Making the connection

Glen Smale discusses racing engine con rod technology with specialist manufacturers from around the world

Making the connection necessary between the top end and the bottom end of the racing engine solid yet as light and efficient as possible has never been more crucial than it is today. Increased pressure on performance and durability has forced connecting rod manufacturers to consider exotic materials and futuristic designs in the pursuit of total performance.

MATERIALS

Whether produced from aluminium, steel or titanium, forged or billet, con rod materials and manufacturing processes differ from one supplier to the next. Brian Crower, Managing Director of Brian Crower, Inc in San Diego, California says: “Aerospace grade 4340 steel is our preferred material for most connecting rod applications”. Some manufacturers use forged blanks and then machine to a billet finish while some machine from flat bar.

Crower notes that 4340 steel rods are cost effective, reliable and deliver a time tested solution for high horsepower applications. Aluminium rods are used for certain disciplines like drag racing, where high boost and/or nitrous are commonplace. While steel and titanium are stronger in terms of overall tensile strength, the aluminium alloy delivers the required ‘give’ during violent operation. However, the aluminium rod is essentially a disposable part, requiring frequent replacement.

“Compared to steel, titanium is a great choice if you’re spending other people’s money”, noted Crower. “At nearly $600 per rod, the lightweight properties of the material are normally far outweighed by the drastic increase in the price of aerospace quality 6AL4V titanium alloy… but it is a very nice rod for the price.”

Stefan Asplund is Managing Director of MX Composites AB in Linköping, Sweden a company that makes con rods in aluminium based Metal Matrix Composite (MMC). “The increased specific stiffness in these materials compared to conventional materials such as steel, aluminium and titanium makes it possible to achieve significant weight savings. We can make savings of 50%, or of 25% when compared to titanium due to the high specific strength of our materials”, Asplund explained.

This weight saving on reciprocating and rotating mass has a great impact on engine performance, as power is increased throughout the rev range with reduced friction and vibration. Asplund notes that the combined effect is a completely transformed engine character that runs more smoothly with a softer and quicker throttle response.

Bushing crower

Arrow

nonferrous materials".

Titanium is sometimes used by Carrillo in applications where weight is the primary driver in the design. Most of the Ti found in connecting rods is from the 6AL-4V family, although Carrillo has made rods using variants of 6-4. However, Ti has never been the low cost alternative and is generally less durable than steel.

The design requirements of aluminium con rods primarily centre around weight and dampening issues. "The dampening effect is driven from the relatively low Young's Modulus ('stiffness') of aluminium as compared to steel or Ti. The lower stiffness can also create difficulties in controlling the center-to-center (piston-crank) distance of the rod in tension as well as bore integrity," Verkooij explained. However aluminium also requires a comparatively large cross-sectional area to achieve the necessary strength, putting space (clearance) at a premium.

Carrillo's 'Gen IV' high-strength steel is an excellent material for con-rods and would be used in applications that require high strength, low weight and durability (fatigue life), and given space limitations. Verkooij outlined that the yield strength of this type of material would suggest a possible reduction in cross-sectional area throughout the rod, as long as attention is paid to the modulus. A properly designed and manufactured forging can optimise the properties of the material to the con-rod design and reduce manufacturing time. By optimising the grain flow of the material around the crank-side (big end) of the con-rod, this increases performance.

Verkooij summarises: "Steel is probably the best choice for connecting rods as many race series prohibit the use of other materials anyway. There are instances where other materials should be employed, but this generally leads to higher costs".

Roslyn Arnold, Sales Manager at Arrow Precision Engineering Ltd in Hinckley, Leicestershire, says: Arrow uses EN24V for the vast majority of our steel rods. This is double air re-melt steel that we have drop forged, ensuring a better grain structure and lower sulphur content (0.25%), which means fewer inclusions and faults". When forged, imperfections are reduced to an absolute minimum, ensuring consistency and it is suitable for most race applications.

