ME 212 EXPERIMENT SHEET #2

TENSILE TESTING OF MATERIALS

1. INTRODUCTION & THEORY

The tension test is the most commonly used method to evaluate the mechanical properties of metals. Its main objective is the determination of properties related to the elastic design of machines and structures. Since the test is fully standardized and well established, one may state that it is a rapid way of obtaining the desired mechanical characteristics of materials.

Basically, in a tension test a metallic specimen of specified dimensions according to relevant standards is pulled under the action of uniaxial forces applied at both ends until the specimen undergoes fracture. A typical tensile test specimen can be seen in Figure 1. The “gage length” corresponds to the effective length of the specimen over which the elongation occurs. Therefore, the initial length of the specimen is taken to be equal to the gage length \( L_{gage} \). Turkish standards (TSE) suggest a formula for the determination of gage lengths depending on the initial cross-sectional area of the specimen, \( A_0 \):

\[
L_{gage} = K \sqrt{A_0}
\]

(where \( K = 11.3 \) for relatively long bars and \( K = 5.65 \) for relatively short bars)

![Figure 1. Typical Tensile Test Specimen](image)

While the applied uniaxial load is continuously increasing, the elongation in the specimen is recorded, such that at the end of the test a set of data for corresponding readings of load and displacement values is obtained. Recalling that the engineering stress is defined to be the ratio of the applied load to the initial cross sectional area, \( \sigma_{eng} = \frac{P}{A_0} \) and that the engineering strain is defined to be the ratio of the elongation to the initial length of the specimen \( \varepsilon_{eng} = \frac{\Delta l}{l_0} \), one can plot the engineering stress-engineering strain curve. A typical stress strain curve for a ductile material is shown in Figure 2.
However, it should be taken into account that the cross-sectional area of the specimen is continuously decreasing due to the conservation of volume principle as the sample elongates during the test. Therefore the true value of stress during a tensile test should be defined as 

\[ \sigma_{true} = \frac{P}{A} \]

, taking A values to be instantaneous area values. Similarly, the engineering equation for strain takes it as granted that the gage length does not change, which is quite unrealistic. A better equation for the strain values is given as 

\[ \varepsilon_{true} = \ln \left( \frac{l}{l_0} \right) \]

 taking the change of gage length into account. The engineering values for stress and strain are most of the time appropriate for engineering purposes, which usually involve only elastic deformations, whereas the true values of stress and strain are needed to understand the behaviour of materials in a better way.

According to the fact that mild steel is the most common engineering material employed in structures, its stress-strain curve at a first sight turns out to be more significant. A typical low-carbon steel would yield a stress-strain curve as in Figure 3, if tensile loads are applied at both ends at room temperature.
The engineering stress-strain curve can be best interpreted by dividing it into two parts, namely elastic and plastic portions.

(i) Elastic Range

As the specimen is loaded, first it behaves like a spring with a definite spring constant according to the so-called Hooke’s Law:

\[ \sigma = E \varepsilon \]

where “E”, defined as Young’s Modulus, acts as the corresponding “spring” constant. In this “elastic” region, the stress-strain curve is linear. The point at which the linearity ends is defined as the yield point. In the stress-strain curve, “E” acts as the slope of the loading line in the elastic region. Typical values of elastic moduli for some common engineering materials are listed in Table 1. As long as the metal is loaded within the elastic region, the strains are totally recoverable and the specimen will return to its original dimensions as the load is relaxed to zero. When the load exceeds the corresponding yield point, the specimen undergoes gross plastic deformation, and is permanently deformed even if the load is returned to zero afterwards.

**Table 1. Elastic Moduli of some common Engineering Materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus, E (Gpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-alloys</td>
<td>72.4</td>
</tr>
<tr>
<td>Copper</td>
<td>110</td>
</tr>
<tr>
<td>Nickel</td>
<td>207</td>
</tr>
<tr>
<td>low-C Steel</td>
<td>200</td>
</tr>
<tr>
<td>Stainless Steel (18Cr-8Ni)</td>
<td>193</td>
</tr>
<tr>
<td>Titanium</td>
<td>117</td>
</tr>
<tr>
<td>Tungsten</td>
<td>400</td>
</tr>
</tbody>
</table>
In the case of mild steel, one should distinguish between the upper and the lower yield strengths (points). The maximum stress reached in the specimen prior to the onset of significant plastic deformation is called the “upper yield strength”, whereas the “lower yield strength” is the stress corresponding to the horizontal portion of the stress-strain curve immediately following the beginning of plastic deformation. The oscillating character of this portion of the stress-strain curve – usually referred to as *serrated yielding* – represents temporary plastic instability, a common characteristic of mild-steel. Beyond the lower *(serrated)* yield point, the material continues deforming as expected until fracture.

