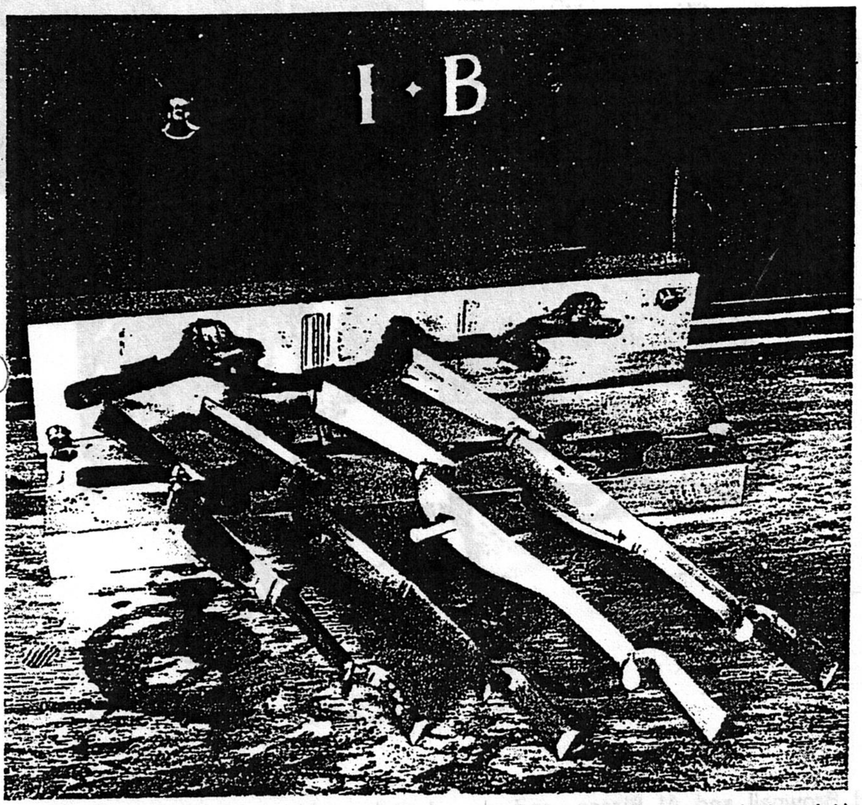
Investment Casting



Resting upon the injection mould are (right to left) trigger-guard pattern, wax pattern, raw casting, and finished casting. Parts shown are brass.