Arrow uses 6AL-4V titanium forgings in extreme performance situations such as World Superbikes, where a light drive train and low reciprocating weights gives instant throttle response and much lower gyroscopic forces, allowing the bike to turn in quicker. A 30% weight saving over steel makes a huge difference to the reciprocating mass of the rod and cap assembly, however they ▶

With input material comprising forged plates, the MX Composites MMC con rods are machined by a patented High Speed Machining method. According to Asplund this results in cost effective manufacturing and outstanding finish. The fine surfaces created by the machining methods make it possible to run these con rods without bearings and bushings.

According to Cindy Verkooij, Marketing and Promotions Manager of Carrillo Industries in San Clemente, California: "Carrillo has been and remains primarily a steel connecting rod manufacturer. We do employ other material types when the operating parameters suggest an improvement or necessitate the properties that can be obtained from

MX One-piece

THE ARROW PRECISION FILE


Ian Arnold

PRODUCT
Connecting Rods, Crankshafts, Flywheels, Cam followers, Shims and Valve guides. Also distributor for ARP Fasteners

RACING MARKET
World Rally Cars, Le Mans Series, Formula Three, Touring Cars, World and British Superbikes, Speedway, Hillclimb, Classic and Vintage and many many more

HEADQUARTERS
Hinckley, Leicestershire, England

WEBSITE
www.arrowprecision.com

KEY PEOPLE
Managing Director: Ian Arnold
Production Director: Jeff Kirton
Design Engineers: David Whitbread, David Currie
Technical Sales: Russell Towlson

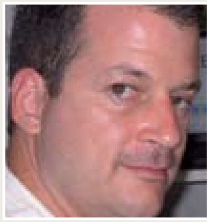
SCALE OF OPERATION
Total workforce of 65; racing is 80% of business

BACKGROUND
Founded by engineer David Arnold in 1974. His son Ian took over as Managing Director in 1997 and the company has gone on to global success. In July 2006 Arrow Precision bought the business and assets of D. Kiddie Engineering Ltd in and thereby successfully added crankshafts to the product range. Still privately owned

GLOBAL DISTRIBUTION
UK and Europe, USA, Australia and Asia

THE BRIAN CROWER, INC. FILE


Brian Crower


Dustin Spencer


Arthur Yang

PRODUCT
High performance, internal engine components including connecting rods, camshafts, crankshafts and assorted valve train parts

RACING MARKET
Circuit, rally, drag, drift, time attack and street performance

HEADQUARTERS
San Diego, California, USA

WEBSITE
www.runbc.com

KEY PEOPLE
Managing Director: Brian Crower
Technical Director: Dustin Spencer
Chief Test Engineer: Arthur Yang

SCALE OF OPERATION
Total workforce of 15; racing is 75% of business

BACKGROUND
Founded by Brian Crower, formerly of Crower Cams, to produce high performance products for late model engine platforms. Dustin Spencer has spent 10 years at Crower in an R&D capacity

GLOBAL DISTRIBUTION
Covering all international markets including Europe, Asia, Australia and the USA

need a lot of care and regular checking for ovality. Arnold again: "We have made great strides in the area of fastener retention, which is the Achilles Heel of titanium rods. Where most titanium rods use a bolt to retain the end cap, we use a stud and nut assembly, thus allows the correct stretch to be achieved without worrying about thread galling".

Based in Long Beach, CA, Venolia Pistons and Rods produce rods for Chevrolet, Ford and Chrysler engines and forgings vary in structure due to the application. According to Venolia: "In drag racing, the choice of material for connecting rods comes down to steel and aluminium. Steel rods have become very popular in midlevel sportsman racing. They do have their limitations, their biggest problem is weight". Typically, a steel rod for a large cubic inch engine could weigh as much as 1200 grams and as the rod becomes longer and heavier the stress on the bolts and cap increase. As a result, steel rods are tough on pistons the make the piston more susceptible to cracking where the pin boss joins the skirt.

