Small Arms Ammunition Manufacturing: Background and Practices

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SMALL ARMS AMMUNITION MANUFACTURING: Background and Practices

Introduction

Knowledge of the evolution of small-arms systems for sporting and military purposes is important for the student of firearms identification. The individual components of the system—firearms and ammunition—are closely interrelated. Small improvements in one continue to lead to small improvements in the other. Understanding this evolution will make the student a better firearm examiner and witness.

As an evolutionary overview, this discussion follows the significant milestones showing how today's technology is connected to the past and tracing the key lines of growth. It is a story of constant improvement, of new strengths from old weaknesses, and of the incredible inventiveness of the human mind.

Ammunition

Ammunition consists of four components:

- Propellant
- Projectile (bullets and shot pellets)
- Cartridge cases
- Primer

Self-contained ammunition, in which the propellant, projectile, and primer are held together by a cartridge case, is called fixed ammunition. Artillery ammunition with separate components is called semifixed ammunition. A cartridge is a single unit of fixed ammunition.

Evolution of Propellants

Propellant materials are the evolutionary product of a basic tenet in weapon technology: *energy must be stored for later use*. The concept of a propellant is that energy can be stored in chemical form, possibly years before it is ultimately released. This demands a material that is reasonably stable, compact, and portable.
It is commonly accepted that the Chinese were among the first to discover that certain materials, blended in the correct proportions and ignited, could propel a rocket or explode to produce a loud report.

A simple rocket is a tube filled with a propellant material, closed at one end and open at the other. The gas produced by the burning propellant spews from the open end and thrusts the rocket in the direction of the closed end. It is simple to imagine that some experimenter conceived the idea of turning the system around. The bodies of ancient rockets likely gave birth to the concept of the first gun barrels.

Black Powder

The pervasive formula for early propellants was a simple mechanical mixture of charcoal, sulfur, and potassium nitrate, known as black powder. This technology did not arise in Europe until the thirteenth century A.D., although it is likely that the Chinese had launched projectiles with black powder two hundred to three hundred years earlier.

Most old formulas called for charcoal made from the wood of certain tree species. Willow wood was highly prized as a source of charcoal. The quality of the charcoal affected many aspects of propellants, including ease of mixture, power, and cleanliness. Varying the ratio of the three components produced different black powders for different purposes. For example, the formula for blasting powder has traditionally differed from that for propellant use.

Modern, propellant-grade black powder is seventy-five parts potassium nitrate (KNO_3), fifteen parts charcoal, and ten parts sulfur.

Manufacturing Process of Propellants

Black powder makers relied on fine grinding of the components to ensure that they were mixed thoroughly. However, military use of propellant-grade black powder gave rise to a serious problem; dry components could separate during transport over rough roads. This caused a degradation of the propellant's power. A short-term cure was to transport the components separately to the battlefield and mix them just before loading. The hazards of a propellant blending operation close to an active line of cannon are easily imagined.

The solution for the separation of the components of this mechanical mixture proved to be the only significant improvement to black powder in its long history. Small amounts of water were added during the milling and grinding operations. Potassium nitrate is soluble in water; adding a small amount of water causes it to become slightly sticky. Then the potassium nitrate can act as a binder to hold the two insoluble components in close contact. The presence of moisture also reduces dust. This largely mitigates the major hazard of blending and grinding as long as an adequate moisture level is maintained. This wetting process is called corning, and the resulting product was called corned powder.

The corned powder is pressed into cakes and allowed to dry. After drying, the cake is broken into granules. All granules contain uniform proportions of the components and maintain those proportions until consumed. Corned powders proved to be much more powerful than the dry mixture, largely due to the incorporation of ingredients. Some cannon that were suitable for the weaker dry-blended powders proved inadequate for corned powder. The improvement in propellant forced an improvement in gun metallurgy.

The granulation process serves another useful purpose; some control of the rate of energy release is afforded by sizing the granules. The granulated pieces are passed through sieves to sort them by size. Larger granules release energy at a slower rate than fine granules. This characteristic means the user can select from several grades to obtain the best velocity from a black powder firearm. Large-bore devices, such as cannon, use coarse granules (up to several millimeters average size). Small-bore devices, such as shoulder arms, use much finer material.

In the U.S., sporting black powder is sold by size as indicated by a coding system with the letter "F." For example:

- 1F: coarse, for .69 to .75 caliber muskets
- 2F: medium, for .45 to .58 caliber rifles and muskets
- 3F: fine, for .31 to .45 caliber rifles and most handguns
- 4F: extra-fine, only for priming flintlock arms

Some have suggested that black powder propels a projectile by a weak but high-order detonation, unlike modern propellants that burn to push the bullet out of the barrel with a progressive increase in pressure. Research on this suggestion, where black powder was loaded in a 45-70 Government cartridge with a 500gr bullet and then test fired in a modern piezoelectric ballistic pressure system, has shown the following:

- Black powder produces time-pressure curves that are remarkably similar to modern propellants, indicating progressive burning and a measured release of energy over time.
- Black powder in finer granulations produced higher pressures than equal quantities of coarser black powder, indicating the burning rate is controllable by granulation.
- Black powder peak pressures were measured as high as 21,000 psi, which is roughly equal to modern factory ammunition for this cartridge.

With the improvements of corning and grading, black powder remained largely unchanged until military and sporting arms transitioned to modern propellants at the beginning of the twentieth century.

Disadvantages

Today, black powder is still a useful propellant for specialized purposes. For example, black powder is somewhat easier to ignite than modern propellants; it is commonly used as a booster charge in large-caliber military applications. In spite of the ability of black powder to allow the use of lethal force at a distance, it was not without problems.

- Black powder has a limited amount of total energy per unit of volume. To gain greater velocity, a larger volume of propellant must be used, necessitating a larger cartridge case. With the trend to repeating firearms, large cartridges common to single-shot black powder firearms could not be accommodated.
- In cartridge firearms, velocities seldom exceed 1400 ft/sec. This again is a limitation of energy content and cartridge size.
- Black powder is volumetrically inefficient. Depending on the grade, granulation, and loading density, gas production is only 45 to 55 percent of the total output. The remaining inert solids, largely dense smoke and fouling, contribute nothing to propulsion.
- Black powder produces a dense smoke cloud. As military tactics shifted from massed troops to individual riflemen, a smoke puff helped the enemy to spot the shooter's position.
- Black powder residue is corrosive to steel. Several by-products of black powder combustion are hygroscopic, releasing corrosive compounds when hydrolyzed. This accelerates wear to the firearm. The goal of researchers then became the development of propellants that overcame these shortcomings.

Replica Black Powders

Pyrodex® (Hodgdon Powder Company) is a late twentieth century development that is today classed as a replica black powder. It was developed to overcome the high transportation costs and storage limitations of black powder. For such purposes, it falls in the same shipping class as modern propellants.

Pyrodex® is formulated to replace black powder on a volume—not weight—basis. In keeping with its replica duties, added materials generate the satisfying puff of white smoke so characteristic of original black powder. Other replica black powders include, but are not limited to, Triple Se7en® (Hodgdon Powder Co), American Pioneer Powder (APP), and Goex Pinnacle (Goex, Inc.).

Modern Propellants

To avoid the shortcomings of black powder, researchers had to consider propellant chemicals that incorporated oxidizers rather than inorganic materials that contribute corrosive by-products. Eliminating sulfur from the material was important for the same reason. The quest for reduced smoke meant that higher combustion temperatures would be required. Most importantly, the new propellant had to be controllable and reproducible to be safe.

Nitrocellulose

In 1845-46, a substance was invented that showed promise. Nitrocellulose was the result of treating common cotton fibers (containing cellulose) with nitric acid. This reaction adds nitrogen and oxygen to cellulose molecules. The nitration process is performed in the presence of sulfuric acid to scavenge extra water generated by the reaction and allows the attachment of the maximum number of nitrate radicals to permit better combustion.

When burned, the added oxygen in the nitrate radicals allows full involvement of the fuels in cotton, releasing significantly more energy than untreated cellulose. This produces a large volume of gas and leaves minimal visible solid by-products. In contrast, black powder would produce smoke and fouling.
Although this development gave chemists the self-contained oxidizer and minimal residue, guncotton could not be predictably controlled in its native state. Its combustion could prove too violent for iron gun systems of that period; numerous accidents were attributed to the attempts to manufacture it for propellant use.

Celluloid

The solubility of guncotton in a mixture of alcohol and ether was discovered a year after nitrocellulose was developed. Dissolved nitrocellulose (celluloid) was used as one of the first plastics. Initially, this critical step in the development of smokeless propellant was used only for coating photographic plates and making consumer items that once had to be carved from tortoise shell or ivory.

Plasticizer

Twenty years later (1884), Paul Vielle, a chemist working for the French government, experimented with the alcohol/ether solubility of nitrocellulose. He formed the wet mass into thin layers and partially dried them into flexible sheets. The residual alcohol/ether mixture acted as a plasticizer that helped prevent the granules from shattering. Cut into small flakes, the material burned inward from the surface. This property meant that the volume of gas produced decreased as the burning granules became smaller, which is a useful characteristic in propellants. Changing the dimensions of the granules resulted in different rates of energy release. Vielle's discovery opened the door to modern propellants. His work was so effective that cut-sheet propellants are in limited use today.

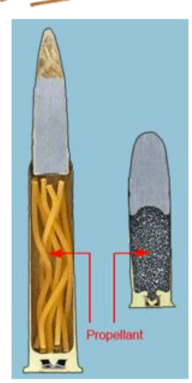
A major disadvantage of Vielle's method was dehydration. If the alcohol/ether plasticizer evaporates in storage, the rate of energy release increases. Dry granules could also break into smaller pieces, increasing surface area and thus the release rate.