techniques for a small shop

by John Bivins

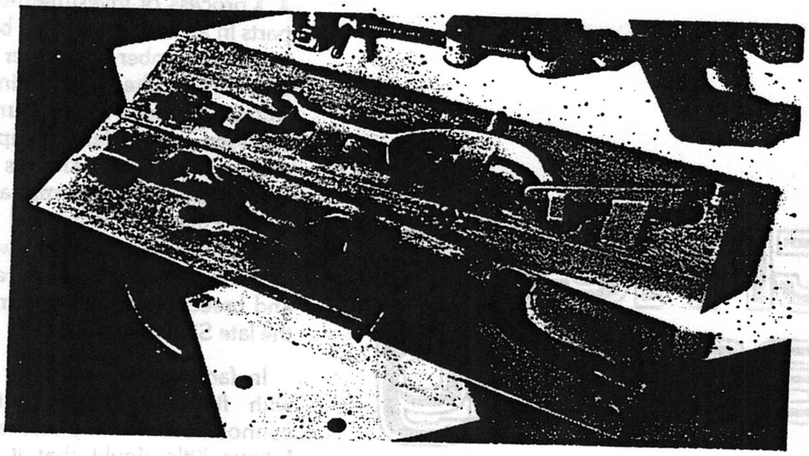
photographs by H. Armstrong Roberts III

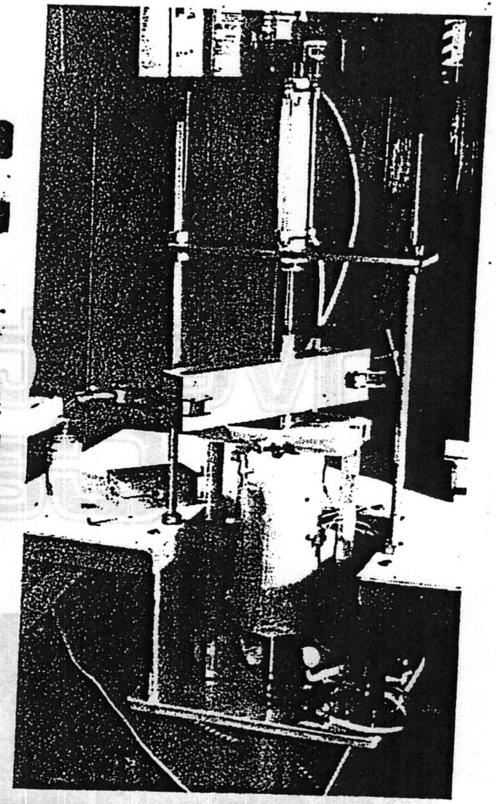
RIFLE REPORTED on the complex process of investment-casting firearms parts in an excellent article by Edward Ezell in the November-December 1969 issue. At that time, the recent introduction of Ruger's Model 77 and Number One had focussed new attention upon the trade, although Bill Ruger and his associates had done pioneering firearms casting well back in the Fifties. The general surprise of the consuming public over two major new centerfire rifles with cast receivers, bolts, and breechblocks opened many an eye in the late Sixties.

In fact, the term casting in connection with firearms had less than pleasant connotations to many before that time, and I have little doubt that it has been the obvious and continuing quality of excellent production arms such as the Rugers that have dispelled that onus by now, nearly a decade later. Arms manufacturers are becoming rightfully less reluctant to reveal which parts they cast, since the consuming public has become a bit more enlightened to the fact that investment casting is a valid production process, taking no back seat to more time-honored machining and forging.

Investment casting, in fact, has ensured the longevity of some firearms designs and has enabled others to be created where production costs would otherwise have prevented new arms from ever leaving the model shops. The Ruger sporting rifles are perhaps the best examples. The graceful, sculptured contours of the Number One frame, for instance, could not have been forged and machined at a cost low enough to permit production of the rifle as we know it. The Model 77, with its Mauser-type extractor and corresponding complex receiver cuts, would no doubt have been subjected to design compromises had it not been possible to use a production medium that permits an unusual degree of surface complexity, and even undercuts, without significantly raising cost.

Investment casting has particularly encouraged the development of the blackpowder industry, especially in replication; Val Forgett saw possibilities in the process in the late Fifties, and no doubt the success of Navy Arms since then has been in part due to precision casting. Today, Ruger casts even the cylinders of the excellent Old Army, since casting greatly reduces the cost of producing the convoluted rear face of a percussion cylinder. Casting has even proved an inexpensive source of reliable leaf springs, making the production of all manner of gun locks financially possible. Some still scoff at the notion, but I have been using flintlocks with all major parts cast for some fourteen years, and in that time, I have had but three springs fail, and no other





This injection mould (above), with fresh wax pattern still in the mould, is of epoxy and aluminum. At right is wax-injection machine in operation, with mould held in place against nozzle by small ram. Below, Wilma Baber is "treeing up" a trigger guard onto a runner. Note the gates on the guard and the pouring cup at the top of runner.

functional parts that I can recall. I don't believe forgings would have had a better record than that.

Of course, investment casting is not a cure for all ills. One thing that I dislike is that it has tended to cause laziness in finishing; manufacturers, and worse, custom gunmakers in some instances, have become satisfied to leave interior and even exterior parts as cast. In locks for muzzleloading arms, such surfaces add nothing to smooth functioning, to say the least, and visually, the result leaves a great deal to be desired. And one sure way to add a really cheesy look to an otherwise good arm is to leave parting lines on the castings.

