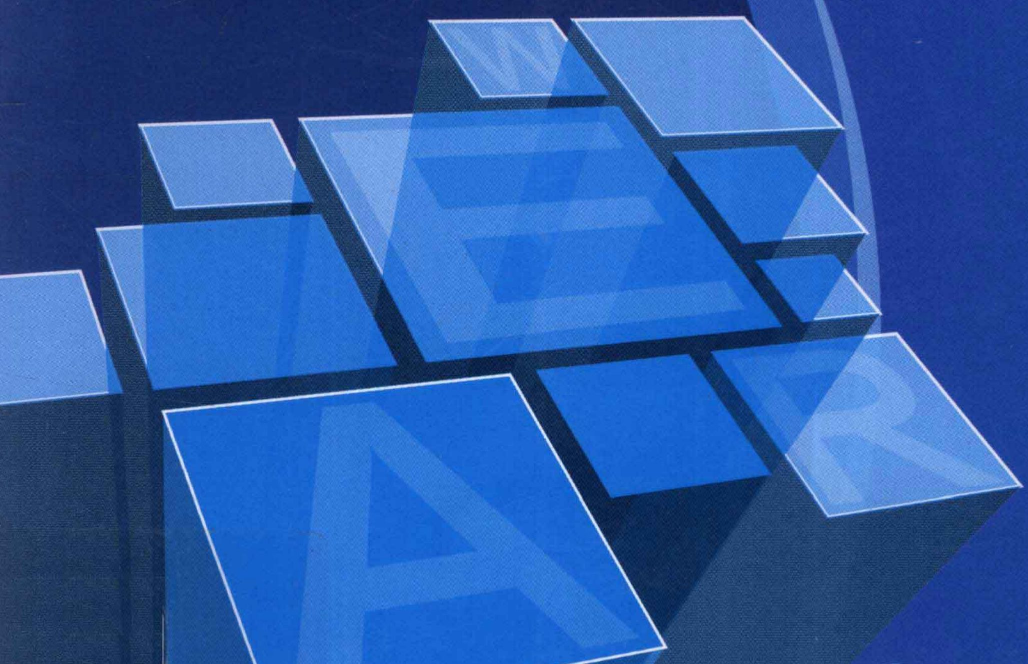
Practical Specialized English for Engineering Mechanics

工程力学实用专业英语

陈华燕　曾祥国　编著



四川大学出版社

工程力学实用专业英语

Practical Specialized English for Engineering Mechanics

陈华燕　曾祥国　编著

四川大学出版社

责任编辑:毕　潜
责任校对:余　芳
封面设计:墨创文化
责任印制:李　平

图书在版编目(CIP)数据

工程力学实用专业英语 / 陈华燕，曾祥国编著.
—成都：四川大学出版社，2012.11
ISBN 978-7-5614-6293-5

Ⅰ.①工…　Ⅱ.①陈… ②曾…　Ⅲ.①工程力学-英语
Ⅳ.①H31

中国版本图书馆 CIP 数据核字（2012）第 272757 号

书名　**工程力学实用专业英语**

编　著	陈华燕　曾祥国
出　版	四川大学出版社
地　址	成都市一环路南一段 24 号 (610065)
发　行	四川大学出版社
书　号	ISBN 978-7-5614-6293-5
印　刷	郫县犀浦印刷厂
成品尺寸	185 mm×260 mm
印　张	9
字　数	276 千字
版　次	2012 年 12 月第 1 版
印　次	2012 年 12 月第 1 次印刷
定　价	22.00 元

◆读者邮购本书,请与本社发行科联系。电 话:85408408/85401670/85408023　邮政编码:610065
◆本社图书如有印装质量问题,请寄回出版社调换。
◆网址:http://www.scup.cn

