How Valves Are Born

BY **FERNANDO CURELLO**

If we could only tell a child that by simply joining an intake with an exhaust valve, we would get baby valves – ha, ha, ha! That would be a straightforward way to make them, but the fact is that the manufacturing of today's engines valves is not an easy job. First, it begins with the highly specialized materials that are needed, and then followed up with the many processes that they must go through. The materials must be forged, heat treated, welded, machined, coated, etc. Every step of the way must ensure the highest quality of their finished dimensions, hardnesses, metallurgical microstructures, tight tolerances, and smooth surface finishing.

In our engine rebuilding industry, we work with a multitude of different engine valves, ranging from small one-cylinder, large heavy duty, marine, high performance, and racing valves. Some of them using sophisticated materials like titanium, or high temperature Nickel alloys.

We all know, through painful and costly experiences, how important a valve is in the engine, because a serious valve failure may cause a catastrophic engine failure. But do we realize the amount of dedication to the manufacturing details and quality we put when buying or reclaiming valves?

So, to help our AERA members with their everyday contact with these apparently simple "big nails", we will concentrate on the main manufacturing steps to making a valve, going from the raw materials to the finished products that they see and install every day; there are so many different types of valves, materials, shapes, sizes, and wide variation on equipment and manufacturers worldwide. We will describe only the main basic steps because there are dozens of intermediate additional processes like washing, tumbling, degreasing, testing, and others that will not be mentioned for the sake of brevity.

Figure 1: From left to right, cut bar, extruded product, and forged valve

FIRST MAIN OPERATION: FORGING

The valves are hot forged, they first begin from round steel (or special alloys) bars that are cut in short or long pieces depending on the forging process to be used. There are basically two ways, one we can say it's the "American way" because it was (and still is) widely used by the valve factories located in the USA, and aiming to big manufacturing volumes, called the extrusion process. In this case the bars go in diameters, let's say from 3/4" to 1" or more, depending on the valve head size and length, and cut in cylinders of approximately 1.0 to 1.5 times its diameter, depending on the stem length and total material volume we need for the forged valve. The cylinder's volume will be transformed in the head volume and stem diameter and length after the two steps stamping process.

Please see Figure 1 for the initial cut bar, the first extruded product and the second stamped that it is the finished forged valve.

The cylinders are heated to the exact required forging temperatures for each material, in the range of 1650-1200ºF (900-1200 ºC) according to the alloy. This is done in automatic and continuous electric furnaces and then charged in the first (extrusion) die of a double die in the stamping press. After the first punch the stem is extruded downwards, leaving a cylindrical portion on top that is going to be the valve head after the second punch. So, with every blow we get two parts, one is the semifinished extruded forging and then the finished forging in the second die. (See Figure 2 for a process scheme.)

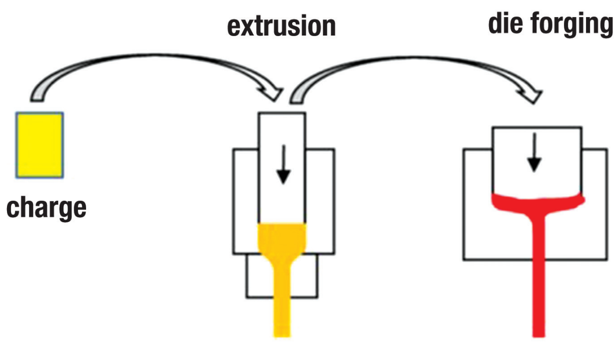


Figure 2: Extrusion process

By the extrusion process big production rates are achieved, so it is the preferred valve forging system for many valves manufacturers working for big OEM's volumes.

The other forging system, that we can call the "European way", because it began in Europe where the volumes were not so big and the forging was slightly better shaped, or at least the stem remains unforged and with a better "as forged" surface finishing, is the so called "upsetting process".

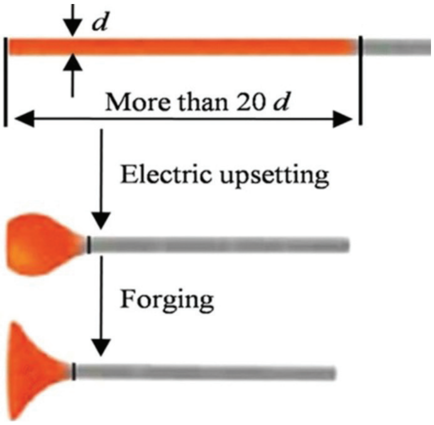


Figure 3: Upsetting scheme

It also begins with steel bars but from smaller diameters than in the extrusion way, with bars sizes close to the final stem diameters, but much longer (usually more than 20 times the bar diameter. Again, the total volume of said bar is the same as the final forged valve from that bar. See Figures 3 and 4 for a scheme and the results of the upsetting steps.

