couple of guys including a British amateur geologist and a German chemist in the late 1700s. The German, Martin Heinrich Klaproth, reportedly named the material titanium for the Titans of Greek mythology. Pretty cool. Maybe this dude was a racer at heart without even knowing it. Eventually, starting in the 1950s, titanium began to see serious use by both the U.S. and the Soviet Union for military applications including submarines and jet aircraft.

Many titanium valves are generally produced by starting with a forging, then machined to final shape, but some are produced using a two-piece inertia-welded design. Citing Xceldyne as an example of this approach, they utilize an inertia welding process to attach a partially machined valve head and stem together. During this process, the two previously machined parts are fused together using state-of-the-art equipment that uses inertia and a force to weld the two pieces into one solid component. Once the valve blank is welded, it's heat treated to alter the grain structure of the titanium through precision heating and cooling at varying temperatures, taking into account the properties of the alloys and the specific application (intake or exhaust). According to Xceldyne, this process is so effective that inertia welded valves have been certified as having a superior grain structure as compared to a one-piece forged design. The valve is then CNC machined and in many cases undercut in the stem area to allow a bed for the inlay of a coating. The valve is then plasma moly coated. Specific sections of the valve are further machined and the stem is ground, leaving the plasma moly coating over only the desired stem area. The head, stem and keeper grooves are then final machined. Stem grinding is then finalized to establish dimensional tolerance to within 0.0002". The valve is then precision polished to reduce the potential for carbon buildup.

Various styles of valve tips are generally available, which includes a hardened steel tip, a diamond-like coating or a ceramic-coated tip (ceramic tips are to be used in conjunction with lash caps) and thin-film technology such as a PVD coating.

As we noted earlier, titanium is a relatively soft material, requiring a protective contact surface at the stem tips, usually requiring hardened lash caps. Xceldyne noted that when valves feature stem diameters smaller than 5/16" (7mm or less in diameter), a specialized hard coating is applied to the stem tip in order to protect the tip from lash cap friction.

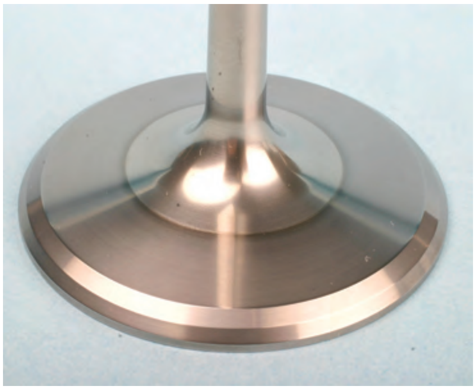
Intake and exhaust valves are available today in a staggering range of choices.

The ceramic coating is a durable hard coating intended to protect the titanium from the friction caused by the lash cap. Other coatings such as a PVD (plasma vapor deposition) treatment, a CrN (chrome nitride) treatment, CVD (chemical vapor deposition) or DLC (diamond-like carbon) or other highly specialized protective applications may be applied to the tips. This hardened feature at the tip prevents material transfer or galling between the tip and lash cap.

Hollow titanium valves are also available, either with hollow stems or with a combination of hollow stems and hollow heads. Hollow stem designs reduce valve weight by about 10%. The hollow head design is a proprietary process that removes an additional 6 to 8 grams of weight (of course, depending on valve size). As part of the proprietary process, the inside of the valve head may be reinforced to provide a support structure for strength and rigidity.

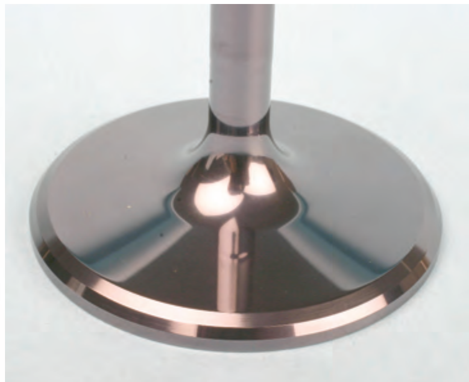
When a stem is gundrilled, according to Xceldyne's Scott Highland, careful attention is paid to achieving a consistent precision surface finish and concentricity in the I.D. to obtain uniform stem wall thickness. Sonic measurement technology (and other proprietary methods) are employed to monitor the I.D. operations.