前　言

在高等教育面向21世纪的改革中，学生的基本素质、知识面及工作能力的培养受到空前的重视，其中专业英语的水平是衡量大学生素质能力的重要指标之一。力学专业英语在培养工科大学生的综合素质方面具有独特的作用，这主要是由力学学科的特点决定的：一方面，力学学科具有基础性，直接为自然科学服务，并且与生物、材料科学、物理、化学、数学形成交叉学科，相互渗透；另一方面，力学学科的思想和成果直接应用于土木、机械、水利、汽车、航空航天等众多技术领域。不论是自然科学或工程技术科学的经典论著，还是最前沿的研究工作，普遍是用英语写成发表的。准确理解科学与技术的发展状态，掌握力学原理的英语表达方式，对提高大学生专业水平的作用是不言而喻的。结合多年的教学实践，我们精选了课文材料，学生在有限的时间内认真精读这些材料对于提高他们的综合素质是大有裨益的。

全书共有18个单元，主要包括材料力学、断裂与疲劳、流体力学、热力学、有限元、分子动力学等学科的基本概念和方法，可作为大学本科32～36学时的教材。由于时间有限，教材涉及的内容较广泛，可能出现错漏，希望广大读者不吝指正，使本书在使用过程中不断改进和完善。

编　者
2012年7月

目录

Unit 1 Stress-Strain Curves

TEXT

Stress-strain curves are an extremely important graphical measure of a material's mechanical properties, and all students of Mechanics of Materials will encounter them often. However, they are not without some **subtlety**, especially in the case of **ductile** materials that can undergo **substantial** geometrical change during testing. This module will provide an introductory discussion of several points needed to interpret these curves, and in doing so will also provide a **preliminary** overview of several aspects of a material's mechanical properties. However, this module will not attempt to survey the broad range of stress-strain curves exhibited by modern engineering materials. Several of the topics mentioned here, especially **yield** and **fracture**, will appear with more details in later modules.

1 "Engineering" Stress-Strain Curves

Perhaps the most important test of a material's mechanical response is the tensile test, in which one end of a rod or wire **specimen** is **clamped** in a loading frame and the other subjected to a controlled displacement δ (see Fig. 1). A **transducer** connected in series with the specimen provides an electronic reading of the load $P(\delta)$ corresponding to the displacement. Alternatively, modern **servo-controlled testing machines** permit using load rather than displacement as the controlled variable, in which case the displacement $\delta(P)$ would be monitored as a function of load.

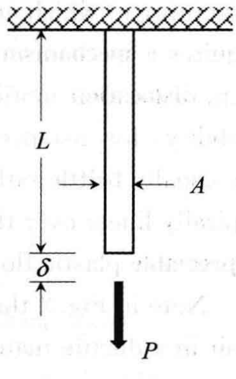


Fig. 1 The tension test

The engineering measures of stress and strain, denoted in this module as σ_e and ε_e respectively, are determined from the measured load and deflection using the original specimen **cross-sectional area** A_0 and length L_0 as

$$\sigma_e = \frac{P}{A_0}, \ \varepsilon_e = \frac{\delta}{L_0} \tag{1}$$

When the stress σ_e is plotted against the strain ε_e, an **engineering stress-strain curve** such as that shown in Fig. 2 is obtained.

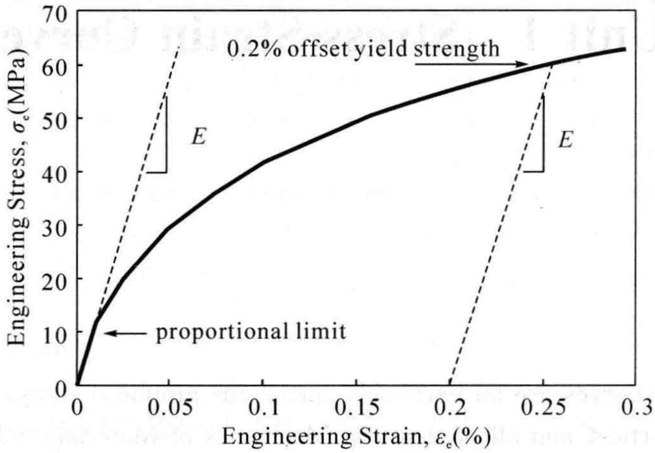


Fig. 2 Low strain region of the engineering stress-strain curve for annealed polycrystalline copper; this curve is typical of that of many ductile metals

