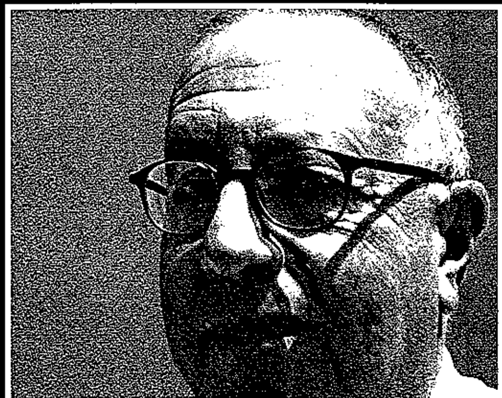
race engine TECHNOLOGY


MATTI HOLTZBERG:
Rebirth of the composite engine

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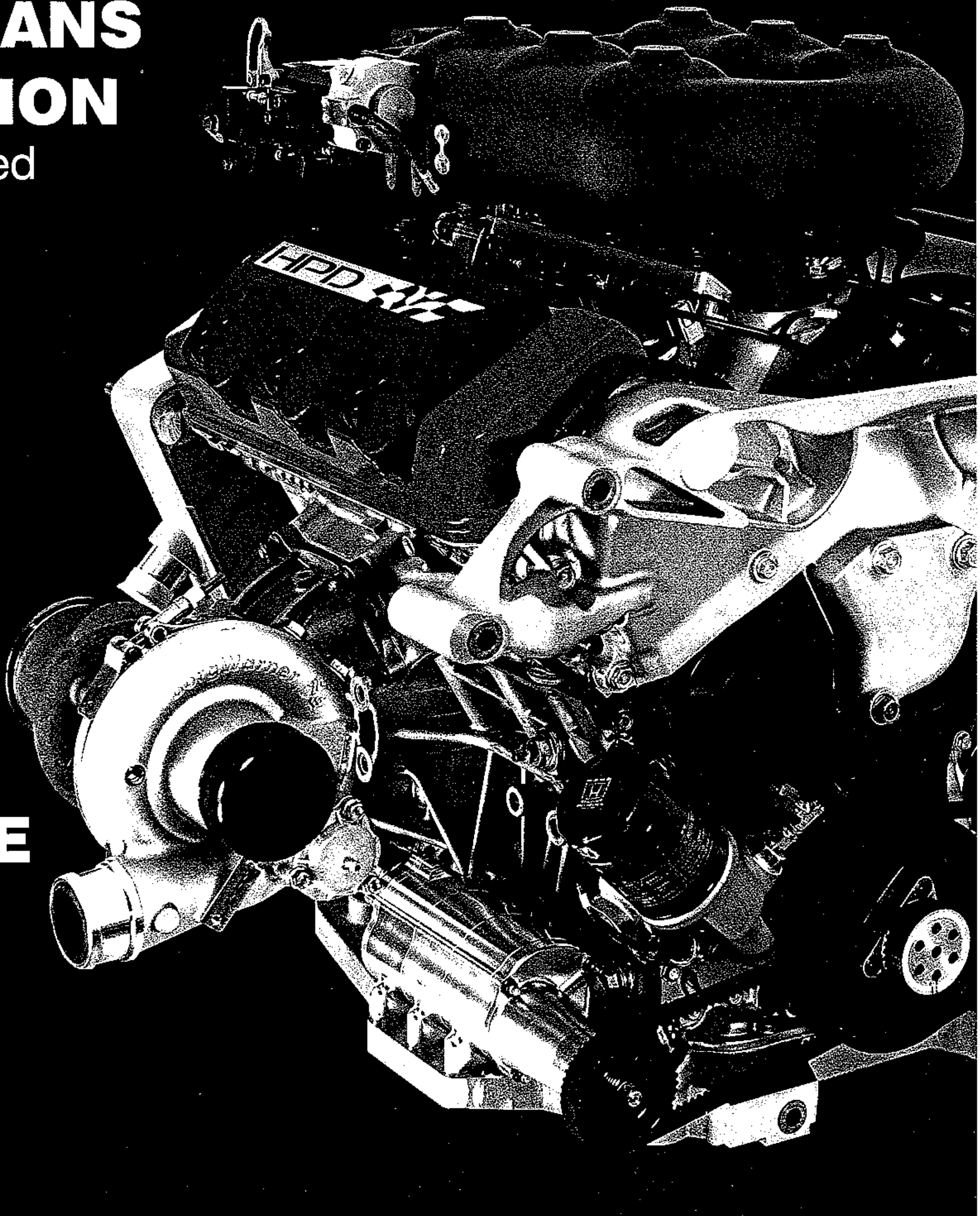