Scott noted that the commonly used lock design for titanium valves is the "super 7" style, commonly referred to as a 7-degree lock, which is actually closer to 8

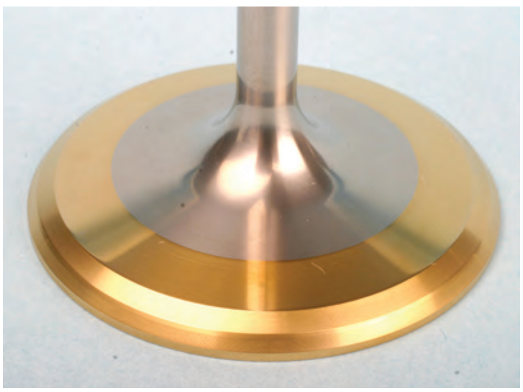


A titanium valve treated with a chromium nitride process, pictured right, provides seat face hardness on this sample. The telltale ring on the valve throat, pictured above, indicates the transition between the CrN coating (applied to the seat area and majority of the head) to the stem base, which is "bare" titanium.

The Formula One titanium valve pictured in the middle features a DLC coating on the stem area for guide wear protection and friction reduction.



The Pro Stock titanium valve pictured left features a PVD-applied DLC (diamond-like coating) for extreme hardness and reduction of friction. Closeup of a PVD-applied DLC coating, pictured above.

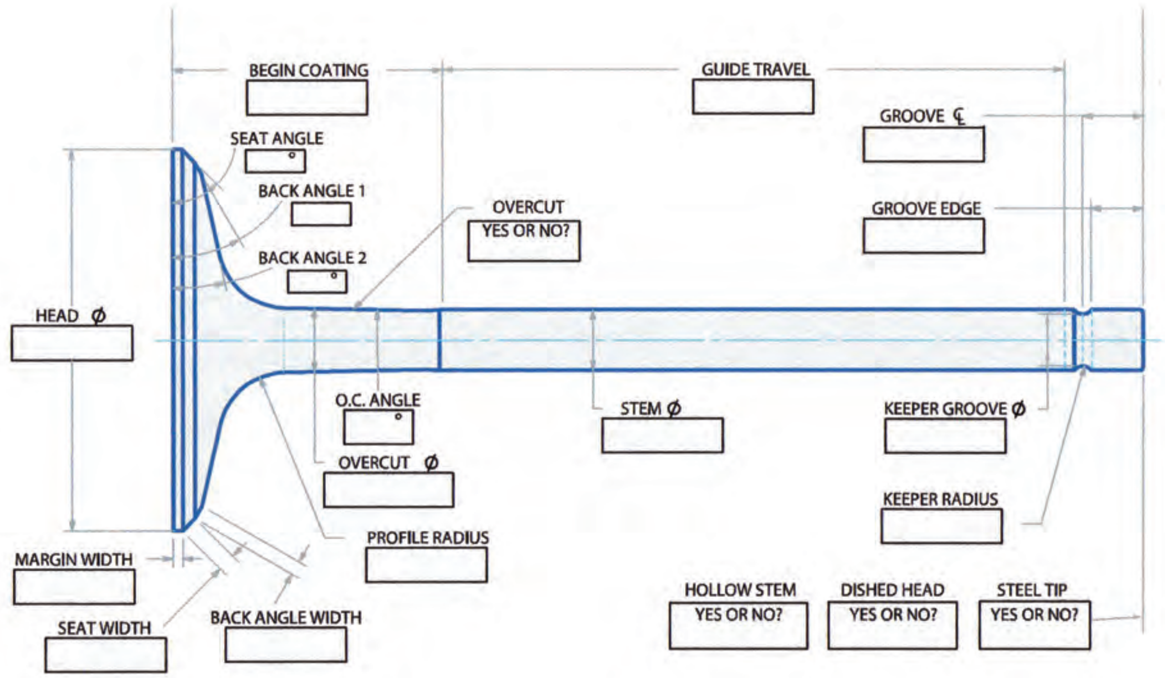


Pictured at the left is a titanium valve treated with a titanium nitride hardness finish on the stem tip and lock area and seat face area. Closeup of a TiN coating on the face area, pictured above.