Aluminium con rods on the other hand weigh about one-third of steel counterparts, and because of this weight advantage, manufacturers can use a thick cross-section without a big weight penalty. According to Venolia another advantage of aluminium rods becomes apparent in the condition of the bearing and the wrist pin when the engine is disassembled.

Venolia reports that all of their aluminium rods are made from Alcoa bar stock (7075-T6). In their manufacturing process, each billet is heated and mechanically forged with a 3000 ton press to obtain the tightest grain pattern in the material, which is then CNC machined to provide a precision finish. Alternatively, steel connecting rods provide longevity at an affordable price but as the horsepower and engine speed increases aluminium rods become a more practical choice.

According to Glenn Salpaka, President of Falicon Crankshaft Components in Clearwater, Florida: "The current engine design trend that we are seeing is for small, compact, and lightweight engines". These short stroke/high RPM engine designs use bore/stroke ratios typically 1.5-2.0:1 and spin at very high engine speeds - 14,000 to 18,000 rpm. This has necessitated the use of lightweight reciprocating components (rods and pistons) and has introduced aerodynamics in crank and rod design.

Through experimentation with lightweight composite materials, Falicon has developed low inertia crank and piston designs connected to lightweight composite rods allowing speed increases of 500-1,000rpm without risk of component failure. The Falicon Knife oval beam rod design is the ideal shape to forge difficult to machine, exotic materials like TI 6246 titanium or AMC 225 XE.

"We are using this ultra-light composite aluminium alloy material in an engine design which uses roller bearing mains and rods without any insert or bearing. The material itself is an excellent bearing material and allows an extra margin of design possibility and we can increase the cross section for strength or produce a lighter weight, more compact design to fit our need", Salpaka explained.

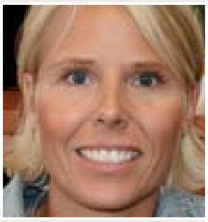
Howards Cams in Oshkosh, Wisconsin, manufactures two types

THE CARILLO INDUSTRIES, INC. FILE


Vince Cipresso


Dieuanh Phan


Stan Bigney


Cindy Verkooij

PRODUCT
High performance custom and prototype connecting rod manufacturer to virtually every major automotive and motorcycle venue

RACING MARKET
Carrillo has supplied components to the winners of virtually all global motorsport venues including Formula One, Two and Three, NASCAR, Champ Car, IRL, World Rally, Superbike, Trans Am, Can Am, GTP, SCCA, Sprint Cars, Modified, Land Speed Record and so on

HEADQUARTERS
San Clemente, California, USA

WEBSITE
www.Carrilloind.com

KEY PEOPLE
Managing Director: Vince Cipresso
Operations Director: Dieuanh Phan
Chief Engineer: Gerhard Oertelt
Sales Director: Stan Bigney
Marketing and Promotions Manager: Cindy Verkooij
Customer Service Manager: Richard Batchelor

SCALE OF OPERATION
Total workforce of more than 50; racing is over 75% of business

BACKGROUND
Founded by noted aerospace engineer Fred Carrillo in 1963 - his true passion was the mechanics of motorsports. The Dover Corporation, under the organisational umbrella of Performance Motorsports, Inc (PMI) acquired Carrillo in 2001

GLOBAL DISTRIBUTION
Covering the global market, concentrating on the USA, Europe and Australian continents

THE FALICON CRANKSHAFT COMPONENTS, INC. FILE


Glenn Salpaka


Raphael Paula

PRODUCT
Manufacturer of con rods, small engine (Power Sports industry) crankshafts, adjustable cam chain sprockets and billet clutch components. Also bottom end components for two and four stroke engines up to four cylinders plus engine design and prototype development and OEM crankshaft repair and modification

RACING MARKET
Products for all forms of motorcycle, ATV, watercraft and snowmobile racing; half of the company's market is the professional engine builder or race teams