Nitroglycerin

The discovery of dynamite in 1887 by Alfred Nobel allowed nitroglycerin to be used as a high explosive. He found that he could blend nitroglycerin with less-nitrated nitrocellulose to form a colloidal mass similar to that used to make Vielle's nitrocellulose. Nitroglycerin served as the plasticizer and added significant energy to the mix. When well mixed with nitrocellulose, the usually unforgiving nitroglycerin was stable, allowing the formation of clean-burning grains without the use of any additional solvents.

Cordite

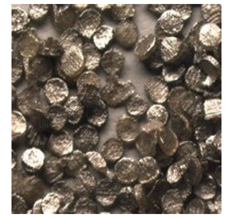
In a race to develop a smokeless powder, the British government commissioned a research group. Their solution was to mix acetone, nitrocellulose, nitroglycerin, and petroleum jelly to form a colloid. After evaporating the acetone solvent, the material could be extruded into long, cylindrical cords. In 1889, the resulting end product was named Cordite (pictured at right).



Vielle's smokeless propellant, with nitrocellulose as the sole storehouse of energy, became known as single-base propellant. Nobel's invention (which he named Ballistite) and the British Cordite, with their dual energy sources, became known as double-base propellants. Both single–base and double-base types are still in use today.

Smokeless propellants still retain the base ingredients used in the 1880s. However, knowledge of granule control, deterrent coatings, and safe processing has produced ammunition suitable for a wide range of uses from the smallest rimfire cartridges to massive naval guns.
Cordite rods

Morphology

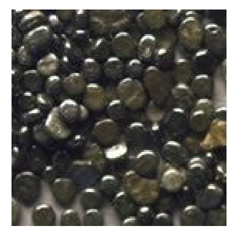


Early research into nitrocellulose propellants revealed that the shape and size of individual propellant granules controlled the rate of energy release. Solid granules, (the correct term for a single piece of propellant) burn from the outside in. As the surface area reduces with burning, energy release decreases. Likewise, a large granule releases energy over a longer time interval than will a smaller granule. Controlling granule shape and size allows propellants to be customized to specific ballistic requirements.

Disk or flake propellants are commonly used in low-pressure, low-volume applications such as handgun and shotshell ammunition. Because most of the burn happens from the large flat sides inward, the rate of release is relatively constant until the final stage of the burn cycle. Disk/flake propellants are produced by die extrusion.

Cut sheet or lamelle were the first shape used in modern propellants. They are most commonly used in smaller and/or low-pressure cartridges and the burning characteristics are identical to extruded disks. However, they are not die extruded. The mass of nitrocellulose is pressed between rollers; the vertical spacing between the rollers determines the final thickness of the sheet. The sheet runs through another set of rollers fitted with raised cutting surfaces that cuts the sheet into square- or diamond-shaped pieces. The term "lamelle," is from the French for "sheet"—coined by forensic examiner Lucien Haag.

Cylindrical, or Tubular, have greater surface area and fall into the medium to slow energy release category. Some propellants have cylinders that are solid; others have perforation(s) running parallel to the long axis of the cylinder. This allows it to burn both from the outside and the inside, keeping the surface area more uniform to achieve and maintain a constant peak pressure.



Ball powders and flattened ball powders start as nitrocellulose suspended in a solution that is agitated to form balls of varying diameters. These powders cover a large range of small arms needs.

A variant of ball propellant is aggregate ball. Seldom encountered today, it was used as a shotshell propellant until the last two decades. They are so named because each “apparent” granule is an aggregate of smaller balls. The size of these subparticles can vary by a factor of ten.

Die Extrusion

Processing the plasticized nitrocellulose mass combines extrusion with rotating cutters to produce the desired shape. Cutters rotate in a plane flush with the exit nozzle of the extrusion die. By varying the size of the extrusion holes, the rate of extrusion, and the speed of the cutter rotation, the manufacturer can produce cylindrical or disk/flake shapes.

A slow extrusion rate combined with a high cutter rotation speed produces disk/flake propellants. A fast extrusion rate with a slow cutter speed produces cylinders.

Extruding sticky pieces of nitrocellulose into air would result in another mass of nitrocellulose. To avoid this, the extrusion nozzle and cutter assembly are submerged in a tank filled with a liquid that will not degrade the material. This floats cut pieces away from the cutter without their sticking together.

Making Ball Propellants

Instead of falling into a tank after extrusion, the granules move immediately into a liquid-filled shaper that keeps the granules in constant motion. The action of granule against granule and against the walls and paddles of the shaper unit "beats" the cut granules into spheroids. The action is much like that of placing a cube of modeling clay into a large can, closing the lid, and shaking it. The clay cube will be rounded. The liquid in the shaper contains chemicals that start to draw off excess moisture from the granules. From the shaper, the granules move to a series of progressive evaporators that drive off unneeded solvents.

Although most finished ball powders are double-base, they start as pure nitrocellulose. In ball powder production, the nitroglycerin is added after shaping. The NG content is created by surface impregnation. The impregnated granules are sorted by size, and any coatings required are added before drying. If the powder is to be flattened ball, the granules are roller pressed at this still-soft stage.

Drying

The newly cut propellant granules contain residual moisture. The granules must be dried to reduce the moisture content to the level required in the finished product. Each grade of propellant has a different moisture requirement. If the granules are too wet, they will stick together in the loading process; if too dry, the granules will be brittle and break into smaller particles. Such breakage increases surface area and therefore the burning rate; if pulverized, an otherwise safe charge of propellant will create high pressures.

High heat can drive off needed solvents in single-base propellants or make double-base propellants more brittle. Therefore, the wet granules are usually dried with large volumes of air blown into a rotating drum. Heat, if any, is kept very low.

During drying, antistatic coatings and other surface treatments are added. Antistatic coatings are typically composed of graphite, which gives the granules the grey color seen in a finished sample. The natural color of nitrocellulose is pale yellow to green-yellow.

Deterrent Coatings and Stabilizers

Deterrent coatings can help to slow the rate of energy release when needed. A propellant loaded in a low-velocity cartridge will carry minimal deterrent; a higher-velocity cartridge requires more deterrent to maintain firing pressure longer. A common strategy is to blend deterred and undeterred granules in the same propellant. This slows energy release through staged burning; the undeterred granules burn first.
Stabilizers are preservatives used to increase storage life. Common stabilizers are found in the diphenylamine family.

Testing, Grading, and Blending

Each new batch of propellant is tested for performance against a retained reference lot of that propellant. The reference lot is generally the first successful lot produced.

Laboratory testing involves a calorimeter bomb, which is a closed, fixed-volume vessel used to measure heat production from a known mass of flammable material. The new lot of powder is tested in the calorimeter bomb and its heat production compared to that of the reference lot. If the heat production tests match the reference lot (within a small tolerance), the new batch moves to ballistic testing.

For each propellant type or grade developed, a number of cartridges are loaded with the reference lot. The critical assembly information for these cartridges is carefully recorded along with the pressure and velocity results. A sample of each new batch is loaded exactly like the reference loads and tested for pressure and velocity. If the results match those of the reference lot (within a small tolerance), the new batch is approved for packaging and shipment.

Ballistic testing reflects the potential use of each propellant. For example, some propellants are suitable for both shotshell and handgun cartridges. They would be tested in cartridges appropriate to each type of firearm.

If the new batch fails to meet either heat production or ballistic tests, existing samples of powder with faster or slower energy release rates may be blended with the new batch to adjust the performance to meet specifications.

Canister and Bulk

A canister propellant is sold in small quantities to hobbyists who reload ammunition. Each cartridge is limited as to how much powder can be safely loaded behind a particular bullet weight or style. Most bullet and propellant manufacturers have tested a range of cartridges with many propellant and bullet combinations and published the data in reloading manuals.

Bulk propellants are sold to manufacturers that possess standard pressure-testing equipment making reliance on published data unnecessary. Based on concurrent testing, the lot control for bulk propellants can be less rigorous because the ammunition manufacturer determines the proper charge weight at the time of loading.

Projectiles

Projectiles are manufactured through multiple methods. The following are some of the methods that have been and are currently used for manufacturing projectiles:

- Casting
- Swaging
- Drop shot production
- Current manufacture
    - Lead free
    - Jacketed
    - Cup and draw operations

Round

The earliest cannon projectiles were ball-shaped stones rounded to fit a crude cannon bore. As metal-casting technology improved, balls were cast of common metals, such as iron. Casting allowed for a more precise shape and uniformity of size and weight.

When small arms evolved, everything had to be scaled down for portability. Small balls of stone or iron were usable but lightweight, losing velocity and kinetic energy faster than heavier ones. A light projectile may have higher muzzle velocity, but the total energy deposited on target is more important than velocity. Lower velocity can be compensated for by increased mass.

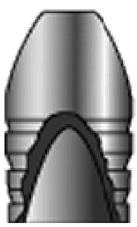
A common ore, galena, could be rendered with primitive smelting equipment to produce metallic lead. Traditionally inexpensive, lead is easily worked by hammering or casting. Lead has a low melting point that does not require the high temperatures of iron smelting; lead could be melted and cast into bullets over a campfire. The high density of lead aided in retaining long-range velocity.

The round lead ball had limitations; the only way to make it heavier for greater impact was to enlarge it, requiring a larger gun barrel. The usability of a personal firearm was limited by weight and bulk. Although large-bore guns for round balls existed, mass-produced arms seldom exceeded .75 caliber (0.75 inch).

