Stress in Target Rifles

Part I

James A. Boatright

Introduction

In this wide-ranging article, we intend to discuss many aspects of stress in the metal parts of a typical bolt-action target rifle. We have long maintained that the most accurate target rifles are those containing the least amount of stress. The first few sections *(Part I)* of this article present a brief, elementary-level tutorial on the physics of material strength assessment, and the characteristics of modern carbon steel alloys that make them so useful in gun-making. Common "American" units of force in pounds, distances in feet and inches, and temperature in degrees Fahrenheit, are used throughout. In *Part II* we will start with example calculations of tension stress and shear stress in resisting the inertial forces of recoil and then go on to perform sample calculations of a rifle barrel's maximum chamber-pressure-holding capacity and the strength of the bolt locking lugs for a typical example of a bolt-action target rifle, followed by discussions of residual stresses in our target barrels. The related topics of (1) a thermally-induced stress on a too-rigidly mounted "tactical" scope, (2) the proper barrel-installation torque levels for target rifles, and (3) the elastic chamber expansions in firing a typical bolt action rifle, including the setback of the bolt-face, have all been expanded into subsequent free-standing articles.

Force, Stress and Strain

In this section, we explain the concepts of ***stress*** *(force applied)* and ***strain*** *(reaction to applied force)* in metal gun parts, and we explain some basic physics to help in understanding these concepts. *The terms* ***force***, ***stress*** *and* ***strain*** *do not have the same meanings and should not be used interchangeably*. Forces applied to the metal parts of a rifle may subject the parts to any of the *three* basic types of simple *stress loading*—*tension*, *compression*, or *shear* loading. The compound stresses of *bending* and *torsion* (twisting) are combinations of these simple stresses and are beyond the scope of this introductory article. And even simple *shear stress* can be analyzed into cross-directional patterns of simultaneous compression and tension stresses, but we can show how to calculate a rifle part's stress, strain and strength *in shear* without resorting to that level of complexity**.**

Force

A ***force*** is necessary to *change the momentum* of an object. In fact, the *size* of a force can be *defined* as the time-rate-of-change in the momentum of an object that it can cause. If we accelerate a 168-grain, 308 Winchester bullet from rest to a velocity of **2600 feet per second** over a barrel dwell time of **0.0013 seconds**, the ***average force*** we applied to the bullet is nearly **1500 pounds**. And the ***peak force*** accelerating the bullet, nearly **4300 pounds,** can be found by multiplying the peak pressure on the base of the bullet (say **57,400 psi** in this example) by the cross-sectional area of the **.308-inch** rifled bore. A force is a *directional* quantity requiring the specification *both* of a scalar, non-directional magnitude (the size of the force) and the direction in which the force acts in three-dimensional space. The direction of the force applied to our example 308 bullet is pretty well determined by the direction in which the barrel is pointing at the instant we fire the rifle.

The magnitude of a force can be properly specified in units of pounds, which are basically units of *weight* (and *not* units of *mass*). Moreover, the weight of an object is another good example of a force (due to universal gravitational attraction acting on the mass of the object). And, as we have just seen, non-gravitational forces can also be specified in pounds acting in a suitable direction. A force is usually represented in a diagram as an arrow, with its length showing the relative amount of the force and the arrowhead pointing in the diagrammed direction of action of the force. Additionally, the location of either the tail or the head of the arrow usually indicates the point at which the force is applied to a diagrammed part. If we apply a small force **F** to a *fixed object* that remains *stationary*, then that object "automatically pushes back" with an exactly matching, but oppositely directed, force **-F** called a ***reaction force***. Since both **F** and **-F** are applied at the same point, they sum to **zero** and produce a condition of *equilibrium* that causes neither linear motion nor rotation.