TiN coating on the valve face adds protection from heat and deposit buildup.

Applying a hard coating such as TiN to the stem tip and lock groove protects the titanium material from galling damage from a lash cap and retainer locks.

Valve nomenclature and custom valve worksheet. (Courtesy of Del West Engineering)



degrees. Lock grooves are square grooved or radiused for superior lock engagement as well as reduced potential for stress risers. Xceldyne notes that they apply a specialized thin-film PVD coating to the locks and retainers to prevent material galling between titanium/titanium materials. Scott mentioned that lock-to-retainer interface is perhaps the biggest galling-potential issue that must be addressed.

Scott also noted that while undercutting is employed on many titanium valve designs, there are occasions where exhaust valves may feature an overcut in order to provide the required additional cross-sectional mass needed for some extreme applications.

Precautions concerning the handling and use of titanium valves

- Do not touch the valve surface with your bare hands, since fingerprint acids may affect the coating). Use gloves or coat the valve with oil before handling.
- Never use a lapping compound, or any abrasive material when the valve is coated with a PVD style coating.
- Valve seats should be replaced during each and every rebuild in order to insure a proper valve-to-seat contact. The width of the contact zone (valve face to valve seat) should be at least 1mm.
- New valve seats should be a relatively soft material, such as bronze or nodular iron (heat treated to Rockwell RC32 or less).
- Unless directed otherwise by the valve maker, always use hardened lash caps on titanium valves. Some makers offer valves built with friction-welded hardened tips. Bare, unprotected titanium tips are relatively soft and will mushroom when exposed to rocker arm forces.

If a titanium valve features a stellite tip (hardened stellite tipped valves don't require lash caps), during valve service, the stellite tips can be ground, but with caution. You should be able to safely remove approximately a maximum of 0.015" to 0.020". ***It is absolutely essential that you check with the valve maker to determine if the tip is hardened or not, and if hard lash caps are required or not! Don't assume anything…. If you run without lash caps when they're required, you'll ruin the valves in a heartbeat.***

As far as valve seats are concerned, again keep in mind that titanium is a relatively soft material. A traditional cast or hard seat can beat a groove into the valve face, so a nickel bronze seat material is recommended.

Del West, for example, now offers a titanium valve that features a steel tip so no lash cap is needed, and the rest of the valve is coated with chromium nitride, making it compatible with ductile iron seats or beryllium-copper seats.

KPMI (Kibblewhite Precision Machining Inc.), to cite an example, recommends the use of their Ampco 45 seat material for titanium valve applications. This material's high 80% copper content provides excellent thermal qualities, and the 5% nickel provides just enough hardness to prevent pounding-out. The remaining aluminum content provides the degree of softness to prevent damage to the titanium valve face.

Titanium valves are extremely lightweight and are designed for applications where valvetrain weight needs to be reduced, for high-rpm and extended high-rpm applications, since titanium valves allow for higher engine speeds and will accommodate highly-


A sample of titanium valves in blank form. Stems have been machined to near-final diameter and the heads are rough formed, prior to CNC machining. (Courtesy of Xceldyne)


A variety of specialty coatings can be applied to valves to enhance specific properties such as lubricity, resistance to wear and thermal performance. (Courtesy of Xceldyne)

aggressive camshaft profiles. The lighter weight contributes to minimized wear on rocker arms and improved valve spring life. As valve weight is reduced, lighter springs can be used. As spring force is reduced, this reduces frictional loads between the lifters and cam lobes. So, the use of titanium valves offer both higher engines speeds, quicker engine acceleration, and reduced friction throughout the valvetrain. While lighter weight and the resulting ability to achieve higher engine speed is of obvious benefit in any form of racing, the ability of the engine to produce quicker acceleration is extremely beneficial in a drag racing application.

It should be obvious that titanium valves are designed for higher engine speeds, which is fine for higher top-end power. However, for extreme temperature situations (blown, turbo, nitro engines), titanium may not be the ideal choice. Also, for many street applications, titanium may not be a good choice for an engine that doesn't need to rev as highly, and for an engine that will be buttoned up and not torn down and serviced regularly. In other words, it's probably best to reserve the use of titanium for naturally-aspirated race or inlet-side forced induction applications where valvetrain weight and sustained high-rpm use is paramount.