Cylindrical

By making the bullet cylindrical, a heavier projectile could be loaded into a smaller caliber musket. Cylindrical bullets fired from a smooth bore would start to tumble a short distance from the muzzle, losing accuracy and velocity at a rapid rate. This began to force the rifling issue because the effective range for aimed fire dropped to a few yards.

As military tactics moved away from the concept of massed fire to aimed fire by individual riflemen, tacticians had to consider ways to use rifled bores without the inconvenience of patched projectiles. Combinations of balls formed with high and low areas to exactly fit the rifling pattern were tested. However, they failed to find lasting favor with the military because they were difficult to load in a fouled barrel. Wooden driving shoes, called sabots, were fitted to round balls, but performance was inconsistent, loading was cumbersome, and they were prone to tipping. Another method that was tried involved loading an undersized ball that would fit past the rifling and any fouling buildup. The ball was then pounded with a ramrod against a surface or projection in the chamber to increase its diameter to fit the rifling. This required a very stout ramrod or mallet. In addition, significant danger was imposed upon the shooter and others due to the shock sensitivity of black powder. These methods were inconsistent and required significant modifications to the metal parts of the firearms.



The best solution proved to be a simple one. Col. Charles C. E. Minié combined the concepts of the cylindrical bullet and the undersized ball. He created a lead bullet with a cavity in the base that could easily slide down a fouled bore. When the powder charge fired, gas pressure expanded the skirt around the base cavity; this caused the bullet to increase in diameter, creating a tight fit in the rifling. Minié’s bullet increased accuracy, provided better gas sealing, and allowed rapid loading for volley fire.

Jacketed

The material surrounding a bullet is referred to as a bullet jacket. The first bullet jackets were comprised of cloth patches applied to round balls. They were intended to engage the rifling, causing the bullet to spin. Early bullet jackets also included paper that engaged the shallow rifling of certain firearms (notably single-shot rifles and target arms).

As smokeless propellants evolved, so too did the use of metallic bullet jackets. Compared with black powder, smokeless propellants produced higher velocities, pressures, and temperatures, and increased frictional forces. This could cause partial melting of lead bullets in the bore and sufficient heat to melt the bearing surface (the area of the bullet that engages the rifling).

Metal jackets were used to:

- preserve the physical integrity of the bullet,
- facilitate engagement of the rifling,
- allow rapid fire of cylindrical bullets.

There are two primary types of metal jacketed bullets, semi- and full. Semi-jacketed bullets are typically used in hunting game because they provide controlled expansion. The full metal jacket bullet became the standard for military ammunition because the rigid tip feeds reliably into the chamber of semi- and fully automatic firearms.

Casting

Surviving to modern times, the all-lead bullet is the oldest type of cartridge projectile. Lead is a soft metal, easily worked by mechanical shaping or casting in molds. With simple equipment, it is readily alloyed with other low-melting-point metals (such as tin and antimony) to produce a harder final product.

Generally, lead projectiles are used for low-pressure and low-velocity cartridges, such as .22 caliber rimfire cartridges. Shotshells use lead pellets, although lead-free pellets are now required for waterfowl shooting.

Bullet Mold

Casting bullets is the oldest manufacturing method, but it has limitations. Pouring molten lead into a mold to make quality bullets requires careful attention. Without monitoring lead temperature, mold temperature, pouring rates, alloy consistency, and cooling rates, the resulting bullets will not have the uniformity required by modern standards.

Casting has advantages, such as the ability to produce sharp edges and detailed surface features. Lead alloys that are too hard for cold forming may be cast. As factories became more reliant on power equipment, cold forming (or swaging) was widely adopted to speed production. Hard alloys were not required for the firearms of the day. Secondary operations (required when swaging failed to produce some bullet features like grooves that would have been cast) had to be developed.

Swaging

Swaging requires a punch and die set mounted in a press, providing a mechanical advantage. The die cavity is shaped to match the desired profile of the bullet. The lead feeding into the swage die is normally a rough cylinder or slug that is somewhat smaller than the finished diameter of the bullet. Excess lead bleeds off as sprue.

The slug is cut from a long wire of lead that has been extruded under great pressure. A large billet of lead (usually cast) is placed in a massive hydraulic press and forced through a small hole in a die to form lead wire.

A post-swaging operation may add cannelures (or grooves) to hold extra lubricant and/or to provide a recess for securing the bullet in the cartridge case by crimping.

After the cannelure operation, bullets are sent to the lubrication area, where synthetic lubricants are applied. In some bullets, the lubricant is applied only in the cannelure, requiring special equipment and slowing the production rate. Most mass-produced bullets are dipped, covering the entire surface with lubricant.

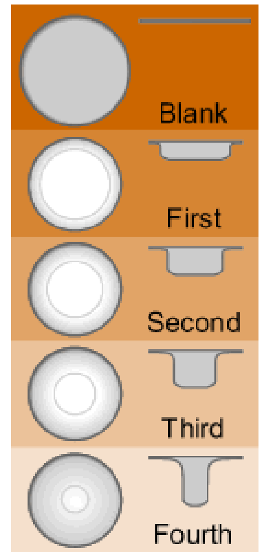
Jacketed Bullets

Bullets with metal jackets largely replaced plain lead bullets at about the same time that smokeless propellants replaced black powder in the majority of rifle ammunition. The higher pressures and temperatures produced by smokeless propellants were more than plain lead could support. This was overcome by adding an outer skin of harder metal to lead bullets.

Since pure copper is difficult to cold-work, copper alloys became the standard jacket material. Two copper alloys are prevalent in modern jackets, gilding metal (copper:zinc ratio of 95:5) and commercial bronze (copper:zinc ratio of 90:10). The choice of alloy depends on jacket thickness and the amount of work required to reach that thickness. The stronger bronze alloy is common in thin jackets, which are used to make handgun bullets.

In some parts of the world, soft steel is the more common jacket material. Steel is inexpensive, but more difficult to work. Nearly all steel jackets are treated with a rust preventative to ensure dimensional stability over time. This is typically accomplished with the application of transparent lacquers or by flash plating the steel with copper.

Cup and Draw Operation for Jackets



Jackets are traditionally produced in cup and draw operations. A shallow cup is formed from a sheet of metal in a cupping press. Dies and punches in the press blank out a disk of the sheet metal and simultaneously form it into a shallow cup. The basic requirements for cups are concentric wall thickness and relatively even tops. The jacket is ultimately trimmed to meet specifications.

A jacket that is not much taller than it is wide (some handgun bullets) can often be used directly from the cupping press if the initial sheet material's thickness is close to the desired jacket thickness. For rifle bullets where the jacket can be two or more times the diameter of the bullet in length, the cup must receive additional processing. This is performed by the draw operation.

In metalworking, drawing a part refers to stretching it under controlled conditions, while reducing the diameter. The control is provided by a die and punch set that maintains constant contact with the jacket walls, ensuring equal stresses at all points on the bullet and controlling concentricity. The draw operation targets the sidewalls of the cup. The resulting part looks like a metal test tube, with a rounded base.

In drawing, several dies may be used in conjunction with one punch. This progressive draw tooling is known as a die stack. The tooling designer must consider the reduction in wall thickness and diameter that the stack must produce. All the dies and the punch must make full contact with the jacket so that no unworked metal remains when the part exits the die stack.

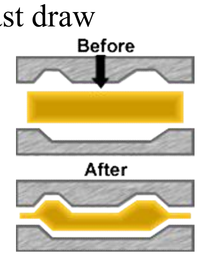
A benefit of drawing for hunting bullets is controlled expansion. Drawing elongates metal grains parallel to the long axis of the jacket. This forms natural parting lines, allowing the jacket to peel back on itself upon impact. Elongation is more prevalent toward the open end and less toward the closed base; the peeling starts quickly and then slows.

Advantages of controlled expansion:

- Bullet maintains integrity after impact.
- Bullet tends to remain in target.
- Energy dissipates more quickly on target.

Bullet Features

Some bullet features cannot be produced during final forming, such as fluted or segmented edges that aid the expansion of hunting bullets. Jacket flutes can be added in the last draw operation by using a punch machined with the reverse of the flute pattern. The pattern transfers to the jacket mouth as the jacket passes through the last die.

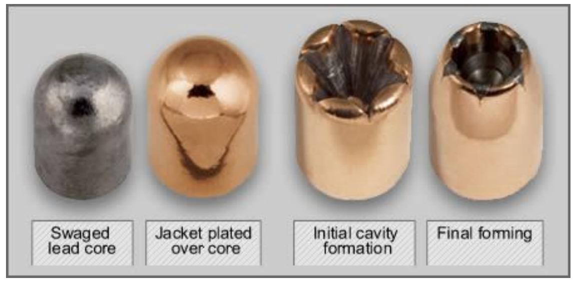


Sharp-pointed full metal jackets (FMJ) are formed in a coining die. This type of die completely traps the jacket between a die and a punch, supporting every surface. The die and punch provide the force and control of material flow needed to create a sharp point. Only coining can form sharp, uniform points on thicker rifle jackets. For other metal-jacketed bullets, forcing the soft core into the thin jacket (supported by the final nose-form die) forms rounded tips.

Other Jacket-Forming Technology

Although the drawn jacket is still the most common method, newer technologies are emerging. Like coining, impact extrusion of jackets is performed in closed dies and can often produce a long rifle bullet jacket in fewer operations than required to draw the same jacket. Impact extrusion provides improved control over wall concentricity and produces a finished jacket edge.

Jackets can be formed through chemical electroplating, bonding the jacket to the lead core. Separation of the jacket from the core was once a major hindrance to bullet performance. The process of plating jackets was first used for fully encased jacketed handgun bullets. These bullets start as an alloyed lead core that is swaged from wire. The core is plated to build up a jacket of uniform thickness.