Simple Stress

A ***mechanical force*** **F** giving rise to a simple stress on a part can be envisioned as the ***sum*** of an infinite number of infinitesimal forces ***distributed*** (more or less uniformly) over a particular ***plane area*** **A** of that part (either an internal plane or a surface facet of the part). As shown in Figure 1, a ***tensile*** or stretching force might be distributed over an internal plane of a part. The summed ***total force*** **F** applied at the *centroid* (center of force) of the above-mentioned plane area **A** of the part can be represented as a ***vector*** and ***resolved*** into the following rectangular vector components with respect to the plane **A**:

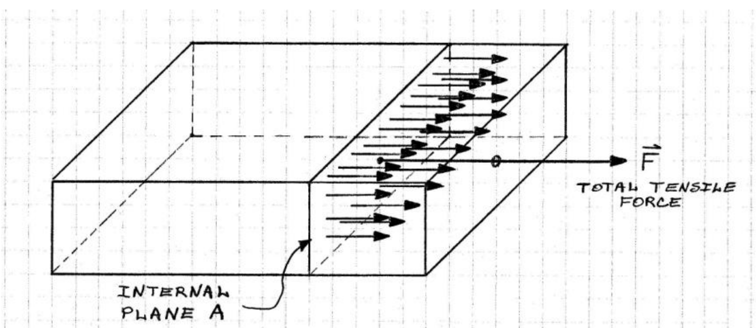

FIGURE 1. A DISTRIBUTED TENSILE FORCE

(1) A ***normal-component*** force vector $\mathbf{F_N}$ standing ***perpendicular*** to the plane **A**, acting either into or out from the surface, and

(2) A ***tangential-component*** force vector $\mathbf{F_T}$ *lying along some azimuthal direction* ***within*** this same plane **A**. [Figure 1 illustrates only ***normal*** tensile forces.]

These two rectangular force-component ***vectors*** must ***sum*** back to equal the original total applied force vector **F**, *for which they can* ***substitute***:

$$\mathbf{F_N} + \mathbf{F_T} = \mathbf{F}, \quad \text{a } \textbf{\textit{vector summing}} \text{ relationship.}$$

Figure 2 shows an example diagram of the resolution of an applied force **F** that includes a *compressive* normal component $\mathbf{F_N}$ with respect to a particular plane surface area **A**. The magnitude of the *normal force component* $\mathbf{F_N}$ in pounds divided by the size of the *plane* *area* **A** in square inches is called either ***tension stress*** or ***compression stress***, depending on the *directional sense* of $\mathbf{F_N}$, and is given in *pounds per square inch* (**psi**), the same units we use to specify a pressure. [In a related side note, we must also know the *size* of the total ***compressive normal force*** component $\mathbf{F_N}$ between two objects contacting each other if we need to calculate the ***force of friction*** between those two objects. The amount of friction turns out to be *proportional* to the size of $\mathbf{F_N}$**,** but independent of the size of the contact area **A**.] The magnitude of the *tangential force component* $\mathbf{F_T}$ divided by the same *plane area* **A** is called ***shear stress***. If tangential force is applied across an *internal* plane of an object, one can readily see that this force $\mathbf{F_T}$, together with its reaction force $-\mathbf{F_T}$, are acting to *cut* the object along the plane area **A** as if it were being "sheared" apart.