The Del West engineers sum-up the benefits of lighter valves succinctly: Creating a broad power band of lower-RPM power for the run off-the-corner has the greatest impact on lap times, and represents the largest challenge to engine builders.

However, whether the goal is maximum peak power or the broadest possible torque curve, titanium valves and other lightweight valve train components give the engine builder greater freedom in choosing camshaft profiles. The lighter mass also promotes faster valve acceleration from any RPM, again giving the engine builder and cam designer more flexibility. The additional benefits of lighter valves, retainers and locks is that they can push valve float to levels of RPM above which you intend to operate the engine.

NIMONIC 90

Nimonic is a nickel-chromium alloy. A specific grade of this material, Nimonic 90, is used by some makers for producing high performance valves. Nimonic 90 is a "super" alloy comprised of nickel-chromium-cobalt, which offers high strength and especially an ability to withstand extremely high temperatures, reportedly well within the 2000 degree F range, without distortion. This material is also widely used in aerospace industries for applications such as valves in turbo motors and blades and discs in gas turbines. Manley reports that they've seen success in such extreme applications as nitromethane and high-boost turbo applications such as multiple-turbo tractor-pull engines.

INCONEL

Inconel is a registered trademark of Special Metals Corporation, referring to a family of nickel-based superalloys. Inconel alloys are oxidation and corrosion resistant materials designed for use in high heat environments. Inconel retains strength over a wide temperature range. As opposed to steel or aluminum, Inconel doesn't creep as much (change dimension) under high heat use. Inconel is commonly used in high stress aircraft applications such as high-speed airframe and jet engine components.

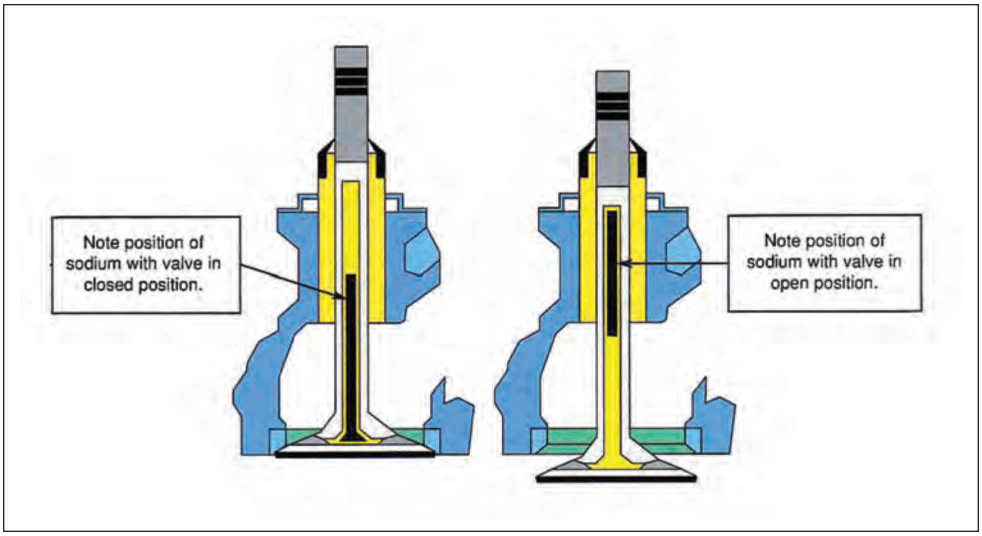
Five "grades" of Inconel are in common use, including 600, 625, 690, 718 and 939. As an interesting sidenote, a special Inconel X material was used in the makeup of the skin for the legendary X-15 rocket plane.

Basically, the benefits of Inconel include light weight, extreme resistance to temperature, high strength and resistance to thermal dynamics.

Inconel alloy makeup (depending on the specific alloy mix) can include carbon, manganese, silicon, phosphorous, sulfer,

PERFORMANCE ENGINE VALVES

BY **MIKE MAVRIGIAN**



Sodium (in a gundrilled sodium-filled valve stem) moves upward as the valve enters the open position, theoretically transferring heat to the guide for improved heat dissipation. (Courtesy of Manley)

nickel, cobalt, chromium, iron, aluminum, molybdenum, titanium, boron and copper, with the heaviest material concentration accounted for with nickel and chromium.