Lead-Free Bullets

Health and safety concerns over lead have necessitated the development and production of bullets that do not contain lead. This is a matter of concern for all firearms users, including those who use indoor ranges, hunters, and the military.

Solid Bullets

Unlike traditional jacketed bullets, solid bullets do not have a lead core. They are formed either through impact extrusion (when using copper) or lathe-turned (when using brass or other harder metals). Hunting bullets of this type usually have hollow points to permit expansion, as required by hunting regulations. It is common now to see a polymer tip inserted into the hollow point to improve the bullet's ballistic coefficient and also aid in bullet expansion. Although expanding solid copper bullets can be manufactured in one step, they are commonly processed in a number of steps that promote bullet expansion.

Hybrid Bullets

Hybrid lead-free bullets typically combine a metal heavier than lead (such as tungsten) suspended in a matrix of polymer thermoplastic. Heavy metals help to reduce the weight gap between lead or lead-core bullets and all-copper bullets. Hybrid bullets are the best alternative for semiautomatic firearms and provide a more realistic training experience.

Frangible Bullets

Frangible bullets are designed to crumble into small pieces on impact with a rigid target or backstop. The most common process for producing frangible bullets is sintering. For example, sintered powders of copper mixed with other metals (such as tin) and binders will crumble as required.

Assembly

Bullet jackets and lead cores must be assembled to form a usable bullet. This involves the following steps:

- Feeding the components into a machine capable of applying pressure

- Providing forming dies in the machine
- Providing a way to move parts from one station to the next

The last requirement allows progressive forming of parts in increments of pressure. Stress on the bullet is reduced by spreading the work over multiple stations.

Machinery

The most pervasive press for bullet assembly is the transfer press, which contains a shuttle device that can shift the parts sideways from one station to the next. This type of press is common to many industries that form metal parts in stages. Because the transfer press has many parts that move, it offers options for powering accessory units for special operations, such as adding a cannelure.

Bullet assembly can also be performed on a dial or rotary press. In contrast to the transfer press, parts are moved in a dial rotating on a horizontal plane. The stages of bullet forming are similar, regardless of the press employed, and are as follows:

- A drawn jacket that is ready for the press has a rounded bottom (closed end); this assists feeding into the press.
- The jacket is fed into the press.
    - If the bullet is to be a military FMJ with a sharp point, the point is coined in one or two stations before core insertion.
    - If the bullet is a boattail sporting bullet, the tapered heel is formed by coining at this point.
- A tamping operation compresses the lead core into the jacket to eliminate any voids between the lead and the jacket. This also holds the core in the jacket so it will not move during subsequent operations.

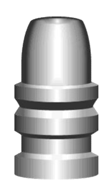
Open Point or Hollow Point

The remaining operations in making an open point, or hollow point, bullet are devoted to shaping the point. Because metal must be displaced and moved, point shaping is performed in multiple steps to avoid excessive load on the bullet and/or the equipment. The point starts by forming a truncated cone in which the lead in the core is squeezed up toward the open end of the jacket. The next die begins the transition to a curved surface called the ogive. The first die starts to round the profile of the ogive; a second or third die finishes forming the pointed shape.

Full Metal Jacket

An essential requirement for the making of a FMJ bullet is that the base is closed after the core is tamped. A small amount of jacket material protrudes beyond the tamped lead core and is folded over the core. This is accomplished in two operations. Folding begins by coning the rear edge of the jacket; a base-finishing die flattens the base.

Finishing



At this stage, bullets are usable but some may require processing to add other features. The most common is the crimping groove or cannelure, which may be functional or cosmetic in nature. This can be accomplished on the bullet assembly press or at a separate work station.

At this point, the bullets are covered in processing oils and need to be cleaned. These oils are removed by washing or dry tumbling in clean, ground corn cob. Cob is absorbent and provides the additional benefit of giving the bullets an attractive polishing.

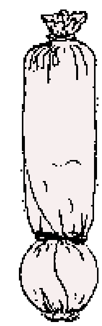
Bullets need to be tested prior to distribution and sale. Sample bullets for each lot are inspected for dimensional compliance and accuracy.

Cartridges

The modern cartridge case serves several important functions:

- Contains the other components (projectile, primer, propellant) in a single unit for convenience of handling and loading
- Resists the firing-pin blow during ignition
- Forms a gas seal (obturation)

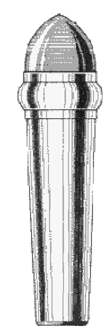
Paper Powder Charge



In the earliest days of small arms, cartridges began to evolve as an alternative to the slower process of handling a powder flask for charging each shot. In a rudimentary cartridge, a charge of black powder was measured into a thin paper or linen tube that was slightly smaller than the bore. A ball was then placed on top of the powder in the tube and secured with glue or a string.

Early breechloaders incorporated a sharpened cutter blade atop the breechblock. A paper cartridge was loaded, but when properly seated, stood slightly out of the barrel. When the shooter closed the action, the cutter sheared off the rear of the cartridge, exposing propellant to the flash hole. This eliminated misfires caused by excess paper blocking the flame from the percussion cap.

Burnside Cartridge

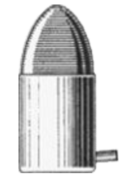


The Burnside rifle used an unusual brass cartridge that was largely supported by the breech rather than the barrel. A small covered hole in the base of the cartridge received the blast from the percussion cap; the seal burned through, igniting the powder charge. The Burnside cartridge walls were stiff and did not expand sufficiently to seal the bore.

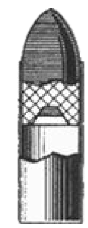
The true modern cartridge is flexible enough to expand under pressure and completely seal the rear of the barrel, yet strong enough to remain intact at peak operating pressure. Its diameter must be slightly smaller than that of the chamber to keep the cartridge case wall expansion to a minimum. The length dimensions have to match the chamber's corresponding support surfaces so that the case can withstand the blow of the gun's firing pin.

Early Metallic Cartridges

The French gunmaker Louis Nicolas Auguste Flobert developed target arms and low-powered cartridges. The ball was loaded in a thin copper case with a hollow rim folded into the base. Fulminate was smeared into the hollow rim, providing all of the power for the ball; no additional propellant was used. The firing pin struck the rim against the rear face of the barrel, igniting the fulminate. This cartridge class is known as rimfire. Smith & Wesson made improvements to the basic Flobert concept, enhancing reliability and power. These improvements were introduced in 1857 with the 22 Short cartridges. Today's 22 Short cartridges are practically indistinguishable in form from the original Smith & Wesson version.

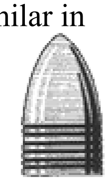


Another cartridge system once popular in Europe was pinfire ignition. A small pocket of fulminate was placed on the sidewall of a copper case. A brass pin was installed in the opposite side of the case; the internal tip of the pin rested on the fulminate. The hammer was unusual in that it fell on the side of the case, driving the pin into the fulminate. This system was not as robust as the rimfire system because the gun chamber must be slotted for the pins, and the ammunition manufacturing cost was greater.



Other early cartridges combined the required components, yet failed to meet the sealing requirement. Needle-fire systems placed the primer in the base of the bullet. A long, sharp firing pin pierced the paper or foil case to reach the primer. The French Chassepot and German Dreyse service rifles were the first successful newly manufactured breechloaders (i.e., not converted from muzzleloaders) in general military issue. Ultimately, other cartridges providing a better gas seal were developed.

The Volcanic cartridge/firearm system made by Robbins & Lawrence around 1854 provides an example of an early innovation from the United States. For all practical purposes, the cartridge was a Minié ball with its base cavity filled with propellant. A paper disc holding a fulminate pellet closed off the back. It was similar in concept to needle-fire but did not require the long and easily damaged firing pin. The cartridges were underpowered and the gas seal was inefficient, but the Volcanic repeating rifle could hold a large quantity of ammunition.



The legacy of the Volcanic ammunition is practically nonexistent, but the legacy of the Volcanic rifle action is significant in firearms technology. Oliver Winchester and B. Tyler Henry used it as the starting point for the famous Winchester line of lever-action repeating rifles.

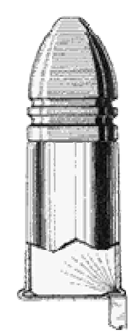
Rimfire Ignition

Rimfire ignition began to supplant other American cartridge concepts by the time of the Civil War because of its simplicity of design and manufacture. Some officers carried Smith & Wesson .22 and .32 caliber rimfire revolvers as secondary arms. A few Union units armed themselves with Henry's repeater (firing a .44 caliber rimfire cartridge) or the fast-loading Spencer repeating rifle (firing bullets of up to .55 caliber). Although not as powerful as the .58 caliber muzzleloaders carried by both Union and Confederate soldiers, the fast-firing Henrys and Spencers could produce a large volume of fire.

As percussion breechloaders were converted to accept true cartridges, those cartridges were mostly rimfire. The U.S. military issued rimfire cartridges as large as .58 caliber. However, there was room for improvement.

Early rimfire cartridges were prone to misfires. The priming compound was essentially glued into the rim cavity with organic binders. The only mechanical positioning came from the pressure of the powder charge against the fulminate. If handled roughly, a piece of the fulminate could fall out of the rim cavity, leaving a void and the potential for misfire. Another rimfire problem was that most cartridges were limited in power by the necessarily thin case. Thickening the case to handle more pressure also thickened the rim, causing misfires.

Rimfire Priming



In rimfire cartridges, the priming chemicals are integral with the case. Making the case with a hollow rim provides the space for the chemicals.

