BASIC MECHANICAL PROPERTIES

Introduction

The concepts of stress, strain and strength of materials are employed in practically every engineering discipline, from mechanical and structural engineering to electrical engineering. Properties such as stiffness, yield strength, tensile strength, ductility, toughness, impact resistance, creep resistance and others all influence the design, fabrication, maintenance, failure and recycling. These are simple concepts but they are extremely useful and by studying them carefully we can gain a better understanding of the practical and fundamental aspects of the behavior of engineering materials.

The types of tests most often used to evaluate the mechanical properties of materials are the hardness test and the tensile test. Hardness testing procedures can range from Mohs test that is used by geologists to compare the hardness of rocks to the micro and even nano-scale tests which are used to measure the hardness of specific microstructural features. Somewhere in between is the Rockwell test which is widely used in industry to gage the effectiveness of heat treatments, mechanical processing and changes in the composition of the material. Its primary value is as inexpensive substitute for tensile testing in so far as there is a correlation between hardness and tensile strength.

Rockwell testing employs a steel or diamond indentor and a specified load to make a small indentation on the surface of a specimen. The hardness is then measured in terms of the depth of penetration of this indentor. While this type of test requires a sturdy, high-precision machine they are very easy to operate and can be relatively small. There are even portable units which can be taken to the construction (or failure) site. One of the best features of the Rockwell-type test, however, is that the specimens require very little preparation before testing. They simply have to be clean and have a reasonably smooth surface. This means that hardness testing can be performed on sheet, plate, bar and rod stock, a finished part, and even the insides and outsides of pipe.

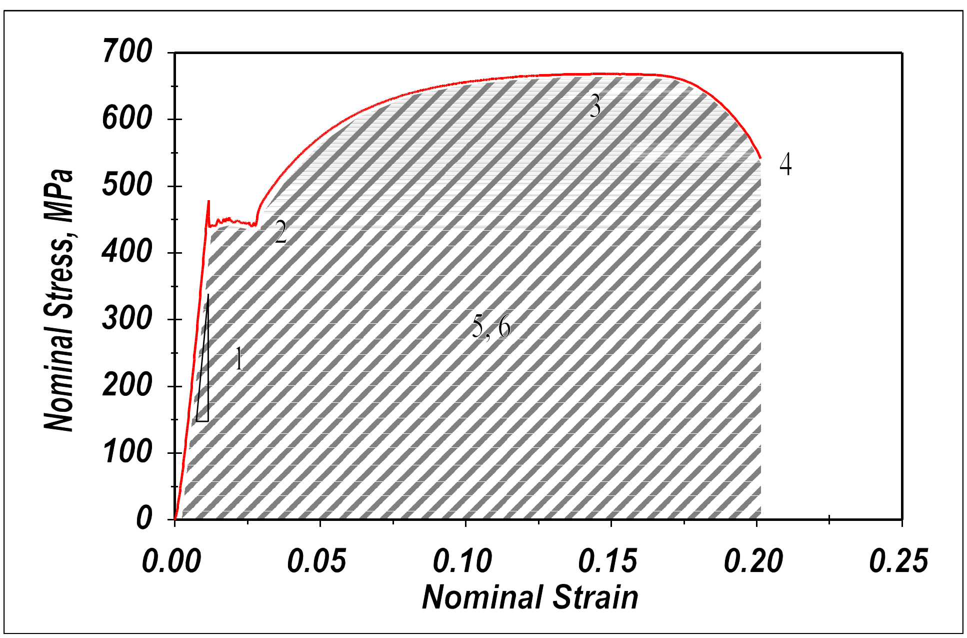

Figure 1. Engineering stress-strain curve for a plain carbon steel.

Tensile testing provides much more information about the mechanical behavior of a material than the hardness test does. While tensile testing is more complicated and requires larger, more expensive equipment it is still a relatively simple procedure which allows one to evaluate a variety of properties. Figure 1 provides a good example of the results of a tensile test. Its prominent features are numbered and are described below:

1. Young's Modulus	Young's modulus is a measure of a material's stiffness when deformed in tension. It is the equal to the slope of the initial linear region on the stress-strain plot. Unfortunately, unless an extensometer is used to measure specimen elongation we will be unable to measure Young's modulus correctly. The data in the stress-strain plot yields a value of 47.8 GPa ($6.9x10^6$ psi) while the correct value is 207 GPa ($30x10^6$ psi).
2. Yield Strength	The yield strength of a material is the stress where deformation changes from being mostly elastic to mostly plastic. It is found at the end of the linear (elastic) portion of the stress-strain plot. Yielding can occur gradually or it can occur abruptly. This specimen yielded abruptly, exhibiting an upper an lower yield point. The yield strength in this case is the lower yield point which is 441 MPa (63.9 ksi).
3. Ultimate Tensile Strength	The UTS is the highest stress on the engineering stress-strain plot and corresponds to the maximum force experienced by the specimen. For this material the UTS is 668 MPa (96.9 ksi).
4. Ductility	There are two ways to represent this property but both are measures of the strain to failure. One is the elongation to failure and the other is the reduction of area in the necked region of the fractured specimen. The elongation to failure for this specimen is 20.1%. The reduction of area has to be measured directly from the specimen.
5. Energy Capacity	The energy capacity of a material describes how much work was done (how much energy was required) to pull the specimen to failure. It is a measure of the specimen's resistance to failure in tension and is equal to the area under the load-elongation curve. For this specimen the total energy capacity is 201 joules.
6. Modulus of Toughness	This is similar to energy capacity except that it is expressed in terms of the energy per unit volume of the specimen. It is also a measure of the material's resistance to failure in tension but it is equal to the area under the stress-strain curve. For this specimen the modulus of toughness is 119 MPa.

The American Society for Testing and Materials (ASTM) has established a number of standards covering practically every aspect of tensile testing. For instance, there are separate standards dealing with the design of the specimens, certifying the testing machine, performing the test, analyzing the results and even comparing the results of tests where different specimen designs were used. These standards are invaluable. They help ensure that results from many different laboratories are consistent and reliable. In fact, they are so important and widely accepted that there are compelling business and legal reasons for adhering to these standards. Even in research, where these standard procedures do not always apply, they provide a solid foundation for the development of unique testing procedures which are based on the basic tensile test. Tensile testing can be conducted at elevated temperatures, at high pressures or in a vacuum, in specific atmospheres or even aqueous environments, or using a true strain rate (constant acceleration) instead of the usual constant rate of extension (constant velocity). Tensile testing in all of its varieties has long been an invaluable research tool, yielding a better understanding of the fundamental aspects of deformation processes. When one looks deeper into this phenomenon one quickly finds out that there is much more to be learned from figure 1 than was described here.

Objective

In this experiment hardness tests and tensile tests will be performed on a selection of common structural materials in order to evaluate many of their basic mechanical properties. The force-elongation data will be plotted on stress-strain graphs and then analyzed to measure selected mechanical properties. These results will be compared to those in reference books and then they will be used to compare and contrast the properties of each type of material tested.

Preparation

Before actually starting the experiment you should pause to look closer at certain details of the procedure and try to anticipate the results. This will help ensure that the experiment goes well. The following questions should get you started.

1. Go to the data books and look up the mechanical properties of the materials you will be testing.

2. Determine maximum load and elongation requirements that the testing machine must meet to be capable of successfully testing each specimen. Does your testing machine meet these requirements?

3. Many steels exhibit an upper and lower yield point. Which yield point would you call out as the yield strength?

4. A particular steel, depending on its processing history, will not always exhibit an upper and lower yield point. What types of processing cause the upper and lower yield points to not be observed?

5. The energy capacity of your specimen can be estimated from the area under force-elongation and stress-strain curves. Devise graphical and numerical methods for estimating these areas.

6. For a given material, how much specimen-to-specimen variation in strength and ductility do you expect to find?

7. Which of the two, the UTS or ductility, would you expect to find larger specimen-to-specimen variations?

8. What are the practical significances of the yield strength and the UTS?

9. What are valid ranges of hardness readings for the Rockwell C, B and F scales? Which indentor and test load does each scale use?

10. After performing a tensile test you decide to compare the final length of the fractured specimen to the final length of the specimen as measured by the testing system. You find that they are different. Which measurement gives the larger value and why is this so?

11. A specimen will often fail suddenly, releasing an amount of energy that you may associate with the loud sound and sudden movement of the two halves of the specimen. Using a force-elongation or stress-strain curve, show how would you estimate the amount energy released.

12. Stress is usually given in terms of force per unit area. Convert this to an equivalent stress using units which includes an energy term.

Materials

The materials to be tested will be common structural metals or possibly polymers or composites. Note the exact compositions or alloy types and their conditions, i.e., heat treatments. These materials will already be machined and ready for tensile testing. Measure each of them to determine their gage lengths and diameters or widths and thicknesses.

Equipment

The following is a generic list of the types of equipment that may be used to perform this experiment. Make sure you have everything you need before starting and note exactly what types of equipment (manufacturer, model, specifications, etc.) you are using.