Inconel valves offer extremely high thermal resistance and are designed for high heat applications as found in turbocharged, supercharged and nitrous applications.

Reducing Valve Mass: A Camshaft Maker's Point Of View

Since valve weight in particular naturally relates to valve spring force and cam profile selection for given race applications, I contacted the folks at Comp Cams for their input.

For the majority of street engines, a quality stainless steel valve is recommended. Billy Godbold of Comp cams noted that they prefer titanium for most race applications, but that some engine builders that specialize in turbocharged applications prefer a high nickel Inconel valve. "We have to leave the final decision up to the engine builder, but it does limit the cam designs we can choose from when going to a heavy valve."

Hollow stem valves tend to work great on the intake side, but they are much more difficult to manufacture and to inspect for defects on the I.D. surface. Many of the upper-echelon engine builders shy away from hollow valves for that reason in endurance (NASCAR or 24-hour style) racing.

Comp's Thomas Griffin noted that stainless steel valves are most common in street and mild-performance racing. Titanium is used when valve weight is important and when budget is not a consideration. Inconel is used when exhaust gas temps get really high. Stainless steel (for street performance) has much better durability characteristics than titanium, and the street guys won't usually see the real benefits of titanium. In racing, use titanium when you want to lose weight and spend a lot of money. Of durability is a concern, and you're already making as much power as you want and are already turning the engine as high as you want, then you need to use a stainless steel material. If you're running nitromethane, then an inconel exhaust valve material will be your best bet if you want to finish a race. NASCAR engines use a variety of titanium materials because of the temperature and impact related issues associated with their severe applications.

Godbold noted, "On the exhaust side, sodium-filling is the best way to increase the head capacity of a hollow exhaust valve. If stock diameter steel valves are required, but a valve weight is not mandated, going to a hollow intake and sodium filled exhaust is certainly a major advantage.

"From our point of view," Godbold continued, "the most critical point is to get mass out of the valve. The lighter the valve, the stiffer the valvetrain system is in relation to the mass it must move. Also, as the valve mass is decreased, you can reduce the spring force needed to control a given valve motion and/or go to a more aggressive cam design that can make more power."