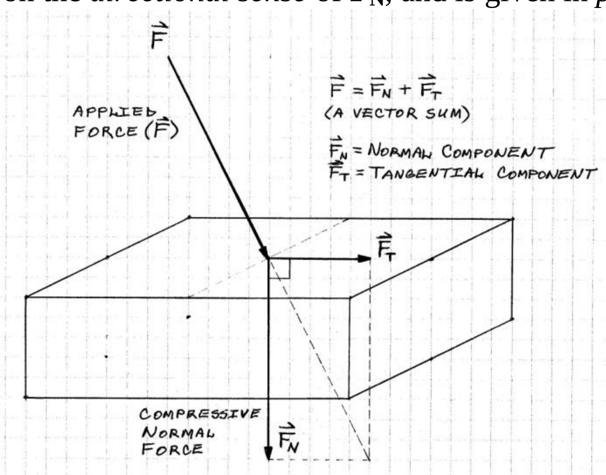

FIGURE 2. RESOLUTION OF A FORCE VECTOR

Simple Strain

Even a small amount of any type of stress applied to a portion of a real, physical part will *always* cause some *movement*, some *distortion*, or some *change in the size* of that part, no matter how rigidly constructed that part might be. A tensile stress applied to a part will result in a *linear elongation* (in fractions of an inch) *per unit length* (inch) *of the part being stretched*, which is called the ***tensile strain*** of the part. Similarly, a compressive stress will produce a proportional shortening (per unit length) of the part along the direction of the compression, and this *linear shortening proportion* is termed the ***compressive strain*** of the part. We *ratio* either this elongation or shortening amount to the length being stressed of the part because we should reasonably expect a longer part to stretch or compress more readily than a shorter one if subjected to the same applied force. [Recall that a longer coil spring or rubber band is easier to stretch than a shorter one of similar construction.] Think of ***linear strain*** (a dimensionless, pure number) as a length-change *ratio*, or as a *fractional* or *percentage change* in length, rather than directly as the *amount* of length change of the part in distance units. As linear stresses increase beyond normal working levels, this *apparent symmetry of tensile and compressive strains* begins to break down, and their stress-versus-strain relationships must be handled differently.

Shear strain is defined as the *trigonometric tangent*, or "slope," of the *shear distortion angle* **a** for the part undergoing shear stress, so shear strain is also a dimensionless number. Figure 3 shows a diagram of a shear stress and the resulting shear distortion angle. Unless we are working with a material like Jell-O®, the shear distortion angle **a** is usually quite small (up to **10 milliradians** or **0.6 degree** in steel) for levels of shear stress that do not permanently distort or even "shear" the material. It may be helpful in visualizing the mechanism of ***shear distortion*** in a metal part to think of it as the sliding of a large number of very thin, flat, equal-area plates stacked over each other (as with a deck of playing cards) with the horizontal shear displacement of each plate being

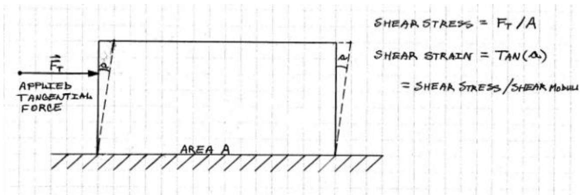

FIGURE 3. SHEAR DISTORTION ANGLE (α)

proportional to its height above a stationary bottom plate. The bottom plate is held stationary by virtue of its face being adhered to the "shear-loaded" attachment area **A** beneath it.

[In another related side note, when an object is submerged in a liquid and is subjected to hydrostatic pressure, the ratio of the change in volume to the original volume of that compressed object (again a dimensionless number) is called its "volumetric strain" or its "*bulk strain*." "Hydrostatic pressure" means a pressure that varies only gradually over time (as opposed to a "dynamic pressure" involving *fluid flows* and *pressure waves*) and is ***isotropic***, or "*equal in all directions,*" at any particular point within the pressurizing fluid. What this property of isotropy also means is that, *for any surface facet of the immersed object, hydrostatic pressure can only cause purely compressive stress* (i.e., all of the compression forces are always *normal* to any part of the surface of the object)—and this is equivalent to saying that, ***the shear stress is always* zero *on every surface facet of the immersed object, regardless of the shape of that object***. The hydrostatic pressure (once again in **psi**, of course) *is **identically*** the *bulk stress* that produces the compressive *bulk strain*. This ***impossibility of shear loading*** a part immersed in a pressurized fluid, explains, for example, why the boat-tails of our VLD match bullets are ***not utterly destroyed in firing***, even by pressures topping **60,000 psi**.]

Elasticity of Materials

If an applied stress is significantly smaller than the strength of a part, then that part returns exactly to its original shape as that applied stress is removed. The range of applied stress levels where this property holds true is called the ***elastic range*** of operations. ***The stress levels on each gun part must remain safely within the elastic range for all normal operations***. Within this elastic range, the *strain* produced in a part is ***proportional*** *to the amount of stress applied* to the part in accordance with Hooke's Law for *elastic deformations*. Another way of saying that the variables, *stress* and *strain*, are *proportional to each other* is to say that their *ratio remains constant*. Within the elastic range for our gun-making materials, the *ratio of an applied stress to its resulting strain* is a rather large constant called the ***coefficient of elasticity*** for each material. The various alloy steels from which our rifle barrels and actions are usually made *all* have coefficients of elasticity for linear tension and compression stresses of between **28.5 and 30** million pounds of force per square inch of cross-sectional area per inch of strain displacement per inch in length of the material being stressed. Notice that the last two units used in this definition are "inches per inch" and, thus, dimensionally cancel each other. This situation occurs because linear *strain* is the *dimensionless ratio of two distances*. While use of the units of *pressure* is perfectly acceptable when specifying a coefficient of elasticity, one should always keep in mind the remainder of its definition to minimize confusion.