Investment casting has become financially feasible for the custom gunmaker because of the larger number of foundries operating now and greater competition. One difficulty lies in the need to find foundries small enough to be able to accept the low-volume work of the gunsmith yet advanced enough to be able to produce high-precision castings with good surface integrity. Foundries that have consistently accepted small jobs in the firearms field and can produce good castings include Rimer Enterprises in Waterville, Ohio (the name of this foundry was recently changed to Muzzle Casts, Incorporated, a curious appellation); Oklahoma Investment Casting Corporation, Blackwell, Oklahoma; Tennessee Investment Casting Company, Incorporated, Bristol, Tennessee; and B&H Precision in Blountville, Tennessee. There are many other foundries, of course, and some specialize in firearms work, such as Pinetree Castings, a wholly owned subsidiary of Sturm, Ruger. Generally speaking, larger facilities such as Pinetree are not in a position to accept small jobs.

Custom gunmakers who have made a considerable success of producing investment castings both for their own use and for the trade have been men such as Lenard Brownell and Al Biesen, and a number of others, particularly shops that do metalwork, are increasingly turning to investment foundries for assistance. I began preparing patterns for casting five years ago, having tired of the time spent in filing and finishing steel forgings for flintlock furniture, and have since expanded my collection of cast parts to nearly thirty-five items, many of which are run in brass as well as steel. Of course, I have considerable financial investment in the patterns and tooling, but the bench time saved has amortized the amount spent many times over. It is difficult now to exist as a custom gunmaker without investment castings, particularly in muzzleloading, unless you can file at the speed of light or can charge a good deal more than most of the market will bear.

Initial problems in having custom investment castings produced lie in pattern and mouldmaking. Some gunmakers have the facilities and skill to produce these items, while others, who lack either equipment or time, must rely on the foundries for tooling-up, which can be considerably more expensive. A certain knowledge of the properties of cast alloys is needed in designing and fabricating patterns. For example, patterns must be oversize enough to compensate for the roughly one percent shrinkage of the injected wax and about two percent shrinkage of the cast part. This three-percent loss in size can be a thorny problem in calculating allowance, and it is compounded by differentials in the mass of various parts of a pattern.

Also, the pattern must be designed so

At left, the tree is dipped into the first slurry mix of 325-mesh ceramic particles. It will go through three slurry-dipping stages (center). These have coarser particles, which build up the shell of the mould. The first fine-mesh slurry determines the quality of finish on the final casting. An eighty-mesh sand dip follows, then the trees are allowed to dry on racks (right). These steps are repeated until mould shell is built up to the required thickness.

that an efficient injection mould can be made from it; such moulds must be kept as simple as possible, without an unnecessary number of sections and removable mandrels, or the tooling becomes too expensive and tedious to use. For relatively small production, epoxy-cored aluminum moulds are satisfactory and relatively inexpensive (depending upon the mouldmaker), and they have a life of many thousands of "shots" if they are not abused. "Permanent" moulds of all-aluminum or aluminum and sintered metal are best for large production runs, but their cost is generally well beyond the pocketbooks of custom gunmakers. For longevity of tooling, I prefer to run waxes for casting in my own shop and have a wax injector for the purpose. Using one of my patterns, a ten-inch trigger guard, let's run through the entire process for a bit of a look at what's involved.