Priming compound is a mechanical mixture of lead styphnate, antimony sulfide, barium nitrate, and other chemicals. This combination will create heat and gas when struck sharply. For rimfire cartridges, raw wet priming mix is placed directly in the hollow rim cavity. Binders provide all the holding power that keeps the primer in place. Some rimfire mixes differ from their centerfire counterparts by the addition of a frictionator (helps ignition in the rimfire system), which may be finely ground glass.

The priming chemicals are blended in controlled facilities, often by remote control. Adding water to the mix makes it less dangerous to handle and allows the mass to be shaped. Even with these precautions, transporting primer mix is hazardous; cartridge cases are moved to the primer chemistry facility rather than moving the primer mix to the case loading location. The priming process steps are as follows:

1. The wet mix is forced into small holes in a nonsparking metal charge plate that sets a fixed volume of mix in each hole.
2. The filled plate is placed over a tray of rimfire cases; the tray has the same hole pattern as the charge plate.
3. A third plate with multiple pins, corresponding to the hole pattern in the charge plate, is pressed through the charge plate.
4. The individual disks of priming mix fall into the cases.

To ensure that the mix is uniformly distributed into the hollow rim cavity of the case, both downward and centrifugal force is applied during the spinning operation. A rotating spinner quill enters each case, causing the case to spin at high speed. The working end of the quill forces the wet mix toward the cavity and the spinning distributes the primer mix to uniformly fill the cavity.

Voids in the mix in the rim cavity can cause a misfire. Most manufacturers have stringent visual or electronic inspection procedures that reject any cases that do not have the proper distribution of priming mix.

Rimfire Primer Testing

After spinning, the cases are placed in low-temperature ovens to eliminate the moisture. Before moving to the load line, the cases are tested for primer sensitivity. A sample of dried cases from each lot is selected. The cases are placed in a test machine with a vertical cartridge chamber beneath a steel ball of known weight. The ball is dropped on the cases from a series of heights. At each height setting, the operator notes the percentage of cases that fire. As the height increases, the energy applied to the case becomes greater, increasing the number of fired cases. Eventually, the height reaches a point where all cases fire.

By applying standard statistical procedures to the data matrix of fired cases and corresponding heights, a value is generated that can be compared to published specifications for primer sensitivity. If that value falls within specifications, the cases are released for loading.

Centerfire Ignition

Development focused on placing the pellet of fulminate so that it was better retained. Most design work placed the pellet in the center of the cartridge base. This cartridge class was known at the time as centrally primed or centralfire; today known as centerfire. Once again, the interdependence of gun and ammunition design and development came into play; firing pins of rimfire firearms had to be moved to strike the center of the case rather than the rim.

Centerfire Primer Construction

Centerfire primers are more complex because of their internal components. These primers have three to four components depending on the brand. All have a primer cup, an anvil, and the priming chemicals or mix. In many types, foil paper is placed between the mix and the anvil to facilitate assembly.

Most metallic primer cups are made of cartridge brass; steel may also be used. Similar to cups for cartridge cases or bullet jackets, primer cups are produced on a cupping press.

After cupping, the parts are tumbled to remove sharp edges at the open end of the cups. This smoothes the cup, making insertion in cartridge cases easier. Most commercial primer cups are nickel-plated for corrosion resistance.

Anvils, the smallest of ammunition components, are made on a small blanking press. Sheets of brass are fed into a press fitted with multiple blanking punches. Dies set below the punches shape the anvil into the three-dimensional form.

At the explosive chemical facility, the hazardous priming mix is blended. As with rimfire priming, the mix is kept wet for safe handling. Cups and anvils are delivered to the chemical facility for assembly.

As with rimfire priming, wet mix is forced into holes in a charge plate to set the correct volume of mix for each primer. The wet pellets are ejected into primer cups. A compaction press forms the pellet to fill the entire bottom of the cup. At this point, foil paper may be placed on top of the pellet to prevent it from sticking to the compaction pins.

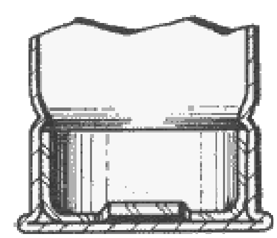
Next, anvils are added to the charged cups. Aligned in close-fitting plates, they are pressed into the cups, leaving part of the anvil exposed above the edge of the cup. To provide moisture resistance and to help hold the parts in alignment, a drop of nitrate sealant is added to the assembled primer.

Visual inspection is important for assuring the quality of centerfire primers. The anvil must not be tipped or inverted; the foil paper must not be out of position. Although electronic image inspection systems are improving, they have not advanced to the standard of the human eye. Wet primers are dried, completing the primer manufacturing process.

Centerfire Primer Testing

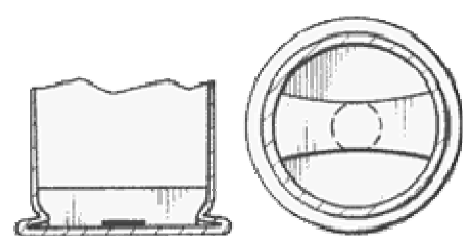
Similar to primed rimfire cases, the centerfire primers are tested for adherence to sensitivity specifications. Unlike rimfire cases, centerfire primers must first be inserted in a standard brass cartridge case and tested as specified in the manufacturer's drop-testing protocol.

Benet-Primed Ammunition



There is a broad range of early centerfire priming systems, many originating in military arsenals. Those classified as internally primed looked like rimfire cartridges when viewed from the base. These have a separate metal structure carrying the priming pellet, which is pushed from the inside to the case's base and crimped in place prior to charging with propellant. There is no evidence of the primer in the physical appearance of the cartridge. Two such designs used by U.S. arsenals in the post-Civil War period were the Benet system and the Martin bar anvil system. Benet-primed ammunition was standard issue for U.S. military rifles and revolvers through the late 1870's.

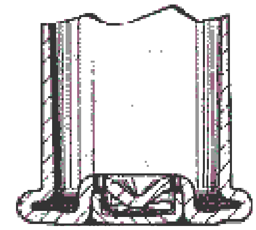
Bar Anvil-Primed Cartridge



Despite the initial success of the internally primed cartridge, development continued. Central priming still required a thin and flexible case to allow the firing pin blow to effectively transmit energy to the internally mounted fulminate pellet. The solution required a stronger cartridge case, while retaining thin metal over the priming pellet. This was accomplished by separating the case from the primer.

Primer Pocket/Folded Head

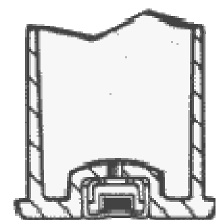
Based on design experiments by Col. Hiram Berdan, the folded-head case was developed. A central pocket for a separate primer and an anvil surface were produced to provide the pinch point that activated the priming compound when the firing pin struck the primer. One to three holes were pierced or drilled around the anvil to allow fire from the primer to reach the main charge. Other than the dimensions, the primer was similar to the familiar percussion cap of the muzzleloading era.



The folded-head case had a weakness; the fold that produced the rim stressed the metal. Over time, the stressed area became brittle, causing the case to fail at the fold. The metallurgical knowledge to properly relieve the stress in this area was in early stages of development; some batches of cases were loaded and issued with brittle rims.

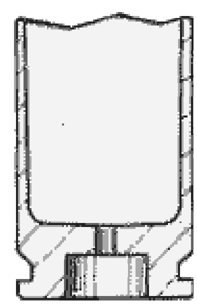
Balloon-Head Cases

Farrington Primer Case



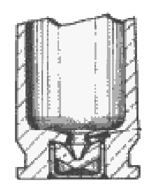
The next evolutionary step was the modern case. The rim of the balloon-head case was forged, rather than folded. It was stronger than the folded-head case and allowed the primer pocket to balloon into the powder space. This design gave the internal volume required for black powder. The rim cavity and the need for the high-stress fold at a critical point were eliminated. The head could fail when the case was very old, but critical rim blowouts were prevented. The balloon-head case continued to be used in some North American ammunition through the 1960s, typically in low-pressure revolver cartridges.

Solid Head Case

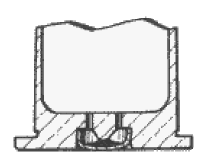


As smokeless propellants were developed, the volume issue was less important; the case could be further strengthened by filling in the area surrounding the primer pocket. This minor improvement (that began in high-pressure cases in the late 19th Century) is now commonplace in military and sporting cartridge cases. This modern design is called the solid-head case. When the balloon-head case was first developed, some ammunition companies referred to it as a solid-head case to emphasize the strength improvement over folded-head construction. Balloon-head is a modern term, coined to separate the current solid-head case from its immediate predecessor.

Modern Primer System Developments



Today, variation in cartridge case construction is seen only in the primer pocket. An English development, Boxer priming, placed the anvil in the primer as a separate part. The primer pocket has a single, large flash hole on the case centerline. The American development, Berdan priming, makes the anvil an integral part of the case and has one to three small flash holes positioned around the anvil.



For most purposes, the type of priming system is transparent to the end user. However, Boxer priming has an advantage to those who prefer to recycle the case by reloading. The centrally placed flash hole in the Boxer system allows the spent primer to be removed with a thin punch tool and a new primer inserted. Ironically, most of the world adopted the American Berdan system while America adopted the English Boxer system.

Berdan Primed Brass Case

Over the years, cartridge cases have been manufactured using a variety of materials. Although aluminum cases have been used to create lower cost disposable ammunition, brass, specifically cartridge brass, (70 percent copper/30 percent zinc) is most common in Western European and American sporting ammunition. Mild steel (steel with low carbon content) has been used where iron is a more abundant resource than copper. Both steel and brass have similar abilities to withstand pressure.