This process begins with long bars being cut to the calculated length each valve design will need, according to its head size and shape, and the overall length. The bars are automatically loaded in the "upsetting machines" that clamp the bars at the middle with jaws connected to electric current and pushed from below by a pneumatically or hydraulically actuated piston that pushes the bar upwards against a top stop, which is also connected to the electric circuit, closing the circuit. The electric current through the upper portion of the bar heats up that portion to red forging temperature according to each material to be forged, and the upward force begins to create a bulb at the top. The process is CNC controlled, the electric current and the force is managed by the computerized control unit to get the shape and volume required on the bulb. Please refer to Figures 5 and 6 for the details and bulb forming.

As soon as the bulb is formed, the semifinished valve forge (still hot at the forging temperature) is unloaded from the upsetting equipment and immediately and automatically loaded to the stamping press. The press hammer stamps the valve head, and a mechanical or robotic arm extracts the formed valve still red hot from the press, while another one is being loaded. Figures 7, 8 and 9 show the valve inside the press just before stamped, finished and ready to be automatically unloaded from the press, and unloading.

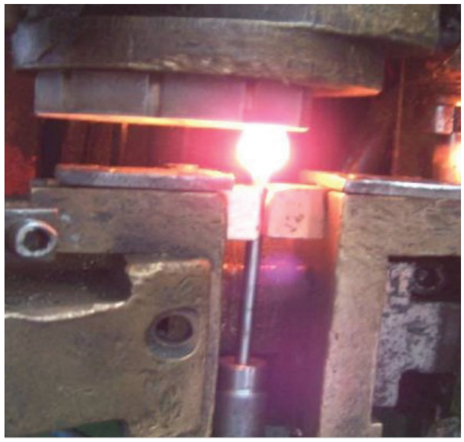
The big advantage of forging the valve head from a bar, with any of the two ways, extrusion or upsetting, is that the material flows to the valve head, with continuous forging lines from the stem, giving a good structure for strength to the head. Please refer to Figure 10 for those forging lines.

SECOND MAIN OPERATION: HEAT TREATMENT

After forging, the valves need to be heat treated according to their materials and final usage. For valves made from martensitic steels (usually intakes) the heat treatment is heating and quenching plus tempering to reach the required tensile strength and hardness, austenitic Stainless Steels or Nickel base alloys must be solution treated and aged for the final characteristics. For those interested in more details on these materials and heat treatments in use for the different alloys and applications, please refer to the "Valve Materials" article from the October-December 2021 issue of Engine Professional.

(continued)

Figure 4: Parts resulting from each upsetting step



Figures 5 and 6: Upsetting forging in process

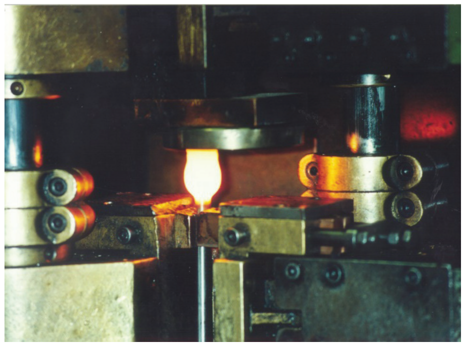


Figure 7: Valve just before being stamped in the press

Figure 8: Finished forged valve

Figure 9: Forged valve extracted from the press

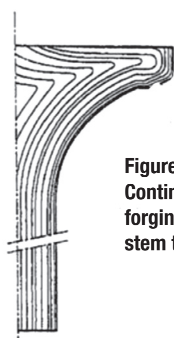


Figure 10: Continuous forging lines from stem to head

These heat treatments are performed in continuous electric furnaces, (or vacuum furnaces for special alloys), and batch furnaces for solution and aging processes, as they require usually more than 16 hours to reach the final hardness and microstructure characteristics for each alloy and final valve application. (See Figures 11 and 12.)