HEADQUARTERS
Clearwater, Florida, USA

WEBSITE
www.faliconcranks.com

KEY PEOPLE
President and Owner: Glenn Salpaka
Marketing: Raphael Paula

SCALE OF OPERATION
20,000 square feet 'lean' manufacturing facility. Total workforce of 20; racing is majority of business

BACKGROUND
Founded in 1976 by Tom Falicon; privately owned by Glenn Salpaka since 2000

GLOBAL DISTRIBUTION
Sales at all levels: retail, dealer and distributor, worldwide. Falicon does business with almost every motorcycle dealership in the USA. Expanding coverage in the European and Mediterranean market plus distributors in Australia, New Zealand and Japan

of steel connecting rods – 4340AQ material formed in a closed die forging process with 100% CNC machining and 4340AQ powder material formed in a closed die powder forging process to produce a powder forged connecting rod. The latter is not 100% CNC machined because this process enables close tolerances to be held, and Fracture Cap Technology enables this cap-rod to reassemble together perfectly with no need for alignment sleeves. Contrary to popular belief, these rods are completely rebuildable by using readily available oversize bearings from all the popular bearing manufacturers. Robert Lou says: "Proper heat treatment is critical to the life of a steel connecting rod. Stress Proof Steel Sleeves for cap-rod bolt alignment and reliable fasteners such as those from ARP are very important."

SURFACE PREPARATION AND COATING

Surface preparation and coatings can be important in the durability of con rods, but not everybody agrees with this technology. Brian Crower expands on this: "Surface prep would include heat treating, finishing, and coatings really are only required for the big end sides of the connecting rod on titanium". Crower uses a Teflon based coating that prevents the titanium from galling itself. "All other coatings are for peace of mind, it doesn't necessarily hurt but the verdict is still out as to whether there are any benefits aside from helping you sleep better at night", Crower added.

Tolerances and trueness are major concerns and the big end housing bore needs to be sized to provide adequate bearing crush on the crank pin with clearances ranging from 0.045mm to 0.063mm while following proper fastener torque procedures. "Added value features that we include in our BC rods are an exclusive oiling groove in the bushing that delivers more oil to the critical pin area as well as the choice of ARP Custom Age 625+ bolts or ARP2000 fasteners depending on usage and horsepower requirements", Crower explained.

Carrillo agrees that surface finishing is an important parameter with respect to the fatigue life of a con rod, and the higher strength material used, the more critical the surface finish. Verkooij explains: "In most cases, a fatigue crack initiates from the surface and propagates due to local tension stress. With shot peening the outer surfaces of the connecting rod, a compressive stress is induced into the surface, which acts as an 'inhibitor' for fatigue cracking".

The shot peening parameters need also to be adjusted for different materials in order to gain maximum benefit. The typical depth for the compressive stress zone in steel achieved through shot peening is ~0.006in. With the process of laser peening, the compressive stress reaches about four times as deep into the material however it can only be applied on specific areas on the rod. This technology is expensive and is only suitable for applications operating on their absolute limit with tight control of all boundary conditions.

The surface roughness on the pin end inner diameter should be low to reduce friction between wrist pin and small end without sacrificing the ability of oil retention. Typical values in the range of Ra 4-10µin are achieved through honing. However, tribological systems like the Pin End are very complex, and their function not only depends upon the friction partner (wrist pin), but also on the engine lubrication system, the oil, the stiffness of the components and many more factors. The use of DLC coated wrist pins allows running the PE without bushing. Assuming sufficient oil supply to the small end, no special coating is required in the PE ID. A bushed PE still allows better serviceability than a steel-on-steel rod, Carrillo reports.

Another frequent point of discussion is the surface finish of the flanges. Carrillo rods used to offer a shot peened flange as standard, but changes in the production process have allowed them to respond to increasing requests for a machined flange finish. However two schools of thought prevail: higher friction due to higher roughness of the shot peened surface versus lower friction due to better oil retention on the shot peened surface. These theories are fighting each other and no engine performance data on a direct comparison basis is available to prove either one of them.