The coefficient of linear elasticity is constant within the elastic range for a particular material. This coefficient is also called ***Young's Modulus of Elasticity*** (**E**) for a particular material and is defined from Hooke's Law to be:

$$\mathbf{E} = (\text{Linear Stress})/(\text{Linear Strain})$$
$$= (F/A)/(S/L)$$

where

E = Young's Modulus of Elasticity in pounds per square inch (psi);

F = Total distributed tension or compression force in pounds;

A = Cross-sectional area of test object in square inches, *perpendicular* to force **F**;

S = Linear strain elongation or compression displacement in inches; and

L = Original (unstressed) length of stressed portion of test object in inches.

Young's Modulus of Elasticity is a macroscopic (or large view) physical constant for a given material, much as is the *density* of that material. *The value of this coefficient is **not affected** by heat treating or hardening of steel materials*. Without delving deeper into the study of elasticity, let us simply give a couple of "rules of thumb" that apply to all gun-making steels. The *Shear Modulus of Elasticity* is the ratio of the applied shear stress to the resulting shear strain, and is just about **40 percent** of the size of Young's Modulus (or about **12,000,000 psi**) for gun steels. And the *bulk modulus* of a material is the ratio of applied hydrostatic pressure to the resulting compressive bulk strain. The bulk modulus for steel is about **80 percent** of Young's Modulus, or **24,000,000 psi**.

Young's Modulus and Barrel Vibrations

Young's Modulus of Elasticity (**E**) pertains to the "internal stiffness" of a material and, accordingly, is a primary characteristic determining the ***acoustic properties*** of our steel. Sound-pressure waves traveling in a solid material produce small, symmetrically alternating, compressive (higher pressure) and tensile (lower pressure) volumetric ***stresses*** which in turn cause small, symmetrically alternating, volumetric compression and dilation ***strains***, that move very rapidly through the material. The speed of the longitudinal (lengthwise) propagation of plane, sound-pressure wave fronts travelling inside a *long, slender rod* (as within a steel rifle barrel, for example) can be calculated directly from the values of Young's Modulus and the density for the material of the rod. This "speed of sound" is about **16,600 feet per second** along a steel rod. And, knowing the length of the rod, we can directly calculate the fundamental resonant frequency of these longitudinal vibrations (about **4,000 hertz** for a typical rifle barrel). We could tap a barrel blank endwise with a small wooden mallet, and measure with very good accuracy the fundamental (lowest) frequency at which the barrel rings. This is actually a preferred way to measure Young's Modulus for steel and similar materials. We see no reason to believe that this (or any other) type of *acoustic vibration* within the barrel steel could affect rifle accuracy in any way.

Transverse, or "shear wave," barrel vibrations depend on the value of Young's Modulus for the barrel steel in a somewhat more complicated way and produce a *much lower frequency* fundamental "standing wave" resonance in the same steel barrel. It is these *transverse waves*, especially those in the *vertical plane* of the installed barrel, that are *exactly* the types of barrel vibrations that do *seriously* affect the rifle bullet's impact point on the target. At the instant of bullet exit from the muzzle of our centerfire target rifle, the muzzle's position, pointing angle and vertical velocity are still being influenced by the barrel's *forced deformations in shear*, as well as by its *natural vibration modes*. These forced deformations are largely produced by the interaction of the recoiling barreled action with its recoil-resisting gunstock and are almost completed when the bullet exits the barrel. The resonant shear wave vibrations are just getting started in response to the driving recoil force (and to its resisting reaction force), and these barrel vibrations will continue long after the bullet leaves the muzzle.