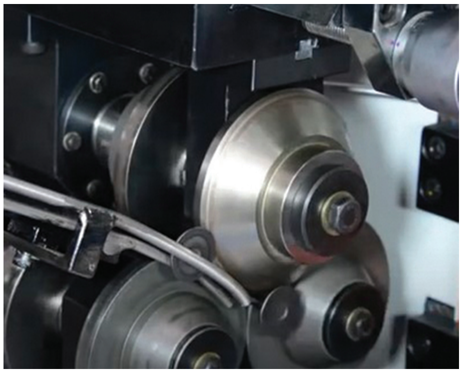
Finally stress relief heat treatments take place to prepare the forging for the machining processes.

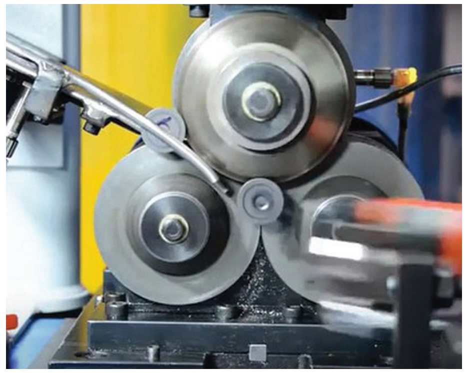
After the furnaces, the valves are tumbled and shot peened to clean them from the scales and burnt products adhered on the treatments.

Another process that it is extremely important before beginning the machining steps, is the valve straightening, which consists of putting the valves inside two (sometimes three) big rollers that push the valves on the stem, while rotating straightens the stem and improves the perpendicularity of the valve head in reference to the stem. (See Figures 13 and 14.)

(continued)

ABOVE: Figures 11 and 12: Continuous Heat and Quench Hardening Furnaces
BELOW: Figures 13 and 14: Valve loading and straightening inside two rollers and a top locating one





HOW VALVES ARE BORN

BY FERNANDO CURELLO

THIRD MAIN PROCESS: FRICTION WELDING

Here we must introduce you to a common process in the valve manufacturing world, which is the friction welding.

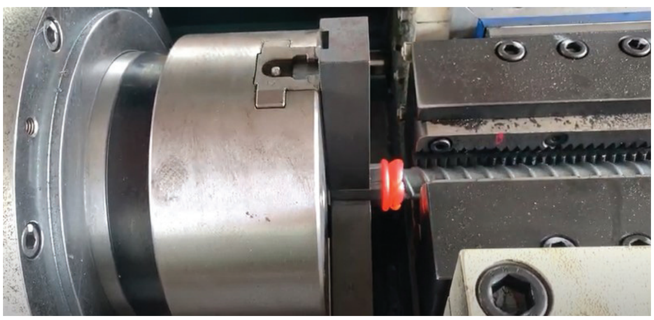
This process may take place even before the upsetting process when the valve will have two different materials on the stem and the head. Again, the reasons and explanations about why two different materials can be found in the previously mentioned "Valve Materials" article.

Rotary friction welding is a solid phase process of joining two different or similar materials by mechanical rotative friction, and axial pressure. The heat generated by the heavy friction leads the two materials to a semi molten state, after applying an axial force, welds firmly the two parts.

This is "no filler material welding", and the safest welding process known for high volume industries. Once the welding parameters are set up properly, the two parts become a single part and all welding is the same in strength properties, i.e., tensile strength and bending fatigue strength. It is widely used not only for valves, but in piping, tubes, shafts, axles, driveshafts, and whenever we need to join two different materials, or the same material with too different shapes and sizes, avoiding excess material machining.

The friction welders have one rotating chuck, with jaws that clamp the bar (or valve stem), and the other part is a fixed jaw that clamps the other portion to be welded. The process consists of varied rpm's and feed rates, a preheating friction to take the two materials to the appropriate temperature, increasing rpm's and pressure against the fixed portion, a final push, and an immediate stop once the welding

ABOVE: Figure 15: Friction welding steps (Left side rotates and pushes against fixed right side). BELOW: Figure 16: Construction steel bar "pin to pin" welded to a highly alloyed steel "head".



