; specimen standard and geometry; strain-measurement method; yield definition and repeat-test scatter; and FE element type, size, material model, loading and convergence evidence.

B. Future scope

Improved ANSYS modelling would use nonlinear static analysis with large deformation, multilinear isotropic hardening from true stress–plastic strain data, and displacement-controlled loading to follow the post-peak response [9], [13]. Validation should use extensometer or

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full-field strain measurement and repeat tests [8]. Rate-dependent laws such as Johnson–Cook [7], [14], condition-specific EN31 data, damage models for necking and failure, and locally refined meshes would extend this, ultimately under a single test-and-simulate protocol applied to both steels.

VIII. Conclusion

Mild steel and EN31 occupy different regions of strength–ductility space while sharing the same elastic stiffness; EN31 properties depend strongly on heat treatment; UTM testing provides the load–displacement response and strength values on which FE models rest; and linear-elastic ANSYS analysis describes stress and deformation up to yield but not plasticity, necking or fracture. Where nonlinear models are calibrated on true stress–strain data and mesh convergence is checked, agreement of a few percent has been documented, although the best-documented case concerns a different steel. Direct comparative studies, EN31 tensile curves and ANSYS tensile validations remain scarce, so the main opportunities are condition-specific EN31 tensile characterisation, nonlinear ANSYS modelling with convergence evidence, rigorous strain measurement and fracture prediction.

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