GRAINGER & WORRALL

CASTING INSIGHTS

New perspectives on lightweighting and total casting solutions

Issue 005

THE HEAT IS ON...

How the drive towards greater thermal efficiency is spawning innovation in the field of high precision engine casting.

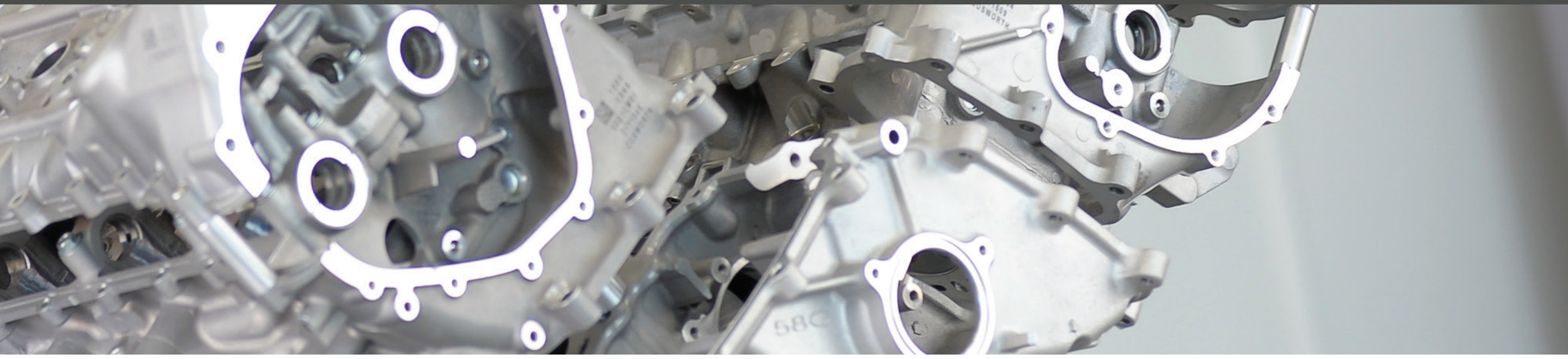
Britain is to ban all new petrol and diesel engined cars and vans from 2040, amid fears that rising levels of nitrogen oxide and particulates pose a major health risk. This announcement of summer 2017, followed a similar pledge in France and is part of the UK Government's clean air plan.

Given the 20-year lifespan of the internal combustion engine (ICE), designers also need to contend with a legislative framework that demands smaller, more efficient, yet lower emission engines.

The trend to downsize engines is also driven by the need for smaller power units that contribute to light-weighting strategies, which are at the top of most vehicle manufacturers' agendas. While this sounds relatively simple in theory, ICE downsizing poses a set of unique challenges further down the supply chain – specifically for those at the forefront of engine casting and it is Grainger & Worrall that is tasked with turning these plans into a practical reality.

One of the key challenges associated with downsizing is the strive for increased specific output with the consequence of increased operating temperature which may approach 3000C in highly stressed areas of the cylinder head.

A further challenge for casting specialists lies in the realisation of engineers' strategies to extract every ounce of power from the fuel. Improving the thermal efficiency of engines now involves a series of innovative techniques, new materials and technologies that have drastically improved the percentage of energy transferred from fuel tank to crankshaft in recent years.



Thermal efficiency and ICE

Thermal efficiency improvement has been remarkably slow where the internal combustion engine is concerned. Back in 1837, when the car engine was first commercialised, thermal efficiency figures of approximately 17% were the norm. Up until 2013, around 140 years since its invention, engines were still achieving efficiency rates of under 30%, which is where we were with the normally aspirated F1 engine – which by coincidence was another area of interest for Grainger & Worrall.

Since then, a leap forward in design – focusing on high speed combustion, intake ports, variable valve timing and cooled exhaust gas recirculation – has enabled achievable thermal efficiencies within the 40-50 per cent range.

However, such strides in ICE performance come at a cost, according to Keith Denholm, engineering and technology director at Grainger & Worrall. He said: “While the higher specific load associated with downsizing creates unwanted heat - which can cause problems for some castings – the complexity of water jackets and cooling systems used in new engines pushes traditional casting processes to the absolute limit.

“The unrelenting drive for even greater thermal efficiency has prompted us to work much more closely with OEMs’ engine development teams, exploring new alloys, coatings, production processes and additive manufacturing to deliver a new generation of engines that are operating in the 40-50% thermal efficiency range.

Alloy and materials development

Given the increased temperatures created by smaller engines, traditional alloys of aluminium – notably used in the block and head – have attracted the attention of Grainger & Worrall’s team. Denholm explains: “We are actively developing alloys that are not giant leaps in technology, but enhancements of existing alloys. You have to remember that the automotive industry is relatively risk-averse, so we’re not about changing the paradigm. Our aim is to build on our knowledge of existing materials to enhance engine performance at higher temperatures.”