Some shooters have postulated some sort of inter-dependence between static stresses in the assembled rifle parts and these important transverse barrel vibrations. In accordance with the well-accepted *superposition principle* for independent vibrational types and modes, any such cross-dependence between residual static stress in rifle parts and these vibrational stresses *should* ***not*** *be expected to be significant*. We know that at least one additional type of independent mechanical vibration *does occur* in the rifle barrel with each firing—small *torsional vibrations,* or rotational oscillations of various barrel segments about the axis of the bore—but, again, we *do not* believe that these torsional vibrations can affect rifle accuracy.

Characteristics of steel

Steel is a wonderful man-made material formed by *dissolving* small amounts of the element carbon (less than two percent by weight) into molten or semi-molten iron—or, more commonly, by using oxygen from the air to remove an excess of the carbon that had been mixed in as a reducing agent during the smelting of iron oxide ore into pig iron. Both carbon and high-grade iron ore are plentiful and relatively cheap, and neither iron smelting nor steel making is a difficult or expensive industrial process. The resulting ***carbon steel*** products are both economical and very useful in a great variety of applications. One reason why steel is so useful in gun-making is that the strength, hardness, toughness and brittleness characteristics of most types of steel can be controlled by mechanical working and by suitably heat-treating the steel *after* it has been manufactured. We have also learned how to add significant amounts of other elements (often chromium, nickel, manganese, cobalt, or molybdenum, for examples) into the heated mix to create even more useful "alloy steels." Certain elements may be allowed to remain as impurities in the steel up to a certain maximum percentage while others may be carefully added to enhance special properties of the steel such as its resistance to *galling* or to *corrosion*.

While steel making is truly an ancient art, steel was always made in small quantities before the development of the Bessemer and open hearth processes about a century ago, and the quality of the steel produced was always somewhat haphazard until even more modern times. Now we can make huge quantities of steel with consistent chemical composition and mechanical characteristics, meeting many different metallurgical specifications established for particular types of steel by various sanctioning organizations. The highly technical modern field of Materials Engineering has replaced the art and skill of Loki, the blacksmith and demi-god of Old Norse mythology.

Seen at a microscopic level, good steel is a fairly uniform, finely *granular* material. Each of the very small, irregularly shaped "grains" of steel (less than **0.001-inch** in length) is actually an independently organized *crystal lattice*, containing huge numbers of atoms (mostly iron and carbon plus some other atoms). The basic *ferrite crystals* are made up of *cubic arrays* of atoms of the metallic element, iron. And, depending on the *precipitation conditions* while they were being formed during cooling from a *critical temperature*, some of these cubic ferrite crystals can take on dissolved carbon atoms either at the centers of the cubes, themselves, or at the centers of the faces of the cubes. The body-centered-cubic crystal has room for one carbon atom per iron atom in its lattice structure, while the face-centered-cubic structure can accommodate three carbons per iron atom. These carbon atoms placed here and there into the ferrite crystals during "heat treatment" ***considerably stress***, and thereby ***considerably strengthen***, the resulting *iron carbide crystal structures* along directions relating to the principal axes of the basic cubic crystal lattice. But these tiny crystalline grains are so numerous and so randomly oriented that good, fine-grained steel can be considered to be a ***homogeneous isotropic*** material at a macroscopic level. This added sub-microscopic, ***crystal-level stress*** is not merely *harmless*, but is *extremely beneficial* in enabling ***heat-treatment*** to increase the ***strength*** of good steel. As manufactured, carbon steel can be *over six times stronger* than good cast iron, and it can be strengthened even more by ***work hardening***, wherein its crystal structures are *further stressed* by being *distorted* and *dislocated* to an even greater extent.

Strengths of Materials

Whenever the ***level of stress*** applied to a part exceeds the ***elastic limit*** for its material composition, the part does *not* return exactly to its original shape as the stress is removed, but assumes a "permanent strain," or "set" condition. The "elastic limit" is the amount of ***tensile stress*** defining the upper end of the "elastic range" for a given material. Slightly exceeding the elastic limit of steel rifle parts, as happens in firing a *proof load*, should produce only small, gradually occurring, permanent plastic (non-elastic) distortions of these parts. Our rifle parts are made of quite *ductile* (non-brittle) metals that tend to stretch quite a bit (up to about **10 to 20 percent** maximum *elongation*) before they finally *break apart* from being over-stressed. Aside from the increased confidence inspired by proof-testing each individual firearm, after having survived the high-pressure proofing process the gun parts should be *slightly stronger than before* due to ***work hardening***, and some parts may be better fitted together, as well. ***Was Mich nicht umbringt, macht Mich stärker.*** (What does not destroy me, makes me stronger.) [F. Nietzsche, 1888.]