According to Carrillo, titanium is an excellent rod material due to the good Youngs Modulus to strength ratio, but when it comes to friction, it performs relatively weakly. The reason for this is the metal's tendency towards galling, but several coatings are available to help overcome this weakness such as DLC, Tungsten Carbide and Titanium Nitride. For thrust faces, Carrillo has had good success with DLC coatings, however the pin end ID is a more critical area and the company is currently investigating different coating options for bushingless Ti rods.

Hardening of the bore ID's (mostly achieved through Case hardening) is applied for connecting rods running on roller bearings. The high local stress in the contact area between the rollers and inner diameter of the bore requires high hardness levels for wear and galling resistance. Hardening the entire rod is to be avoided since the higher hardness also causes embrittlement making the rod less forgiving for any type of surface imperfections.

According to Arrow three factors determine the performance of a competition steel rod: weight, strength and balance. Over the past couple of years many small but significant advances have been made in the design and manufacturing process, making its rods lighter and stronger. Ros Arnold explains: "One of the most important of these steps has been the introduction of fully automated peening. It is vital to harden the surface to an exacting standard, removing stress raisers and attaining an even surface hardness right across the rod. We have run saturation tests to determine the optimum exposure to the process and are now satisfied that our rods have the ultimate consistent surfaces in the industry today."

On titanium rods Arrow uses a thermal molybdenum coating, which stops the titanium 'picking up' or galling.

Robert Lou of Howards Cams says: "Cryogenic Treatment appears to have some value but the cost has to be taken into consideration".

THE GIANNONE PERFORMANCE PRODUCTS, INC. FILE

PRODUCT
Specialist in Custom Aluminum Connecting Rods
RACING MARKET
NHRA, IHRA
HEADQUARTERS
Colorado Springs, Colorado, USA
WEBSITE
www.mgpconnectingrods.com
KEY PEOPLE
Managing, Technical,
Chief Test Engineer and Sales Director:
Michael Giannone
SCALE OF OPERATION
Total workforce of five; Drag Racing is 100% of business
BACKGROUND
Founded by Mechanical Engineering/Machinist Specialist Michael Giannone and his wife, a Business Management Graduate, in January of 1990; still privately owned
GLOBAL DISTRIBUTION
Covering the United States, Australia, Canada and Europe

DESIGN

Due to the different performance demands and race category regulations, engine builders need to work within certain parameters placing pressure on materials and component design. As regards on the advantages of I- or H-section, two-bolt or four, Brian Crower says: "This question comes up on a daily basis and the true answer is that if it is a high quality rod, made to exacting tolerances, using proven fasteners, the actual design of the rod is irrelevant".

The H-beam is often the preferred design in the international market, so Crower has opted to incorporate the H-beam with its new radial beam design, which ensures weight removal in a manner that actually makes the rod stronger. Finite Element Analysis and on-track testing have shown that just building a heavy weight rod is not the answer to high horsepower, severe-duty use. The added weight of the rod produces undue stress on the crank, whereas a lighter weight rod, designed with the radial beam technology, produces a stronger beam configuration, capable of more horsepower, without putting added weight on the rotating mass.

Verkooij of Carrillo offers this view: "When considering any connecting rod, the configuration of the beam does not dictate the strength of the connecting rod. Different applications place different requirements on a rod design, hence also suggesting different beam configurations. Deciding factors on which beam type to use include weight, clearance and actual load conditions in the engine."

Considering the dynamics of a connecting rod, the axial compression-tension load, combined with twist and bending forces ▶

exerted, the H-beam is most suitable to withstand the tremendous abuse endured by the connecting rod, according to Carrillo, which was the first to develop the H-beam connecting rod. Simply stated, when considering the most critical strength and durability requirements of a high performance connecting rod, Carrillo has found that a well-developed H-beam configuration is the best solution to meet most customer's specific needs and requirements.