In the early (low strain) portion of the curve, many materials obey **Hooke's law** to a reasonable approximation, so that stress is **proportional** to strain with the constant of proportionality being the modulus of elasticity or **Young's modulus**, denoted E:

$$\sigma_e = E\varepsilon_e \tag{2}$$

As strain is increased, many materials eventually **deviate** from this linear proportionality, the point of **departure** being **termed** the proportional limit. This nonlinearity is usually associated with stress-induced "plastic" flow in the specimen. Here the material is undergoing a rearrangement of its internal molecular or **microscopic** structure, in which atoms are being moved to new **equilibrium** positions. This **plasticity** requires a **mechanism** for molecular mobility, which in crystalline materials can arise from **dislocation** motion (discussed further in a later module). Materials lacking this mobility, for instance by having internal microstructures that block dislocation motion, are usually **brittle** rather than ductile. The stress-strain curves for brittle materials are typically linear over their full range of strain, eventually terminating in fracture without **appreciable** plastic flow.

Note in Fig. 2 that the stress needed to increase the strain beyond the proportional limit in a ductile material continues to rise beyond the proportional limit; the material requires an ever-increasing stress to continue straining, a mechanism termed **strain hardening.**

These microstructural rearrangements associated with plastic flow are usually not **reversed** when the load is removed, so the proportional limit is often the same as or at least close to the material's **elastic limit**. Elasticity is the property of complete and immediate **recovery** from an imposed displacement on release of the load, and the elastic limit is the value of stress at which the material experiences a permanent **residual strain** that is not lost on unloading. The residual strain induced by a given stress can be determined by drawing an unloading line from the highest point reached on the $\sigma_e - \varepsilon_e$ curve at that stress back to the strain axis, drawn with a **slope** equal to that of the initial elastic loading line. This is done because the material unloads elastically, there being no force driving the molecular structure back to its original position.

A closely related term is the **yield stress**, denoted σ_y in these modules; this is the stress needed to induce plastic deformation in the specimen. Since it is often difficult to **pinpoint** the exact stress at which plastic deformation begins, the yield stress is often taken to be the stress needed to induce a specified amount of **permanent** strain, typically 0.2%. The construction used to find this "offset yield stress" is shown in Fig. 2, in which a line of slope E is drawn from the strain axis at $\varepsilon_e = 0.2\%$; this is the unloading line that would result in the specified permanent strain. The stress at the point of intersection with the $\sigma_e - \varepsilon_e$ curve is the offset yield stress.

Fig. 3 shows the engineering stress-strain curve for copper with an enlarged scale, now showing strains from zero up to specimen fracture. Here it appears that the rate of strain hardening **diminishes** up to a point labeled UTS, for **Ultimate Tensile Strength** (denoted σ_f in these modules). Beyond that point, the material appears to **strain soften**, so that each increment of additional strain requires a smaller stress.