However, we should never fire more than one or two proof loads in any given rifle. Repeatedly firing a bolt-action rifle at ***excessive chamber pressures*** will cause *permanent plastic deformations* to accumulate in the areas of the bolt-locking lugs and their corresponding lug seats in the receiver, always working *to increase the rifle chamber's headspace dimension* with the bolt locked in its firing position. Increasing the rifle's headspace could lead eventually to a cartridge case failure, due to case stretching, and to the release of high-pressure powder gasses within the action. The term "grenading" is aptly used in describing what could happen to the rifle during this mode of catastrophic failure. At the least, a single high-volume release of high-pressure powder gasses inside the receiver of a target rifle would likely ruin its action forever.

The as-manufactured ***strength*** of a given alloy of ***carbon steel*** (which includes any of our stainless or chrome-moly alloy steels used in gun-making) *varies considerably*, depending mostly upon the *carbon content* of the steel and upon its *complete working and heat-treatment history*. The most commonly used and numerically largest of the different strength ratings for a steel sample is properly termed its ***ultimate tensile strength***, but we usually just call it the ***tensile strength*** of the material being described. This ultimate tensile strength rating is the *maximum static tensional stress* that a test sample from a batch of steel could withstand before finally separating suddenly [BANG!] at its "breaking point." Note that, once again, this "tensile strength" parameter is properly specified in units of *linear stress* (that is, in **psi**, the same pressure units we might use in specifying tire inflations).

Fortunately, if a piece of steel has not been *surface-hardened*, or "case-hardened," a surface-penetration hardness test is a good indicator of the tensile strength of the underlying material for a known alloy of carbon steel. A standard surface-penetration test result—usually a Rockwell C-scale hardness test number ($\mathbf{R_C}$) for gun-making steels—should give us a good idea of the quality of the steel and just how successfully the basic sequence of heat-treatment steps (annealing, hardening, tempering and stress relieving) was carried out for that particular steel part.

The ***yield strength*** of the steel is a more conservative and more useful tensile strength rating (also given in **psi**, of course). The yield strength rating is the stretching force in pounds per unit cross-sectional area to which a sample of a material must be subjected in order for the test sample to have been *permanently elongated* by a specified minimum amount after the stretching force has been removed. The threshold amount of *permanent plastic deformation* used in defining this yield strength rating for the high-strength, ductile steels used in gun-making is usually set at a *strain ratio* of **0.20 percent**. This small amount of linear strain is usually called the "strain offset" at the yield strength rating. The ***0.20-percent yield strength*** is just slightly larger than the "elastic limit" for steels of interest here, but it is well into the range of "plastic" strains for our steel part. As another "rule of thumb," the yield strength is approximately **80 percent** of the ultimate tensile strength for the steels with which we are working, and both the yield strength and the *slightly lower* elastic limit *do* vary considerably with the heat treatment and work history of the steel. Except in proof testing as mentioned above, we ***must avoid*** stressing any rifle part to a level approaching its ***elastic limit***.

In fact, if we can determine the ***ultimate tensile strength*** rating for the particular steel from which a gun part is made (perhaps by surface-penetration hardness testing), we can estimate the ***maximum elastic strain*** that part should be able to withstand without suffering a permanent plastic deformation. For example, our AISI Type 416R stainless barrel steel, with a Rockwell C-scale hardness of $\mathbf{R_C}$ **28**, has a ***tensile strength*** rating of **130,000 psi**, and has a corresponding ***0.20-percent yield strength*** rating of about **104,000 psi** by the aforementioned "80-percent" rule of thumb. We can then estimate the ***elastic limit*** for this steel to be safely above about **100,000 psi**. Recalling the definition of the coefficient of elasticity, we can calculate the ***maximum elastic strain*** for our steel part by dividing our **100,000 psi** estimate of its ***elastic limit*** by the appropriate value of Young's Modulus of Elasticity **E** for our part (or **29,000,000 psi** for our example 416R stainless steel alloy). Then the estimated ***maximum elastic strain*** for our rifle barrel steel is **0.35 percent**. That is, we should be able *repeatedly* to apply up to about **100,000 psi** of tensile stress to our barrel steel, producing up to about **0.35 percent** elastic strain with each application, and, theoretically, the part should still return *exactly* to its original shape each time we remove this stress.