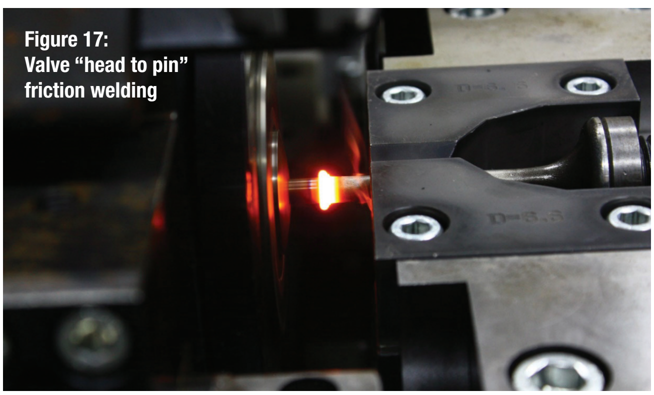


Figure 17: Valve "head to pin" friction welding

has been achieved. (If not, the rotating chuck would break the weld that was just created). Old friction welders used to have heavy hydraulic disk brakes for sudden stopping, nowadays the whole process is managed through electric motors electronically controlled and the stopping is done in milliseconds.

In the valve manufacturing industry, we can have bar to bar welding (called pin to pin), or bar to head (called pin to head) welding, which is usually the case when the process forging is extrusion. (The stem from a martensitic steel is welded to the austenitic or high Nickel valve head with a short portion of the stem).

When the upsetting forging process is used, usually the bars are welded first, and the bimetallic bar is upsetted, with careful handling to put the upper portion to be deformed upwards, if not the head material will be forged in martensitic steel, and not appropriate for the valve head running temperatures.

In Figure 15, we can see the welding steps, and in Figures 16 and 17, the process with pin to pin, and the head to pin one.

The excess material after the welding, generated as flash, is then eliminated by clipping in the same friction welder, or turned in a lathe and centerless ground to leave a uniform and straight stem.

FOURTH AND FOLLOWING STEPS: MACHINING

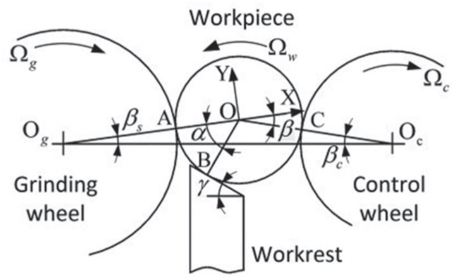
From now on the valves must be machined based on their features, like stems, heads, under-heads or fillet radii, tips, grooves, faces, etc. There are widely varied processes and equipment utilized worldwide and that is primarily driven by volume. For that reason, we are going to cover the more standard processing practices, rather than a part that is produced 24/7/365 or in other words, around the clock.

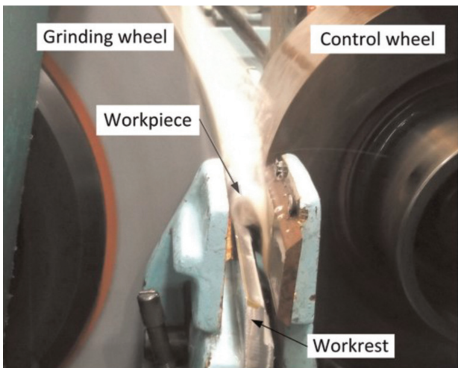
The first operation in the valve machining section must be centerless grinding the stem, because from then on, all processes will use the stem as the main reference for the other machining steps.

The valves are automatically loaded to centerless grinders, which have two big wheels (the grinding wheel and the control wheel). The valve rotates inside them, supported on a blade work rest, and after some seconds the stem is coarse ground. (There will be one or two more centerless grinding steps along the machining line, an intermediate and a final finish to very tight tolerances).

Please refer to Figures 18, 19 and 20 for a typical centerless grinder and the centerless scheme basics.

Figure 18: Typical centerless grinder, with the grinding wheel at the middle left.





Figures 19 and 20: Centerless grinding basics

After the stem is coarse ground, the valve advances to the tip and head front coarse grinding to define a preliminary overall length for the next machining steps. Next is head machining; first the head O.D., seat area and front of the head if required. And after that, some valves will require the fillet radius also to be machined, (in some instances this portion remains "as forged"). These steps can be done in automatic centerless shape grinders, (usually for large volume). For medium size volumes, these are usually turned in these areas using two different CNC lathes for the head OD, face, and front, and the second one for the fillet radius if needed. Please refer to Figures 21 and 22 for these steps.