AUGUST 2011

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"It seems that Mercedes thought they had pulled a fast one, and are now rather upset to find it has been rebalanced"

ADRIAN NEWEY, RED BULL
PAGE 6

"We sat down with the FIA [ahead of Silverstone] and explained what we wanted to do, and they said, 'Yes, you can'"

ANDY COWELL, MBHPE
PAGE 11

"The advantage of the turbo route is development cost – we have to adhere to the ACO price cap on 2011 LM P2 engines"

STEVE ERIKSEN, HPD
PAGE 20

"Since the 908 V8 first ran on track we have improved combustion and reduced losses, but our main job has been to ensure reliability"

BRUNO FAMIN, PEUGEOT SPORT
PAGE 48

"The engine was designed for 6000 km between rebuilds and, given the mileage accumulated on track, we were confident for Le Mans"

NORIO AOKI, TOYOTA
PAGE 48

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Reinvent or die!

Motorsport has always tended to be governed by mature folk who understand what they know – folk who, by and large, have historically failed to resist the uncertainty that comes with change due to the sheer overwhelming force of the technological advances to which motorsport has been subjected. Gradually though, over the past 20 years or so, our conservatively inclined governors have found that motorsport's rate of change has become controllable, as the trajectory of technological evolution has flattened.

The upshot of change being kept comfortably in check is that we now find the audience for many professional racing series growing older. There is no longer anything new to excite the youngsters, who constitute the bulk of the all-important emerging new audience. Indeed, right now many professional racing series are starting to slip into decline, as the demographic sought by most key sponsors slides away.

IndyCar didn't grasp this fundamental fact, and rejected change that could have rejuvenated it. Happily though the ACO isn't so short-sighted, and has embraced the radical, youth-friendly 'Delta Wing' racecar proposal that IndyCar shunned. But what engine will power that exciting, groundbreaking concept car when it occupies the '56th garage' at next year's Le Mans 24-hour race?

Personally I hope the project will embrace the Polimotor engine block described in this issue. Like the Delta Wing itself, the Polimotor is a futuristic concept, one to which the upcoming generation of audiences can relate.

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Plastic surgeon

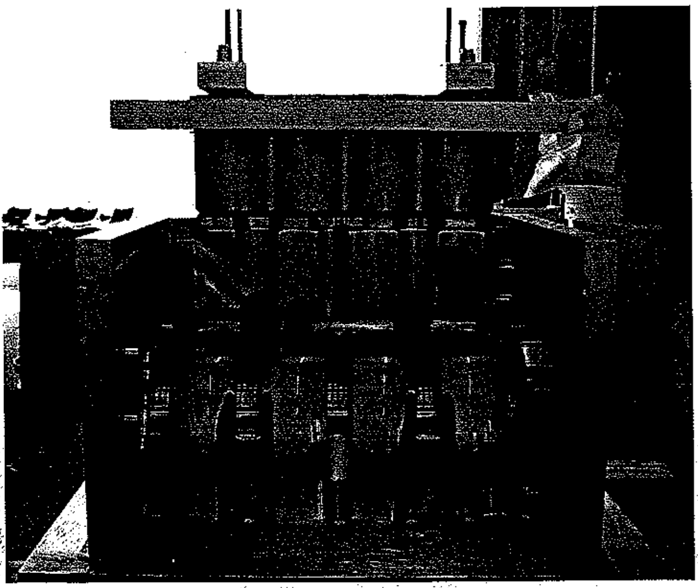
John Stowe charts the history of the Polimotor engine and the man who made it possible, Matti Holtzberg

The world is getting serious about energy efficiency, and racing classes such as Formula One and Le Mans are increasingly reflecting this trend. 'Lightweighting' powertrain components for road-going vehicles have become a major focus for auto companies worldwide as well. Alternative materials have become interesting as a result, so much so that Composite Castings, the producer of the original Polimotor, is now making a plastic composite replacement for the Ford Duratec engine block.