But now let us look at what happens if we *just once* apply a tensile stress of **104,000 psi** to our barrel, that is, a stress equal to the full *0.20-percent yield strength* for this steel. This stress should produce a strain ratio of **0.55 percent** in our barrel steel. Then, as we relax this tensional stress, the barrel steel should contract by the amount we just estimated for its *maximum elastic strain*, or **0.35 percent**, leaving it lengthened by the expected **0.20-percent *permanent strain***, or ***plastic deformation***, while under *no external stress*. The *yield strength rating* of our barrel steel will now have been *increased* by this ***work hardening*** process, so that applying another subsequent stress equal to the old **104,000-psi** yield strength would ***not*** cause additional plastic deformation. Consider also how the button-rifling process increases the Rc-hardness of the steel surface in the bottoms of the grooves in the bore of the newly-rifled barrel blank. And, as yet another example of the work hardening process, carbon steel *piano wire* is routinely *stretched* during manufacturing by "drawing" it through a reduced diameter aperture to improve its tensile strength rating to as much as **300,000 psi**, which is very high for steel.

In this little exercise, we have illustrated the distinctions between *material stress* and *material strain* and between the *elasticity* and *strength* ratings of a given material. The great French physicist Coulomb (for whom the basic unit of electric charge is named) was the first to publish this clear distinction between the elasticity and the strength of a material as recently as the 1790's at the dawn of the industrial revolution. Actually, the ***elastic limit for linear stress*** is only one of about a half-dozen different definitions of "material strength" that we find useful in mechanical design and analysis work. So, the "mechanical strength" of a given structural material is ***not*** such a basic property of that material as we might have imagined.

The characteristics of the stress loads being borne are also important in specifying material strengths. *Shock loads* are much more difficult to withstand than are slowly applied, steady loads. The normal processes of the deflagration and combustion of gunpowder do *not* produce shock loading. However, shock loads do occur in a self-loading rifle when a metal rifle part is allowed to get a "running start" before *impacting* another metal part. On the other hand, the brief time-duration of the peak chamber-pressure spike makes peak firing stresses *much easier* to withstand than would have been the case had the same maximum pressure been *steadily applied*. Of course, *repeatedly applied* loads are more difficult to resist than one-time loads, and a load that *repeatedly reverses its direction* is even tougher to bear. Stress loads applied to a steel part at *unusually high or low working temperatures* can also be more difficult to withstand than those applied at temperatures nearer to the range where steels are strongest, from ambient (room temperature) to about 200 degrees Fahrenheit. Damage from an *accumulated history of overstresses*, or from *corrosion* allowed to occur while in a stress-loaded condition, will shorten the ***fatigue life*** of structural steel materials.

Summary

The concepts of force, and material stress, strain, elasticity and strength have been introduced and concisely explained—including how the curious situation came to pass that each of the three basic types of simple stresses, all material elasticity values, and all

material strength values can properly be specified in pressure units. Some simple equations, some useful physical constants, and some "rules of thumb" have been presented to guide interested readers in calculating basic stress, strain and elasticity parameters for themselves. We also mentioned the internal, crystal-level stresses within modern carbon steels that allow them to be so useful in gun-making. We are now ready to begin *Part II* by showing examples of how to calculate tension and shear stresses and how to use Lamé's equations to calculate the maximum pressure-holding capability and the radial expansion of the chamber end of an example target barrel, followed by a calculation of the strength of the front locking lugs on the bolt of our example target rifle. We will then wrap up this subject in *Part II* with a short discourse on the effects of residual stress in target barrels. We plan to address several other important aspects of stress in target rifles in subsequent, single-topic articles.