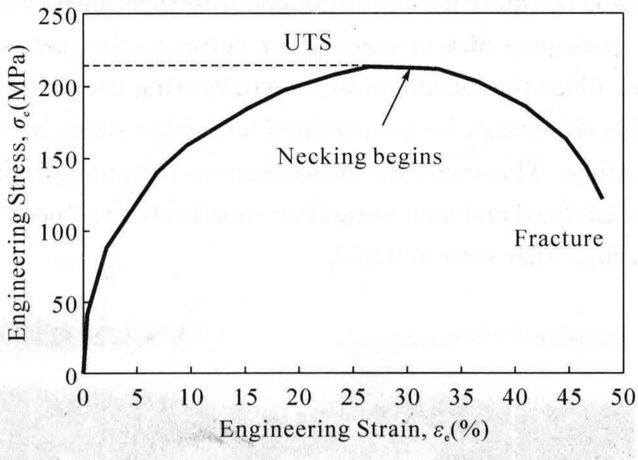


Fig. 3 Full engineering stress-strain curve for annealed polycrystalline copper

The apparent change from strain hardening to strain softening is an **artifact** of the plotting procedure, however, as is the maximum observed in the curve at the UTS. Beyond the yield point, molecular flow causes a substantial reduction in the specimen cross-sectional area A, so the **true stress** $\sigma_t = P/A$ actually **borne** by the material is larger than the engineering stress computed from the original cross-sectional area ($\sigma_e = P/A_0$). The load must equal the true stress times the actual area ($P = \sigma_t A$), and as long as strain hardening can increase σ_t enough to **compensate** for the reduced area A, the load and therefore the engineering stress will continue to rise as the strain increases. Eventually, however, the decrease in area due to flow becomes larger than the increase in true stress due to strain hardening, and the load begins to fall. This is a geometrical effect, and if the true stress rather than the engineering stress were plotted, no maximum would be observed in the curve.

At the UTS the **differential** of the load P is zero, giving an analytical relation between the true stress and the area at **necking**:

$$P = \sigma_t A \rightarrow dP = 0 = \sigma_t dA + A d\sigma_t \rightarrow -\frac{dA}{A} = \frac{d\sigma_t}{\sigma_t} \quad (3)$$

The last expression states that the load and therefore the engineering stress will reach a maximum as a function of strain when the fractional decrease in area becomes equal to the fractional increase in true stress.

Even though the UTS is perhaps the materials property most commonly reported in tensile tests, it is not a direct measure of the material due to the influence of geometry as discussed above, and should be used with caution. The yield stress σ_y is usually preferred to the UTS in designing with ductile metals, although the UTS is a valid design criterion for brittle materials that do not exhibit these flow-induced reductions in cross-sectional area.

The true stress is not quite uniform throughout the specimen, and there will always be some location—perhaps a **nick** or some other defect at the surface—where the local stress is maximum. Once the maximum in the engineering curve has been reached, the localized flow at this site cannot be compensated by further strain hardening, so the area there is reduced further. This increases the local stress even more, which accelerates the flow further. This localized and increasing flow soon leads to a "neck" in the **gage length** of the specimen such as that seen in Fig. 4.

Fig. 4 Necking in a tensile specimen

Until the neck forms, the deformation is essentially uniform throughout the specimen, but after necking all **subsequent** deformation takes place in the neck. The neck becomes smaller and smaller, local true stress increasing all the time, until the specimen

fails. This will be the **failure** mode for most ductile metals. As the neck shrinks, the **nonuniform** geometry there alters the **uniaxial stress state** to a complex one involving **shear** components as well as **normal stresses.** The specimen often fails finally with a "cup and cone" geometry as seen in Fig. 5, in which the outer regions fail in shear and the interior in tension. When the specimen **fractures**, the engineering strain at break—denoted ε_f—will include the deformation in the necked region and the unnecked region together. Since the true strain in the neck is larger than that in the unnecked material, the value of ε_f will depend on the fraction of the gage length that has necked. Therefore, ε_f is a function of the specimen geometry as well as the material, and thus is only a crude measure of material ductility.

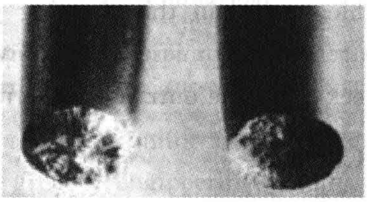


Fig. 5 Cup and cone fracture in a ductile metal

Fig. 6 shows the engineering stress-strain curve for a **semicrystalline thermoplastic.** The response of this material is similar to that of copper seen in Fig. 3, in that it shows a proportional limit followed by a maximum in the curve at which necking takes place. (It is common to term this maximum as the yield stress in plastics, although plastic flow has actually begun at earlier strains.)

