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A schematic diagram for the stress-strain curve of low carbon steel at room temperature is shown in the figure. There are several stages showing different behaviors, which suggests different mechanical properties. To clarify, materials can miss one or more stages shown in the figure, or have totally different stages. In this case we have to distinguish between stress-strain characteristics of ductile and brittle materials. The following points describe the different regions of the stress-strain curve and the importance of several specific locations.Fracture PointThe fracture point is the point of strain where the material physically separates. At this point, the strain reaches its maximum value and the material actually fractures, even though the corresponding stress may be less than the ultimate strength at this point. Ductile materials have a fracture strength lower than the ultimate tensile strength (UTS), whereas in brittle materials the fracture strength is equivalent to the UTS. If a ductile material reaches its ultimate tensile strength in a load-controlled situation, it will continue to deform, with no additional load application, until it ruptures. However, if the loading is displacement-controlled, the deformation of the material may relieve the load, preventing rupture.In many situations, the yield strength is used to identify the allowable stress to which a material can be subjected. For components that have to withstand high pressures, such as those used in pressurized water reactors (PWRs), this criterion is not adequate. To cover these situations, the maximum shear stress theory of failure has been incorporated into the ASME (The American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Pressure Vessels. This theory states that failure of a piping component occurs when the maximum shear stress exceeds the shear stress at the yield point in a tensile test.Brittle vs Ductile FractureIn the tensile test, the fracture point is the point of strain where the material physically separates. At this point, the strain reaches its maximum value and the material actually fractures, even though the corresponding stress may be less than the ultimate strength at this point. Ductile materials have a fracture strength lower than the ultimate tensile strength (UTS), whereas in brittle materials the fracture strength is equivalent to the UTS. If a ductile material reaches its ultimate tensile strength in a load-controlled situation, it will continue to deform, with no additional load application, until it ruptures. However, if the loading is displacement-controlled, the deformation of the material may relieve the load, preventing rupture. It is possible to distinguish some common characteristics among the stress–strain curves of various groups of materials. On this basis, it is possible to divide materials into two broad categories; namely:Ductile Materials. Ductility is the ability of a material to be elongated in tension. Ductile material will deform (elongate) more than brittle material. Ductile materials show large deformation before fracture. In ductile fracture, extensive plastic deformation (necking) takes place before fracture. Ductile fracture (shear fracture) is better than brittle fracture, because there is slow propagation and an absorption of a large amount energy before fracture. Any fracture process involves two steps, crack formation and propagation, in response to an imposed stress. The mode of fracture is highly dependent on the mechanism of crack propagation. Cracks in ductile materials are said to be stable (i.e., resist extension without an increase in applied stress). For brittle materials, cracks are unstable. That means crack propagation, once started, continues spontaneously without an increase in stress level. Ductility is desirable in the high temperature and high pressure applications in reactor plants because of the added stresses on the metals. High ductility in these applications helps prevent brittle fracture.Brittle Materials. Brittle materials, when subjected to stress, break with little elastic deformation and without significant plastic deformation. Brittle materials absorb relatively little energy prior to fracture, even those of high strength. In brittle fracture (transgranular cleavage), no apparent plastic deformation takes place before fracture. In crystalography, cleavage is the tendency of crystalline materials to split along definite crystallographic structural planes. Any fracture process involves two steps, crack formation and propagation, in response to an imposed stress. The mode of fracture is highly dependent on the mechanism of crack propagation. For brittle materials, cracks are unstable. That means crack propagation, once started, continues spontaneously without an increase in stress level. Cracks propagate rapidly (speed of sound) and occurs at high speeds – up to 2133.6 m/s in steel. It should be noted that smaller grain size, higher temperature, and lower stress tend to mitigate crack initiation. Larger grain size, lower temperatures, and higher stress tend to favor crack propagation. There is a stress level below which a crack will not propagate at any temperature. This is called the lower fracture propagation stress. For brittle fracture, the fracture surface is relatively flat and perpendicular to the direction of the applied tensile load. In general, brittle fracture requires three conditions:Flaw such as a crackStress sufficient to develop a small deformation at the crack tipTemperature at or below DBTT Yunus Cengel Yunus A. Çengel is Professor Emeritus of Mechanical Engineering at the University of Nevada, Reno. He received his B.S. in mechanical engineering from Istanbul Technical University and his M.S. and Ph.D. in mechanical engineering from North Carolina State University. His areas of interest are renewable energy, energy efficiency, energy policies, heat transfer enhancement, and engineering education. He served as the director of the Industrial Assessment Center (IAC) at the University of Nevada, Reno, from 1996 to 2000. He has led teams of engineering students to numerous manufacturing facilities in Northern Nevada and California to perform industrial assessments, and has prepared energy conservation, waste minimization, and productivity enhancement reports for them. He has also served as an advisor for various government organizations and corporations. Dr. Çengel is also the author or coauthor of the widely adopted textbooks Differential Equations for Engineers and Scientists (2013), Fundamentals of Thermal-Fluid Sciences (5th ed., 2017), Fluid Mechanics: Fundamentals and Applications (4th ed., 2018), Thermodynamics: An Engineering Approach (9th ed., 2019), and Heat and Mass Transfer: Fundamentals and Applications (6th ed., 2020), and all published by McGraw Hill LLC Education. Some of his textbooks have been translated into Chinese (Long and Short Forms), Japanese, Korean, Spanish, French, Portuguese, Italian, Turkish, Greek, Tai, and Basq. Dr. Çengel is the recipient of several outstanding teacher awards, and he has received the ASEE Meriam/Wiley Distinguished Author Award for excellence in authorship in 1992 and again in 2000. Dr. Çengel is a registered Professional Engineer in the State of Nevada, and is a member of the American Society of Mechanical Engineers (ASME) and the American Society for Engineering Education (ASEE). 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He is also a member of the American Society for Engineering Education (ASEE), and the American Physical Society (APS).

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