Aluminium has an unfortunate characteristic of losing nearly all of its working strength when it gets to about 250°C – perilously close to the temperatures being anticipated by engineers designing the new generation of smaller engines.

Another area of interest for Grainger & Worrall is the minimisation of heat loss within the system. The theory is based on the idea of harnessing as much work potential that is left after the power-stroke is finished.

To achieve this, Denholm and his team are working with insulating materials, such as ceramics and Inconel alloys, as well as using additive manufacturing to create complex ‘castings within castings’. GW is also working with customers on advanced compound engines that minimise heat losses in the exhaust transfer process enabling thermal efficiencies of circa 50% without the use of turbochargers.

While it might appear that heavy ferrous alloys are out of the race where thermal efficiency is concerned, you’d be wrong. “Engines with high outputs running at high temperatures may need to move from aluminium alloys”, comments Denholm, “but there is a potential role for iron and compacted graphite alloys. It may seem like a retrograde step, given their weight, however often the use of these materials allows us to make smaller, whole engine packages, which enable the creation of a smaller, lighter vehicle overall. This was the concept behind the Ford F150 V6 block which we developed engine castings for; despite the heavier casting, the OEM was able to design a smaller engine, which led to a lighter finished vehicle.

Developments in cylinder bore coatings

Cylinder bore liners have been extensively used to provide a hard bearing surface for the piston, however, the use of bore coating technologies is gaining credibility among OEMs.

Denholm comments: “Using steel liners, or sleeves is robust but they are space hungry and can add significant weight to the powertrain. As with everything in engineering, it’s all about compromise. The opportunity with coated bores is to make more compact engines with possible benefits in reduced friction, improved temperature control, or both.”

Working closely with cylinder bore honing and coating specialists, Grainger and Worrall is confident that the use of bore coatings, certainly for small series engine programmes, could be a reality at its UK facility within the next couple of years.

Innovations in process and controls

Given its position as one of the industry’s leading prototype and small series casting specialists, Grainger & Worrall exploits a range of technologies and processes to achieve world-class engineering solutions. One of the longstanding approaches used by the business to ensure consistency when filling complex moulds is the Cosworth (Coscast) Process. Pioneered by the eponymous race engine manufacturer in the late eighties, the low-pressure sand casting methodology was first adopted by Grainger & Worrall’s motorsport team before it was introduced to a broader scope of high performance vehicle engines.

Commenting on the Cosworth process, Denholm said: “It may be approaching 40 years-old, but the Cosworth Process still affords the best process for filling complex moulds. If we could apply those principles over all our product range we’d be delighted. Looking ahead, this is a key objective for us.”

Linked to the Cosworth process is a better understanding of the properties and behaviours of metals during the filling process. “How one melts, holds, launders and fills moulds are all critical stages of the casting process that sometimes keep us awake at night,” says Denholm.

As an aide to insomnia, the engineering team at Grainger & Worrall are increasingly using powerful simulation technology – specifically its Magma system, which allows faster development and better prediction of key casting attributes such as mechanical properties and residual stress.

The business now has the ability to integrate these data sets into those of our customers to enhance the value of virtual engineering.

Additive Manufacturing

Grainger & Worrall's significant investment in 3D printing is another technology it is harnessing in the race to improve the thermal efficiency of engines. One of the first manufacturers in Europe to use 3D printing to enhance the quality and complexity of commercial sand castings, GW first adopted this for rapid prototyping. Over the past five years, the company has invested around £2million into both hot and cold cure additive manufacturing machines and expanded its use across much of its high-performance client base.

"What started as one-off investment with our motorsport clients in mind has now become a mainstream part of our casting process. The ability to print very complex shapes in sand and resin has opened new possibilities for water jackets, ducts and pipework that was never previously thought possible. This all contributes to solving the thermal efficiency challenge."

Logically, the next major step for the business in additive manufacturing is metal printing. And despite high cost, this technology is already being trialled by the company to deliver further integration of solutions in the engine system.

Conclusion

Clearly, the new legislative framework in which the internal combustion engine operates – combined with its anticipated demise in most economies – has acted as a catalyst for technological change. The need to generate more energy from less fuel, while reducing harmful emissions, has focused engineers' minds to improve the thermal efficiency of engines by nearly 30% in recent years.

Such huge strides in engine performance have in part been down to the dedication and expertise of organisations such as Grainger & Worrall, who are operating at the forefront of engineering. Like all complex problems, the challenge of thermal efficiency will never be solved by a single technology. It is for this reason that the precision casting expert continues to invest in such a broad span of technology adoption to achieve ICE performance figures never before considered possible.

Keith Denholm
Technical Director