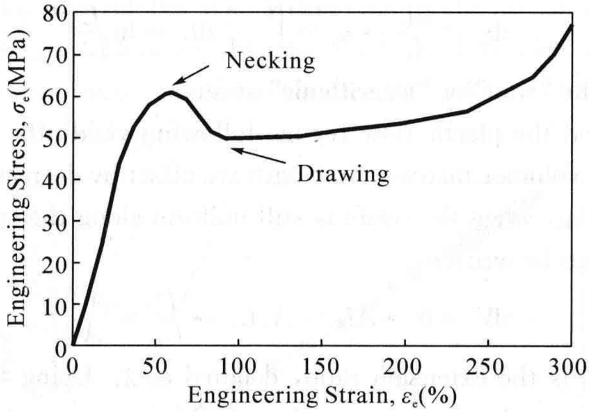


Fig. 6 Stress-strain curve for polyamide (nylon) thermoplastic

The polymer, however, differs dramatically from copper in that the neck does not continue shrinking until the specimen fails. Rather, the material in the neck stretches only to a "natural draw ratio" which is a function of temperature and specimen processing, beyond which the material in the neck stops stretching and new material at the neck shoulders necks down. The neck then **propagates** until it spans the full gage length of the specimen, a process called drawing. This process can be observed without the need for a testing machine, by stretching a **polyethylene** "six-pack holder", as seen in Fig. 7.

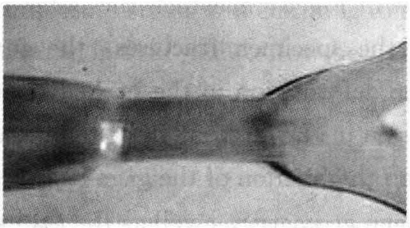


Fig. 7 Necking and drawing in a six-pack holder

Not all polymers are able to **sustain** this drawing process. It occurs when the necking process produces a strengthened microstructure whose breaking load is greater than that needed to induce necking in the untransformed material just outside the neck.

2 "True" Stress-Strain Curves

As discussed in the previous section, the engineering stress-strain curve must be interpreted with caution beyond the elastic limit, since the specimen dimensions experience substantial change from their original values. Using the true stress $\sigma_t = P/A$ rather than the engineering stress $\sigma_e = P/A_0$ can give a more direct measure of the material's response in the plastic flow range. A measure of strain often used in conjunction with the true stress takes the increment of strain to be the incremental increase in displacement dL divided by the current length L:

$$d\varepsilon_t = \frac{dL}{L} \rightarrow \varepsilon_t = \int_{L_0}^{L} \frac{1}{L} dL = \ln \frac{L}{L_0} \quad (4)$$

This is called the "true" or "**logarithmic**" strain.

During yield and the plastic-flow regime following yield, the material flows with negligible change in volume; increases in length are offset by decreases in cross-sectional area. Prior to necking, when the strain is still uniform along the specimen length, this volume constraint can be written:

$$dV = 0 \rightarrow AL = A_0 L_0 \rightarrow \frac{L}{L_0} = \frac{A_0}{A} \quad (5)$$

The ratio L/L_0 is the extension ratio, denoted as λ. Using these relations, it is easy to develop relations between true and engineering measures of tensile stress and strain:

$$\sigma_t = \sigma_e(1+\varepsilon_e) = \sigma_e \lambda, \quad \varepsilon_t = \ln(1+\varepsilon_e) = \ln\lambda \quad (6)$$

These equations can be used to derive the true stress-strain curve from the engineering curve, up to the strain at which necking begins. Fig. 8 is a replot of Fig. 3, with the true stress-strain curve computed by this procedure added for comparison.