Following the machining processes, we need to grind or turn the stem grooves for the locks, which can be the single square typical grove, single or multiple radiused groves according to each design. Again, this can be performed in centerless grinders or

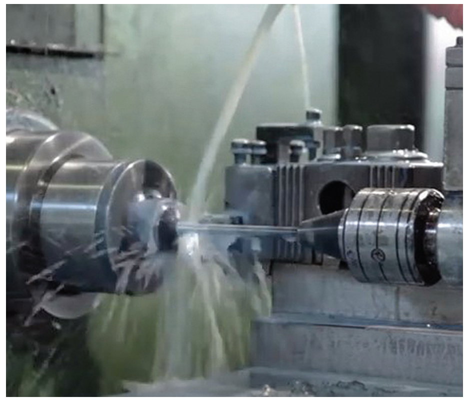


Figure 21: Fillet radius CNC turning

Figure 22: Taper stem end and fillet radius CNC turning

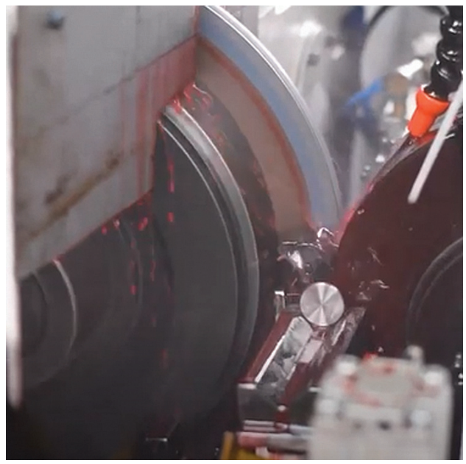


Figure 23: Valves grooves grinding

CNC lathes. In Figure 23 we can see the valve inside a centerless groove grinder.

Now the valves need to be hardened at the tips, grooves, and on some Intake valves the faces (when higher hardness is required at the seat surface than in the stems or heads).

The multiple grooves must be hardened because the valve always rotates inside the three or four radiused grooves, so to avoid premature wear the groves' surfaces must have a higher hardness than the rest of the stem. At the same time and operation, the tip is hardened, and this is usually

BY FERNANDO CURELLO

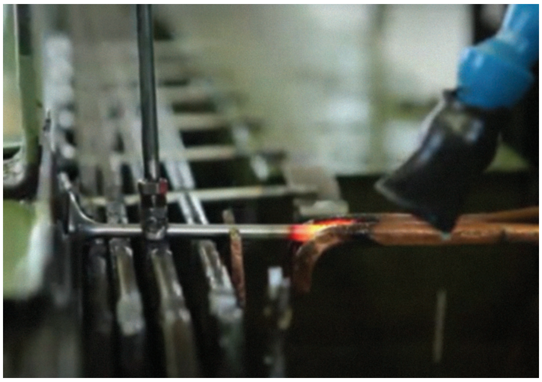


Figure 24: Tip and grooves induction heating


Figure 25: Tip and grooves quenching

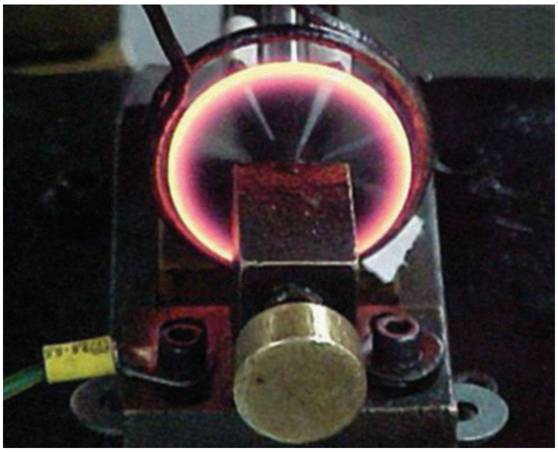


Figure 26: Intake valve seat area induction hardened.

performed in continuous automatic induction heating and liquid quenching lines, as seen in Figures 24, 25 and 26.

Another way for valve face surface fortification, when austenitic Stainless Steels or Nickel alloys exhaust valves are used, (that can't be hardened enough), is the application of a welded deposition in the face area, called the PTA process (from Plasma Transferred Arc), which is an automatic plasma process to apply special alloys with high resistance to high temperatures. Hot Hardness is the term, that is to say that keep their hardness's at the high temperatures of the exhaust gases in heavy duty or turbo applications. These alloys known as Stellite®, Triballoy®, etc. are applied as powders in the PTA equipment and a plasma generated torch, while the valve is rotating which produces a perfect and smooth welding over the valve face area. If interested in the alloys and additional

BY FERNANDO CURELLO

data on this process, you can read about them them in the previously mentioned issue of Engine Professional (October-December 2021).