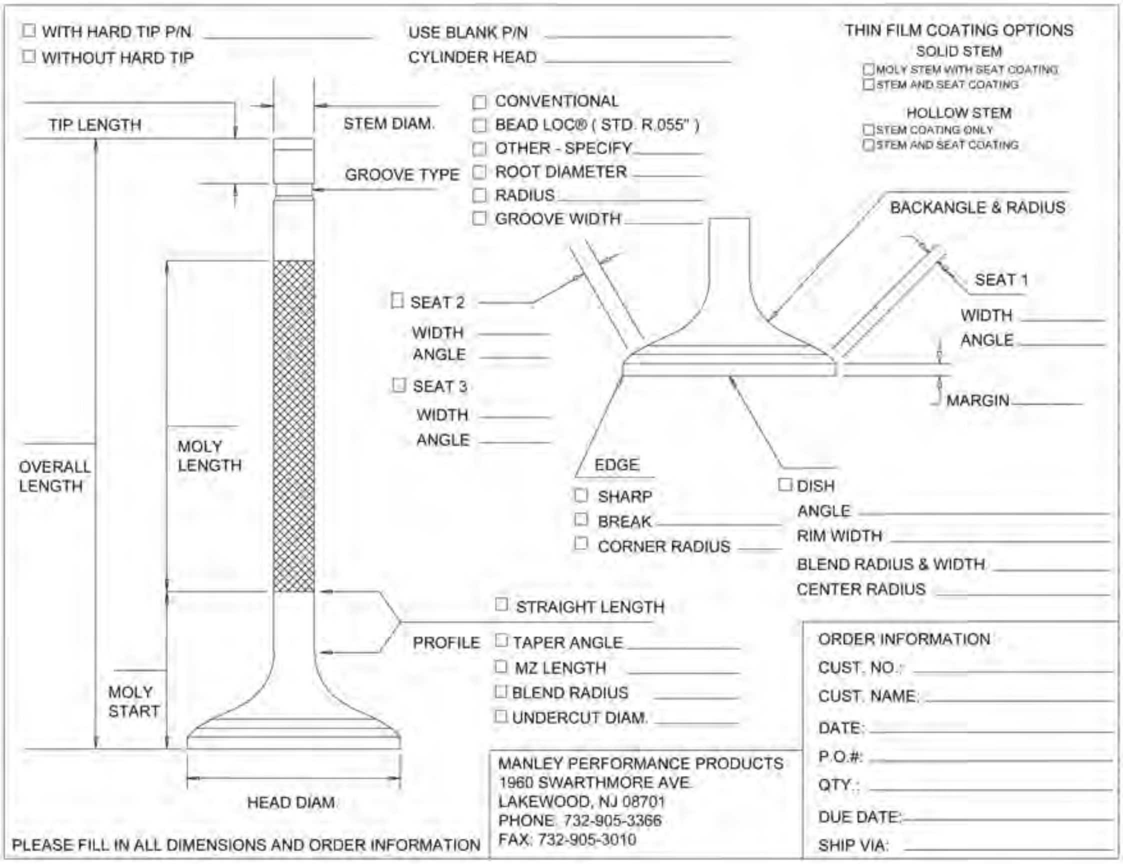
To prevent excessive tip wear on titanium valves (especially the small O.D. non-hardened tip variety), using a lash cap provides an excellent wear surface for the roller tip, sliding contact or cam follower. While you always want the rocker to push down on the section of the cap directly over the stem, using a lash cap certainly gives you a better sense of safety as you approach the edge of the valve in high lift applications with a very small (5 to 7mm) stem.

Griffin noted that since engine builders and cam designers push limits, the stems get smaller and the lift gets higher. As a result, lash caps are used with smaller valves to better distribute the load across a larger area than the base stem tip area. They are also used with higher lift because when the lift is increased, the rocker arm sweep length usually increases across the valve or lash cap as well, compounding the issues caused by the smaller valve stem diameter.

We only provide solid stem designs through Comp Cams, but the hollow stems certainly provide lower mass. Theoretically, these would be the best way to go, but there are very serious manufacturing and inspection hurdles to jump when producing a hollow valve.

The question becomes "where is the safest and best way to invest my money when building this engine for this specific application and within this budget? Sometimes your answer will be a hollow valve, but in most cases it would probably be a solid valve stem unless we see a major technical jump on the manufacturing side. As the OEMs start pursuing that route on the mass market side, we could find new technologies available to make these parts on the performance and racing side. We have certainly seen that effect with the availability of several new Beehive valve springs and now nitrided flat tappet cams that we offer. Just a few years ago, we could not provide either of those technologies dependably, at a high level, and for a reasonable cost, but lower

BY **MIKE MAVRIGIAN**



This custom-order chart, courtesy Manley, is an example of the data required when ordering custom valves. Variables include stem diameter, overall valve length, lock groove type, head diameter, type of head edge, width and angles of mating face area and seat margin.

machine cost (although the cheapest machine was still on the order of a quarter-million dollars plus) for the tools to manufacture these parts became available in recent years.

Per Griffin, solid stems are stronger, hollow stems are obviously lighter, but the quality control of an inside stem surface is very difficult to control. Because of the pounding of the valve upon closing, the sensitivity to failure is compounded if there are machining marks that can neither be controlled nor removed because they cannot be seen.

While 95% of our market uses a square groove lock, the stresses in the valve are minimized with a single round groove. The lowest stress system is a top lock design with a small round groove at the top of the lock, and the lock is designed with a slightly smaller angle than the retainer so that the valve is held by the collet force squeezing more at the bottom region of the lock-to-valve interface.

"Round grooves are best because they address the issue of stress concentration zones associated with a very small radius of the inside corner of a square groove lock. In high-end racing with any material valves, retainers and locks," Griffin stated, "I would use only a single groove because it forces the lock to grip the valve stem and hold it in place." Many OEM engines feature multiple-groove steel locks and valves that allow the valve to spin in the locks, which is fine for street and low-end performance. Because there is a loose fit between the valve and locks, it could cause an over-stress condition if used in severe racing.