Primer Compound Evolution

Primers are devices that, when sharply struck, burn or explode to provide the heat source required to ignite the propellant charge. All modern small arms primers are chemical initiators, that: Primers

- provide an initial spark or flame
- establish the preignition pressure for the main charge
- provide a gas seal for the cartridge

For decades, mercury fulminate was the most commonly used primer. Although contemporary with fulminating powders containing potassium chlorate (whose residues promoted rust), mercuric priming was preferred because it did not rust the gunmetal.

When brass cartridges were adopted for use, it became apparent that mercuric residues (when in contact with brass), resulted in brittle cartridge cases. Such cartridges were fine for the first firing but could not be safely reloaded. The brittle brass could fail the next time it was fired, releasing hot gases. Thus, mercuric priming was replaced with chlorate priming. The U.S. military arsenals abandoned mercuric priming in 1898 at the beginning of the smokeless powder era.

Smokeless Primers

In the 1920s, lead styphnate was used as an initiating compound because it did not produce corrosive residues. Many other mixtures were tried and some were released for market trials. The combination of materials that worked best was a blend of lead styphnate, antimony sulfide (fuel), and barium nitrate (oxidizer). By the 1930s, all U.S.-made commercial primers were using this basic formula.

Styphnate priming compounds may contain other materials in addition to the three main compounds, such as the following:

- Sensitizer - makes the material more shock sensitive. The most prevalent sensitizer is tetracene.
- Finely powdered aluminum - added fuel used to project incandescent particles into the propellant.
- Organic binder - keeps the dried primer pellet consolidated, e.g., gum acacia.
- Dye - facilitates visual inspection of primers during manufacturing.

A Boxer primer used for a rifle or handgun has a minimum of three components: the metal cup, the priming compound, and the anvil. Many have an additional component—a thin paper cover between the compound and the anvil. This is known in the industry as the foil paper because original percussion caps had a layer of foil over the mixture for protection.

Shotshell primers are more complex. Because the shotshell case is largely nonmetallic, an extra part, the battery cup, is added to better support the anvil and resist operating pressures. In addition, the large flash hole has a paper or thin plastic cover, a relatively recent feature.

The lead styphnate percussion primer has remained nearly unchanged in form or chemistry since the 1930s. The discharge residue of these primers contains lead oxides and nitrates. Recent concerns over airborne lead in poorly ventilated indoor ranges have led to the investigation of lead-free primers and toxic metal-free primers. Current primer development focuses on additional improvements to low-toxicity compounds.

Case Design

The basic shape of the cartridge case is linked to firearms evolution and development. Most early cartridge cases were straight walled, which was the optimum shape for use with black powder. Protruding rims at the rear positioned the case in the chamber and provided the support needed to prevent the firing pin blow from driving the case deeper into the chamber. The rim also allowed the extractor to grasp and withdraw a fired case from the chamber. This design was successful for single-shot arms, shotguns, and repeating arms with tubular magazines.

Eliminating the protruding rim was key to box magazine success. The simpler box magazine was less expensive to produce because the complex feed parts (required in tubular magazines) were eliminated.

The machine gun shown at right is chambered for the 303 British, a rimmed cartridge. Removing the rim required that:

- the case provide positive support for proper positioning
- the case resist the firing pin blow
- some gripping surface be provided for the extractor

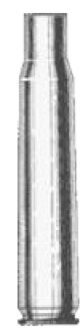
Cartridge Naming Systems

In North America, there is no defined, universally accepted cartridge naming system. Cartridge naming has been commercially driven and naming is typically determined by the original manufacturer.

In Europe, cartridge naming systems are controlled by government agencies and the systems are adhered to by all manufacturers.

Naming systems are varied and covered extensively in *Cartridges of the World*.
[40-90 Sharps Bottleneck (left) and 40-90 Sharps Straight (right)]

Bottlenecked case



Getting the required positive support relied on other features of the case. Some straight-wall or straight-taper cases (e.g., .30 U.S. Carbine, .45 ACP) use the case mouth to support the cartridge. Larger cartridges were bottlenecked and the sloping shoulder became the support point. Some bottlenecked cases did not have enough shoulder for support.

In another variation, the British firm of Holland & Holland developed the belted case; a small ring placed forward of the extractor groove supported the case.

The gripping surface was provided by designing a rimless case. Although the rim is present, it does not protrude beyond the body of the case. The extractor groove is an undercut made in the solid portion of the case in front of the rim.

Cartridge Case Manufacture

Cartridge cases fall into two broad categories—metallic and shotshell. Metallic cartridges are used in rifles and handguns and are comprised completely of metal. Shotshell cases are most often hybrids, combining a small amount of metal with paper or plastic.

Metallic Cases

Metallic case production is similar to bullet jacket production, except that the raw material is brass (copper: zinc ratio of 70:30). In brass mills, the standard name for this alloy is cartridge brass. Rimfire and centerfire cases require different processing.

Rimfire

Rimfire cases start as rolled, thin sheets of cartridge brass, which are mounted and fed through rollers to reflatten them. The sheet moves into a cupping press that:

- lubricates the sheets,
- blanks out disks of brass,
- drives the disks into a cupping die to form shallow cups.

A draw press reduces the diameter and increases the length of the cup in the same manner as copper bullet jackets. The punch and die set in the draw press captures all surfaces of the cup except the base (closed end) and stretches the brass to the desired diameter. The drawn length is longer than that required for the finished case to allow trimming the case mouth to uniform length. The inside of the case mouth may be beveled during trimming to facilitate bullet seating.

At this point, the case has a finished diameter and case mouth, but the closed end is not shaped into a functional case head. The heading operation shapes the closed end using a press called a header. Heading accomplishes the following:

- Forms the rim and rim cavity (for holding the priming charge)
- Sets the rim diameter
- Sets the rim thickness
- Sets the final case length
- Applies the identifying headstamp

In most factories, all of the heading processes can be accomplished in a single operation. The case is held securely in a stationary die; an inner back-up punch and an outside forming punch come together to apply the required force. The outer punch (bunter) has raised characters on the punch that impress the headstamp into the base.

After cold working, the brass may have residual stresses, which may affect the long-term performance and safety of the case. This contributes to age hardening. Stress relief ovens raise the metal temperature enough to relax the stresses without changing the grain structure of the case.

The rimfire case is fully formed, but covered in oils that could contaminate the priming compound. Washing removes these oils, leaving water in its place. The cases must be oven dried to remove all traces of moisture.

Centerfire

Similar to rimfire cases and metal bullet jackets, most centerfire cases start as cups. Since the raw sheet brass required for these cases is often thicker than that used for rimfire cases, preformed cups are frequently purchased by the manufacturer.

Drawing is the most widely used method in the manufacture of brass cases. It reduces diameter and increases length and is the best method for case fabrication. There is little difference in tooling between case-drawing dies and those used to make bullet jackets.

Depending on the length of the finished case, the cup may be drawn from one to five times. For cases requiring three to five draws, an intermediate stress relief heat treatment may be applied to keep the material ductile. The dies and punches maximize the diameter and length and fully shape the cavity. This profile defines the wall thickness of the finished part. The case will be thinnest at the mouth to allow flexibility for holding the bullet. To withstand firing pressures, the walls will be thickest at the closed end.

Drawing Operations

The draw operation leaves enough material in the base to form the web of the case. The web provides support for the primer and reduces the amount of swelling that can occur during firing.

After drawing, the cylinder is closed at one end, leaving extra material in the closed end. That end is convex after drawing; the draw dies work only the metal in the walls of the case. The next operation flattens the base, squaring it and applying the head stamp.

Heading also forms the rim for a rimmed case or removes the excess material when creating a rimless case. Heading forms a primer pocket in the web. The cylindrical case is mounted in a die to prevent changes in diameter; a support punch is placed inside the case to resist the blow of the bunter. The bunter has a central protrusion that will form the primer pocket (the recess that accepts primer during cartridge assembly).

If the case is to have a protruding rim (e.g., 30-30 Winchester), the supporting die requires a step in the end facing the bunter. The step allows all of the extra metal to flow toward the end and creates the mass of material that will eventually form the rim. The die that supports a rimless case (e.g., 5.56 mm NATO) has a slight enlargement at the exact same point. This enlargement provides that there is plenty of extra metal to ensure that subsequent operations keep the case head concentric.

Head-Turning Operations

The next operation finishes the exterior shape of the case head. Head turning is performed in a small automated lathe, with the cutter blade mounted at ninety degrees to the long axis of the case so that it can create all needed surfaces in one pass. When the factory switches from producing 30-30 Winchester cases to manufacturing 5.56 mm NATO cases, the cutter is changed to meet the new specifications.

The head turning machine grips the cases in a collet, a hollow die with longitudinally split walls that can grip and release a round object. When the case is fed into the machine, force is removed from the collet, allowing it to accept the next case to be processed. As the case seats, the machine applies pressure to the collet forcing it to firmly grip the case. The case and collet spin to high speed before the cutter touches the case, ensuring a clean accurate cut. The collet opens and a punch dislodges the case. Good head-turning machines will process 60 to 120 cases per minute.

Some head turning machines can also drill or punch the flash hole, which is the hole that allows fire from the primer to reach the propellant charge. If the case will be loaded (as opposed to being sold as a component), the maker will probably punch the flash hole in the case just before the primer is inserted on a device called a pierce-and-prime machine.

Taper, Trim, and Neckdown

After head turning, the case is slightly longer than the finished product and is a near-perfect cylinder. Most cases are ultimately tapered to some degree. The case is run into a die. If a small taper is needed, one die can suffice; for more pronounced tapers, the taper is produced progressively to reduce stresses.

Many rifle cartridges have a distinct bottlenecked shape. The neck and shoulder that create the bottleneck shape are also produced in a die or in a series of dies (if the neck diameter is much smaller than the case body).