Please refer to Figure 27 for a PTA plasma torch welding in process.

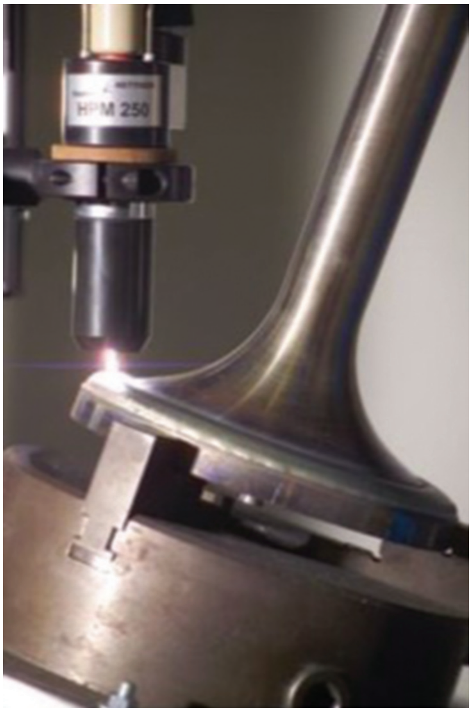


Figure 27: PTA welding on valve seat

After the welding, these valves enter the machining line for head turning on the valve face area.

FINAL STEPS: FINISH MACHINING AND COATINGS

Now the valves begin their final processes, such as an intermediate stem centerless grinding, and the final grind to reach the tight stem diameter tolerances. Then they advance to the stem coatings; which could be the hard chromium process; a black oxidizing; a salt bath (or gaseous) nitrocarburizing or ion nitriding; or PVD (Physical Vapor Deposition) Process. The most popular ones are the chromium bath for hard chromium, and the salt nitriding baths. The PVD processes are mainly used to coat the Titanium valve stems with Chromium Nitride, CrN (gray color) or Titanium Nitride, TiN (yellow color).

Depending on the final stem roughness specified, some chromed valves require a final superfinish stem grinding (or stem polishing) to get the smoothest surface finish required.

Now that the valve has its stem perfectly finished, the valve face needs its final grinding. The production valve grinders must be very heavy, rigid, and big compared with the valves to be machined there, because it's the only way to achieve the specified surface roughness and critical seat concentricity in reference to the stem, and total absence of vibrations, chatter, etc.

Also, the grinding wheels are much bigger than the ones we see in a typical shop valve grinding machine. Please refer to Figure 28 for a close look at a valve being production grinded at the seat.

(continued)

BY FERNANDO CURELLO

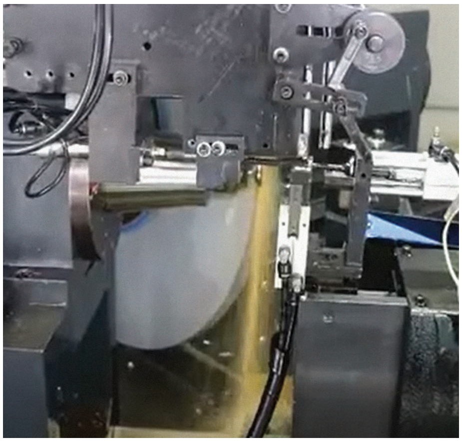


Figure 28: Valve seat grinding in process

When the valve face is finished, the valve goes to the tip grinder, to get, not only the correct overall length and surface finish, but what is most important, the precise distance between valve face and tip, because that will give the assembled installed valves the same length when located in their final home, the cylinder head.

After several ultrasonic washing steps, final Laser marking, and final Quality Control measurements, our beautiful valves are ready to be packaged and shipped to somewhere in the engine world.

I'm fairly sure that now, after reading these pages about valve manufacturing, you'll be ready to handle these "big nails" with the same care and love that many people put in factories around the world to give us such a critical engine part with the highest quality and reliability. And as I always like to say, the combustion engine manufacturing is a never-ending improvement process and the best is yet to come – follow us in EP magazine and be part of it! ■

Fernando Curello
Technical Specialist
815-201-0779 • fernando@aera.org