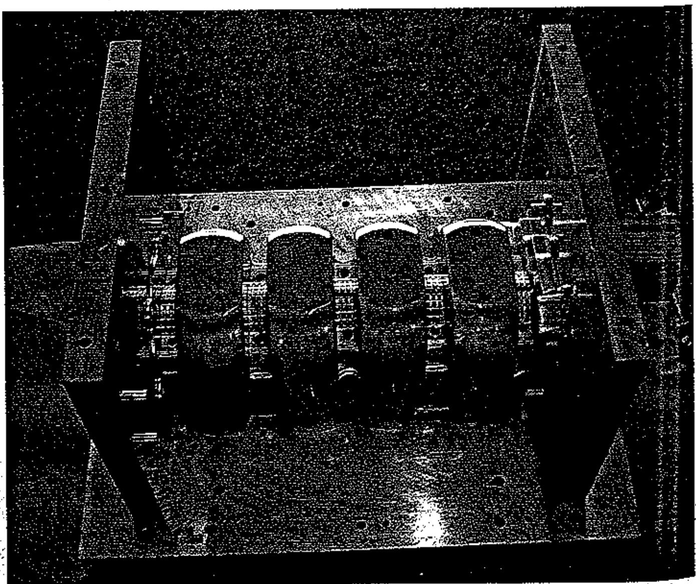
This first 'latest generation' offering was selected by Composite Castings because of its widespread potential application in various 2 litre (+/-) competition classes, and its broad acceptance among speciality car constructors. A host of high-performance aftermarket components are available for this engine family, making it a logical choice for engine builders. Composite Castings believes there will be no issues with acceptance for its new product. After all, engineered plastic components are reasonably commonplace these days, and are increasingly used for valve covers, pans, induction systems and so on. A high-strength composite plastic engine block should not therefore represent a big leap of the imagination these days, but this was not always the case.

In the early 1980s, the news came as a shock – a plastic engine? It quickly became a topic of conversation throughout the engineering and performance community. It was featured on the cover of an issue of *Popular Science* magazine, and was written up in a number

View of partially assembled mould. Water jacket core is perched above the mould

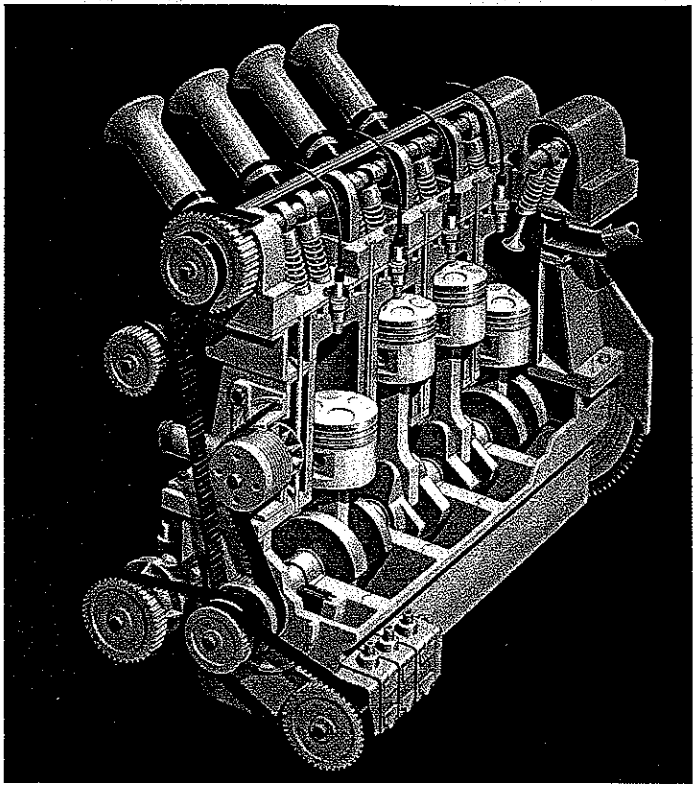


View from above. Grooved components between crankcase compartments are bearing saddle inserts



of publications. Yet despite all the attention it generated and its competition success, this very promising technology never received the broader acceptance it deserved, even though it first emerged a full quarter-century ago. Here we can only reinforce the previous editorial opinions expressed in *RET* concerning design and material restrictions for top-level racing, and add that there is a real danger of production vehicles becoming more advanced than their competition counterparts, which will ultimately undermine the public's belief in the value of the entire motorsport industry.