The Carrillo A-beam is made from the same high-quality proprietary steel as used in the H-beam rod, and is well-suited for less demanding, high-performance, aftermarket applications. Carrillo's Pro-A design is much lighter than its standard Pro-H and is used in moderate horsepower applications such street turbo, drag, street and strip applications and has been credited with reducing windage inside the engine through its streamlined design. Carrillo also offer the Pro-A Limited and Pro-Super A versions for specific applications.

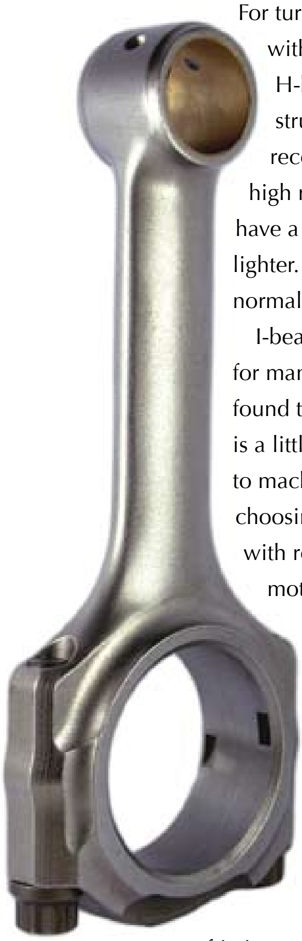
Frequently raised is the issue of ring dowel versus dowel pin for the positioning of the cap. The ring dowel is more common in the North American market, whereas the dowel pin is more often a European preference. The ring dowel arguably gives a superior positioning due to a large contact area, which is also more forgiving in the assembly process. Dowel pins wear out more easily, but allow decreased bolt spacing. This can give advantages in the stability of the big end, meaning less ovalisation under tension load.

Arrow often gets asked about H and I-section rod choice and while many engine designers have their own personal preference, the company reckons that in most engines both types would be suitable. For turbocharged and supercharged engines with high gas loading Arrow recommends an H-beam as this is stronger as a compressive strut. Arnold comments: "We generally recommend the H-beam although in some high revving engines an optimised I-beam may have a small advantage as they can be slightly lighter. But I-beams are only really suitable for normally aspirated engines."

I-beam rods are also a more authentic option for many restoration projects and Arrow has found that on fully machined rods the I-section is a little more expensive as it takes longer to machine, another factor to consider when choosing which option. Specialist I-beam rods with roller bearings are normally used in motorcycle and kart applications.

Salpaka of Falicon talks about its recently introduced Knife rod: "Our rod design is a unique solution to the problem of windage and aerodynamics in the engine crankcase. The oval beam of the Knife rod cuts through the air and oil much like an airplane wing".

Falicon manufactures bolt-together plain bearing designs and also low friction roller bearing designs like those used in the NHRA Pro Stock motorcycle class. These 1.6 litre motorcycle engines use ultra-low viscosity oil for the ultimate in low drag performance enhancement. Roller bearing connecting rod designs are also much more durable in situations like off road and sand racing or where vehicle turn over is possible. The oval beam shape is also very strong and resists the tendency of other beam designs to flex and twist under heavy loads such as is experienced in the high combustion pressure of turbocharged engines.



Falicon knife

"Many of our customers have commented that the oval beam rod design gives a margin of durability when an engine begins to fail as the rod is tolerant to adverse loading and will not fold like an H-beam design when things go wrong", adds Salpaka.

Most of Howards Cams connecting rods are of I-Beam design. Lou says: "Both I-Beam and H-Beam designs are proven in strength and elasticity areas. We feel the I-Beam is a stronger design".

