SHEng
SMART HEALTHCARE ENGINEERING
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TENSILE TESTING

Class content material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

Project website: www.smarthealtheng.com

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SMART HEALTHCARE ENGINEERING

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Introduction

In modern engineering and manufacturing, delivering a product that is safe, reliable and compliant with international standards is not an afterthought, it is the foundation of the entire design and production cycle. Whether fabricating an impressive, welded structure or producing micro-components, engineers must guarantee that every material and joint performs exactly as predicted under load. To achieve this, industries rely on a structured framework of Quality Assurance (QA) and Quality Control (QC). While both terms are used in casual discussion, Quality Assurance and Quality Control are distinct and complementary areas. The first one is focused on the process, while the other is focused on the product.

Quality assurance is a proactive, systemic approach and its primary goal is to establish processes, documentation and organizational methodologies that prevent defects before they ever occur. Quality control is reactive and inspection-based discipline. It represents the physical checks where the actual product is compared against the design criteria. Tensile testing is the most fundamental static mechanical characterization method. By subjecting a standardized sample of a material to a controlled, uniaxially increasing tensile load until failure, engineers can quantify how the material responds to the pulling forces. The primary objective of a tensile test is to establish the fundamental mechanical properties required for structural design, numerical modeling (such as finite element analysis), quality assurance and failure analysis.

This standardized specimen is machined into a “dog bone” geometry to ensure failure occurs within a controlled gauge length, and it is clamped into the jaws of a universal testing machine and slowly pulled apart at a controlled strain rate. As the tensile load is applied, the machine continuously records force (F) and the sample changes in length (ΔL). These values are converted into engineering stress (s) and engineering strain (ε) determined using the original cross-sectional area of the specimen (A_0) and the original gauge length (L_0).

$$\sigma = \frac{F}{A_0} \quad (1)$$

$$\varepsilon = \frac{\Delta L}{L_0} \quad (2)$$

Fig. 1. Universal tensile machine [1]

Fig. 2. Sample clamped for tensile testing

The resulting stress-strain curve identifies several critical transition zones:

- Elastic region – the initial linear region of the curve corresponds to the elastic deformation range, where all deformation is fully recoverable upon unloading. The slope of this region represents the Young's modulus (E) of the material.
- Yield strength (R_e) – the point at which the material transitions from elastic to plastic (permanent) deformation. For materials without a distinct yield point, a 0.2% offset method is standard ($R_{p0.2}$).
- Ultimate tensile strength (R_m) – the maximum stress point on the engineering stress-strain curve. Beyond this peak, localized deformation or "necking" begins in ductile materials.
- Fracture point – as its name implies, the point where the specimen breaks.

The initial phase of the tensile test represents completely reversible, elastic deformation. When the load is applied, the atoms within the metal's crystal lattice are pulled slightly apart from their equilibrium interatomic spacing (r_0). Because this displacement is so small, the interatomic bonding forces act as elastic springs. No permanent changes occur to the crystal structure, and no dislocations move permanently out of their local potential wells. As the force increases, the

resulting elongation is directly proportional to the applied load. This linear relationship is governed by Hooke's Law:

$$\sigma = E \cdot \varepsilon \tag{3}$$

The elastic limit and proportional limit – the upper boundary of this region is defined by the proportional limit (where the stress-strain curve begins to deviate from a straight line) and the elastic limit. If the load is removed at any point within this region, the specimen will snap back instantly to its original dimensions, dissipating all stored elastic strain energy as heat or kinetic recovery.

Yielding marks the critical transition where elastic behavior ends and permanent, irreversible deformation begins. The physical mechanisms here depend heavily on the crystal structure and alloy composition: Many structural steels exhibit an upper yield point followed by a sudden drop to a lower yield point. This behavior is caused by interstitial solute atoms (like carbon and nitrogen) locking dislocations in place – a phenomenon known as Cottrell atmospheres. Once the applied stress is high enough to tear dislocations away from these atmospheres, they move freely, causing localized yielding that spreads across the gauge length via Luders bands – or yield point elongation. Most engineering alloys do not have a sharp, well-defined yield point. Instead, the curve transitions smoothly. To establish a standardized, reproductible engineering threshold, metallurgists define the 0.2% offset yield strength ($R_{p0.2}$). A straight line is drawn parallel to the elastic slope starting from a strain value of $\varepsilon = 0.002$ (0.2%). The point where this line intersects the stress-strain curve defines the yield strength. This ensures that the material is not subjected to an unacceptable level of permanent distortion (plastic "set") in service.