Sometimes a definite yield point as in mild-steel cannot be observed in other ductile metals. Nevertheless an offset yield strength can be determined by drawing a parallel line to the elastic portion of the curve, starting from the 0.2% strain level. Therefore, the offset strength of a metal can be obtained this way, and the determined value may be employed in the calculations.

The term “toughness” associated with stress-strain curve for a given material, is defined as the ability of the material to absorb mechanical energy until fracture. Toughness can be defined as the strain integral of the stress-strain curve, such that:

$$ U_T = \int_0^\varepsilon \sigma \, d\varepsilon $$

From this definition, one may deduce that toughness is the area under the stress-strain curve until the fracture strain. Since most of the time, the exact functional dependence of stress on strain is unknown in the plastic zone, some approximation formulas to calculate the toughness of brittle and ductile materials have been proposed in the literature. One of these approximating formulas can be found in the “Tasks” section of these experiment sheets.

The ability to absorb energy solely in the elastic region is defined as “resilience”. The calculation of “resilience” again involves the calculation of the area under the stress-strain curve up to the yield point, thus forming a triangle with sidelengths of $\sigma_{yp}$ and $\varepsilon_{yp}$.

**(ii) Plastic Range**

Although extensive discussion of plastic deformation mechanisms is beyond the scope of this laboratory session, brief information regarding the mechanisms will be given here.

As one loads the specimen beyond the yield point and then relaxes the load to zero, the material does not recover its initial dimensions completely, instead a permanent strain is observed. This property characterizes the induced deformation as “plastic” and the portion of the stress-strain curve beyond the yield point is defined as the plastic “range”. Beyond the yield point, Hooke’s Law is not applicable any more, since the stress needed to produce continued plastic deformation increases with increasing strain in the plastic region. This phenomenon is defined as “strain-hardening”. The maximum point in the engineering stress-strain curve corresponds to the “ultimate tensile strength, UTS” of the material, which is at the same time the minimum necessary stress to cause the phenomenon known as “necking”. Necking is defined as a localized decrease in the cross-sectional area of the specimen, which results due to the imperfections which act as local stress raisers in the material. Upon
application of the UTS, all further plastic deformation is concentrated in the “necking” region and rapid fracture follows.

Compression Test

Simple tensile testing usually yields sufficient data to determine the mechanical properties of ductile materials. In those materials, the yield limits under tension and compression are generally the same. Therefore, it is not necessary to perform the compression test on highly ductile materials such as mild steel or most Al-alloys.

However, in some materials such as brittle and fibrous ones, the tensile strength is considerably different from compressive strength as seen in Figure 4 and Figure 5. Therefore it is necessary to test them under tension and compression separately.

![Compression and Tension stress-strain curves for GCI and Concrete](image)

**Figure 4 – 5.** Compression and Tension stress-strain curves for GCI and Concrete

Brittle materials, such as cast iron and concrete, are often weak in tension because of the presence of submicroscopic cracks and faults. However, these materials can prove to be quite strong in compression, due to the fact that the compression test tends to increase the cross sectional areas of specimens, preventing necking to occur. In general, the average compressive strength to tensile strength ratio of brittle materials is around 8/1.

Wood is a commonly used engineering material showing different mechanical behaviour under tensile and compressive loadings. However, contrary to Gray Cast Iron or Concrete, it does not show brittle characteristics under tensile loading and surprisingly, it’s considerably stronger in tension than compression. The fact that the cell structures in the material are stronger in the longitudinal than transverse direction is the major factor leading to this unusual mechanical behaviour of wood.

3. TASKS

Please perform the tasks assigned during the experiment in the “Results&Discussion” part of your experiment reports.
REFERENCES