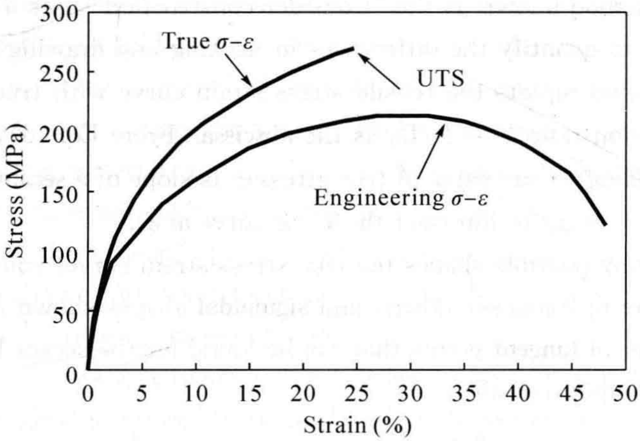


Fig. 8 Comparison of engineering and true stress-strain curves for copper. An arrow indicates the position on the "true" curve of the UTS on the engineering curve

Beyond necking, the strain is nonuniform in the gage length and to compute the true stress-strain curve for greater engineering strains would not be meaningful. However, a complete true stress-strain curve could be drawn if the neck area were monitored throughout the tensile test, since for logarithmic strain we have

$$\frac{L}{L_0} = \frac{A_0}{A} \rightarrow \varepsilon_t = \ln\frac{L}{L_0} = \ln\frac{A_0}{A} \tag{7}$$

Ductile metals often have true stress-strain relations that can be described by a simple power-law relation of the form:

$$\sigma_t = A\varepsilon_t^n \rightarrow \log\sigma_t = \log A + n\log\varepsilon_t \tag{8}$$

Fig. 9 is a log-log plot of the true stress-strain data for copper from Fig. 8 that demonstrates this relation. Here the parameter $n=0.474$ is called the strain hardening parameter, useful as a measure of the resistance to necking. Ductile metals at room temperature usually exhibit values of n from 0.02 to 0.5.

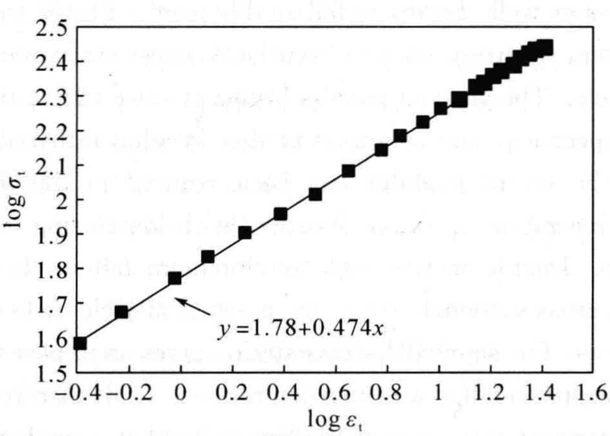


Fig. 9 Power-law representation of the plastic stress-strain relation for copper

A graphical method known as the "Consider construction" uses a form of the true stress-strain curve to **quantify** the differences in necking and drawing from material to material. This method replots the tensile stress-strain curve with true stress σ_t as the **ordinate** and extension ratio $\lambda = L/L_0$ as the **abscissa.** From Eq. (6), the engineering stress σ_e corresponding to any value of true stress σ_t is slope of a **secant line** drawn from origin ($\lambda = 0$, not $\lambda = 1$) to intersect the $\sigma_t - \lambda$ curve at σ_t.