The name Polimotor can still be encountered in all sorts of racing and high-performance chat rooms, blogs and so on, and it is astonishing how much misinformation there is about this family of engines. Part of the reason is that most people assume there was only one Polimotor. In fact, there were a number of engines created by Polimotor Research, and in a number of these online forums, people are contradicting each other because they are talking about different versions. One blogger the author came across authoritatively stated that the 1985 Polimotor redlined at 15,000 rpm, while yet another countered equally that it never actually existed – it was just a fabrication by Ford's publicity department! This last claim is particularly amusing because, despite the stock base for the original engines, Ford never really had any substantial involvement in the project.



Cutaway of original laminated-style block, circa 1984. Yellow indicates plastic composite material; Torlon was used for internal moving parts shown

Early development

The very first Polimotor was essentially a 2.3 litre four-cylinder Pinto rendered in plastic. The best way to describe its construction is as a laminated pre-preg system, whereby the material was layered up to create basic geometric shapes that were then bonded together. "We even used pre-preg for the cam cover. It might have been the most over-engineered component attached to the motor," observes Matti Holtzberg, the engineer-entrepreneur who made it all possible.

This engine was simply an exercise in viability; no attempt was made to maximise horsepower or any other performance characteristic. Virtually all the moving parts in the engine were stock, and the engine unsurprisingly produced stock power of about 88 hp. Nevertheless, this motor made the point: it was less than half of stock Pinto weight, and it surprised the naysayers by running quite well. Intended mainly for use as demonstration units, about 20 were built, some of which still exist.

Within two years, the Polimotor had evolved into a serious high-performance motor, with 16 valves and overhead cams. The head-and-block construction method was the same as the earlier Pinto-style engine, but even though it had been de-stroked down to 2 litres, its power had risen to as much as 270 bhp on gasoline.

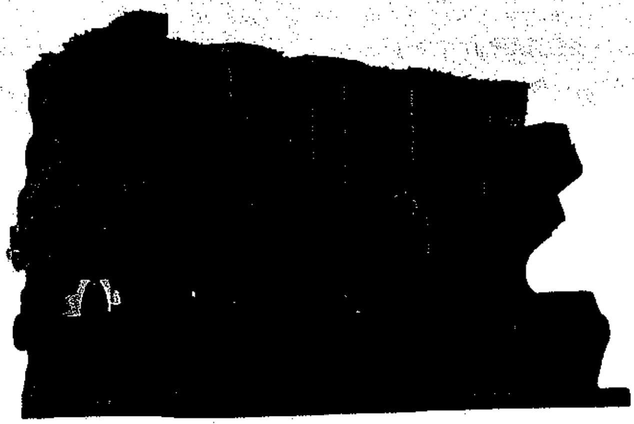
This was the engine that motorsport enthusiasts became most familiar with as the definitive unit installed into the Amoco Chemical Company-sponsored Camel Lights racecar. It advanced the state of the art yet further by adopting a high-performance mouldable plastic for most of its internal moving parts. That material was Torlon, as supplied by Amoco, which recognised the Polimotor as the ideal medium to demonstrate its capabilities. "The intake valve stems, cam buckets, piston pins, piston skirts and con rods were all plastic. We even started to experiment with Torlon lobes on steel camshafts," Holtzberg recalls.

The one performance disadvantage of the laminated pre-preg slab construction was in the cylinder head, as this feature forced a horizontal intake port with an abrupt bend right at the intake valve. Photographs of the engine are deceptive, as the ports appear to be angled upwards, but this was just for external packaging, and the intake layout must have cost the engine some power.

Another problem was with the fuel injection system. The Polimotor was originally fitted with Hillborn fuel injection, a continuous flow system that was never at its best on road racing circuits. "At the time [1984] we could not get our hands on a Lucas injection system for love or money," says Holtzberg. Eventually, a substantial Kugelfischer pump-and-plunger unit was successfully adapted to the motor, but it was a very large lump in the engine bay. The engine competed with reasonable success in its first year in the IMSA series, finishing reliably and performing better as time went on – much to the dismay of the traditionalists!

For Polimotor Lola's second season, the composite head and cylinder block were entirely different. The built-up carbon fibre pre-preg construction was replaced by squeeze-casting a new glass-filled phenolic moulding compound – the first step towards a true production method of manufacture. The internal components were essentially unchanged. This package shared the same bore centres as those of the previous year's, but was trimmed down 'at the edges' for a more compact overall layout. Reliability was quite good, with the Lola T616 consistently running with the leaders, and there were podium finishes for the Polimotor team in 1985.