Once past the yield point, the material enters the strain hardening region, where extensive plastic deformation takes place uniformly across the entire gauge length of the specimen. Macroscopic plastic deformation is driven by the massive, coordinated movement of line defects called dislocations along crystallographic slip planes. However, as these millions of dislocations move, they intersect, cross paths, and block one another. They form dense networks and tangles that impede further movement. Because the existing dislocations become jammed and harder to move, the material requires progressively higher macroscopic stress to force further plastic deformation. This manifests on the stress-strain curve as an upward-sloping curve of decreasing slope. This

homogenous plastic flow region can often be mathematically modeled using the Hollomon equation for true stress and true strain:

$$\sigma_T = K\varepsilon_T^n \tag{4}$$

where K is the strength coefficient and n is the strain hardening exponent which dictates how rapidly the material resists further deformation through hardening. This uniform straining continues until the curve reaches its absolute peak: the ultimate tensile strength.

Fig. 3. Tensile test samples – no. 1 after tensile test, no. 2 before tensile test

Past the ultimate tensile strength (R_m), the material can no longer uniformly distribute plastic deformation, and a localized mechanical instability takes over. Up to ultimate tensile strength, the material's ability to strain-harden compensates for the reduction in cross-sectional area caused by stretching. However, at R_m, the rate of cross-sectional area reduction outpaces the rate of strain hardening. Deformation ceases to be uniform across the gauge length and concentrates in one weak local zone, forming a visible inward constriction known as neck. Because the "neck" localizes all subsequent deformation, the actual force required to continue pulling the specimen down actually decreases. On an engineering stress-strain curve, this appears as a downward slope after R_m because engineering stress is calculated using the original constant cross-sectional area (A_0). In contrast, a true stress-strain curve would continue rising right up to the point of fracture because it divides the instantaneous force by the rapidly shrinking local area (A). Inside the heart of the necked region, triaxial stress states open micro-voids around second-phase particles, inclusions or precipitates. These micro-voids grow, link up and coalesce, eventually resulting in rapid crack propagation

across the remaining cross-section. For ductile metals, this culminates in a characteristic cup-and-cone fracture surface, signifying the end of the test.

Fig. 4. Tensile test sample for necking

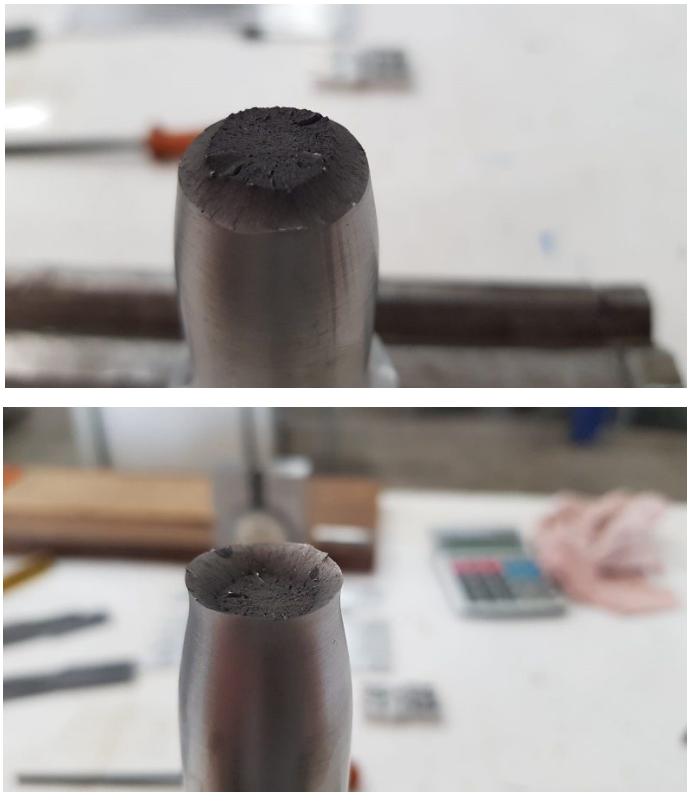

Fig. 5. Tensile test ductile sample

There are three types of samples – type A, B and E. All of them have the same dimensional characteristics that you should pay attention to. They are explained in Table no. 1.