Among the many possible shapes the true stress-strain curves could assume, let us consider the **concave** up, concave down, and **sigmoidal** shapes shown in Fig. 10. These differ in the number of **tangent** points that can be found for the secant line, and produce the following yield characteristics:

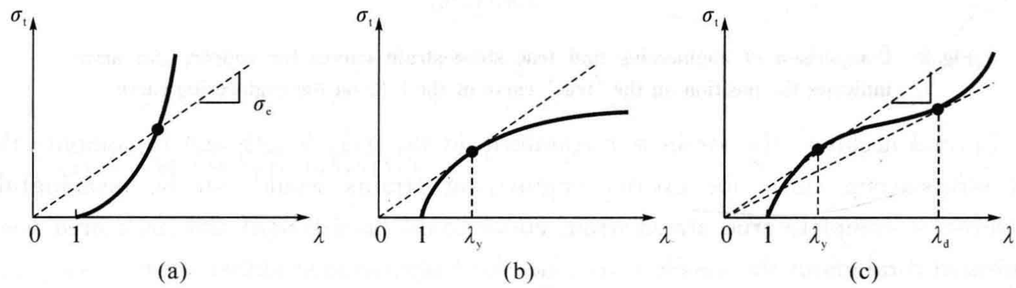


Fig. 10 Considered construction. (a) True stress-strain curve with no tangents—no necking or drawing, (b) One tangent—necking but not drawing, and (c) Two tangents-necking and drawing

(a) No tangents: Here the curve is always concave upward as in part (a) of Fig. 10, so the slope of the secant line rises continuously. Therefore the engineering stress rises as well, without showing a yield drop. Eventually fracture **intercedes,** so a true stress-strain curve of this shape identifies a material that fractures before it yields.

(b) One tangent: The curve is concave downward as in part (b) of Fig. 10, so a secant line reaches a tangent point at $\lambda = \lambda_y$. The slope of the secant line, and therefore the engineering stress as well, begins to fall at this point. This is then the yield stress σ_y seen as a maximum in stress on a conventional stress-strain curve, and λ_y is the extension ratio at yield. The yielding process begins at some adventitious location in the gage length of the specimen, and continues at that location rather than being initiated elsewhere because the secant modulus has been reduced at the first location. The specimen is now flowing at a single location with decreasing resistance, leading eventually to failure. Ductile metals such as aluminum fail in this way, showing a **marked** reduction in cross sectional area at the position of yield and eventual fracture.

(c) Two tangents: For sigmoidal stress-strain curves as in part (c) of Fig. 10, the engineering stress begins to fall at an extension ration λ_y, but then rises again at λ_d. As in the previous one-tangent case, material begins to yield at a single position when $\lambda = \lambda_y$, producing a neck that in turn implies a nonuniform distribution of strain along the gage length. Material at the neck location then stretches to λ_d, after which the engineering stress there would have to rise to stretch it further. But this stress is greater than that needed to stretch material at the edge of the neck from λ_y to λ_d, so material already in the neck stops stretching and the neck propagates outward from the initial yield location. Only material within the neck shoulders is being stretched during propagation, with material inside the necked-down region holding constant at λ_d, the material's "natural draw ratio", and material outside holding at λ_y. When all the material has been drawn into the necked region, the stress begins to rise uniformly in the specimen until eventually fracture occurs.

The increase in strain hardening rate needed to sustain the drawing process in semicrystalline polymers arises from a dramatic transformation in the material's microstructure. These materials are initially "**spherulitic**", containing flat **lamellar** crystalline plates, perhaps 10 nm thick, arranged radially outward in a spherical domain. As the induced strain increases, these spherulites are first deformed in the straining direction. As the strain increases further, the spherulites are broken apart and the lamellar fragments rearranged with a dominantly axial molecular orientation to become what is known as the **fibrillar** microstructure. With the strong **covalent bonds** now dominantly lined up in the load-bearing direction, the material exhibits markedly greater strengths and stiffness—by perhaps an order of magnitude—than in the original material. This structure requires a much higher strain hardening rate for increased strain, causing the upturn and second tangent in the true stress-strain curve.