The IMSA powerplant has sometimes been described as a "plastic BDA clone" but this is not really accurate. The BDA was based on the ▶



Raw, unfinished block as removed from mould. Note the highly developed surfaces. Earlier blocks were slab-sided inside and out

THE AMOCO LOLA

For two seasons, a Lola T616 ran in the IMSA series, with the name 'Torlon' proudly emblazoned on its sides. Amoco's goal was to raise its profile in the automotive world, and the Lola-Polimotor certainly succeeded in this. At the close of its first season, the racecar was taken on a tour of the Big Three auto research centres, generating a large amount of interest and publicity in the process – Amoco went from number eight to number one in industry brand recognition. The Polimotor-powered vehicle performed on the track too, frequently finishing well up and scoring a fine third place at Road America in 1985.

The opposite of today's practice, which is normally an aluminium engine in a composite chassis, the Lola-Polimotor was a composite engine in an aluminium chassis. Polimotor acquired the vehicle from Carl Haas, the well known Lola importer. "When we first saw the car, we were surprised," Holtzberg remembers. "It was much larger than we expected, more like a full Group C machine than a C2 vehicle."

The Polimotor team fabricated a rear bay to accommodate the engine, and went racing. The reality of racing then set in: lots of small parts were constantly being fabricated, there was testing to be done, and repairs when the inevitable mishaps occurred. To service these needs, the team grew to ten people, and the 1985 season wound up as a success. When Amoco pulled out at the end of 1985, its goals had been fully met. "Unlike many sponsors, Amoco had the decency to provide me with some transition support for the following year," Holtzberg says. "They were one of the best companies I've ever worked with. My only regret is that I never got to drive the car!"

In two short, intense years, the Polimotor proved that a composite motor was possible, and spurred the development of leading-edge structural plastics.

Ford Kent block, whereas the Polimotor had been originally designed around the larger Pinto ohc dimensions, plus there was the different inlet porting style. The block also separated unconventionally: the pan and crankcase were combined and split off from a combined head and water jacket assembly. By the end of the second year, the engine weighed about 156 lb, which was quite remarkable considering a crankshaft weight of 38 lb and the large basic envelope.

After the end of the 1985 season, Amoco's management changed, and it withdrew from IMSA competition, effectively curtailing Polimotor's ability to develop plastic moving parts for the engine. With Amoco's support and sponsorship thus withdrawn, Holtzberg was forced to shut down the Polimotor race shop, selling off much of its equipment. He continued to improve the engine, however, now with conventional components for its internal moving parts. He also began to work on a new, pourable liquid resin system, one that would make volume production truly viable.

The next generation

These efforts resulted in his first engines designed with resale in mind. The material used was a 25% carbon fibre-filled resin. The chemistry for this material was still in its infancy, however, so although its compressive strength was quite good, its tensile strength was only about one-third of the current pourable system from Composite Castings.

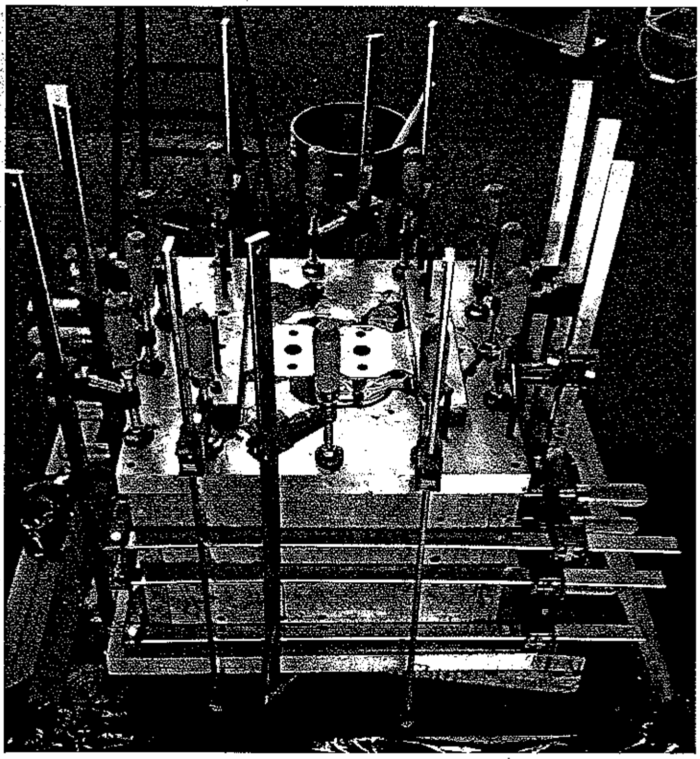
From the start, all the Polimotor engines had through-bolted architecture, where the cylinder head bolts and main bearing bolts were the same, effectively putting the entire plastic structure in compression. The piston liners of course were metal, adding stiffness to the engine 'sandwich'. This became an important feature for this generation of engines, as it improved their strength tremendously.