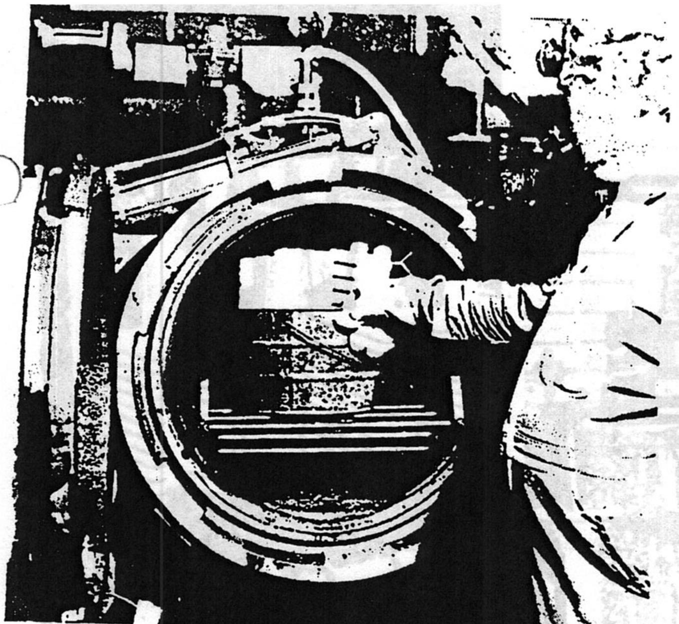
The wax injector that I use was designed by Dru Hedgecock of Walkertown, North Carolina, with some input from me, and it's a good size for a custom gunshop in terms of capacity and cost — about fifteen hundred dollars. The purpose of such a machine is to inject wax under pressure into a mould to produce a wax pattern, and this is done by a ram mounted under the unit, actuated by compressed air. The head of the ram pushes up a piston fitted inside a cylinder filled with wax; this cylinder is enclosed within a heavy aluminum jacket, which is fitted with thermostatically controlled cartridge heaters that keep the wax at 140 degrees — about the consistency of mayonnaisse. Hotter wax tends to create "flashing" at mould joints and excess shrinkage, though the relatively cool 140 degrees requires some 150 pounds of head pressure in my three-inch cylinder for clean waxes. The jacket on my machine is hinged to facilitate changing cylinders, which reduces downtime. This could otherwise be a problem, since one of my heavier buttplates, for example, can exhaust a cylinder after no more than twenty-five shots.

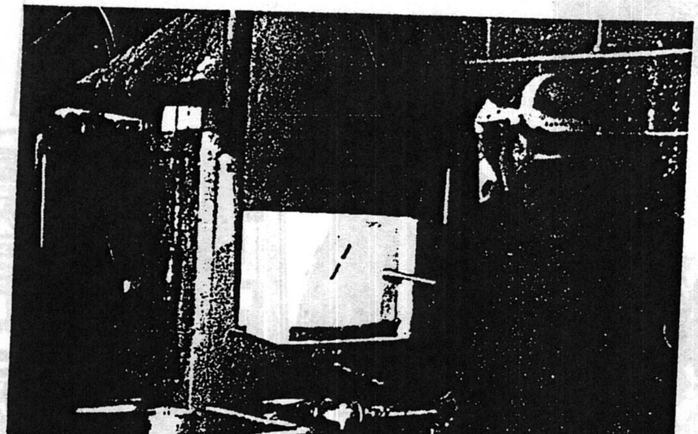
At the top of the machine is a small compressed-air ram, which holds the injection mould against the wax nozzle on top of the jacket. Using such moulds requires frequent shots of silicone release spray to prevent the wax pattern from sticking in the mould.

Briefly, the use of an injection machine involves spraying and clamping-up the mould, placing the mould on the nozzle, lowering the top or holding ram, opening the wax valve, closing the valve after a few seconds, raising the ram, and setting the mould aside for cooling. Cooling can require from half a minute to several minutes, depending upon the mass of the part; as the wax cools, it shrinks slightly, facilitating removal from the mould cavities. Various types of waxes are used in the casting industry, each color-coded to indicate different properties. We prefer the pink variety since it has exceptional fidelity of reproduction and readily shows minute flaws when they occur. Waxes are exceedingly fragile and cannot be shipped easily without breakage, which means that if you decide to run your own wax patterns, you'd best be within driving distance of the foundry that is to run your work.