NEW WORDS AND EXPRESSIONS

subtlety *n*. 微妙；敏锐；精明
ductile *adj*. 柔性的，延性的
substantial *adj*. 大量的；实质的；内容充实的 *n*. 本质；重要材料
preliminary *n*. 准备；预赛；初步措施 *adj*. 初步的；开始的；预备的
yield *vt*. 屈服；出产；放弃 *vi*. 屈服，投降 *n*. 产量；收益
fracture *n*. 破裂，断裂 *vi*. 破裂；折断 *vt*. 使破裂
specimen *n*. 样品，样本；标本；试样
clamp *vt*. 夹紧，固定住 *n*. 夹钳，螺丝钳
transducer *n*. ［自］传感器，［电子］变换器，［电子］换能器
servo-controlled testing machine 伺服试验机
cross-sectional area 横截面面积
engineering stress-strain curve 工程应力应变曲线
Hooke's law 虎克定律
proportional *adj*. 比例的，成比例的
Young's modulus 杨氏模量

deviate *vi*. 脱离；越轨 *vt*. 使偏离
departure *n*. 离开；出发；违背
term *n*. 术语；学期；期限；条款 *vt*. 把……叫做
microscopic *adj*. 微观的；用显微镜可见的
equilibrium *n*. 均衡；平静；保持平衡的能力
plasticity *n*. 塑性，可塑性；适应性；柔软性
mechanism *n*. 机制；原理，途径；进程；机械装置；技巧
dislocation *n*. 位错
brittle *adj*. 易碎的，脆弱的；易生气的；脆性的
appreciable *adj*. 可感知的；可评估的；相当可观的
strain hardening 加工硬化，应变硬化，应变强化
reverse *adj*. 相反的，逆的
elastic limit 弹性极限
recovery *n*. 恢复，复原；痊愈；重获
residual strain 残余应变
slope *n*. 斜率
yield stress 屈服应力
pinpoint *vt*. 查明；精确地找到；准确描述 *adj*. 精确的；详尽的 *n*. 针尖；精确位置；极小之物
permanent *adj*. 永久的，永恒的；不变的
diminish *vt*. 使减少；使变小 *vi*. 减少，缩小；变小
Ultimate Tensile Strength 极限拉伸强度
strain soften 应变软化
artifact *n*. 人工制品；手工艺品
true stress 真应力
borne *v*. 忍受；负荷
compensate *vi*. 补偿，赔偿；抵消 *vt*. 补偿，赔偿；付报酬
differential *adj*. 微分的；差别的；特异的 *n*. 微分；差别
necking *n*. 颈缩
nick *vt*. 刻痕；挑毛病；用刻痕记 *n*. 刻痕；缺口 *vi*. 刻痕；狙击
gage length 标距
subsequent *adj*. 后来的，随后的
fail *v*. 失效
failure *n*. 失效
nonuniform *adj*. 不均匀的；不一致的，不统一的
uniaxial stress state 单轴应力状态
shear *v*. 剪切
normal stress 正应力

fracture *n*. 破裂，断裂；骨折 *vi*. 破裂；折断 *vt*. 使破裂
semicrystalline *adj*. ［岩］半晶质的 *n*. 半晶质
thermoplastic *adj*. 热塑性的 *n*. ［塑料］热塑性塑料
propagate *vt*. 传播；传送；繁殖；宣传 *vi*. 繁殖；增殖
polyethylene *n*. ［高分子］聚乙烯
sustain *vt*. 维持；支撑，承担；忍受；供养；证实
logarithmic *adj*. 对数的
quantify *vt*. 量化；为……定量；确定数量 *vi*. 量化；定量
ordinate *n*. 纵坐标；纵线
abscissa *n*. ［数］横坐标；横线
secant line ［数］割线
concave *adj*. 凹的，凹面的 *n*. 凹面 *vt*. 使成凹形
sigmoidal *adj*. S形的；C形的；反曲的（等于 sigmoid）
tangent *adj*. 切线的，相切的；接触的 *n*. ［数］切线，［数］正切
intercede *n*. 截距
marked *adj*. 显著的
spherulitic *adj*. 球粒状的；球状的
lamellar *adj*. 薄片状的；薄层状的
fibrillar *adj*. 纤维状的；纤丝状的；根毛的
covalent bond *n*. ［物化］共价键