Now without their own assembly and testing facility, Polimotor took these engines to Ted Wenz at MWE for dyno testing and further work. "One thing we noticed right away was how vibration-free the engine was," Wenz recalls. "Also, you could touch it while running – the outside never got very hot." Among other improvements, electronic injection was successfully adapted to the motor, ending the packaging complication arising from the bulky mechanical unit.

Eventually, about a dozen engines were made. Normally they were set up and installed by privateer teams, and were used mainly for hillclimbing and Midget racing. These powerplants achieved some real success: one of them set the track record for Midgets at Hazleton 'right out of the box', while another was exported to the UK, where it won the 1994 British 2 litre Hillclimb Leaders Championship. It accomplished this feat in a front-engined clubman-class car running against substantial mid-engined formula car competition.

By this time, however, it became apparent to Holtzberg that marketing customer engines represented a challenging business plan. Changes in Midget engine rules strongly favoured large-displacement pushrod engines over smaller dohc units like the Polimotor, while the potential British hillclimb customers were 3000 miles away, and therefore difficult to support (and educate). "For example, not everyone realised the importance of our special gasket material," Holtzberg says. "Silicon RTV did not adhere to that generation of Polimotor plastics. Sometimes a slightly larger radiator would be needed because the plastic motor does not radiate heat the way a metal block does."

So Polimotor began to search for additional new markets, its lightweight characteristics making the engine an obvious candidate for aircraft applications. A special engine was also built for the US Navy. Still, it became clear that qualifying and supporting engines for these markets would represent a substantial new investment, and an entirely speculative one at that. Recognising this, and with growing demand for his other services to the plastics industry, Holtzberg



Clamped mould shown just after pouring the resin-fibre mixture

decided to make these first pourable-resin powerplants the last generation of Polimotors.

Now fast forward to the mid-2000s, when the world is starting to get concerned again about energy efficiency. Some astute engineers and journalists begin to entertain "Whatever happened to..." thoughts about the Polimotor, and Holtzberg starts getting enquiries about the engine and its technology. It turns out that he has kept busy in the intervening period, and has a new, far stronger pourable plastic material ready, just waiting for such an application.

"Chemical and mechanical engineers can work from a much broader palette of materials and processes than they could a generation ago," remarks Holtzberg. "In fact, virtually any property of thermosetting resins can now be altered." Basic resins are modified for different applications by adding mineral fillers, flexiblisers, viscosity reducers, colourants, thickeners, accelerators, adhesion promoters and so on. Such modifications reduce costs, produce better performance characteristics and improve processing convenience.

One goal of the chemical engineer is to tailor a given formulation to the needs of a specific market or application. The most recent resin system from Composite Castings approaches 50,000 psi tensile strength, and has close to a 50% fill ratio with special carbon fibre additives. This yields about twice the strength:weight ratio of a good solution heat-treated silicon aluminium alloy, such as A357, although the elongation is lower.

"If I had to characterise our latest material in 'metallic' terms, I would describe it as resembling a fully equiaxed, randomly cross-linked grain structure," Holtzberg says. "It is therefore isotropic, contrary to some reports." This most recent material is actually one of a family of reinforced resin systems that can be adjusted for configuration, anticipated loading, mould-filling requirements and filler materials. "I am working with both 3 mm and 6 mm fibres," he remarks, "and we can also incorporate continuous long-strand fillers."

The basic chemistry is a thermosetting 'epoxy hybrid', rather than an off-the-shelf thermoplastic or phenolic. The plastic has also been developed to produce high bond strength at the resin-fibre interface. "I have worked with them all – epoxies, vinyl esters, polyesters, cast nylon C, phenolics. Each has its own applications, and requires chemical 'tweaking' to get the best produceability and performance for a particular function. For example, I can readily envision a modified resin system combined with glass fibre for some high-performance production applications," Holtzberg says.