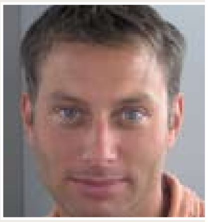
THE FUTURE

Looking toward the future, Brian Crower says: "We feel the radial beam technology incorporated into the proven H-beam design, using premium ARP Custom Age 625+ fasteners and added pin oiling features is the future of connecting rods".

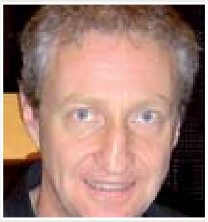
Stefan Asplund of MX Composites sees it this way: "MMC con rods offer great benefits and outperform Titanium con rods both in performance and total cost of usage. From a more long term perspective, MMC con rods even rival steel con rods in the OEM segment when considering the benefits".

THE MX COMPOSITES AB FILE

Stefan Asplund



Jonas Råsbäck



Lennart Nilsson

PRODUCT
High performance components in Metal Matrix Composites (MMC) with MMC connecting rods a speciality
RACING MARKET
Motorcycle racing
HEADQUARTERS
Linköping, Sweden
WEBSITE
www.mxcomposites.com
KEY PEOPLE
Managing Director: Stefan Asplund
Technical Director: Jonas Råsbäck
Sales Director: Lennart Nilsson
SCALE OF OPERATION
Total workforce of six working with design, testing, production development and sales; manufacturing is outsourced in a network of sub-suppliers manufacturing to MX Composites' specification. Racing is majority of business
BACKGROUND
Founded as a spin off from Saab Aerospace in 2002 and still part of the Saab group
GLOBAL DISTRIBUTION
Covering the European market, concentrating on the Italian market beside the Swedish home market; exploring possibilities in the USA

Arrow

Falicon's production Knife connecting rod is 100% machined from Timken Var300M Steel forging and it uses ARP 625+ alloy bolts in all of its products. The H-beam design has remained virtually unchanged for over thirty years, and Salpaka predicts, "The oval beam design is in our opinion the next level of technology especially when used in modern engine designs where high RPM engines are common".

However, Salpaka points out, some of these exotic materials are not allowed in certain race disciplines due to motorsport regulations. "One solution is a hollow beam steel rod, which is stronger than an H- or I-beam rod when subject to load or tension in more than one direction; an oval beam hollow rod may be the ultimate design", he adds.

Falicon has produced rod designs with the knife edge coated to increase laminar flow, dimpled like a golf ball or tapered like a stiletto. Through their advanced designs, they can port oil through the rod to the piston or use the rod as a heat pipe to effectively conduct heat away from the combustion area. "We can fill the void within the oval with a gas, liquid or solid; there are many new possibilities if you take our oval beam design to the next level", Salpaka adds excitedly.

Howards Cams has developed a Parabolic X Beam Design that combines the I-Beam and H-Beam designs. Lou adds confidently: "This is still in the experimentation process at this time, but so far seems to have an extraordinary increase in strength and load capabilities". ■

Verkooij offers an in-depth view: "The future in development of high end connecting rod designs will be driven by simulating real world load conditions through Finite Element Analysis (FEA). The more precise the actual load conditions are defined, the better the design can be adjusted to have uniform stress distribution in the rod assembly". This of course involves more detailed measurement studies on the engine and new design evolutions will most likely show more uniform changes in cross section between the bores and the beam, however the material properties do influence the design of the rod significantly.

"In addition, the industry keeps looking for the 'magic rod material'. The decision on what material to use is mostly controlled through production costs and limitations in motorsport regulations", she adds.

Carrillo expects that alloy systems (steel, titanium or aluminium) will be refined and optimised in the future, but will lead only to slight evolutionary, not revolutionary improvements. The main focus on these materials in combination with their surface treatments is to achieve maximum fatigue properties, which does not always relate directly to the static strength properties of an alloy (Ultimate Tensile Strength). Coating technology is advancing apace and this will allow friction optimisation, especially in the pin end ID which increases the durability of the rod and reduces friction losses in the engine.

Carrillo