The wax pattern is the heart of the ancient lost-wax casting process known for centuries. Just how it is "lost" in the modern process we'll examine as we go along.

After the desired number of wax patterns are run and packed, I deliver them by car to the foundry. In hot country, that bloody well means you'd best have an air-conditioned car, incidentally, unless you want to arrive with waxes that better resemble Dali sculpture than gun parts. In this case, Bob Roberts, Mark Silver, Paul Forster, and I took a trip to B&H Precision in Tennessee. B&H is a relatively new firm





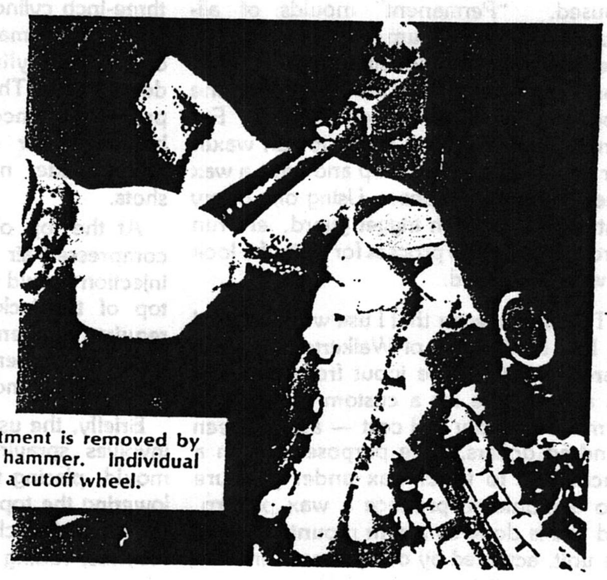
The autoclave (left) melts wax from shell moulds, then burnout oven (upper right) vaporizes residual wax and improves tensile strength of shell. Finally, the pour (right). Pot is induction furnace, entire liner of crucible being surrounded by a massive induction coil.

run by Jerry Baber and his perky wife Wilma — hard-working types who frequently stay up all night nursing delicate parts through the various stages of the process, with the help of several highly skilled foundry technicians. The Babers, in fact, prefer to work at night, since there is less interference from the telephone.

B&H is a small foundry specializing in firearms parts, and the quality of the steel parts run there has quickly brought in work from a number of armsmakers. Currently run at B&H are various parts for the Shiloh 1874 Sharps, all of the castings for Bud Siler's fine locks, and numerous other parts such as M-14 receivers, parts for .50 machineguns, and massive components that make up the impressive Casull .454 revolver.

Jerry Baber seems a natural for the business, having acquired a certain probing inquisitiveness while working for some years as an electronic engineer in defense systems. He entered investment casting some ten years ago, and the knowledge he has acquired regarding this complex business is impressive.

At B&H, as in any other foundry, the casting process begins with "treeing" the wax patterns. Each pattern is cast with integral tab-like "gates," which permit the pattern to be attached to the tree. The gates perform the dual role of providing an exit for the molten wax and an entry for the molten metal, as we shall see. In any event, the center of a tree is a long square of wax with an integral pouring cup at one end; these runners, like the wax patterns themselves, are made in moulds on a wax injector, of the same wax that the patterns are "shot" from. A metal hook is screwed



After the tree cools, the investment is removed by striking the pouring cup with hammer. Individual parts are then cut from tree with a cutoff wheel.

into the pouring cup while the runner is soft, enabling the tree to be hung from a rack. Treeing-up the patterns simply involves sticking the gates of the pattern to the runner by melting the ends of the gates slightly with a hot spatula or small soldering iron.

It is of considerable economic advantage to affix as many patterns as possible to one tree. Completed trees are allowed to cool before being sent to the investing or dipping room, and they are also cleaned with methyl ethyl ketone to remove silicone spray from the patterns; the water-based investment material otherwise wouldn't adhere to the pattern later.