Godbold noted that "because Comp Cams only offers a street valve, we tend to defer many of these questions to the experts at the valve engineering and manufacturing end. We have worked very closely with Del West and Xceldyne on projects in the past and will continue to do so in the future."

The Bottom Line

As a quick summary, high quality EV8 stainless steel valves are a good choice for street and naturally-aspirated race engines, while titanium valves accommodate high engine speeds in race engines that don't experience uncommon extremes in temperatures, and Inconel (and other similar nickel content) valves are suggested for extreme cylinder pressure/extreme temperature applications (primarily exhaust). For extreme-temperature applications such as very high cylinder pressure nitromethane, blown or supercharged use, a combination of titanium intake valves and Inconel or Nimonic exhaust valves are appropriate.

Valve Coatings: More Than Meets The Eye

Instead of simply listing the names for the various valve coatings, we wanted to provide a bit of information about each of these specialized coatings. The information that follows was provided courtesy of Del West Engineering and Xceldyne.

- **PVD (Physical Vapor Deposition)** occurs because of a physical reaction. Inside a vacuum chamber plasma environment, metals are deposited via evaporation, sputtering or arcing fragments of the metals which are physically moved on to the substrate. In other words, there is no chemical reaction which forms the coating on the substrate.
- **CVD (Chemical Vapor Deposition)** occurs because of a chemical reaction.

BY **MIKE MAVRIGIAN**

This entire custom-order Del West titanium intake valve also features chromium nitride coating on the entire valve, allowing the faces to accommodate either ductile iron or beryllium-copper seats.

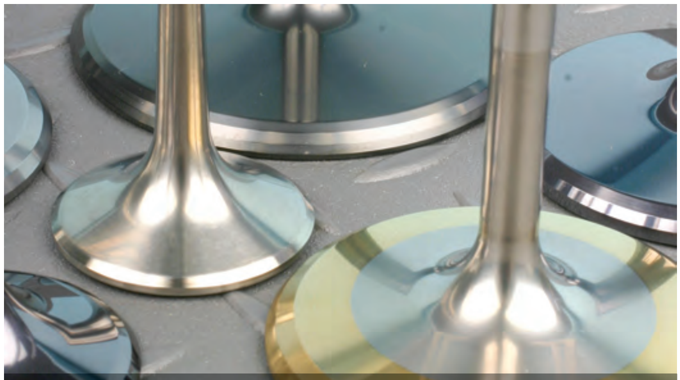
This titanium intake valve (made by Del West) features an integrated steel tip, which requires no lash cap.

The process exploits the creation of solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material. The product of that reaction is a coating material which condenses on all surfaces of the part to be coated and inside the vacuum chamber plasma environment.

- **DLC (Diamond Like Carbon)** coating is a thin-film coating applied via a plasma-assisted Chemical Vapor Deposition (PaCVD) process. This coating combines very low frictional resistance and extreme hardness. The coatings are used to reduce wear and friction for rapidly-reciprocating components, where friction reduction is a primary goal. Common applications include finger followers, tappets and piston pins.
- **CrN (Chromium Nitride)** is a thin-film coating also applied using a PVD process. According to Del West, a cathodic arc is discharged at the target to evaporate the chromium into a highly ionized vapor, which is done in a partial pressure of nitrogen. This provides a higher level of adhesion as opposed to a PVD sputtering method in which a glow plasma discharge bombards the material and sputters some material away as a vapor. Del West commonly uses this process for titanium, steel and nickel-based valves.

Thermally-sprayed coatings can provide thick coatings over a large area at high deposition rate as compared to other coating processes such as PVD or PaCVD. These are coatings that include plasma spraying and High Velocity Oxygen Fuel (HVOF) spraying that are widely used to protect valve stems and tips.

Thin-film coating options such as CrN (Chrome Nitride), TiAlCrN (Titanium Aluminum Chrome Nitride), DLC (Diamond-Like Carbon) and a:SiC (Amorphous Silicon Carbide) are selected during the valve design process based on the



SOURCES

The following is merely a sample list of performance valve manufacturers.