Once the final profile is formed, the case is trimmed to the specified length. Trimming can be performed on a machine with a cutter that is moved to work the open end of the case (similar to the head-turning machine). Trimming can also be performed in a machine with a rotating cutter; the cutter axis aligns with the case axis. It moves down onto the case mouth, and a preset stop halts the cutter when the correct length is reached.

Stress Relief, Annealing, and Hardness

Residual stress from the forming operations can affect both rimfire and centerfire cartridge cases. For many cases, especially those with bottlenecks, the stresses are so great that high-temperature annealing must be used.

After forming, a bottleneck case may appear perfectly serviceable. However, massive stresses are likely to remain in these areas. If the ammunition is loaded and stored without addressing these stresses, cracks can appear in the bottleneck area.

Case bottlenecks are normally flame-annealed by the following process:

- Placed on a moving rail or rotary disk system, the case passes before a set of gas burners that rapidly heat the neck and shoulder area to glowing.
- As the case becomes incandescent, the brass grains grow larger.
- The heated area of the case is immediately tipped into a water bath to quench the case, establishing the large grain size.
- The treatment causes a dark, but harmless, discoloration to the neck area. In commercial ammunition, this dark area may be polished out for cosmetic reasons; in U.S. military ammunition, the discoloration remains visible.
- The application of heat treatment technology to vary the grain size gradually, from small grains in the head area to large ones at the case mouth, determines case hardness.

All high pressure cases must have variable metallurgical properties depending on the part of the case, as follows:

- Head - must be tough and relatively unyielding, small brass grains contribute to the toughness.
- Body - the case walls must combine flexibility and strength to contribute to the obturation system.
- Mouth - must be softer (larger brass grains) to prevent cracks from the strain of holding a bullet.

Inspection

After processing oils are removed, the case must be inspected. The physical dimensions are checked against engineering specifications. Some cases may be set aside for grain structure evaluation and/or micro-hardness testing. This test requires the following:

- Sample cases are sectioned and the cut surfaces polished.
- The polished surface is etched in acid to define the grain boundaries.
- The average grain size is measured, using a microscope with a calibrated eyepiece.
- A hard, sharp point is pressed into the metal with a known amount of force, leaving a tiny, diamond-shaped impression.
- The metallurgist measures micro-hardness using a microscope. The dimensions of the impression are measured; the smaller the impression, the harder the brass.

Some cartridge cases are nickel plated for appearance and/or corrosion resistance. Cosmetic plating is performed after all heat treating is completed and usually accomplished after passing inspection.

Alternate Materials

Brass is the most commonly used material in the production of the modern cartridge case. Mild steel cartridge cases and bullet jackets are manufactured outside of the United States. Another alternative material is aluminum alloy, which is used to produce centerfire cartridge cases. Other materials, such as plastic, have been tried but have not been widely accepted.

Cartridge Assembly

All ammunition assembly requires:

- priming the cartridge case (except rimfire - already primed ahead of time)
- charging the cartridge case with propellant
- inserting the bullet or shot/wad charge
- crimping and/or sealing
- testing and inspection

The cartridge assembly process depends on the cartridge class (rimfire, centerfire, and shotshell) and the type of machinery used.

Rimfire

At this stage of assembly, the rimfire case is primed and ready for the loading of a propellant charge.

Charging with Propellant

Regardless of cartridge class, charging with propellant requires great control over the amount placed in each case. Too little propellant and the bullet may stick in the gun barrel; too much and the case could fail, injuring the shooter or damaging the firearm. This problem is compounded due to the small amount of propellant required for rimfire ammunition. Important factors to be considered when measuring rimfire charges are grain size and shape.

Propellants are metered by volume because there is no feasible method of weighing each charge while meeting production demands. Volumetric metering of granulated materials in a production environment requires the ability to produce consistent charges throughout the run. Various methods are used, depending on the loading equipment.

After charging, the cases are inspected for uniform propellant levels. This is the last point in production where it is possible to inspect for the presence of a charge.

Bullet Seating

Rimfire bullets have the same diameter as the outside of the cartridge case. For the bullet to hold in the case, its base section is smaller to match the inside case diameter. The most common rimfire bullets are found in .22 Short, .22 Long, and .22 Long Rifle ammunition. The common term for this style is heeled bullet.

In the bullet-seating operation, the cases are held on either a continuous conveyor mechanism or in plates holding hundreds of cases. If the conveyor system is used, an alignment die falls lightly on each cartridge mouth and a bullet is fed into the die. Shaped to match the bullet tip, a seating punch presses the bullet into the case, resulting in a friction fit.

If the plate-loading system is used, cases are held in one plate and bullets in another. The upper plate serves the same purpose as the alignment die. The two plates are aligned and placed in a seating press. The ram of the press is fitted with a seating pin for each case, and all bullets are seated in one stroke.

Crimping

Crimping is the folding or bending of the case mouth to grip the bullet. For conventional bullets, this is a relatively simple operation because the case diameter is larger than the bullet diameter. A simple die with an internal shoulder can form the crimp quickly.

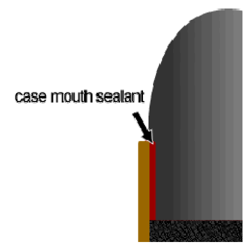
This is not possible for rimfire bullets; a rotary crimper is used instead. Loaded cartridges fall onto a plate and are driven against a rotating steel wheel with protrusions that roll the crimp into the case and bullet at the correct location. Simultaneously, any cannelures (for the purpose of retaining lubrication) are rolled. For additional weatherproofing, a knife cut may be used to force lead onto the new crimp; this is also performed on the rotary crimper.

Lubrication is added to lead bullets to reduce bore fouling. Rimfire bullets can be prelubricated or lubricant can be added after the cartridge is loaded. The final steps are testing, inspection, and packaging of the loaded cartridges.

Centerfire Ammunition

Rifle and handgun ammunition differ primarily in cartridge length. Other than selecting a machine with an appropriate stroke length, the loading operations are nearly identical.

Case Mouth Sealant



If the cartridge is to be sealed to prevent moisture infiltration around the bullet, a sealant must be applied to the inside of the case mouth before beginning other loading operations. Traditionally, the preferred sealant was a black asphaltic tar. It was applied wet and set aside for drying and curing. Once the sealant dried, the frictional heat of bullet seating partially remelted the tar, ensuring a good seal.

Today, manufacturers are using newer synthetic materials that can be applied and flash dried before loading.

Priming

Cases that do not have a flashhole opened during case manufacture are candidates for off-line priming using the pierce-and-prime machine. Cases are fed into a large rotating dial that grips each case firmly and moves it through the priming process. The workstation is fitted with a heavy-duty sharp punch beneath the dial. As the case stops at the station, a hollow backer punch enters the case to hold it down and the sharp punch moves up. It strikes the center of the primer pocket and produces a flashhole of the correct diameter. Both punches are withdrawn and the case moves to the next workstation.

After the operator has confirmed that the case is ready, it moves to a priming station. The case is still seated upright in the dial. Primers are fed through a magazine to a position directly under the case. A lower punch rises, picks up a primer, and pushes it into the case while a backer punch enters the case mouth to provide support for accurate seating.

After priming, a sealant is added to the narrow circular depression formed where the primer meets the case. A single drop of liquid acetate or other suitable material is applied to one side of the pocket; capillary action wicks the liquid to fill the depression.

In addition to being sealed, military ammunition primers used in semiautomatic rifles or fully automatic weapons must be further secured in place beyond the usual frictional fit by annular crimping or staking. Without such measures, chamber pressures may force the primer backward out of position causing the weapon to malfunction.

Annular primer crimps alter the entire edge of the primer pocket. A hollow steel tube, slightly larger than the primer pocket, is centered over the pocket and force is applied. The resulting rim of brass that overhangs the primer ensures a secure lock.

Staking accomplishes the same purpose in a different way. Three small indentations spaced 120 degrees apart surround the primer pocket in the base of a cartridge case containing the primer. Staking can be observed in some forms of foreign military ammunition.

Propellant Charging

As with rimfire ammunition, centerfire charging methods depend on the machinery used. More high-speed continuous loading machines are used, forcing the adoption of sophisticated propellant meters. The sliding powder measure is capable of handling faster production rates. Lower-volume cartridge production is still performed on slower interrupted sequence machines.

Most centerfire loading operations include inspection immediately after the charging station. A pin will drop into the case, determining if the volume of propellant is out of specification. Electronic or mechanical sensors read the position of the pin.

Bullet Seating

After the inspection station, the case is ready to receive the projectile. Potential problems in seating bullets in a high-speed environment are:

- inverted projectiles
- misalignment, which can cause case damage

Mechanical loaders operate too fast for an operator to hand-feed bullets into the mouths of charged cases. Bullets must be mechanically fed, requiring a dedicated station upstream of the bullet seater. To avoid inverted projectiles, a discriminator (that either turns all bullets the same direction or rejects any that are improperly oriented) must be installed in the feed mechanism.

To avoid misalignment problems, the seater die (that pushes the bullet to its final position) is fitted with a sliding sleeve having an inside diameter a few thousandths of an inch larger than the bullet diameter. Even if the bullet is tipped when placed on the case, the sleeve aligns it vertically, ensuring that the bullet heel does not snag on the case mouth.

Once the bullet is aligned in the sleeve, a seating punch moves down the sleeve and contacts the nose of the bullet. Pressure seats the bullet, and a stop ring on the punch sets the proper seating depth.