The treed patterns are now ready for investment. Two basic methods may be used, either the flask or shell method. The former, more representative of ancient techniques of investment casting, is still used extensively for sculpture, jewelry manufacture, and dental-laboratory work. In the flask method, the wax pattern is surrounded by a relatively large volume of investment material poured around the pattern in the form of a liquid ceramic slurry. When this slurry has dried and hardened, the "green" mould is fired to consolidate it and to melt out the wax pattern. The greatest disadvantage of the flask method is the extensive burn-out time needed, since a fast heat would crack the thick mould before it had cured out.

The greatest percentage of gun parts are produced by the ceramic-shell process. As in the flask method, slurries are used, but only by dipping rather than as deep masses surrounding the patterns. B&H Precision uses three slurries, the first containing ceramic particles of 325 mesh and the next two of a much coarser 120 mesh. The slurries are held in suspension by constant agitation, much like slip used in making cast household ceramics, and they are mixed with a colloidal silica. Number three dipping bath at B&H has an alcohol base to promote rapid drying.

Here's the process of working a tree of patterns through the dipping room. The tree is twice dipped slowly and carefully in number one bath, the 325-mesh slurry that also contains a wetting agent. This first die is the most critical, since it creates the surface that will determine the quality of finish of the casting, hence the finer mesh of the first dip.

While the slurry is still damp, the tree, now covered with white ceramic, is lowered into a vat filled with a special 80-mesh sand, which is aerated from below to loft the sand particles and thereby prevent damage to the delicate waxes. The sand is a silicon carbide that has to be re-fused into silicon oxide and then crushed and reground, making it thermodimensionally stable; its purpose is to add bulk to the ceramic shell, thus reducing the number of dips required to invest a tree. The sand also provides porosity in the shell, an attribute needed to prevent the entrapment of air in the shell when it is poured full of metal.

After the first dipping and sanding, the tree is allowed to dry for a day. It is then dipped in water briefly, drained, and then dipped again into the number-one slurry and sanded again. After an additional twenty-four hours, the same process is carried out again, but this time the tree goes into number-two, or 120-mesh, slurry and is sanded in a coarser fifty-mesh sand. Four more dippings and sandings follow this for a total of seven dips, the last dip being made in the number-three vat of alcohol-based 120-mesh slurry. Drying between dips is increasingly slower as the mass of the investment builds up; the final shell may be as little as 3/16 to over half an inch thick, depending upon the mass of the part, and when the green shell is dry after the last dipping, it is a self-supporting monolithic coating on the waxes.

In the investment-casting process, when shell moulds are used, the wax is "lost" or melted out in an autoclave, a large and sophisticated steam "pressure cooker" fed by a steam generator that provides a hundred pounds per square inch of pressure at three hundred degrees Fahrenheit. When the trees are inserted into the autoclave, the door is closed and the valves opened, the unit reaching full pressure in eight seconds. The steam pressurizes the shell, penetrating the porous surface; the fast pressure rise is needed so that the wax begins to melt and flow before it has a chance to expand and possibly fracture the shell. After about twenty minutes, virtually all of the wax is melted out, flowing out the bottom of the autoclave into a bucket.

Now the shell is placed in a gas-fired burnout oven at a temperature of 1,400 to 1,600 degrees Fahrenheit for three to five hours, depending upon the nature of the shell. Burning-out vaporizes residual wax on the inside surfaces of the shell, and brings the shell walls up to a tensile strength of four thousand pounds per square inch. The shell may now be cooled and put on the shelf for later pouring, or it may be taken to preheat temperature if it is to be poured right away.