- **Comp Cams**
  3406 Democrat Rd.
  Memphis, TN 38118
  800-999-0853
  www.compcams.com
- **Crane Cams Inc.**
  530 Fentress Blvd.
  Daytona Beach, FL 32114
  386-252-1151
  www.cranecams.com
- **Del West Engineering Inc.**
  28128 W. Livingston Ave.
  Valencia, CA 91355
  800-990-2779
  www.delwestusa.com
- **Electronic Chrome & Grinding**
  9128 Dice Rd.
  Santa Fe Springs, CA 90670
  562-946-667
  www.ecgrinding.com
- **Elgin Industries**
  1100 Jansen Farm Dr.
  Elgin, IL 60123-2555
  847-742-1720
  www.elginind.com
- **Ferrea Racing Components**
  2600 NW 55th Ct. Suite 234
  Ft. Lauderdale, FL 33309
  888-733-2505
  www.ferrea.com
- **KPMI (Kibblewhite Precision Machining)**
  580 Crespi Dr. Suite I
  Pacifica, CA 94044-3426
  650-359-4704
  www.blackdiamondvalves.com
- **Manley Performance Products**
  1960 Swarthmore Ave.
  Lakewood, NJ 08701
  800-526-1362
  www.manleyperformance.com
- **Milodon Inc.**
  2250 Agate Court
  Simi Valley, CA 93065
  805-577-5950
  www.milodon.com
- **Pioneer Inc.**
  5184 Pioneer Rd.
  Meridian, MS 39301
  800-647-6272
  www.pioneerautoinc.com
- **Racing Engine Valves**
  4704 NE 11th Ave.
  Ft. Lauderdale, FL 33334
  954-772-6060
  www.revalves.com
- **RPM International Inc.**
  16313 Arthur St.
  Cerritos, CA 90703
  800-981-0776
  www.racingpartsmax.com
- **SI Valves**
  4477 Shopping Lane
  Simi Valley, CA 93063
  800-564-8258
  www.sivalves.com
- **Supertech Performance Inc.**
  3580 Charter Park Dr.
  San Jose, CA 95136
  408-448-2001
  www.supertech performance.com
- **Xceldyne Technologies**
  37 High Tech Blvd.
  Thomasville, NC 27360
  888-481-2310
  www.xceldyne.com
- **Zanzi Spa**
  Corso Vercelli 159
  10015 Ivrea (TO), Italy
  +39 0125251540
  www.zanzi.com

suitability of the coating properties for the specific engine application and with reference to historical post-engine teardown feedback and analysis.

In certain applications, a combination of coatings may be selected for an individual valve.

For example, the “ductile” properties of a CrN coating (Hardness 1,600 HV) will be selected for application to the valve tip, while the “low friction” attributes of a DLC or a:SiC coating (Friction coefficients 0.1 or less) will be chosen for application to the critical valve seat head region.

Dry fuels such as those with low-sulphur content or alcohol based are suitable environments for certain low-friction and inert thin-film coatings. The application of a coating upon the valve head and valve stem can be exploited as a “solid lubricant” minimizing adhesive wear between the valve-seat or valve-guide interface. Adhesive wear, also known as scoring, galling, or worse case seizing, results when two solid surfaces slide over one another under pressure. Surface projections, or asperities, plastically deform and eventually weld together under the high localized pressure. As sliding continues, these bonds break. This creates cavities on one surface and projections on the other. Tiny abrasive particles can also form causing additional wear.

Specific to applications associated with excessive exhaust gas temperature, hybrid coatings (Pt, Pd, Nb based) have been examined as a means to retard embrittlement of the base Ti material by minimizing the ingress of oxygen through the coating and represent novel strategies to yield robust coatings for ultra-high temperature environment applications.■

Coating Material	AlTiCrN	CrN	TiAlN	DLC	a:SiC
Structure	Multilayer	Monolayer	Multilayer	Multilayer	Monolayer
Microhardness HV	3500	1,750	3,300	2,500	1000-2200
Friction coefficient	0.5	0.5	0.32	0.1	0.13
Max Service Temp (oC)	900	700	900	400	500
Max Service Temp (oF)	1652	1292	1652	752	932

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