Crimping

Crimping is the controlled deformation of the cartridge case mouth to strengthen the grip on the bullet. Crimping:

- provides a smoother contour for feeding ammunition (especially in repeating arms)
- prevents bullet set-up during ammunition feeding
- aids with ignition of the main charge by adding additional friction to retard the bullet as it exits the cartridge case when pressure builds

Cartridge crimping tool

In centerfire revolver cartridges and some rifle cartridges, crimping is applied by a die with an internal shoulder that rolls the case mouth against the bullet, forming a roll crimp.

The presence or absence of a crimp and the depth to which the crimp is formed are dependent on the type of cartridge. Some cartridges (e.g., 9mm Luger and .45 ACP) use the case mouth to stop the cartridge from feeding too deeply into the chamber of the firearm. These cartridges are said to headspace on the case mouth. Applying a deep roll crimp to these types of cartridges will likely cause poor accuracy and misfires; they can be successfully loaded without a crimp. However, a very light crimp (barely observable) can smooth handling burrs at the case mount and improve reliability, while providing the required headspace support. This subtle crimp (taper crimp) is applied with a die having a gradually tapered crimping shoulder.

Most factory rifle cartridges and all revolver cartridges receive a substantial crimp at assembly. Revolvers that produce noticeable recoil can cause uncrimped ammunition to lengthen. The effects of inertia during recoil can cause poorly secured bullets to slide forward, possibly causing a malfunction in revolvers. Cartridges can also elongate under heavy recoil in box magazine rifles. In repeating rifles, feeding can force an unsecured (uncrimped) bullet to move too deeply into the case to continue feeding properly.

Roll crimping is common for revolver ammunition; a different system is used for many rifle cartridges, including military cartridges. A roll crimped case is assembled with a crimp shoulder to reinforce placement of the bullet in the mouth of the cartridge case.

Collet crimping applies force perpendicular to the case axis. A tapered steel tube with partially slit walls, a collet has a step machined on its interior surface that corresponds to the position of the case mouth. The collet moves up and down in a hollow die. As the vertical position of the collet changes, the tapered exterior moves against the support die, forcing the fingers formed by splitting the walls to move inward. This applies pressure to the case mouth where it meets the internal step. Examining the case mouth can identify collet crimping. The crimp area will have short vertical lines between the compressed areas consistent with the number of segments in the collet.

Taper crimping is the least stressful of the three crimp methods and can be used with any bullet. Roll crimping and collet crimping require that bullets have a recess into which the case mouth can be deflected. Without this, crimping will damage the case and/or the bullet.

Cleaning

Loaded cartridges are often covered in processing materials, excess sealant, and tiny chips of metal from cases and bullet jackets. Before inspection and testing, the cases must be cleaned. In a factory setting, it is common to tumble the cases in corn cob with a small amount of solvent. Tumbling live ammunition is not safe in a hobby environment. Factory tumblers are robustly constructed so that accidental firing (caused by the tip of a bullet striking the primer of another cartridge) does not pose a danger to the workers.

Ballistic Testing

After final assembly, the cartridges must be tested before packing and shipping. The testing process is similar for all classes of ammunition; they are tested against company standards as well as those recommended by the Sporting Arms and Ammunition Manufacturers' Institute Inc. – SAAMI. While the SAAMI standards are voluntary, failure to follow these may result in a product that is unsafe and dimensionally incompatible with some firearms. The cartridges undergo testing in the following areas:

- Pressure testing
- Velocity testing
- Function firing
- Accuracy testing
- Customized specifications
- Cosmetic evaluation

Testing is destructive; tested cartridges are expended. Consequently, valid and reliable testing must be based on accepted statistical sampling procedures. Both in-process and final acceptance testing is performed. The samples tested must meet the pressure standards.

Sample cartridges are measured to ascertain that all physical dimensions meet factory specifications and the guidelines recommended by SAAMI. They are also examined for cosmetic defects.

Pressure

The most important factor in testing newly manufactured ammunition is to ensure that the pressure generated at firing does not exceed the standards.

Crusher testing is generally an obsolete method but is still retained for some cartridges for which standards have not been converted to current methods. In this method, the test barrel is placed over the cartridge case and a steel piston touches the case. A soft copper rod (crusher) sits atop the piston and is restrained by an anvil. When the cartridge fires, pressure pierces the case and drives the piston into the copper crusher. This force shortens the crusher and the length is measured. Postfiring lengths are compared to calibration tables accompanying each lot of crushers to find the pressure value for each shot.

In the most commonly used method (piezoelectric transducer testing), cartridges are fired in a barrel fitted with sensors that detect pressure. When compressed, the transducer in the test barrel creates an electrical signal - the greater the pressure, the greater the signal. This method tests ammunition at a rapid rate with a high degree of accuracy.

Compared to transducer testing, crusher testing is extremely slow. Crusher testing provides only a snapshot of maximum pressure; there is no time reference. Transducer testing generates pressure readings over a period of time. If the output of ballistic pressure testing is compared to photography, crusher results are like low-resolution black-and-white snapshots; transducer results are like high-definition digital video clips.

Velocity and Function Firing

At the same time that the cartridge is tested for pressure, equipment mounted in the test tunnel determines the bullet velocity. Velocity is also a parameter that must fall within a range of values in order to ensure uniform performance and to reflect the advertised specifications for the load.

Function Firing

A portion of the statistical sample must be fired in production firearms. This is termed function firing. For each cartridge type, the most popular firearms likely to receive the ammunition are selected for testing. Semiautomatic arms are the most critical because they can malfunction due to minor changes in loading that would not show up in testing with a bolt-action firearm.

Accuracy and Custom Specifications

Accuracy testing is the last major test for all except shotshell ammunition. Accuracy testing is performed in fixed mount barrels to reduce the human factors that can contribute to poor accuracy. A typical accuracy test for handgun ammunition is measured at a distance of twenty-five yards or twenty-five meters, depending on the country. Centerfire rifle ammunition and a considerable amount of rimfire ammunition is tested at one hundred yards (or one hundred meters).

It is group size, not proximity to point-of-aim that is measured. Generally, four or five five-shot groups are fired and the results are analyzed statistically.

Custom Specifications

Testing against customized specifications is performed when a particular lot of ammunition is assembled for a customer with specific needs. Their needs may include a slightly different velocity specification or a tighter accuracy specification. For example, a large police department might request performance testing according to their custom specifications using only the firearm issued by that agency.

Handloading and Reloading

Individual shooters may handload or reload their own ammunition, using hand tools to perform the tasks done by machines in commercial ammunition factories. The process is nearly equivalent:

- Handloading is the process of assembling ammunition from components, typically for personal use
- Reloading is the process of assembling ammunition using previously fired cartridge cases as well as some new components: propellants, projectiles, and primers

There are several reasons to handload or reload ammunition:

- Economy - over the counter ammunition is more expensive
- Enhanced accuracy - the accuracy of handloaded or reloaded ammunition precisely loaded by a hobbyist typically exceeds industry standards
- Customized loadings - the variety of combinations of bullet and powder loads specific to the needs of the shooter and the firearm are much greater than the limited offerings of commercial loadings
- Obsolete cartridge types - commercially unavailable ammunition for obsolete or historical firearms

The essential ammunition components for reloading are:

- Smokeless powder appropriate for reloading (handgun, rifle, shotgun)
- Primers of the appropriate size and type
- Projectiles for the type of ammunition
- Cartridge cases manufactured for Boxer primers (used cases if reloading)

The first three are typically new, unless the loader is casting new lead bullets. Cartridge cases may be acquired new or used. Used cartridge cases have undergone dimensional changes as a result of the effects of exposure to internal pressures and obturation. Used cartridge cases must be:

- compressed to original factory specifications using a resizing die
- trimmed lengthwise at the mouth to meet specifications
- expanded at the mouth to fit the bullet to be inserted

Reloading Process

The reloading process is similar for handgun and rifle ammunition with minor exceptions:

- Removing the old primer using a decapping die (depriming)
- Cleaning the cases using soap and hot water or a commercial case cleaner
- Optional polishing using a cleaning medium in a tumbler or vibrating cleaner
- Inspecting cases to ensure physical integrity
- Lubricating the cases prior to resizing in a cartridge case resizing die
- Resizing the cases
- Trimming the case to length, if necessary
- Priming the cases (swaging used military cases)
- Charging the case with the correct amount of powder
- Seating the bullet using a bullet seating die
- Crimping the cartridge case mouth into a bullet cannelure used as a crimping groove
- Inspecting the result for physical flaws
- Testing the ammunition for accuracy

Reloading equipment provides a mechanical advantage and the dies to form the cases and assemble the components. The basic tool is the single-stage press, which produces one completed cartridge at a time. More advanced reloading machines have multiple die stations set up on a rotating base allowing several operations to be performed with a single stroke of a lever. These operations include the following:

- Depriming
- Resizing
- Expanding the case neck

- Seating the primer
- Charging with powder
- Seating and crimping the bullet

The dies and tools used in these operations can leave unique, identifiable toolmarks on the ammunition produced. Firearms/toolmarks examiners and crime scene personnel should realize the implications for associating fired or unfired ammunition with reloading equipment.

Potentially identifiable striated or impression-type marks on cartridge cases may be produced by

- the cartridge case holding tool, which secures the base of a cartridge case in the reloading press,
- resizing dies used for returning expanded cartridge cases to their original dimensions,
- crimping tools used at the mouth of some types of cartridge cases.

Reloading marks on bullets may result from bullet-seating dies and may be in the surface of a bullet, especially the nose.

Shotshell ammunition reloading is similar to handgun and rifle ammunition reloading using either a single-stage press or a semiautomated operation. However, fewer potential toolmarks are left by the equipment. The toolmarks of interest would be on the brass base of most shotshells made by a resizing die.

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