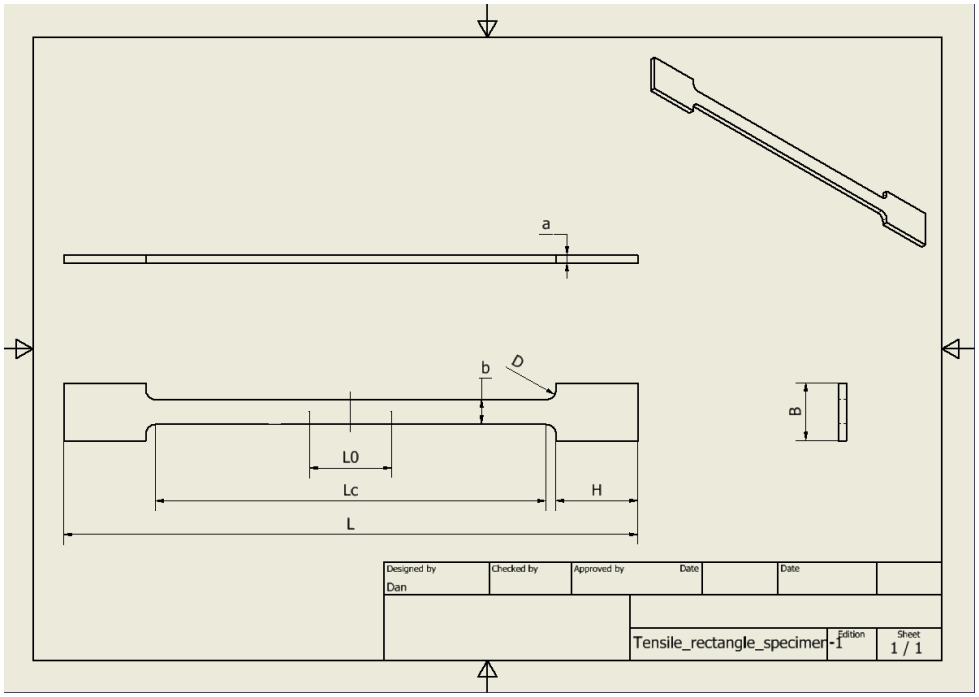

Fig. 6. Tensile test specimen type E – rectangular sample

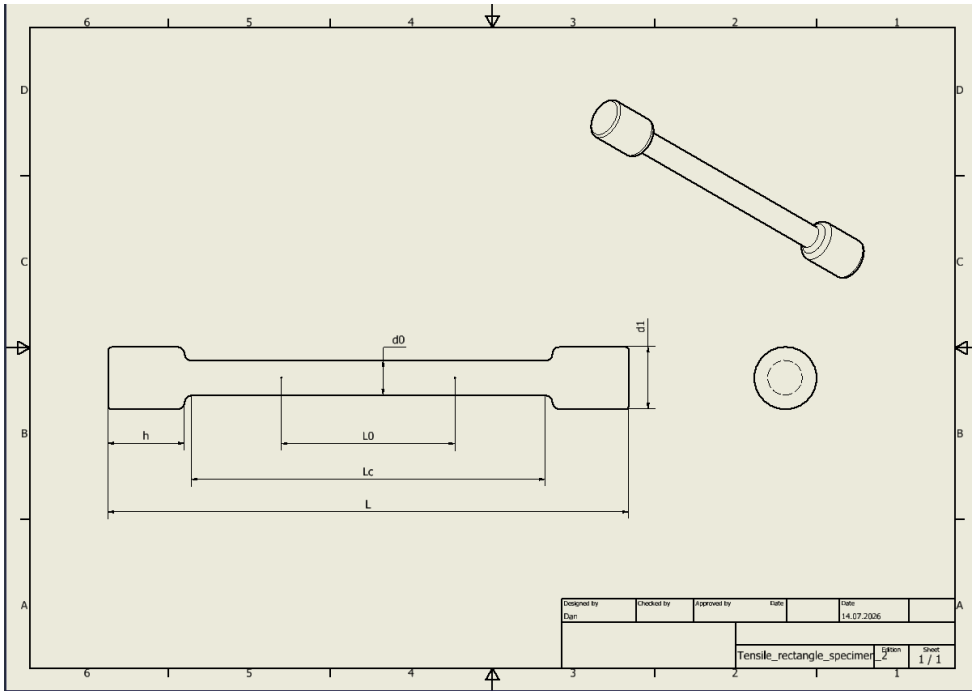

Fig. 7. Tensile test specimen type A – round sample

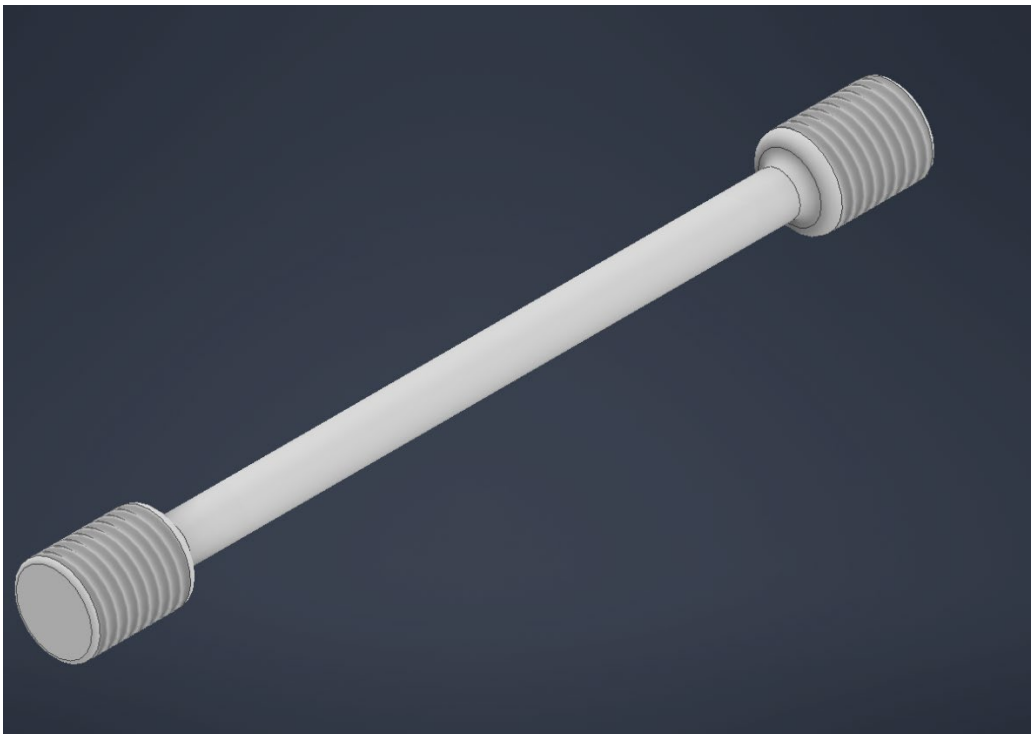

Fig. 8. Tensile test specimen type B – round sample with threaded heads

Tabel no. 1 – Dimensions and explanations for the tensile test samples

Specimen type E		Specimen type A + B	
Dimensions	Explanation	Dimensions	Explanation
a	Thickness	D_0	Sample diameter – calibrated diameter
b	Width		
B	Grip width	D_1	Grip diameter (A) / Thread dimension (B)
h	Grip length		
L_0	Initial gauge length	h	Grip length
L_c	Calibrated length	L_0	Initial gauge length
L	Total length	L_c	Calibrated length
D	Minimum radius – 35 mm	L	Total length

Tensile testing is not merely a qualitative demonstration of material behavior. It is the primary empirical methodology used to generate foundational constitutive data. Below is an expanded, technical breakdown of why tensile testing is indispensable across research, manufacturing and structural design.

When designing load-bearing components, engineers cannot rely on qualitative descriptions of strength. Material selection requires precise, standardized metrics to evaluate candidates against specific operational constraints. A tensile test yield baseline mechanical parameters – such as $R_{p0,2}$, R_m, A, Z. These values are measured under strictly controlled strain rates and thermal conditions in accordance with standards like ISO 6892-1 or ASTM E8, eliminating operator bias. In wrought, rolled or extruded metals, crystallographic texture and inclusion alignment create mechanical anisotropy. Tensile testing specimens extracted parallel (longitudinal) and perpendicular (transverse) to the principal working direction quantify these directional disparities, ensuring that structural components are not deployed in orientations vulnerable to low transverse ductility. Engineers use these metrics to construct performance indices to optimize weight-critical applications in aerospace, automotive, healthcare without compromising structural integrity.

Tensile testing serves as a vital verification tool for quality control. Variations in quenching rates, tempering temperatures or solution annealing cycles directly precipitate changes in dislocation density, grain size and precipitate distribution. Internal casting defects (such as shrinkage microporosity, gas entrapment) act as stress concentrators that severely degrade ductility and fracture strain. A drop in elongation (A) or ultimate tensile strength during routine testing often serves as the first indicator of systemic process degradation on the factory floor. In welded fabrications, tensile tests performed across the weldment (transverse tensile tests) evaluate the strength mismatch between the parent material, the weld metal and the heat affected zone ensuring that the joint satisfies the minimum load-bearing requirements of the parent plate.

Mechanical design must account for service loads while preventing both catastrophic fracture and unrecoverable permanent deformation. Structural design codes dictate that operational stresses must remain strictly within the elastic regime. By establishing accurate yield strength and ultimate tensile strength values, we can determine the maximum allowable working stress. Safety factors are applied to yield or ultimate strengths to account for uncertainties in service loading, environmental degradation and material variability.

Bibliography:

[1].https://icdt.unitbv.ro/ro/centre-de-cercetare/eco-tehnologii-avansate-de-sudare/infrastructur%C4%83.html

Acknowledgments

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