1. Rockwell-type hardness tester
2. Tensile testing system
3. Computer and data acquisition system to record the force and elongation data. If a computer is not available then a strip chart or flatbed recorder can be used.
4. Calipers to measure the specimens

Safety

During this experiment high forces are generated by the tensile testing machine. It has pinch zones large enough to trap a finger, a hand and even an arm. Injuries, if they should occur, could be quite serious. A detailed operating procedure is included in this laboratory manual. Read it before you start using this equipment and refer to it during every step of the experiment. Be especially careful when installing a specimen, stay clear while the test is running and keep in mind that some types of specimens may shatter when broken.

Chemical Hazards	Normally none, but this will depend on the materials the specimens are made from. Specimens used in this experiment are usually made of steel, copper, brass, aluminum alloys or other conventional structural materials.
Physical Hazards	Tensile testing machines can generate tens of thousands of pounds force. Be very careful when installing a specimen and stay back when the test is running.

	Brittle specimens and composites tend to send small debris flying about the room when the specimen breaks. Compression testing any material or structure poses the same hazard. If these types of specimens are used or if you plan to do a compression test then either a scatter shields should be installed on the load frame or everyone should be wearing safety glasses.
Biohazards	None.
Radiation Hazards	None.
Protective Equipment	Recommended: safety glasses Required: safety glasses and/or scatter shields if compression testing is done or if brittle materials or composites are tensile tested.

Procedure

Examine the experimental setup. Find out what each instrument and tool does and how each works. Make sure everything is working properly and if possible try a couple of dry runs of the experiment.

Hardness test each tensile specimen. Do not perform these tests on the gage section of the specimens. You don't want to damage the section which you will be tensile testing. Test the heads of the specimen instead. Also, make sure you are using the appropriate hardness scale. For example, the Rockwell B scale is usually used to test medium strength alloys but if your hardness readings are greater than 100 HRB or less than 0 HRB then another hardness scale must be used.

Tensile test each specimen to failure using the protocol provided by your instructor. Preview this protocol before you use it and note details such as the crosshead speed and the data acquisition rate. If the system is capable of providing a report along with the data then make sure you get a copy of this report.

Results

Before you put much more work into your data you should review each of the force-elongation curves, looking for anything unusual or anything that might indicate that errors were made during the tests. Certain defects in the data are normal and can easily be corrected but others may indicate serious errors were made and the results should be thrown out and the test repeated.

Construct engineering stress-strain curves for each specimen tested plus a true stress-strain curve for at least one of them. Label all significant points on each graph and measure the following properties:

1. Young's modulus
2. Yield strength (specify the method you used to locate the yield point)
3. UTS
4. Ductility in terms of elongation to failure. If round specimens were used then you should be able to measure final reduction in area.
5. Energy capacities: the total energy required to pull the specimen to failure, the modulus of resilience and the modulus of hyper-resilience at the UTS and at fracture
6. Modulus of toughness.

All of the above properties should be organized and presented in a table. This will make your job of describing and discussing the results easier and it will help the reader locate the information they are most interested in.

Discussion

Your discussion might begin by comparing your results with those in your reference books. Since this type of experiment and the materials you tested are quite ordinary it will probably be sufficient to simply establish the validity of your results. Next you might want to make qualitative and quantitative comparisons of the mechanical properties of each material tested. In doing so you might be able to see that every material has a unique set of properties, an insight that is essential to successful materials selection and design.

At this point you might want to consider the finer points of the deformation process itself. Try comparing the engineering and true stress-strain curves and explaining their differences. You should notice that the true stress, calculated assuming uniform cross-section, begins to decrease after the UTS and that this is not correct. The true stress should have kept on increasing until the specimen fractured. If you were able to measure the final reduction of area you should be able to estimate the correct true stress and true strain at the end of your tensile test. If you then draw a straight line from this point back to but tangent to the true stress-strain curve you would have a good idea of how the correct true stress-strain curve should look. But if this were correct, if the maximum true stress occurs at the end of the stress-strain curve, then how could one ever determine the UTS using only true stress-strain curves?

However you handle the discussion part of your report you should be developing a central idea or furthering a hypothesis. In the next section of the report you will sum it all up and finally make your point.

Conclusion

In your discussion you explored the mechanical properties of the materials you tested, comparing and contrasting your results with those of others and with principles you have been taught. Hopefully you have learned something new and possibly this is new knowledge which you should share with your colleagues. A final statement which sums up what has been learned will provide a satisfying and possibly a memorable end to your report, as long as your conclusions also address the stated objectives of this experiment.

References and Other Resources

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