Preheating at 1,800 to 1,900 degrees brings the shell up to the temperature necessary for pouring. The shell is held at this temperature for at least half an hour. When the furnace melt is ready, the shell is simply forked out of the burnout furnace and handed to a foundryman, who places it on the floor for pouring. Though the man handling the shell wears exceedingly heavy asbestos gloves, the white heat of the shell permits no more than ten seconds of manipulation of the shell before things become uncomfortable. B&H has arranged its burnout ovens close to the furnace to avoid significant drops in shell temperature.

B&H uses an induction furnace, the

induction coil housed in the pouring pot itself. The furnace is controlled by a large console, which is actually a solid-state frequency converter, converting sixty cycles per second to three thousand, feeding seven hundred volts direct current to the furnace, switching off and on that heavy "zap" three thousand times a second. This energy creates a powerful 60,000-watt magnetic field in the induction coil and consequently in the bar of alloy placed in the pot. As the alternating flux lines of the magnetic field sweep back and forth, the molecules in the ingot align themselves and follow the sweep, creating friction as the molecules of the alloy are rubbed together. This friction heating, along with resistance in the ingot caused by an eddy current coursing through the bar, melt the ingot down in a matter of minutes.

The melt is checked several times with a handheld pyrometer, and when pour temperature is reached, a quantity of slag fluxing compound (in the case of steel) is dumped on the surface of the melt. The induction coil is actually shut down at a higher temperature than the correct pour level, since the pot loses some heat between shutdown, during fluxing, and just before the pour. In the case of the trigger guard being poured here, the furnace was shut down at 3,020 degrees. Specified pouring temperature for SAE-4140 steel, of which the guards were to be poured, is 2,950 degrees.

When the melt is ready, the shell is quickly forked out of the burnout oven and set on the floor inside a heavy sheet-steel box open at the top. The pour is immediately made, and several other shells are pulled out one after another and poured. A paper cup filled with an organic hydrocarbon compound is then set on the pouring cup of one of the shells, and a lid is quickly fitted to the steel box. The hydrocarbon is converted by the heat to alcohol, which flames off inside the box, driving off oxygen from around the shells. The presence of oxygen around cooling shells can pit steel castings considerably, hence the use of this technique.

This describes a gravity or static-pressure pour, though special applications requiring the flow of alloy into critical shapes may require assistance from either a centrifugal force or vacuum. Dental labs, for instance, commonly use spring-driven centrifuges to insure perfect filling of flasks. Whatever the pour method, correct handling of the procedure is critical if usable parts are desired. For example, many steel alloys expand one percent per hundred degrees of temperature past the melting point; if a melt is allowed to heat too much, the resulting cast parts can shrink unduly or even lose carbon, which causes considerable difficulty in parts that must undergo critical heat-treating.

After cooling, the trees are cleaned of investment by vibration or by simply striking the pouring cup with a hammer. If necessary, a mixture of ninety-percent sodium nitrate and ten-percent sodium hydroxide can be used to dissolve the ceramic binders of the investment; this compound must be heated to nine hundred degrees, and a steel part so cleaned requires a muriatic-acid cleaning afterward. Usually, the tree is simply sandblasted in an enclosed booth after vibrating away the bulk of the investment; the parts are then cut off the tree with cutoff wheels.

Steel castings are then annealed for four to six hours at 1,500 degrees; B&H uses an argon atmosphere to prevent scaling the castings. Annealing leaves SAE-4140 castings at zero on the Rockwell C scale, though they cast at twenty-one. Carbon steel parts generally experience surface decarburization during casting, generally at least 0.007 inch below the surface, and foundries use various recarburization processes for restoring the surfaces when it is needed. Parts that will receive surface machining to any degree often don't need this.

Investment casting is a complex art, requiring considerable knowledge, skill, and financial outlay. We gun nuts should be thankful for the existence of this fine industry. Without it, the future of firearms production at affordable prices would certainly be a dim one. As it is, we still have quality production and custom arms through the assistance provided by precision casting, and these arms need be of no lower quality than guns produced totally from forged and machined alloys.