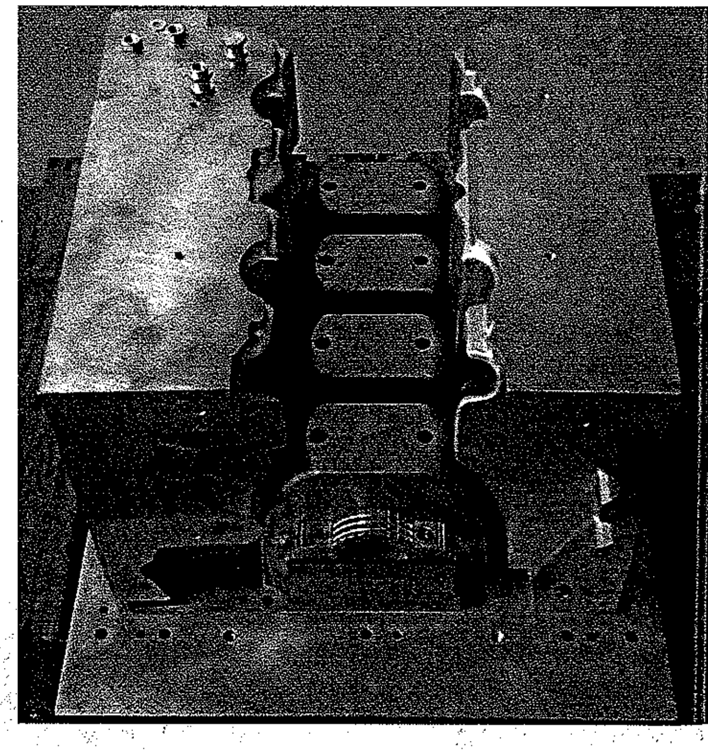
In addition to its resin formulation, the current Duratec-based engine block is different from all previous Polimotor blocks in another way – it is the first 'engineered shape' to emerge from the Composite Castings workshop. "Earlier blocks were simplified, squared-off designs; they only had to mate with our other bespoke components," remarks Holtzberg, "whereas this product will quite likely be combined with the stock head, covers, pan and so on. In addition, we wanted to demonstrate the net shape manufacturability of our latest resin systems and technology."

Current state of the art

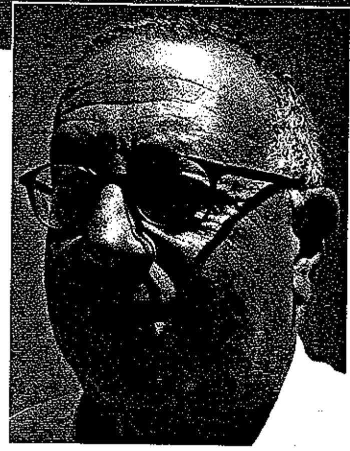
The new block's overall strength to weight is also improved. "The castability of these resins allows us to put the material where it is most needed, and add bosses and ribs where the anticipated mounting points will be located," Holtzberg says. Accordingly, the new 'Poliblock' looks a lot like the stock component it replaces, but is much lighter and stronger.

One departure from standard blocks is that there is no water pump housing. It seems that electric water pumps are increasingly taking the place of the traditional belt-driven mechanical units, so this was seen as an unnecessary appendage. For those who still desire a mechanical pump, there are stout bosses strategically placed just below the water inlet to allow for their straightforward mounting. The pourable, near net-shape capability makes the material a viable option for gearbox housings and similar applications, not just engine blocks. The anti-

View from rear. End bearing insert clearly visible



MATTI HOLTZBERG



Starting off in mechanical engineering, Matti Holtzberg completed his formal education with a doctorate in polymer chemistry from Rutgers University, New Jersey. After a brief spell serving with the US Army, his first job was with a manufacturer of automatic transmission components, working on friction plate adhesives. This work required close interaction with chemical manufacturers, setting a pattern for his professional career.

Holtzberg soon became an independent consultant to the industry. "I discovered I had a talent for developing formulas to fit applications, and applications to fit formulas," he says. Since then, he has been in constant contact with chemical companies, contract manufacturers and users of plastics, adhesive compounds and the like. This inevitably included motorsport.

Recalling his early experiences of the industry, Holtzberg recalls, "The racing world was different then; people were more accessible. Sometime in the early '70s I sent a letter to Frank Williams to discuss a composite chassis. He probably wouldn't remember this, but he agreed to meet me for breakfast during the Watkins Glen Grand Prix weekend. The conversation was enjoyable, and he seemed interested in the concept, but nothing emerged from it." It was about then that Holtzberg began to start fabricating individual components such as pistons and pushrods, and set up Polimotor Research for this purpose.

During this period, Holtzberg began doing a lot of work with companies such as 3M and Amoco, who were particularly interested in developing high-strength plastic materials such as Torlon for the automotive market. "As soon as we would make a chemical formulation improvement, we would begin developing a new working part from it," he says. "Before long, we had so many components under prototype manufacture that Ford, our major customer, asked why didn't we build an entire engine?"

The idea resonated with Holtzberg, so he pitched it to Amoco's management, who gave him their blessing to go ahead with an engine project. Striking while the iron was hot, Polimotor Research then acquired a Lola chassis. Amoco decided to sponsor the entire effort, and made its resources available to Polimotor Research. "Amoco was a terrific company to work with," says Holtzberg. "They gave us great support and encouragement, and those were some of the most exciting – and chaotic – years I've ever had."

The full responsibility of maintaining a race team now fell onto the shoulders of one man – Holtzberg. "For two years I was in a constant frenzied pace. We actually had no time to do much engine development. All our time was taken up with ancillaries, packaging and making the chassis work," he says. Then, after two years, it was all over.

Holtzberg continued to develop Polimotor engines for a while, but at the same time he maintained his by now well established consulting company. With several material formulations and processes available for manufacturing customers and licencees, it became increasingly difficult to find time to continue in the motorsport arena on his own. By this time he had amassed 18 patents, and his consulting and engineering services were in great demand.

So Holtzberg changed the name of his firm to Composite Castings, to reflect the more general customer base he was now serving. Eventually he developed a group of 17 licenced manufacturers using various of his formulations and process technologies, and this has remained the core of his business. "A few of these manufacturers are automotive-oriented, but many are not," he says. "In fact most of them are involved in highly specialised work – they won't tell me what they are making." Holtzberg relocated Composite Castings during the winter of 2010, and the new 'Poliblock' products are now being produced in a facility in West Palm Beach, Florida.

vibration, sound-deadening qualities are beneficial for all of these uses, and less extensive ribbing is needed to achieve acceptable results in these areas. In fact, Holtzberg prefers to use added unidirectional fibres or woven fabric in those few cases where extra strength is required (instead of traditional ribbing). "It is lighter, stronger and makes for a cleaner design," he says.

Nevertheless, there is much more to the process than just dumping a quantity of resin-and-fibre 'batter' into a mould (which can be lightly pressurised to assist filling). Every fastener gets its own cast-in insert, and there are about 70 of these distributed throughout the block, along with the bearing saddle inserts. These all need to be accurately located and sealed off to prevent resin from creeping into the threads. The cylinder bore sleeves comprise a single slip-fit component (designed to add to the structure's rigidity) and not press-fit as reported elsewhere. Both aluminium and cast iron can be used, along with any of the appropriate surface coatings currently available. The use of standard bore materials means that heat is carried away from the cylinders in the same manner as with a conventional engine, but the plastic block does not radiate high temperatures like its metal counterparts.

To develop the new block, a substantial mould was constructed from solid aluminium plate by Anhared Powertrain Components. The tooling is structured with six major sections designed to draw from each face of a six-sided box. "CNC machining from solid wrought material is neither the fastest nor the cheapest method to produce a prototype, but I knew there would be the usual trial-and-error experiments with processing and formulation," observes Holtzberg. "So I wanted durability. Plus we wanted to ensure accuracy that would not be possible from an SLA-derived soft tool."

Chemistry and temperature variations allow the moulder to alter the working and setting times to his requirements. The process can function as a strictly prototype method or, with mechanisation, it can produce blocks at a production pace. It is this flexibility that makes it possible to meet the varied demands of the performance and competition customers that Composite Castings plans to serve. Now that the basic production problems have been dealt with, Holtzberg says lower-cost 'soft' tools will be able to be used for moulding limited production components. "We can produce an engine block for virtually any application with this new formulation, and unlike our earlier pourables, silicon RTV adheres to it nicely," he says. One thing has not changed from the old material, however: "You can have any colour you want, as long as it's black." ■